Standard Operating Procedures Carbon Monoxide (CO) Monitoring in Ambient Air by Non-Dispersive Infrared Radiation, Gas Filter Correlation (NDIR-GFC) Spectrophotometry

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ACKNOWLEDGEMENTS

Since the late 1970s, carbon monoxide (CO) air pollution has been recognized as a public health concern in Alaska’s larger cities. Both Anchorage and Fairbanks were determined to be non-compliant with the CO NAAQS. The State of Alaska Department of Environmental Conservation (DEC) wishes to thank past and current members of the Municipality of Anchorage, Environmental Services Division, the Fairbanks North Star Borough, Air Quality Division.

DISCLAIMER

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1. PURPOSE & SCOPE

This document establishes standard operating procedures (SOP) for the collection, review, processing, and reporting of carbon monoxide (CO) ambient air quality monitoring data, either collected by the Alaska Department of Environmental Conservation (DEC) or subject to a regulatory review by DEC.

2. APPLICABILITY

This document provides the basic procedures to collect ambient air quality CO monitoring data in accordance with federal regulations and EPA quality assurance/quality control (QA/QC) and State of Alaska Quality Assurance Project Plan (QAPP) requirements. This document is specific to CO monitoring programs which use *non-dispersive infrared radiation – gas filter correlation spectrophotometry* (NDIR-GFC) as the measurement technology. This document does not address site specific issues.

This document serves as the SOP for all CO monitoring performed by DEC or other local air pollution control agencies at SLAMS sites to determine compliance with the Alaska Ambient Air Quality Standards (AAAQS) and National Ambient Air Quality Standards (NAAQS), multi-pollutant NCORE monitoring sites and special purpose monitoring station (SPMs). This document may serve as a generic template for industry, monitoring contractors, or other community based monitoring programs in the development of a site-specific SOP.

3. SUMMARY OF METHOD

This SOP covers procedures for using the analytical technique known as *Non-Dispersive Infrared Radiation by Gas Filter Correlation (NDIR-GFC) Spectrophotometry* to perform CO measurements.

3.1 Analytical Technique

CO absorbs IR radiation maximally at a wavelength of 4.7 micrometers (µm), which is in a spectral range where few other atmospheric species absorb to interfere with accurate quantification.

Since NDIR is a spectrophotometric method, the concentration of CO can be determined using the Beer-Lambert law which relates the concentration of an absorbing species to the degree of light attenuation (***Equation 1)***:

Equation 1. Beer-Lambert Law of light absorption as it applies to spectrophotometry

$$\frac{I}{I_o} = e^{(-axC)}$$

Where:
I = light intensity after absorption by absorbing species
Io = light intensity before absorption by the absorbing species
e = base of the natural logarithm
a = absorption coefficient for the absorbing species
x = path length between light source and detector
C = concentration of the absorbing species

By measuring the degree of light attenuation through a sample cell of known length in both the presence and absence of CO, the concentration can be accurately determined if the absorption coefficient of CO is known.

In GFC CO monitors (Figure 1) a broad band of IR radiation is emitted from an IR source, passes through a gas filter alternating between CO and N_2 and enters the sample cell. The light passes through a bandpass filter which allows only a narrow bandwidth of radiation centered on 4.7 µm. to reach the detector. The CO gas filter acts to produce a reference beam by alternately scrubbing all CO from the IR beam, then rotating and allowing all IR light through the N_2 side of the filter. The difference in light intensities of the two beams at the detector is proportional to the concentration of CO in the sample cell.

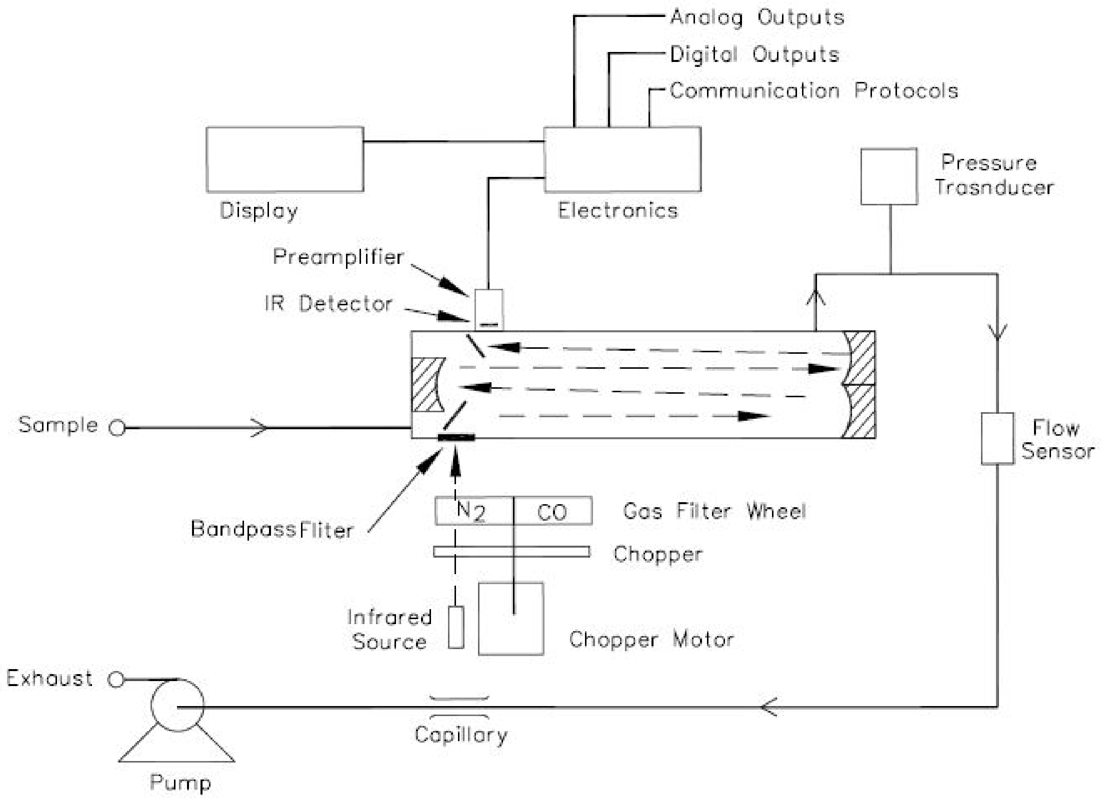

Figure 1 schematic of a NDIR-GFC CO Analyzer (Diagram courtesy of the Thermo Scientific Environmental Instruments, Model 48i Gas Filter Correlation CO Analyzer Instruction Manual)

3.2 Interferences

CO_2 and water vapor are the main interferences for GFC CO analyzers. These two compounds are present in the atmosphere in large quantities and absorb at or near the 4.7 µm region of the IR spectrum. Removal of water vapor from the sample air is necessary to avoid positive interferences in the determination of CO concentration and is achieved by a permeation tube or Nafion™ drier that selectively removes water vapor from the sample gas without removing CO. High sensitivity CO analyzers use a bandpass filter to effectively remove CO_2 interference. Bandpass filters also limit interference from water vapor.

3.3 Basic Monitoring System Configuration

An air monitoring station contains instruments and equipment linked together to form a functional system that will sample, measure, calibrate, record, and store ambient air data. **Figure 2** presents a typical basic configuration of a CO monitoring system.

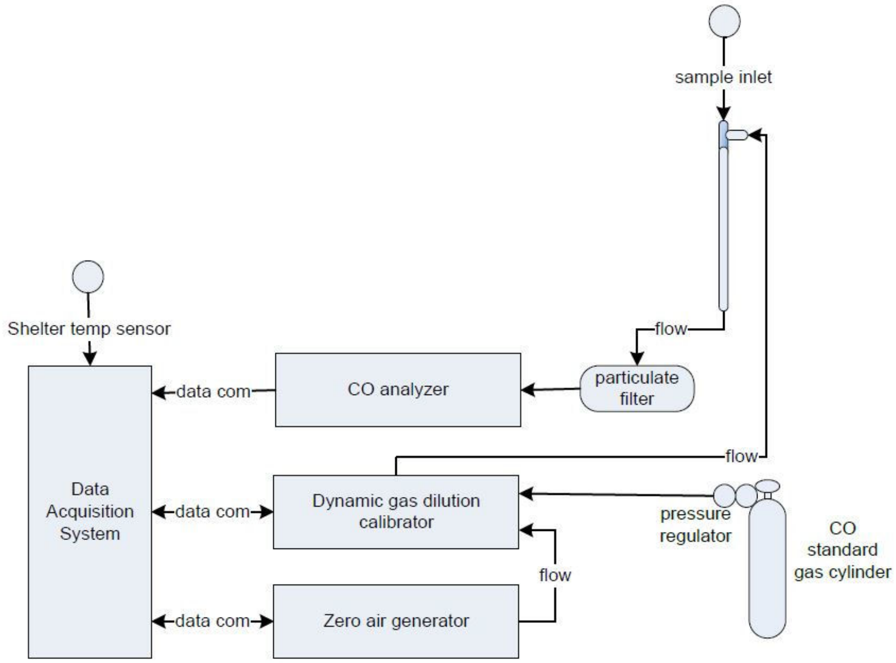

Figure 2. Typical equipment configuration for a CO monitoring system

Specific information regarding site selection, monitoring shelter and equipment specifications, data and measurement quality objectives are provided in the *Quality Assurance Project Plan for the State of Alaska Air Monitoring & Quality Assurance Program*, DEC, February 23, 2010[1].

3.4 Health and Safety Precautions

Carbon monoxide (CO) is a poisonous gas. The gas is colorless, odorless, nonflammable and heavier than air. Symptoms of mildly acute poisoning include lightheadedness, confusion, headaches, vertigo, and flu-like effects. More acute, higher concentration exposures can lead to significant toxicity of the central nervous system and the heart, and can result in death. Carbon monoxide can also have severe effects on the fetus of a pregnant woman. Chronic exposure to low levels of carbon monoxide can lead to depression, confusion, and memory loss.

The following basic precautions must be taken while working with CO instrumentation:

1. Operate all monitoring instruments with the available grounding plug (3-wire plug);
2. Exhaust the analyzer to the outside of the shelter;
3. When working/troubleshooting/replacing components of any electrical instrument, the power must be turned off and the power line disconnected;

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[1] *Quality Assurance Project Plan for the State of Alaska Air Monitoring & Quality Assurance Program*, ADEC, February 23, 2010; http://dec.alaska.gov/air/doc/ADEC_AMQA_QAPP_23FEB10-final.pdf

4. Risk of electrical shock or damage to the electronic components should be minimized by wearing an antistatic grounded wristband when working on the optical bench and other components. Remove rings, watches and other jewelry when working inside the instrument;
5. Ensure that all high-pressure gas tanks are securely chained or otherwise attached to something solid so that the tanks remain in an upright and secure position at all times.

4. QUALITY CONTROL

4.1 Calibrations versus Verifications

Calibration is defined as: "*the comparison of a measurement standard, instrument, or item with a standard or instrument of higher accuracy to detect and quantify inaccuracies and to report or eliminate those inaccuracies by* ***adjustment****.*[2]" An adjusted calibration of the CO analyzer at multiple concentration points is performed initially, following a repair, when the system fails a QC performance criteria, or when some change is made to the monitoring system. The same principle would be true for calibration of any other system measurement device such as temperature and pressure transducers or mass flow controllers.

A verification check is a standard comparison to assess on-going data quality and is performed ***without correction***. Verification checks are typically QC procedures performed on a prescribed routine schedule or when some event would necessitate a data assessment. Examples would be a routine six-month multi-point verification of a CO analyzer performed to assess data accuracy and linearity, or single-point QC checks for zero/span/precision after a prolonged power outage at a station.

IMPORTANT NOTE: To properly assess data quality over time, there shall be an initial calibration followed by routine verifications. For the purposes of data review and validation, this establishes the data quality from the beginning of the period with a traceable standard to the time of the verification check where the data quality are again assessed with a traceable standard. This is often referred to as "bracketing the data." Whenever a measurement device fails a QC performance check or the device becomes inoperable, the data are invalidated from that time back to the last verification check or calibration which passed QC criteria. Unless the measurement device has totally failed, a verification check shall be performed before any adjustment or repair. *"As Found"* verifications are a check to assess data quality without correction. *"As Left"* verifications refer to the data quality once an adjustment has been made.

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[2] American National Standard Quality Systems for Environmental Data and Technology Programs ANSI/ASQ E4 http://www.asq.org/

4.2 Full Scale versus Calibration Scale

"Full scale" is a multi-point calibration performed over the entire measurement range of the instrument using five evenly spaced points from 80 percent of full scale down to zero. However, the primary CO NAAQS is established at an 8-hour average of 9 ppm and a 1-hour average of 35 ppm and, in a typical ambient air scenario, most CO observed concentrations will be less than 5 ppm. The analyzer response to the above calibration concentrations do not provide much information regarding the stability and accuracy within the range of observed measurements. The EPA suggests monitoring organizations calibrate using points that are more applicable to observed measurements while maintaining a measurement range to assess concentrations above the NAAQS. A monitoring agency may select a lower measurement range for the instrument (e.g. 0 to 5 ppm) or maintain a higher measurement range but use additional concentration points at lower levels within the range where ambient CO concentrations are expected. This is referred to as the "calibration scale."

5. STARTUP PROCEDURES

5.1 Equipment Acquisition, Inspection, and Testing

Prior to startup of any monitoring program all system components will need to be acquired, thoroughly inspected, tested, and the monitoring personnel thoroughly trained. The instrument must be designated as a federal equivalent method (FEM) in accordance with 40 CFR 53.[3] The calibration system, all standard gases or permeation devices, zero air generator and data acquisition system (DAS) must be capable of meeting the specifications outlined in EPA *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Ambient Air Quality Monitoring Programs.* Refer to the manufacturer's manual for complete set-up and testing procedures.

New instruments should be carefully unpacked and inspected for damage resulting from shipping. Previously used instruments and devices shall have maintenance logs reviewed to assess time in service, compliance with scheduled maintenance, previous system problems and parts replacement. All used equipment shall have maintenance and parts replaced as determined appropriate by the inspection.

Monitors and components must be bench tested including leak testing and calibrating mass flow controllers to ensure the accuracy of all flow measurements with traceability to NIST. It will also include initial programming of micro-processor based calibration systems to configure the

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[3] Title 40 of the Code of Federal Regulations, Part 53, Ambient Air Monitoring Reference and Equivalent Methods http://www.epa.gov/ttn/amtic/files/ambient/criteria/reference-equivalent-methods-list.pdf

concentration of standard gases, manual and automated gas blending functionality, event scheduling, and telemetry for data communication.

Zero air generators will require leak testing, compression pump testing, checking the functionality of pressure relief valves, moisture drain valves and heated catalysts, and replacing filters and chemical scrubber media. Comparison testing to a certified zero air cylinder is required before start-up, and annually.

The DAS unit shall be checked to ensure accurate data transfer from the monitor to data memory and between the monitoring site and base computers or database servers.

5.2 Installation Procedures

The analyzer, calibration system, zero air generator, and DAS may be mounted in standard 19-inch instrument racks or bench mounted. Access to the components for future maintenance activities is essential. Sample flow connections shall be as short as practical to meet sample residence time. Compressed gas cylinders must be thoroughly secured in accordance with applicable safety regulations. An organized work area with storage space for station records, equipment manuals, standard operating procedures, consumable supplies, and spare parts must be available.

All system components must be powered up and allowed to warm-up for at least an hour; overnight is optimum.

5.3 Data Documentation & Recordkeeping Procedures

A general station log must be kept in which the site operator will record any event, circumstance or condition that affects or has the potential to affect data quality. Records will include:

- periodic site visit & operational checklists;
- shelter maintenance logs for routine cleaning, repairs, and equipment change outs;
- individual system component repair and maintenance logs (i.e. for the monitoring system analyzer, calibrator, and zero air generator); and,
- a file of all equipment certifications and standard traceability.

Notes shall be clear and concise but sufficiently thorough to provide an understandable explanation to a third-party responsible for reviewing, validating, and reporting monitoring results. Relevant information must include:

- date and time (in local standard time);
- name of the person recording the log entry and, if applicable, the name of other persons involved in on-site activities;

- if appropriate, system component identification of manufacturer (make), model number, serial number and, where applicable, certification date of traceable standards; and
- specific notes relating to the procedure, event, circumstance or condition and the effect on data quality.

Most records are kept and recorded in logbooks or on paper checklists. However, modern DAS systems and software packages have a variety of options for keeping these types of records in an electronic format. Precautions shall be taken to provide secure data backup in a format that (as much as possible) protects against data losses and record alteration.

5.4 Operator Training

All personnel involved with on-site operations must be qualified and thoroughly trained in all aspects of system equipment operation **and** have a thorough understanding of the data qualification process, the QAPP and this SOP manual. A significant time investment may be required of the site operator(s) and a senior level instructor to achieve competence.

6. OPERATIONAL PROCEDURES

6.1 Calibration Procedures for the CO Analyzer

The calibration performed on a continuous CO analyzer shall consist of a multi-point calibration, in which the analyzer is challenged with zero air and at least four up-scale points of known concentration to assess the analyzer response over the selected measurement range. An initial adjusted multi-point calibration ensures the instrument is performing accurately and establishes a beginning benchmark or bracket that documents the instrument has successfully met QC performance criteria. Calibration of the CO analyzer must be performed *"in situ"* (in place) at the permanent monitoring site. Calibrations should be performed with the standard gas introduced directly to the back of the instrument as to negate any systematic bias that may be introduced from the sample flow system.

Calibration may be performed by any of the following three methods:

- a manual calibration using a direct connection to the analyzer with certified standard gas cylinders (a cylinder of zero air gas or a zero air generator, and four individual CO standard gas cylinders each with a different concentration);
- a calibration using a dynamic dilution calibration system to precisely blend zero air with a certified gas from a high-pressure cylinder to produce multiple concentrations of CO; or,
- a calibration using a dynamic dilution calibration system to precisely blend zero air with a certified gas from a CO permeation device to produce multiple concentrations of CO.

An analyzer shall be calibrated (or recalibrated):

- upon initial installation and commencement of data collection;
- following physical relocation;
- after any repairs or service that might affect its calibration;
- following an interruption in operation of more than a few days;
- upon any indication of analyzer malfunction or change in calibration; and,
- at some routine interval as required by QC criteria and the QAPP.

An initial calibration is conducted to adjust the instrument response to ensure data accuracy over the selected measurement range of the instrument. The procedure sequence is listed below.

> **IMPORTANT NOTE:** During any calibration procedure care shall be taken to not over pressurize the analyzer sample flow system. Excess flow generated from the calibration system must be vented to an atmospheric dump and exhausted outside the monitoring shelter.

1. Attach calibration tubing directly to the sample port on the rear of the analyzer and initiate the flow of zero air. Allow sufficient time for the analyzer to respond and the output signal to stabilize. In accordance with the instrument operating manual adjust the analyzer controls until the output response is stabilized at 0 ppm. The values on the analyzer visual display and the DAS should be the same. If not, make appropriate electronic adjustments in accordance with the instrument operating manual.
2. Reset the calibration system to produce a reference gas at a concentration of approximately 80 percent of the selected operating range of the instrument (e.g., 40 ppm on a 0-50 ppm operating range). Calculation of the reference gas concentration is shown in ***Equation 2***.

Equation 2. Calculation of CO reference gas concentration at the calibrator output manifold

$$[CO]_{OUT} = \frac{F_{CO} \times [CO]_{STD}}{F_{CO} + F_D}$$

Where:
$[CO]_{OUT}$ = *CO concentration at the calibrator output manifold (ppm)*
F_{CO} = *flow rate of the CO standard gas (sccm)*
$[CO\}_{STD}$ = *concentration of the CO certified cylinder gas standard (ppm)*
F_D = *flow rate of diluent zero air (sccm)*

3. Allow sufficient time for the analyzer to respond and the output signal to stabilize. In accordance with the instrument operating manual adjust the analyzer output to match the reference gas concentration. The analyzer visual display value and the DAS should be the same. If not, make appropriate electronic adjustments in accordance with the instrument operating manual.

   IMPORTANT NOTE: If significant adjustments to the instrument electronics were needed to set the zero and upscale calibration concentration, the operator may want to repeat steps 1 – 3 to fine tune the calibration.

4. Once both the zero and upper range calibration adjustments are completed, record the calibration factors on the analyzers visual display in the calibration log.
5. **Without further adjustment**, recheck the analyzer response to zero air. Allow sufficient time for the analyzer response to stabilize and record the average response from the DAS.

   IMPORTANT NOTE: DEC recommends a minimum period of **at least** 15 minutes at each calibration point. Allow about 10 minutes for the analyzer to respond and stabilize, then record the next five (or more) 1-minute values to calculate an average value..

6. Recheck the analyzer response to a reference gas at 80 % of the selected operating range of the instrument and record and calculate the average response from the DAS.
7. In successive steps, check the analyzer response to at least three more reference gas concentrations evenly spaced over the selected operating range of the instrument or (as discussed in Section 3.3) within an appropriate range of concentrations expected to be observed. Additional concentrations may be included if deemed necessary. Record and calculate the average analyzer response from the DAS for each reference concentration point.
8. With the data collected for the zero air and 4 (or more) up-scale points, plot and perform a least squares regression analysis comparing the reference gas concentrations ($[CO]_{OUT}$) on the x-axis to the actual analyzer responses from the DAS on the y-axis. Generate a best-fit calibration line using ***Equation 3***.

Equation 3. Least squares regression equation for calculation of best-fit calibration line.

$$\boldsymbol{y = mx + b}$$

Where:
y = the analyzer response as calculated from the best-fit equation
x = the reference gas concentration
m = the slope of the best-fit line
b = the y-axis intercept of the best fit line

9. The linear regression will provide a slope (m) and a y-axis intercept as shown by ***Equation 3***.
10. For each upscale point re-calculate the analyzer response (y) using the best-fit calibration expression from ***Equation 3.***
11. Using ***Equation 4***, for each point calculate and record the percent difference between the actual analyzer response recorded during steps 6 and 7 and the calculated best-fit analyzer responses determined from ***Equation 3.***

Equation 4. Calculation of percent difference for calibration results

$$d_i = \left[\frac{actual\ average\ analyzer\ response - calculated\ best\ fit\ analzyer\ response}{calculated\ best\ fit\ analyzer\ response}\right] * 100$$

12. The QC operational criteria for “Verification/Calibration” as shown in the *CO Validation Template* (May 2013) in Appendix A is a percent difference of “All points within ±2 percent of the calibration range best-fit straight line.”
13. An example CO calibration data sheet with example results is shown in **Figure 3.**

Figure 3, Example CO calibration data sheet with example results

CO Calibration Data Sheet

Station	Eagle Glenn	Date	3/19/2014
Street Address	1700 Post Road	Calibrator Manufacturer	Environics
City	Anchorage	Model No.	6103
Calibrated by	Albert Fudputter	Serial No.	0000-0000
		Last Flow Calibration Date	3/1/2014
Inst. Manufacturer	Thermo Scientific Environmental Instruments		
Model No.	48i CO Ambient Air Quality Analyzer		
Serial No.	xxxx-xxxx		

CO Reference Gas Standard

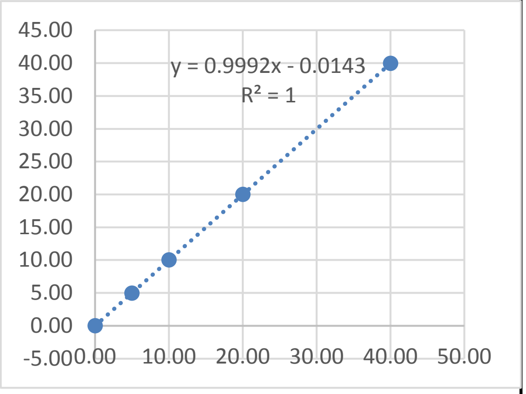
Gas Vendor Name	Scott-Marrin	Cylinder Serial No.	ALXXXX-XX
Concentration $[CO]_{STD}$ ppm	5010 ppm	Cylinder Pressure	1500 psig
		Certification Date	1/1/2014
		Expiration Date	1/1/2020

Instrument Calibration Factors

Instrument Background	*As Found*	*As Left*	Calibration Coefficients	*As Found*	*As Left*
CO	0.00	0.01	CO	1.0000	0.9992

CO Calibration and Linearity Checks

Calibration Points	$[CO]_{OUT}$	CO Analyzer Response	CO Analyzer Response from y=mx+b	Percent Difference d_i
units	ppm	ppm	ppm	%
Zero Air	0.00	0.00	0.01	na
80% URL	40.00	39.95	39.98	-0.1
1	20.00	19.98	20.00	-0.1
2	10.00	10.00	10.01	-0.1
3	5.00	4.94	5.01	-1.4
CO Linear Regression		**m =**	**b =**	
y=mx+b		0.9992	0.0143	



14. The EPA has also developed a Data Assessment Statistical Calculator (DASC) that automates this process. This MS-Excel multi-spreadsheet workbook is available from http://www.epa.gov/ttn/amtic/qareport.html. Worksheets are available for calibration calculations of 4, 5, and 6 upscale calibration concentrations.

15. If the calibration results do not pass the QC criteria, consult the instrument's operating manual to troubleshoot the equipment. Take corrective actions to resolve any technical malfunctions.
16. Once resolved, repeat the adjusted calibration steps described above.
17. Once the calibration results pass the QC criteria, reconnect the sample inlet tubing to the normal configuration with the inlet flow passing through the particulate filter.
18. Conduct single point QC verification checks for zero air, a span gas concentration, and a precision gas concentration to verify any bias from the sample system. The step-by-step procedures for zero air, span, and precision are discussed in Section 6.3. The QC critical criteria as shown in the *CO Validation Template* (May 2013) in Appendix A for zero drift have been recently revised to 0.4 ppm over a 24-hour period or 0.6 ppm over a14-day period[4]. The QC critical criterion for span and precision gas checks is a difference of ±10 percent.

    IMPORTANT NOTE: These QC criteria are set as limits which, if exceeded, would result in data invalidation. To reduce the possibility of data losses, DEC has established a lower threshold limit to trigger a prompt corrective action (e.g., maintenance, recalibration). This is discussed further in Section 6.4.

19. If the results from the zero air, span, and precision checks do not pass QC criteria take corrective actions to resolve any bias errors introduced by the sample system and repeat the single-point QC checks for zero air, span, and precision.
20. Once the results pass QC criteria begin sampling ambient air and commence data collection.

6.2 Routine QC Status Verification Checks

Routinely scheduled QC checks are essential for verifying the operational status of the monitoring system and evaluating the on-going quality of the data. Unlike calibration procedures, **verification checks are conducted without prior correction** to the sample system and its components or the monitoring shelter. These QC checks range from physical inspections of the shelter and sample system to status checks of the various equipment components.

Sample System Inspection

The sample introduction system consists of:

a. sample intake;
b. (if applicable) a sampling manifold with moisture trap and blower motor;
c. gas connection from the calibration system;

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[4] USEPA Memorandum, Revision to the Zero Air Drift Acceptance Criteria in the QA Handbook, Lewis Weinstock, June 3, 2014

d. particulate filter;
e. all sample tubing within the sample flow system to the analyzer; and
f. exhaust manifold

The site operator must conduct a visual inspection of the above components during each site visit. Inspection items should include:

a. breakage, crimps, constriction of flow or discoloration in any of the tubing;
b. moisture, particulates or foreign matter deposition in the sample manifold or tubing;
c. tight, secure connections to prevent leaks;
d. exhaust manifold flow is unrestricted to the exterior of the shelter.

Any irregularities noted from the above inspections will require immediate corrective action and must be thoroughly documented in the site log.

The site operator must conduct a visual inspection of the sample system particulate filter on a regular basis to assess local dust conditions and determine the frequency of necessary filter changes. Any particulate matter accumulation that discolors of the filter material shall prompt a replacement. At a minimum, the particulate filter should be replaced on a monthly basis. A system leak check is to be performed following each change.

Monitoring Shelter Status Checks

The *CO Validation Template* as presented in Appendix A states that the monitoring shelter must incorporate a heating and cooling system to maintain temperature within a range of 15°C to 30°C[5], and have an electronic sensor connected to the DAS or some other device to record temperature data. Operational criterion for shelter temperature is based on hourly average values with a variation of less than or equal to a standard deviation of ± 2°C for a 24-hour period.

In addition to temperature control, the monitoring shelter must be kept dry, clean, well-organized and free of clutter. All instruments should be operated with electrical surge protection and preferably with a UPS or other power purification system. These systems must be included in status checks.

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[5] Due to wintertime temperature extremes, ADEC has been granted a variance of the normal QC operational criteria of 20 to 30° C to a range of 15 to 30° C.

Calibration System Status Checks

The status of the multi-gas calibrator must be checked to determine that:

- the unit power is on and the display is visible, indicating functionality;
- the current time and date are correct according to NIST-AST; and
- the unit operational mode is scheduled for the next set of automated QC performance checks.
- if a permeation device is used, it is currently certified and has the proper permeation chamber temperature and flow.

The zero air generator must be checked to insure the unit is on, the display indicates functionality, the output pressure is within acceptable limits and the moisture drain is operating and not blocked. The last change of scrubber media must be recorded and assessed for scheduled replacement.

The CO reference gas cylinder, and the ultrapure air cylinder, if used, must be checked to insure line pressure is within acceptable limits and tank pressure is adequate. To minimize the potential of introducing impurities into the system, it is recommended that cylinders be refilled when pressure drops below 100 psi.

Analyzer Status Checks

Status checks performed on the CO analyzer will vary among instrument manufacturers but in general they will include:

- power on and the display indicative of functional;
- current CO concentration from the display;
- current date and time (±1 minute of NIST-AST);
- operating access mode (set to local or remote);
- status (sample or in alarm); and
- if in alarm condition, identify the alarm parameter.

Data Acquisition System Status Checks

Operational checks of the data acquisition system (DAS) should include:

- DAS powered on and functional;
- current date correct;
- current time correct (±1 minute of NIST-AST); and
- modem and/or router operational.

Figure 5 is an example checklist for weekly operational status checks.

Figure 4. Example of a CO weekly operational checklist.

Date of Operational Checks	YYYY/MO/DD				
Time (AK Std Time in military notation)	HR:MN				
Site Operator or Technician Name	Name				
Operational Checks	**Acceptable Operating Limits**				
Shelter or Room Temperatures					
Current Temperature °C	(15 to 30 °C)				
Max Temperature °C in last 24 hrs	≤ 30 °C				
Min Temperature °C in last 24 hrs	≥ 15 °C				
Variability in last 24 hrs	SD ≤ 2° C				
Electrical Surge Protection or UPS	Yes or No				
Sample Sytem Inspection					
Sample Inlet open & debris free	Yes or No				
Sample manifold open & debris free	Yes or No				
Sample tubing open & debris free	Yes or No				
Any indication of moisture	Yes or No				
Exhaust tubing open & debris free	Yes or No				
Exhaust exterior open & debris free	Yes or No				
Calibration Gas Cylinder Pressures					
Cylinder Valve and Line Valve	Open				
Tank Pressure psig	200-2000 psig				
Line Pressure psig	25 ± 2 psig				
Teledyne/API Zero Air Generator					
Power On	On				
Output Pressure psig	20 to 25 psig				
Pressure Tank Moisture Drain	Operational				
MultiGas Calibrator					
Power On	On				
Program Mode	Flow/Conc/Auto				
Auto Cal Program Schedule	1 MO 00:00 PROG 1				
Current Date & Time	± 1 min NIST Clock (In AK Std Time)				
Permeation Chamber Temperature	±0.01° C of Set Pt. Temp				
Permeation Chamber Flow	Set Pt Flow sccm				
Date of Last Calibration	YYYY/MM/DD				
Thermo Envir. Instruments Model 48i CO Analyzer					
Power On	On with Run Display illuminated (√)				
Display Line 1 (CO Concentration)	CO ppm (##.##)				
Status Bar (Mode)	Sample or Zero or Span				
Status Bar (Time)	HR:MN in AK Std Time				
Status Bar (Alarm)	Identify ALARM				
Date of Monthly Particulate Filter Changeout	YYYY/MO/DD				
ESC Model 8800 Data Logger with Modem and Data Line					
Data Logger Power On	Power Switch On (in the up position)(√)				
Current Date & Time	± 1 min NIST Clock (In AK Std Time)				
Modem/Router Power On	Indicators Light On(√)				
Power Supply Protection					
Surge Protector	Indicators Light On(√)				
Uninterruptable Power Supply (UPS)	Indicators Light On(√)				

If any irregularities are noted in the above readings, provide a full explanation and any corrective actions take in the station logbook.

6.3 Routine QC Performance Verification Checks

The primary verification of data quality from a gaseous pollutant monitoring system is achieved by conducting performance testing using certified reference gases. The analyzer response is statistically compared to the known concentrations of the reference gases and the results demonstrate if the monitoring system is performing within required EPA quality control (QC) limits.

These checks consist of a *"Zero Air Check,"* a "*Span Check*," and a "*One-Point QC Check"*, formerly referred to as a *"precision check."* The *span check* is typically performed with a reference gas concentration of 70 to 90 percent of the instrument operating range, or at a concentration which brackets the upper end of 80 percent of the observed ambient air concentrations. The *CO Validation Template* (Appendix A) requires the one-point QC check for CO to be within the range of 0 to 5 ppm.

These performance verification checks may be conducted manually by the site operator while on-site or programmed as a function to be initiated automatically on a routine schedule.

> **IMPORTANT NOTE:** All reference gases used for performance verification checks shall be introduced (to the greatest degree practical) to the entirety of the sampling system. This will assess any zero and calibration drift by the analyzer and any systematic bias introduced from the sample system.

The step-by-step procedures for the single-point QC checks are described below.

Zero Air Check

1. Configure a certified cylinder of zero air, or program the dilution calibration system, to initiate the flow of zero air through the sample system.

> **NOTE:** Care should be taken not to over-pressurize the analyzer with reference gas. With calibration gas flow connected to the sample system near the probe inlet, an atmospheric dump is typically not required. Any excess flow of reference gas is vented out the inlet or through the sample manifold. This typical configuration is shown in Figure 2 of section 3.3.

2. Allow sufficient time for the analyzer to sample the zero air and provide a stable response. As discussed in Section 5.1, DEC recommends 10 minutes to allow the analyzer response to stabilize and the next 5 minutes to determine the average response value to be recorded.

Span Point Check

3. Configure a certified cylinder of span gas or program the dilution calibration system to initiate the flow of reference gas for the span point through the sample system.

4. Allow sufficient time for the analyzer to stabilize. Determine and record the 5-minute average response to the reference gas.

One Point QC Check

Repeat Steps 3 & 4 with the appropriate QC check gas concentration.

Zero Air Purge

Briefly purge the calibration and sample system with zero air before returning to sample mode to remove residual CO from the sample system.

Calculation of QC Performance Verification Results

The results of the zero air check are calculated by subtracting the certified concentration of the zero air reference from the analyzer response.

The results of the span point and one-point QC checks are calculated as Percent Difference as defined in 40 CFR 58, Appendix A, paragraph 4.1.1 and presented in ***Equation 5***.

Equation 5. Calculation of percent difference for one-point QC checks

$$d_i = \left[\frac{(meas - audit)}{audit}\right] * 100$$

Where,
d_i = Percent Difference (%)
meas = the average analyzer response (ppm)
audit = the concentration of the reference gas (ppm)

Performance Verification QC Limits

The acceptance limits for CO zero drift have recently been revised to a 24-hour drift of ≤ 0.4 ppm and a 14-day drift of ≤ 0.6 ppm. The acceptance limits of span drift and calibration drift at the one-point QC check are ≤ ±10 percent.

Frequency of Performance Verifications

These single-point QC verification checks are required to be performed **at a minimum of once every two weeks** but more frequent checks are highly recommended to minimize potential data invalidation. If daily checks are performed, the required interval for analyzer calibrations is reduced from once every six months to annually; however, one hour of data is lost every day a QC check is conducted. It is up to the monitoring organization to determine a frequency which is compatible with available resources and will meet data recovery goals.

In addition to routine performance checks, unscheduled checks may be conducted as a tool to diagnose problems associated with the monitoring system. For example, checks may be performed to troubleshoot the calibration system or evaluate a potential bias from the sample system.

6.4 Corrective Actions

To achieve program DQOs, the project manager, site operators, and other monitoring staff must respond whenever equipment status checks deviate from operational norms or performance QC verification results approach corrective action thresholds or fail acceptance limits. In most cases the site operator should consult the appropriate technical manuals to make adjustments, perform repairs or replace parts. Specific thresholds have been set by DEC which must trigger corrective action before the analyzer fails QC acceptance limits and data is invalidated. Figure 6 presents the DEC model for instrument drift corrective action thresholds. Any corrective actions must be thoroughly documented in the station log or electronic record to be available during audits and the data review and validation process.

Figure 5. Corrective Action Thresholds for CO Instrument Drift

Zero Drift ppm	Description of Corrective Action	Calibration Drift as d_i (%)
> +0.4 ppm over 24 hours > +0.6 ppm over 14 days	Invalidate Data, Adjust and Re-calibrate	> +10%
+ 0.3 ppm	Adjust and/or re-calibration recommended	> +7%
0 ppm	No adjustment recommended	0 %
-0.3 ppm	Adjust and/or re-calibration recommended	< - 7%
< -0.4 ppm over 24 hours < -0.6 ppm over 14 days	Invalidate Data, Adjust and Re-calibrate	< -10%

6.5 Instrument Self Adjustments

Most CO analyzers are capable of automatically adjusting zero and calibration factors following zero-air and span checks. The DEC prohibits the use of automatic calibration adjustments but considers zero adjustments to be allowable under the following conditions:

1. the zero air is introduced (to the greatest degree practical) to the entirety of the sample system,
2. the zero check is performed daily, and
3. both the unadjusted and adjusted zero response values are recorded by the DAS.

6.6 Preventative Maintenance and Station Maintenance

Maintenance procedures or activities that prevent equipment failures, costly repairs, and subsequent data losses need to be performed on a routine basis. **Figure 5** is an example of a weekly operational checklist while **Table 1** presents an example preventative maintenance schedule. Instrument manufacturer's recommended preventative maintenance procedures in the operation and service manuals should be followed. Maintenance schedules should be established for site specific SOP manuals. These activities should be performed as scheduled, or more often if status or performance verifications indicate the need.

Table 1. Example Preventative Maintenance Schedule for CO Monitoring

Preventative Maintenance Schedule	
Maintenance Activity or Procedure	**Minimum Frequency**
Sample System - Sample probe intake, down tube, manifold & tubing Visual Inspection	Weekly
Sample System - Sample probe intake, down tube, manifold & tubing Cleaning	Semi-annually
Sample System – Particulate filter inspect and replace	Weekly to monthly depending on local dust conditions
Sample System – Exhaust tubing and manifold Visual Inspection	Weekly
Sample System – Sample flow residence time verification (< 20 seconds)	Annually
Cal System – Certified reference gas cylinder pressure	Weekly – replace when pressure drops to < 200 psig
Cal System – Certified reference gas cylinder traceability certification	Recertify or replace in accordance with the certification expiration date
Cal System – Permeation device time in service	Track and replace at recommended interval (or annually)
Cal System – Permeation chamber temperature device	Recertify semiannually
Cal System – Calibrator leak check	Semi-annually
Cal System – Verification of mass flow controllers	Semi-annually
Cal System – Recertification of flow standard	Annually
Cal System – Inspection of zero air generator pressure-relief vent and moisture dump	Weekly
Cal System – Replacement of zero air scrubber materials	Semi-annually
Cal System – Verification of dry air specification with digital hygrometer for zero air generator	Semi-annually
Cal System – Compressor pump check/rebuild	Annually
Preventative Maintenance Schedule	
Maintenance Activity or Procedure	**Minimum Frequency**
Analyzer – Diagnostic indicators for voltages, temperatures, pressures, flow, etc.	Semi-annually or every calibration, recommended to be recorded by the DAS as data indicators.
Analyzer – Analog output test	Semi-annually
Analyzer – General interior visual check	Semi-annually
Analyzer – Fan filter inspection/cleaning	Semi-annually
Analyzer – Capillary inspection/replacement	Semi-annually/replace as needed
Analyzer – Leak/flow check	Semi-annually
Analyzer – Pump rebuild/replacement	Annually/as needed
Analyzer – IR Source replacement	As needed

Analyzer – Optical bench cleaning/rebuild	As needed
DAS – General interior inspection/cleaning	Annually
DAS – Cooling fan filter inspection/cleaning	Annually
DAS – Verification of channel signal input	Annually
Consumable materials and spare inventory & resupply	Semi-Annually

Station maintenance is performed on an "as needed" basis. Examples include:

- Snow removal and safe access;
- General housekeeping;
- Safety inspections & maintenance;
- Security inspections & maintenance;
- Heating and air conditioning system inspections & maintenance;
- Inspection/maintenance of weather seals around roof and wall penetrations; and,
- Weed abatement and grass cutting.

Each of these items when performed should be briefly noted in the station log.

7. DATA REVIEW, VALIDATION & REPORTING

7.1 Data Acquisition, Review, and Validation

Data may be directly downloaded from the analyzer or the on-site DAS to a laptop or other portable device, or by a telecommunication system to a base computer at the monitoring organization on a regular interval. Data must be provided and stored in 1-minute averages, which in turn are used to calculate 1-hour averages. In addition to concentration data, the data management software may also poll for performance QC results from zero, span, and one-point QC checks as well as analyzer diagnostics.

Data may be transmitted to a public-access web server to advise the public of current air quality conditions. The data are automatically processed by the server, presented as (near real-time) pollutant concentration values and used to calculate an area wide Air Quality Index (AQI) value. The webpage must include a disclaimer that the data presented are based on raw observations and have not been reviewed or validated.

Real-time data should be reviewed daily for indications of system malfunction which would require corrective action(s).

Data Validation

The first level of data validation is to accept or reject monitoring data based upon on the results of routine QC performance verification checks. The critical criteria for each zero, span, and one-point QC checks (Appendix A) must be met or all data shall be invalidated back to the last successful QC performance verification check. Anomalous data trends or status checks or analyzer diagnostic values may indicate more investigation is required to assess data validity. For each period of suspect, missing or invalid data, an explanation must be determined and documented in order to correctly edit and, if necessary, flag the data.

The DAS and data management software must record and maintain two separate memory registers of raw data; one write-protected to serve as a permanent record, and one for editing functions.

Data Editing

Data acquisition systems will identify, flag and exclude from averaging calculations any data from routine events such as zero, span, and one-point QC checks. The system may also be configured to flag episodes when data collection is interrupted such as power outages, maintenance or alarm events. However, these flagged data will be reported.

> **IMPORTANT NOTE:** Any analyzers with the capability of self-adjustments for zero drift must report the "unadjusted zero value" to determine if the QC performance verification check met QC critical criteria.

The data management software will provide a program function to edit the data either automatically triggered by a programmed event or to allow for manual edits due to data invalidations. The software will allow editing data in a batch over long periods of time or individual data averages. Most software packages will allow for data adjustment based on an input algorithm such as adjustment to the instrument linearity.

> **IMPORTANT NOTE:** In most cases, the EPA discourages post-date correction of data based on new calibration data.

The data management software shall document each edit in memory and be capable of generating an audit log record of all editing activities.

As is standard practice for all computer and software systems, adequate security and data backup precautions must be in place.

7.2 Data Precision and Bias

The statistical assessments of precision and bias are performed on the results of one-point QC checks compiled for the specified reporting period or at least on an annual basis. The statistical methods for the estimation of data precision and bias are described in 40 CFR 58, Appendix A. The EPA Data Assessment Statistical Calculator (DASC) provides a spreadsheet calculation and may be found at the following link: http://www.epa.gov/ttn/amtic/qareport.html.

7.3 Data Reporting

In the case of SLAMS, SPMS, or NCORE monitoring, it is incumbent upon the local agency and the DEC data manager to decide whether to invalidate or include any flagged data in the air monitoring database. For PSD monitoring it is incumbent on the contract project manager to report all of the original (raw) data and the finalized (flagged) data to the project director for submission to DEC.

Reports shall be submitted to DEC for SPM, NCORE, and SLAMS[6] on a monthly (or at a minimum) quarterly[7] basis. PSD data reports shall be submitted to DEC annually in accordance with the approved QAPP. The report information shall include (but is not limited to) the following QA documentation:

1. All valid or flagged 1-hour averages;
2. Minimum and maximum 1-hour and 8-hour averages and other summary statistics;
3. Data which has exceeded the full scale range of the analyzer shall be flagged and explanation(s) provided;
4. Reasons for each hour of missing/invalid/flagged data shall be identified and explained;
5. Details of all maintenance activities and any changes to instrument and standard operating procedures;
6. Results of all operator QC performance verifications for zero air, span, and one-point QC checks;
7. Results of all audits;
8. Results of all operator flow checks;
9. Results of all calibrations including the resulting calibration setting for zero background and CO calibration coefficient.
10. Copies of all certifications which establish traceability to NIST for all reference gases, materials and devices used for calibrations, QC performance verification checks, audits and other maintenance procedures;
11. Results of raw data comparison between the primary data acquisition system and a backup data acquisition system (e.g., the station DAS as compared to an instrument internal DAS, or an instrument internal DAS as compared to a chart recorder).

Further details concerning data reporting and report submissions will be covered by a separate standard operating procedure.

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[6] 40 CFR 58.16(g) only specifies SLAMS monitoring but ADEC assumes that this will be applied to NCORE sites also as NCORE recommendations are codified into requirements in the near future..

[7] 40 CFR 58.16 (b) requires that ADEC load data by the end of the next quarter (i.e., 1st quarter data, from January, February and March, must be loaded to AQS by June 30th of that year).

8. PERFORMANCE AUDIT PROCEDURES

The performance audit is the responsibility of the agency or group conducting the monitoring program. At any time, DEC may choose to conduct oversight audits of any monitoring project for which DEC is designated as the principal quality assurance organization (PQAO).

The performance audit assesses the accuracy of the monitoring system by quantitatively comparing the site CO analyzer to an independent audit system. The CO audit shall be performed using independent reference standards and equipment by an independent auditor trained and experienced in the CO method. All performance audit activities shall be conducted in accordance with 40 CFR 58, Appendix A, Section 3.2.2. .

8.1 Audit Reference Devices, Gas Standards & Auxiliary Equipment

NIST-traceable equipment and reference devices needed to conduct a CO audit include:

- A dynamic gas dilution system which blends a CO reference gas with zero air to produce audit concentrations accurate to ± 2%;
- A zero air generator which will produce dry ultra-pure zero air at a flow rate equal to or greater than 10 liters per minute;
- A calibrated time piece;
- A digital thermometer; and
- A digital barometer.

Alternatively, individual gas cylinders containing NIST-traceable, known concentrations of CO may be used. Prior to the audit, the quality of the zero air generator should be evaluated by comparing the air from the generator to the analyzer response to air from a certified cylinder of ultra-pure zero air. The EPA QC operational guidance for zero air is a CO concentration less than 0.1 ppm.

Auxiliary equipment required for the audit include:

- Two-stage brass pressure regulator with outlet valve to control gas flow from the compressed gas cylinders;
- Teflon™ tubing and compression fittings to convey audit gases;
- Appropriate tools; and
- Audit logbook.

8.2 Audit Procedures

Prior to the audit, inspect all reference devices, standard gases, and other equipment to ensure that they are in good working order and all applicable traceability certification are current. The site operator should, if possible, be present during the audit. Once on site, allow adequate time for all audit system components and gases to warm-up and equilibrate, preferably overnight.

Data recorded during a CO audit includes:

1. The manufacturer, model, and serial numbers of each of the monitoring system components as well as the specialty gas vendor, cylinder serial number, concentration, tank pressure, certification date and expiration date for each of the station reference gas cylinders. The same specifications of the audit system components and gases will also be recorded.
2. Current analyzer data for measurement range, calibration factors for zero background and calibration coefficient, signal averaging time, and date of last calibration.
3. Current room temperature from the station temperature recording device and/or the DAS, and the audit reference device. Calculate the difference in °C.
4. Current time from the monitor and the DAS and the NIST calibrated audit time piece. Calculate the difference in hours, minutes, and seconds. All monitoring time records must be maintained as Alaska Standard Time (AST).

The audit will challenge the station CO analyzer with a zero concentration and at least three upscale CO gas concentrations selected from the list of expanded audit levels (**Table 2**) as presented in the *USEPA Memorandum of November 10, 2010 Use of Expanded List of Audit Levels for Annual Performance Evaluation for* SO_2*,* NO_2*,* O_3*, and CO as Described in 40 CFR 58, Appendix A. Section 3.2.2.* The three selected audit concentrations shall bracket 80 percent of the ambient concentrations observed at the site.

To evaluate sample system bias, introduce the audit gas into the sample system at a point near the inlet, to the greatest extent practical. This will allow the audit gas to be exposed to the manifold, any connecting tubing, valves, fittings, and the particulate filter. If the audit gas is plumbed direct to the back of the analyzer an in-line atmospheric dump must be configured.

After allowing the system response to stabilize to the audit gas, record the average of the values over the next 5 minutes of both the analyzer and the DAS. Record the audit concentration from each individual audit gas cylinder or the gas blending process for comparison to the DAS 5-min average (**Equation 6**). Repeat for all points including zero.

Table 2. List of Expanded Audits Levels for CO Performance Audit

Audit Level	CO Concentration Range, ppm
1	0.020 – 0.059
2	0.060 – 0.199
3	0.200 – 0.899
4	0.900 – 2.999
5	3.000 – 7.999
6	8.000 – 15.999
7	16.000 – 30.999
8	31.000 – 39.999
9	40.000 – 49.999
10	50.000 – 60.000

5. For each upscale audit concentration, calculate a percentage difference in accordance with ***Equation 6***.

Equation 6. Calculation of percent difference for performance audits results

$$d_i = \left[\frac{(meas - audit)}{audit}\right] * 100$$

Where,
d_i = *Percent Difference (%)*
$meas = the\ averaged\ analyzer\ response\ (ppm)$
audit = the concentration of the audit gas (ppm)

Plot the audit results with audit concentration on the x-axis versus the DAS response on the y-axis, performing a least square regression analysis to generate a best-fit line of the results**.**

Equation 7. Least squares regression equation for calculation of best-fit audit line.

$$\boldsymbol{y = mx + b}$$

$$r^2 = correlation\ coefficient$$

Where:
y = the analyzer response as calculated from the best-fit regression equation
x = the audit gas concentration
m = the slope of the best-fit line
b = the y-axis intercept of the best fit line
r^2 = correlation coefficient is the measure of how close actual data are to the best-fit line

An example CO performance audit report is shown in **Figure 6**.

Figure 6. Example CO Performance Audit Report

ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION

DIVISION OF AIR QUALITY | **AIR MONITORING & QUALITY ASSURANCE PROGRAM**

Carbon Monoxide (CO) Calibration Performance Audit by Multiple Gas Cylinders

Network Agency: Municipality of Anchorage — Anchorage Air Pollution Control Authority
Site Name: Turnagain **GPS:** Latitude: 61°11.485' N Longitude: 149°56.080' W **Elevation:** 16 meters
Location: Turnagain Unitarian Universalist Church **Date:** 28-Mar-14 **Time:** 7:40-8:50 AST
Auditor: Dan Fremgen **Observer:** Matt Stichick

ANALYZER SYSTEM INFORMATION

Equipment	Make	Model Number	Serial Number	State/MOA Tag
Analyzer	Thermo	48C	48C-71762-369	R007273
Data Acquisition System	ESC	8800	1588	R007276
Strip Chart Recorder	Linear		61225	R007350
min./max. Hg Therm.	VWR			

CO Analyzer Calibration Factors

background	coefficient	Range	Avg. Time
5.18	1.042	0 - 50 ppm	30 sec

last multi-pt. calibration: 6-Jan-14
last zero/span/prec check: 21-Mar-14

Cylinder Gas Standards

Gas Type	Cyl #	Cyl Vendor	Cyl psig.	[CO ppm]	Analysis date	Cert. date	Uncertainty	Cert. by	Exp. Date
UP Air	LL10570	Scott-Marrin Inc.	1645	< 0.01	14-Sep-12			Scott-Marrin	
precision	LL10571	Scott-Marrin Inc.	1685	8.96		14-Sep-12	± 1%	Scott-Marrin	3-Sep-20
span	LL10558	Scott-Marrin Inc.	1640	39.9		14-Sep-12	± 1%	Scott-Marrin	9-Aug-20

AUDIT SYSTEM INFORMATION

Audit Standard	Mfg.	Model Number	Serial Number	Range	Accuracy	Certification Vendor	Cert. Date	Exp. Date
Temperature meter	Cole Parmer/Innocal	DigiSense 8525-00	M97008056	-30° to+40°C	±0.1°C	INNOCAL	8-Jul-13	8-Jul-14
Temperature probe	Cole Parmer/Innocal		M97008056P	-30° to+40°C	±0.1°C	INNOCAL	8-Jul-13	8-Jul-14
Pressure Device	BGI Inc.	deltaCal	1046		± 5mmHg	BGI Inc.	29-May-13	29-May-14

Cylinder Audit Gas Standards

nominal audit range	Cylinder #	Cylinder Gas Vendor	[CO ppm]	cert accuracy	cert. type	cert. date	shelf life	certification by
UP Air	JJ695	Scott-Marrin Inc.	<0.01	w 380 ppm CO_2, bal Air		12/15/2010		analysis by Scott-Marrin
3 - 8 ppm	CLM002491	Scott-Marrin Inc.	6.42	± 1%, w/ 380 ppm CO_2, balance air	Traceable 2 yrs	1/24/2013	1/24/2015	Scott-Marrin Inc.
15 - 20 ppm	JJ8566	Scott-Marrin Inc.	17.75		EPA Protocol	12/15/2010	12/15/2013	Scott-Marrin Inc.
35 - 45 ppm	JJ25889	Scott-Marrin Inc.	37.8		EPA Protocol	12/15/2010	12/15/2013	Scott-Marrin Inc.

Room Environmental Conditions					Alaska Standard Time (AST)					
Audit		Room Recording (°C)		Room-Aud	Audit Time		DAS Time		Difference (Δ)	
(mmHg)	(°C)	as found	Last 24 days	Δ (°C)	Date	hour:minute:second	Date	hour:minute:second	Date	hour:minute:second
	23.0	22.5	20.5 - 24	-0.5	28-Mar-14	8:45:21	28-Mar-14	8:46:00		0:00:39

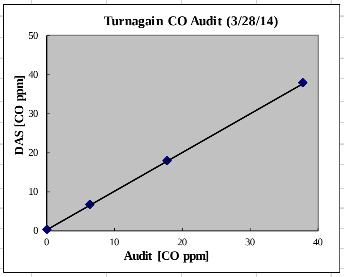
Audit Data				Analyzer/DAS Data			Difference (D)		
Cylinder Gas				DAS	Analyzer	chart recorder	DAS-Audit	Absolute (DA Aud) / Aud*1	Mean Abs % Δ
Audit Point	cylinder #	(psig)	[CO ppm]	[CO ppm]	[CO ppm]	[CO ppm]	[CO ppm]		
zero	JJ695	1000	0	0.237	0.254	0	0.2		
3 - 8 ppm	CLM002491	1800	6.42	6.625	6.63	6.6	0.21	3.2	1.1
15 - 20 ppm	JJ8566	1470	17.75	17.77	17.81	17.6	0.02	0.1	
35 - 45 ppm	JJ25889	1400	37.8	37.81	37.8	37.6	0.0	0.0	

DAS CO Data versus Audit CO Data

Linear regression equation (y = mx+b)
where:
y = analyzer's DAS reported value, [CO ppm]
x = audit true value, [CO ppm]
m = slope
b = y intercept
r^2 = correlation coefficient

CO Performance Audit Results

m = 0.99362
b = 0.21683
r^2 = 0.99999
Mean absolute % Δ = 1.1



	Audit Criteria		Performance Rating		Required Action(s)
A.	≤ ± 5% slope (m = 0.95 to 1.05)	A.	excellent	A.	none
	≤ ± 10% slope (m = 0.90 to 1.10)		acceptable		none
	± 10% ≥ slope ≤ ±15% (m = 0.85 to 1.15)		unacceptable		correct problem & recalibrate
	slope > ± 15% (m> .85 or >1.15)		unacceptable		data invalid, recalibrate
B.	y intercept ≤± 3% of analyzer full scale range	B.	acceptable	B.	none
	y intercept > ± 3% of analyzer full scale range		unacceptable		data invalid, correct problem and recalibrate
C.	correlation coefficient ≥ 0.995	C.	acceptable	C.	none
	correlation coefficient < 0.995		unacceptable		correct problem & recalibrate
D.	Analyzer/DAS Time - Audit Time ≤± 1 minute	D.	acceptable	D.	none
	Analyzer/DAS Time - Audit Time > ± 1 minute				reset DAS clock to correct AST

8.3 Acceptance Criteria and Correction Actions

The acceptance limits of QC operating criteria for CO audits are shown in the *CO Validation Templates*[8] which are presented in Appendix A. In addition to the QC operating criteria, **Table 3** presents separate categories for the audit results with corresponding performance ratings and any required corrective actions.

Table 3. Audit Results with performance ratings and corrective actions

Audit Criteria		Performance Rating		Required Action(s)	
A.	≤ ± 5% slope (m = 0.95 to 1.05)	**A.**	excellent	**A.**	none
	≤ ± 10% slope (m = 0.90 to 1.10)		acceptable		none
	± 10% ≥ slope ≤ ±15% (m = 0.85 to 1.15)		unacceptable		correct problem & recalibrate
	slope > ± 15% (m> .85 or >1.15)		unacceptable		data invalid, recalibrate
B.	y intercept ≤± 3% of analyzer full scale range	**B.**	acceptable	**B.**	none
	y intercept > ± 3% of analyzer full scale range		unacceptable		data invalid, correct problem and recalibrate
C.	correlation coefficient ≥ 0.995	**C.**	acceptable	**C.**	none
	correlation coefficient < 0.995		unacceptable		correct problem & recalibrate
D.	Analyzer/DAS Time - Audit Time ≤± 1 minute	**D.**	acceptable	**D.**	none
	Analyzer/DAS Time - Audit Time > ± 1 minute				reset DAS clock to correct AST

8.4 Frequency of Performance Audits

For SLAMS/SPMS/NCORE CO sites, each CO analyzer shall be audited once per calendar year with 25 percent of the network sites audited each calendar quarter. For PSD monitoring, all operating CO analyzers shall be audited each calendar quarter.

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[8] As revised by the USEPA Memorandum of June 3, 2014, *Revision to the Zero Drift Acceptance Criteria in the QA Handbook.*

REFERENCES

USEPA *Guidance for Preparing Standard Operating Procedures (SOPs), EPAQA/G-6,* EPA/600/B-07/001, April 2007.

Title 40 of the Code of Federal Regulations, Part 50, National Primary and Secondary Ambient Air Quality Standards.

Title 40 of the Code of Federal Regulations, Part 53, Ambient Air Monitoring Reference and Equivalent Methods.

Title 40 of the Code of Federal Regulations, Part 58, Appendix A - Quality Assurance Requirements for SLAMS, SPMS, and PSD Air Monitoring.

USEPA *Quality Assurance Handbook for Air Pollution Measurement Systems,* Volume II, Ambient Air Quality Monitoring Program, EPA-454/B-13-003, May 2013.

"Quality Assurance Project Plan for the State of Alaska Air Monitoring & Quality Assurance Program," QAPP, State of Alaska, Department of Environmental Conservation, Division of Air Quality, Air Monitoring and Quality Assurance (AMQA) program, http://www.dec.state.ak.us/air/doc/DEC_AMQA_QAPP_23FEB10-final.pdf, February 2010.

"Technical Assistance Document (TAD) For Precursor Gas Measurements in the NCORE Multi-Pollutant Monitoring Network," Version 4, EPA-454/R-05-004, U.S. EPA, September 2005.

USEPA Technology Transfer Network, Ambient Monitoring Technology Information Center, Quality Indicator Assessment Reports, *"Data Assessment Statistical Calculator (DASC) – Software to assist those in calculating precision and bias statistics and calibrations (MS Excel).* http://www.epa.gov/ttnamti1/qareport.html

USEPA Memorandum of November 10, 2010 *Use of Expanded List of Audit Levels for Annual Performance Evaluation for SO_2, NO_2, O_3, and CO as Described in 40 CFR 58, Appendix A. Section 3.2.2.*

USEPA Memorandum of February 17, 2011 *Guidance of Statistics for Use at Audit Level 1 and 2 of the Expanded List of Audit Levels for Annual Performance Evaluations for SO_2, NO_2, O_3, and CO as Described in 40 CFR 58, Appendix A, Section 3.2.2.*

USEPA Memorandum of June 3, 2014 *Revision to the Zero Drift Acceptance Criteria in the QA Handbook*

DEFINITION OF SYMBOLS & ACRONYMS

DEC	Alaska Department of Environmental Conservation
AMQA	Air Monitoring and Quality Assurance
CFR	Code of Federal Regulations
CRM	Certified Reference Material
°C	degrees Celsius
cm^3/min	cubic centimeters per minute (at ambient conditions)
EPA	U.S. Environmental Protection Agency
F_{CO}	calibration flow rate of the CO standard gas in sccm
F_D	calibration flow rate of diluent gas (zero air) in sccm.
FEM	Federal Equivalent Method
FRM	Federal Reference Method
in. Hg	inches mercury, pressure
IR	infrared radiation
LDL	lower detectable limit
MDL	method detection limit
mm Hg	millimeters mercury, pressure
NAAQS	National Ambient Air Quality Standards
NCORE	National Core Monitoring Network (multi-pollutant)
NDIR-GFC	Non-Dispersive Infrared Radiation – Gas Filter Correlation
NIST	National Institute of Standards and Technology
NIST-SRM	National Institute of Standards and Technology - Standard Reference Material
NTRM	NIST Traceable Reference Material

PEP	performance evaluation program
ppb	parts per billion
ppm	parts per million
PQAO	principal quality assurance organization
QA	quality assurance
QC	quality control
PSD	prevention of significant deterioration
sccm	standard cubic centimeter per minute (at 25° C & 760 mm Hg)
SLAMS	state and local air monitoring station
SPMS	special purpose monitoring station
CO	carbon monoxide
SOP	standard operating procedure
TAD	technical assistance document
Zero Air	dry, clean, pollutant free air

APPENDIX A: CO VALIDATION TABLE (May 2013)

CO Validation Template

1) Requirement (CO)	2) Frequency	3) Acceptance Criteria	Information / Action
CRITICAL CRITERIA-CO			
One Point QC Check Single analyzer	**1/ 2 weeks**	≤ ± 10% (percent difference)	1 & 2) 40 CFR Part 58 Appendix A Section 3.2 3) Recommendation based on DQO in 40 CFR Part 58 App. A Sec. 2.3.1. QC check conc. range 1-10 ppm relative to routine concentrations.
Zero/span check	1/ 2 weeks	Zero drift ≤ ± 0.4 ppm over 24 hours* Zero drift ≤± 0.6 ppm over 14 days* Span drift ≤ ± 10%	1 & 2) QA Handbook Volume 2 Section 12.3 3) Recommendation.
OPERATIONAL CRITERIA-CO			
Shelter Temperature Range	Daily (hourly values)	20 to 30° C. (hourly avg) Or Per manufacturer's specifications if designated to a wider temperature range.	1,2 &3) QA Handbook Volume 2 Section 7.2.2 Generally the 20-30° C range will apply but the most restrictive operable range of the instruments in the shelter may also be used as guidance. FRM/FEM list found on AMTIC provides temp. range for given instrument. FRM/FEM monitor testing is required at 20-30° C range per 40 CFR Part 53.32
Shelter Temperature Control	Daily (hourly values)	≤ ± 2° C SD over 24 hours	1, 2 &3) QA Handbook Volume 2 Section 7.2.2.
Shelter Temperature Device Check	1/ 6 mo.	± 2° C of standard	1, 2 &3) QA Handbook Volume 2 Section 7.2.2.
Annual Performance Evaluation Single Analyzer	***Every site 1/year 25% of sites quarterly***	Percent difference of audit levels 3-10 ≤ ± 15% Audit levels 1&2 ± 0.03 ppm difference or ± 15%	1 &2) 40 CFR Part 58 App. A Sec. 3.2.2. 3) Recommendation- 3-audit concentrations not including zero. AMTIC guidance 2/17/2011 http://www.epa.gov/ttn/amtic/cpreldoc.html
Federal Audits (NPAP)	1/year at selected sites 20% of sites audited.	Audit levels 1&2 ± 0.03 ppm difference all other levels percent difference ± 15%	1) 40 CFR Part 58 App. A Sec. 2.4 2) NPAP adequacy requirements on AMTIC 3) NPAP QAPP/SOP
Verification/Calibration	Upon receipt/adjustment/repair/ installation/moving 1/ 6 months if manual zero/span performed biweekly 1/ year if continuous zero/ span performed daily	All points within ± 2% of calibration range of Best-fit straight line	1) 40 CFR Part 50 Appendix C Section 4 2&3) Recommendation See details about CO_2 sensitive instruments Multi-point calibration (0 and 4 upscale points)
Gaseous Standards	All gas cylinders	NIST Traceable (e.g., EPA Protocol Gas)	1) 40 CFR Part 50 Appendix C Section 4.3.1 2) NA Green book 3) 40 CFR Part 50 Appendix C Section 4.3.1 See details about CO_2 sensitive instruments. Gas producer used must participate in EPA Ambient Air Protocol Gas Verification Program 40 CFR Part 58 App. A Sec. 2.6.1
Zero Air/Zero Air Check	1/ year	< 0.1 ppm CO	1) 40 CFR Part 50 App. C Sec. 4.3.2 2) Recommendation 3) 40 CFR Part 50 App. C Sec. 4.3.2

1) Requirement (CO)	**2) Frequency**	**3) Acceptance Criteria**	**Information / Action**
Gas Dilution Systems	1/ year or after failure of 1 point QC check or performance evaluation	Accuracy ± 2%	1, 2 &3) Recommendation based on SO2 requirement in 40 CFR Part 50 App. A-1 Sec. 4.1.2
Detection (FEM/FRMs)			
Noise	1/ year	***0.2 ppm (standard range)*** ***0.1 ppm (lower range)***	1) 40 CFR Part 53.23 (b) (definition & procedure) 2) Recommendation- info obtained from LDL 3) 40 CFR Part 53.20 Table B-1
Lower detectable level	1/ year	***0.4 ppm (standard range)*** ***0.2 ppm (lower range)***	1) 40 CFR Part 53.23 (c) (definition & procedure) 2) Recommendation 3) 40 CFR Part 53.20 Table B-1
SYSTEMATIC CRITERIA			
Sampler/ Monitor	NA	***Meets requirements listed in FRM/FEM designation***	1) 40 CFR Part 58 App. C Sec. 2.1 2) NA 3) 40 CFR Part 53 & FRM/FEM method list
Standard Reporting Units	***All data***	***Ppm (final units in AQS)***	1, 2 &3) 40 CFR Part 50.8 (a)
Rounding convention for data reported to AQS	***All data***	***1 decimal place***	1, 2 &3) 40 CFR Part 50.8 (d) (for averaging values for comparison to NAAQS, not for reporting individual hourly values.)
Completeness	***8-hour standard***	***75% of hourly averages for the 8-hour period***	1) 40 CFR Part 50.8 (c) 2) 40 CFR Part 50.8 (a-2) 3) 40 CFR Part 50.8 (c)
Sample Residence Time Verification	1/ year	< 20 seconds	1, 2 &3) Recommendation. CO not a reactive gas, but suggest following same methods of other gaseous criteria pollutants.
Sample Probe, Inlet, Sampling train	All Sites	Borosilicate glass (e.g. Pyrex®) or Teflon ®	1, 2 &3) Recommendation. CO not a reactive gas but suggest following same methods of other gaseous criteria pollutants. FEP and PFA have been accepted as an equivalent material for Teflon. Replacement/cleaning is suggested as 1/ year and more frequent if pollutant load dictates.
Siting	1/ year	***Meets siting criteria or waiver documented***	1) 40 CFR Part 58 App. E, Sec. 2-6 2) Recommendation 3) 40 CFR Part 58 App. E, Sec. 2-6
Precision (using 1-point QC checks)	***Calculated annually and as appropriate for design value estimates***	***90% CL CV ≤ 10%***	1) 40 CFR Part 58 App. A Sec. 3.2.1 2) 40 CFR Part 58 App. A Sec. 4 (b) 3) 40 CFR Part 58 App. A Sec. 4.1.2
Bias (using 1-point QA checks)	***Calculated annually and as appropriate for design value estimates***	***95% CL ≤ ± 10%***	1) 40 CFR Part 58 App. A Sec. 3.2.1 2) 40 CFR Part 58 App. A Sec. 4 (b) 3) 40 CFR Part 58 App. A Sec. 4.1.3
Annual PE Primary QA Organization (PQAO) Evaluation	1/ year	***95% of audit percent differences fall within the one point QC check 95% probability intervals at PQAO level of aggregation***	1) 40 CFR Part 58 App. A Sec. 3.2.2 2) Recommendation 3) 40 CFR Part 58 App. A Sec. 4.1.4 & 4.1.5

* As revised in the USEPA Memorandum of June 3, 2014, *Revision of to the Zero Drift Acceptance Criteria in the QA Handbook.*