Chapter 13

Quality Assessment and Statistical Analysis of Air Monitoring Data

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1.0 Introduction

On April 26, 2016, the U. S. Environmental Protection Agency (USEPA) amended its national air quality monitoring requirements and changed a number of requirements in 40 CFR Part 58 Appendix A, which describes the planning, implementation, assessment, and reporting of the ambient air monitoring quality system. One important change was a simplification of the statistical techniques used to estimate the precision and bias of the various quality control and performance evaluation checks included in Appendix A. The statistics used to estimate precision and bias (then called accuracy) were developed in the late 1970's; in 1983, the guidance document titled "*Guideline on the Meaning and Use of Precision and Accuracy Data Required by 40 CFR Part 58 Appendices A and B*" was developed to help explain the rationale for the statistics and how they were used. On October 17, 2006 the USEPA included the statistical techniques for assessing precision and bias within Appendix A of 40 CFR Part 58.

1.1 Ambient Monitoring Objectives

The USEPA's Ambient Air Quality Monitoring Program is implemented under the authority of the Clean Air Act to provide air quality data for one or more of the three following objectives:

- Provide air pollution data to the general public in a timely manner.
- Support compliance with air quality standards and emissions strategy development.
- Support air pollution research studies.

In order to support these objectives, monitoring networks are designed with a variety of monitoring sites that generally fall into the following categories:

1. Determine the highest concentrations expected to occur in the area covered by the network;
2. Determine typical concentrations in areas of high population density;
3. Determine the impact on ambient pollution levels from significant sources or source categories;
4. Determine the general background concentration levels;
5. Determine the extent of regional pollutant transport among populated areas, and in support of secondary standards; and
6. Measure the air pollution impacts on visibility, vegetation damage, or other welfare-based effects.

These different objectives can potentially require information of varying quality. USEPA recognized the importance of collecting data of acceptable and consistent quality. In the late 1970's USEPA started developing consistent techniques to identify the objectives that required the highest quality data and then to develop a set of requirements to collect and assess this measurement quality information. The USEPA embarked on the process very similar to what is now called the Data Quality Objective (DQO) Process and determined that the comparison of data to the National Ambient Air Quality Standards (NAAQS) was the highest priority objective

and that data would be collected in a manner that minimized the uncertainty in making attainment decisions. The ambient air monitoring regulations were revised in 1979 and at that time two Appendices were added:

- Appendix A- Quality Assurance Requirements for State and Local Monitoring Stations (SLAMS)
- Appendix B-Quality Assurance Requirements for Prevention of Significant Deterioration (PSD) Monitoring

These appendices established the development of a quality assurance program to be implemented at the reporting organization level of aggregation. The appendices identified quality control, audits, and performance evaluation techniques that would be implemented and established the statistical techniques to evaluate the data quality indicators (DQI). The primary DQI for the ambient air program were identified as precision and accuracy (P&A). As was written in the guidance document titled "*Guideline on the Meaning and Use of Precision and Accuracy Data Required by 40 CFR Part 58 Appendices A and B*", "the P&A statistics represented a compromise between (a) theoretical statistical exactness, and (b) simplicity and uniformity in computational procedures." The P&A statistics were aggregated by reporting organization over various time periods (e.g., annually) and combined to form a probability limit estimate.

In 1998, with the promulgation of the $PM_{2.5}$ NAAQS, USEPA formally implemented the DQO process and established acceptance criteria for precision and bias using statistics which were a departure from the statistics in the 1983 Guideline.

1.2 Data Quality Objectives

In order to provide decision makers with data of acceptable quality, USEPA uses the DQO process to determine the data quality requirements for the ambient air criteria pollutants. DQO are a full set of performance constraints needed to design an environmental data operation, including a specification of the level of uncertainty (error) that a decision maker (data user) is willing to accept in the data to which the decision will apply. The *decision maker* is the ultimate user of ambient air data and may be responsible for: setting the NAAQS, developing a quality system, evaluating the data, or comparing data to the NAAQS. The data used in these decisions are never error free and always contain some level of uncertainty.

Because of these uncertainties or errors, there is a possibility that decision makers may declare an area "nonattainment" when the area is actually in "attainment" or "attainment" when actually the area is in "nonattainment." Figures 1 and 2 illustrate how errors can affect a NAAQS attainment/nonattainment decision based on an annual mean concentration value of 15. [Note Figures 1 and 2 are from the "*Guideline on the Meaning and the Use of Precision and Bias Data Required by 40 CFR Part 58 Appendix A" (EPA-454/B-07-001, October 2007*]. There can be serious political, economic, and health consequences of making such decision errors. Therefore, decision makers need to understand and set limits on the probabilities of making incorrect decisions with these data.

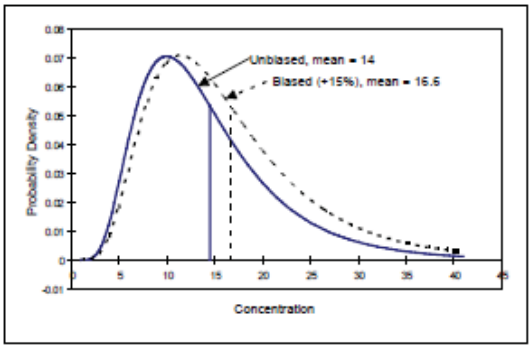

Figure 1. Effect of positive bias on the an annual average

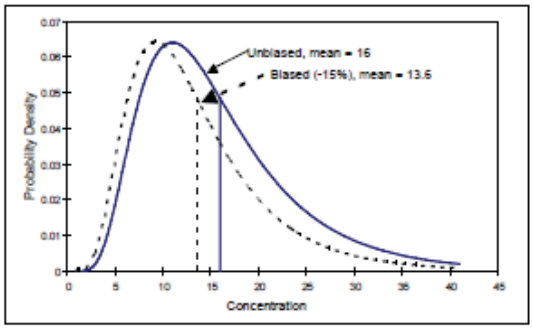

Figure 2. Effect of negative bias on the annual average.

In order to set probability limits on decision errors, one needs to understand and attempt to control uncertainty. Uncertainty is used as a generic term to describe the sum of all sources of error associated with an environmental data operation.

Uncertainty can be illustrated as follows:

$$S_o^2 = S_p^2 + S_m^2$$

Where:

S_o = overall uncertainty
S_p = population uncertainty (spatial and temporal)
S_m = measurement uncertainty (data collection)

The estimate of overall uncertainty is an important component in the DQO process. Both population and measurement uncertainties must be understood. The DQOs are assessed through the use of DQIs which are the quantitative statistics and the qualitative descriptors used to interpret the degree of acceptability or utility of data to the user. The DQIs can then be used to establish the measurement quality objectives (MQOs). Once the MQOs are established and monitoring is implemented, data quality assessments are performed to determine whether the DQOs were achieved. If not, the monitoring program should take steps to identify the major sources of uncertainty and find ways to reduce these uncertainties to the acceptable levels.

1.2.1 Data Quality Indicators

DQI associated with ambient air monitoring are:

Representativeness – The degree in which data accurately and precisely represents a characteristic of a population, parameter variation at a sampling point, a process condition, or an environmental condition.

Precision – A measure of mutual agreement among individual measurements of the same property usually under prescribed conditions. This is the random component of error. Precision is estimated by various statistical techniques using some derivation of the standard deviation.

Bias – The systematic or persistent distortion of a measurement process which causes error in one direction. Bias will be determined by estimating the positive and negative deviation from the true value as a percentage of the true value.

Detectability – The determination of the low range critical value of a characteristic that a method specific procedure can reliably discern.

Completeness – A measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under correct, normal conditions.

Comparability – A measure of confidence with which one data set can be compared to another.

Accuracy has been a term frequently used to represent closeness to "truth" and includes a combination of precision and bias error components. This term had been used throughout the CFR but has been replaced with bias when there is the ability to distinguish precision from bias.

The quality system for the ambient air monitoring program focuses on understanding and controlling, as much as possible, measurement uncertainty and because of that, mainly focuses on the DQI of precision, bias, detectability, completeness, and comparability. Representativeness is addressed through network designs and is not something that the quality system can control through better measurements.

Quantitative measurements of precision and bias for the criteria pollutants are outlined in the following sections of 40 CFR Part 58 Appendix A:

- §2.3.1.1 $PM_{2.5}$ (automated and manual)
- §2.3.1.2 O_3
- §2.3.1.3 Pb
- §2.3.1.4 NO_2
- §2.3.1.5 SO_2

Additional information on DQI can be found in the USEPA "*Quality Assurance Handbook for Air Pollution Measurement Systems" Volume II (EPA-454/B-17-001 January 2017).* This reference can be located on the USEPA website using the following URL:

https://www3.epa.gov/ttn/amtic/files/ambient/pm25/qa/Final%20Handbook%20Document%201_17.pdf

1.2.2 Measurement Quality Objectives

For each DQI a level of uncertainty or error that is acceptable must be identified that will achieve the overall DQO. MQOs are designed to evaluate and control various phases (e.g., sample preparation, sampling, and analysis) of the measurement process to ensure that total measurement uncertainty is within the range prescribed by the DQOs. Various quality control checks, like the one-point quality control check for the gaseous pollutants or the particulate matter flow rate audits, are established in Appendix A and the USEPA "*Quality Assurance Handbook for Air Pollution Measurement Systems", Volume II (EPA-454/B-17-001 January 2017).* These checks help quantify a data quality indicator and the acceptance criteria for those checks are the MQOs. Ambient air monitoring MQOs can be found in Appendix D of the *"Quality Assurance Handbook for Air Pollution Measurement Systems", Volume II (EPA-454/B-17-001 January 2017).*

1.3 Primary Quality Assurance Organization

Ambient air monitoring data is collected and can be submitted to USEPA by the reporting organization. Results from one-point quality control checks, performance evaluations, flow rate verifications, and audits are submitted to USEPA by the Primary Quality Assurance Organization (PQAO). A PQAO is defined as a monitoring organization or a coordinated aggregation of such organizations that is responsible for a set of stations that monitor the same pollutant and for which data quality assessments can logically be pooled. Each criteria pollutant sampler/monitor at a monitoring station in the SLAMS network must be associated with one, and only one, PQAO. Under the above definitions, it is possible to have a PQAO with more than one associated reporting organization.

Each PQAO shall be defined such that measurement uncertainty among all stations in the organization can be expected to be reasonably homogeneous, as a result of common factors. Common factors that should be considered by monitoring organizations in defining PQAOs include:

(a) Operation by a common team of field operators according to a common set of procedures;
(b) Use of a common QAPP or standard operating procedures;
(c) Common calibration facilities and standards;
(d) Oversight by a common quality assurance organization; and
(e) Support by a common management, laboratory, or headquarters.

PQAOs are not necessarily related to the organization reporting data to the Air Quality System (AQS).

1.4 Air Quality System

The AQS is a database administered by the USEPA to assess the status of the nation's air quality. The system includes a repository of ambient concentrations of air pollutants and associated meteorological data, and software used to provide statistical analysis of this data. Quality control checks and performance evaluation data, which assess the quality of the air pollutant data, are also contained in AQS.

The AQS performs a statistical analysis of the quality control checks and performance evaluation information to produce quantitative values for the precision and bias DQIs. In addition, AQS will calculate statistical values for completeness based on the quantity of ambient data submitted. This information can be accessed through the following AQS reports:

- AMP 600 – Certification Evaluation and Concurrence Report
- AMP 430 – Data Completeness Report
- AMP 256 – Data Quality Indicator Report

On an annual basis, USEPA summarizes the submitted criteria pollutant quality control data in a report titled "*Criteria Pollutant Quality Indicator Summary Report*." This report provides box-and-whisker graphs of all QC data submitted in the ten USEPA regions for the criteria pollutants. The reports can downloaded from USEPA at the following site:

https://www3.epa.gov/ttn/amtic/qareport.html

In addition, USEPA has a website (https://www.epa.gov/outdoor-air-quality-data) that provides access to outdoor air quality data collected from PQAOs (Federal, state, local, tribal and industrial monitoring agencies) across the United States. One of the features of the website is that one can generate monitor-level precision and bias summaries for gas parameters and comparability reports of a $PM_{2.5}$ continuous monitor collocated with an FRM sampler.

1.5 External Evaluations

The Indiana Department of Environmental Management (IDEM), Office of Air Quality (OAQ) participates in USEPA's National Performance Audit Program (NPAP) and the PM Performance Evaluation Program (PEP) program. The NPAP and PEP program provides an independent assessment of the air monitoring instrumentation used by Air Monitoring Branch (AMB). Technical systems audits of the air monitoring program are conducted by USEPA Region 5 at least every three years and results are reported to the AQS.

2.0 Gaseous Precision and Bias Assessments

2.1 One-Point Quality Control Check for SO_2, NO_2, O_3, and CO

One-point quality control (QC) checks are required to be performed once every 14 days on each analyzer used to measure SO_2, NO_2, O_3, and CO. The IDEM AMB has increased the frequency of QC checks to once every 7 days, because it has equipped all of its air monitoring stations with automated gas calibration systems. The QC check is made by challenging the analyzer with a QC check gas of known concentration between 0.005 and 0.08 parts per million (ppm) for SO_2, NO_2, and O_3, and between 0.5 and 5 ppm for CO analyzers. The ranges allow for appropriate check gas selection for sites that may have different monitoring objectives. If monitoring at an NCore site or for trace level monitoring, the QC check concentration should be selected to represent the mean or median concentrations at the site. If monitoring for NAAQS decisions, the QC concentration can be selected at a higher concentration within the prescribed range, but should also consider QC concentrations around mean or median monitor concentrations.

2.1.1 Single Analyzer 1-Point QC check

All 1-point QC checks start with a comparison of an assessment concentration (the audit concentration) to the resulting concentration measured by the analyzer (measurement concentration) and use the percent difference as the comparison statistic as described in Equation 1. For each single analyzer 1-point QC check, the percent difference, d_i**,** is calculated as follows:

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

Where, *meas* is the concentration indicated by the monitoring organization's analyzer and *audit* is the audit concentration of the standard used in the precision (QC) check being measured.

2.2 Precision Assessment

The precision estimator is used to assess the agreement of all the individual one-point QC checks for a gas parameter conducted during a prescribed time period (e.g., quarter, annual). The precision data quality indicator is estimated by the coefficient of variation (*CV*) upper bound and is calculated using Equation 2.

Equation 2:

$$CV = \sqrt{\frac{n \cdot \sum_{i=1}^{n} d_i^2 - \left(\sum_{i=1}^{n} d_i\right)^2}{n(n-1)}} \cdot \sqrt{\frac{n-1}{X^2_{0.1,n-1}}}$$

Where, *n* indicates the total number of QC checks, *i* is each individual check, $X^2_{0.1,\,n-1}$ is the 10th

percentile of a chi-squared distribution with *n-1* degrees of freedom.

2.3 Bias Assessment

The bias estimator is used to assess the systematic distortion of the overall measurement process. It is estimated using the results of the one-point QC checks for a gas parameter. The bias data quality indicator is estimated using the upper bound on the mean absolute value of the percent differences as described in Equation 3:

Equation 3:

$$|\,bias\,| = AB + t_{\,0.95,n-1} \cdot \frac{AS}{\sqrt{n}}$$

Where, n is the aggregated number of single QC checks; $t_{0.95,\,n-1}$ is the 95th quartile of a t-distribution with *n-1* degrees of freedom. The quantity *AB* (Equation 4) is the mean absolute values of all the d_i's (Equation 1), while AS is calculated using Equation 5.

Equation 4:

$$AB = \frac{1}{n} \cdot \sum_{i-1}^{n} |\,d_i\,|$$

The quantity *AS* is the standard deviation of the absolute value of the d_i's (Equation 5):

Equation 5:

$$AS = \sqrt{\frac{n \cdot \sum_{i=1}^{n} |\,d_i\,|^2 - \left(\sum_{i=1}^{n} |\,d_i\,|\right)^2}{n(n-1)}}$$

Since the bias statistic calculated in Equation 3 uses absolute values, it does not display an associated positive or negative tendency. The tendency is designated by rank ordering the percent differences, d_i, of the 1-point QC checks from a given site for a particular assessment interval and observing the positive/negative signs corresponding to the 25th and 75th percentiles. The value of the absolute bias upper bound (|bias|) should be flagged as positive if both the 25th and 75th percentiles are positive and negative if both percentiles are negative. The absolute bias upper bound would not be flagged if the 25th and 75th percentiles are of different signs.

2.4 Performance Evaluation Audits

Estimates of the "accuracy" of gas parameter methods are calculated from the results of independent performance evaluation (PE) audits. Although not required by the USEPA, the QAS recommends that all reporting agencies conduct PE audits not less than once each quarter for each analyzer. More frequent PE audits are encouraged to help troubleshoot problems and to observe the linearity of the analyzer over the whole sampling range. The audit device used for the accuracy audit must be different from the device used to calibrate the analyzer.

The updated 40 CFR Part 58 Appendix A expanded the PE audit levels from five to ten as shown in Table 1. The new PE audit levels incorporate trace level NCORE analyzer ranges along with the traditional ambient level analyzer ranges and are specific to the continuous measurements of:

- SO_2 – Sulfur Dioxide
- CO – Carbon Monoxide
- NO_2 – Nitrogen Dioxide
- O_3 – Ozone

Table 1
Performance Evaluation Concentration Levels

	Concentration Range (ppm)							
Audit	O_3		SO_2		NO_2		CO	
Level	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
1	0.0040	0.0059	0.0003	0.0029	0.0003	0.0029	0.020	0.059
2	0.006	0.019	0.0030	0.0049	0.0030	0.0049	0.600	0.199
3	0.020	0.039	0.0050	0.0079	0.0050	0.0079	0.200	0.899
4	0.040	0.069	0.0080	0.0199	0.0080	0.0199	0.900	2.999
5	0.070	0.089	0.0200	0.0499	0.0200	0.0499	3.000	7.999
6	0.090	0.119	0.0500	0.0999	0.0500	0.0999	8.000	15.999
7	0.120	0.139	0.1000	0.1499	0.1000	0.2999	16.000	30.999
8	0.140	0.169	0.1500	0.2599	0.3000	0.4999	31.000	39.999
9	0.170	0.189	0.2600	0.7999	0.5000	0.7999	40.000	49.999
10	0.190	0.259	0.8000	1.0000	0.8000	1.0000	50.000	60.000

2.4.1 Analyzer Performance Evaluation Results

Performance evaluation calculations depend on the percent difference (d_i) for each audit concentration level using Equation 1.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

Where, *meas* is the concentration indicated by the monitoring organization's analyzer and *audit* is the audit concentration of the standard used in each audit concentration level being measured.

3.0 Particulate Matter Precision and Bias Assessments

3.1 Precision Assessment from Collocated Particulate Samples

Precision, for $PM_{2.5}$, $PM_{10,}$ or Pb samplers, is estimated using concentration measurements from collocated samplers running concurrently. At low concentrations, agreement between the measurements of collocated particulate samplers, expressed as relative percent difference or percent difference, may be relatively poor. For this reason, collocated measurement pairs are selected for use in the precision calculations only when both reporting and duplicate (collocated) sampler measurements are above the concentrations listed in Table 2.

Table 2
Minimum Concentration Levels for
Particulate Matter Precision Assessments

Parameter	Limit ($\mu g/m^3$)
$PM_{2.5}$	3
PM_{10} (Lo-Vol)	3
PM_{10} (Hi-Vol)	15
Pb (methods approved prior to 3/4/10)	0.02
Pb (methods approved after 3/4/10)	0.002

For each collocated data pair, the relative percent difference, d_i, is calculated by Equation 6.

Equation 6:

$$d_i = \frac{X_i - Y_i}{(X_i + Y_i)/2} \times 100$$

Where X_i is the concentration from the primary sampler and Y_i is the concentration value from the audit (collocated) sampler.

The precision estimator is the coefficient of variation (*CV*) upper bound statistic of the relative percent differences of the collocated sampler. CV_{ub} is a standard deviation of d_i with a 90 percent upper confidence limit (Equation 7).

Equation 7:

$$CV_{ub} = \sqrt{\frac{n \cdot \sum_{i=1}^{n} d_i^2 - \left(\sum_{i=1}^{n} d_i\right)^2}{2n(n-1)}} \cdot \sqrt{\frac{n-1}{X^2_{0.1,n-1}}}$$

Where, *n* is the number of valid data pairs being aggregated, and $X^2_{0.1,\,n-1}$ is the 10th percentile of a chi-squared distribution with *n-1* degrees of freedom. The factor of 2 in the denominator adjusts for the fact that each d_i is calculated from two values with error.

3.2 Bias Assessment from One-Point Flow Rate Verification

The $PM_{2.5}$, PM_{10}, and Pb bias estimate is based upon the monthly flow rate verifications using Equation 1 to calculate the percent differences of the flow rate.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

Where, *meas* is the flow rate indicated by the particulate matter instrument and *audit* is the actual flow rate indicated by the auditing flow transfer standard.

The bias estimator is an upper bound on the mean absolute value of the percent differences as described in Equation 3:

Equation 3:

$$|\,bias\,| = AB + t_{\,0.95,n-1} \cdot \frac{AS}{\sqrt{n}}$$

Where *n* is the number of flow rate verifications being aggregated; $t_{\,0.95,n-1}$ is the 95th percentile of a t-distribution with *n-1* degrees of freedom. The quantity *AB* (Equation 4) is the mean of the absolute values of the flow rate differences d_i's (Equation 1), while AS is calculated using Equation 5:

Equation 4:

$$AB = \frac{1}{n} \cdot \sum_{i-1}^{n} |\,d_i\,|$$

The quantity *AS* is the standard deviation of the absolute value of the flow rate differences d_i's and is calculated using Equation 5 as follows:

Equation 5:

$$AS = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} |d_i|^2 - \left(\sum_{i=1}^{n} |d_i|\right)^2}{n(n-1)}}$$

Since the bias statistic as calculated in Equations 3 of this chapter using absolute values, it does not have an associated sign direction (negative or positive bias). A sign will be designated by rank ordering the percent differences of the flow rate verifications from a given site for a particular assessment interval and determining the values of the 25th and 75th percentiles of the percent differences. The absolute bias upper bound should be flagged as positive if both percentiles are positive, or negative if both percentiles are negative. The absolute bias upper bound would not be flagged if the 25th and 75th percentiles are of different signs (i.e. straddling zero).

3.3 Bias Assessment from Semi-Annual Flow Rate Audits

Flow rate audits are required to be performed on a semi-annual frequency spaced no closer than five months apart and no more than seven months apart. IDEM performs flow rate audits each calendar quarter (4 per year) using the same spacing criteria between the first and third audits, and the second and fourth audits.

The flow rate audits are used to assess the results obtained from the one-point flow rate verifications and to provide an estimate of flow rate acceptability. For each flow rate audit, calculate the percent difference using Equation 1 where *meas* is the flow rate value indicated by the particulate matter sampler and *audit* is the actual flow rate indicated by the flow transfer standard.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

The bias estimator is an upper bound on the mean absolute value of the percent differences as described in Equation 3:

Equation 3:

$$|bias| = AB + t_{0.95, n-1} \cdot \frac{AS}{\sqrt{n}}$$

Where n is the number of flow rate audits being aggregated; $t_{0.95,n-1}$ is the 95th percentile of a t-distribution with $n-1$ degrees of freedom. The quantity AB (Equation 4) is the mean of the absolute values of the flow rate differences d_i's (Equation 1), while AS is calculated using Equation 5:

Equation 4:

$$AB = \frac{1}{n} \cdot \sum_{i-1}^{n} | d_i |$$

The quantity AS is the standard deviation of the absolute value of the flow rate differences d_i's and is calculated using Equation 5 as follows:

Equation 5:

$$AS = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} | d_i |^2 - \left(\sum_{i=1}^{n} | d_i | \right)^2}{n(n-1)}}$$

Since the bias statistic as calculated in Equations 3 of this chapter using absolute values, it does not have an associated sign direction (negative or positive bias). A sign will be designated by rank ordering the percent differences of the flow rate audits from a given site for a particular assessment interval and determining the values of the 25th and 75th percentiles of the percent differences. The absolute bias upper bound should be flagged as positive if both percentiles are positive or negative if both percentiles are negative. The absolute bias upper bound would not be flagged if the 25th and 75th percentiles are of different signs (i.e. straddling zero).

4.0 Lead Analysis Bias Assessments

4.1 Lead Analysis Test Procedures

Six audit samples, comprised of three strips at each of two different concentration ranges, are required to be analyzed each quarter. These audit sample strips are prepared by depositing a Pb solution on unexposed glass fiber filter strips of dimensions 1.9 centimeters (cm) by 20.3 cm (3/4 inch by 8 inch) and allowing them to dry thoroughly (reference: Audit Method for Analysis of Lead Strips, S-064-OAQ-AMB-QA-17-T-R5). The audit samples must be prepared using batches of reagents different from those used to calibrate the Pb analytical equipment being audited. Prepare audit samples in the following concentration ranges:

Range	Pb concentration µg/strip	(Equivalent ambient Pb concentration, µg/m^3)[1]
1	9-30	.045-0.15
2	60-90	0.3-0.45

[1] Equivalent ambient Pb concentration in µg/m^3 is based on sampling at 1.7 m^3/min for 24 hours on a 20.3 cm x 25.4 cm (8 inch x 10 inch) glass fiber filter.

The lead audit samples must be extracted using the same extraction procedure used for exposed filters. The audit sample analyses shall be distributed as much as possible over the entire calendar quarter. The audit concentrations (in µg Pb/strip) and the corresponding measured concentrations (in µg Pb/strip) are reported to AQS. The relative percent differences between the concentrations are used to calculate analytical bias.

4.2 Lead Analysis Bias Assessment

For each lead strip audit, calculate the percent difference, d_i in mass by Equation 1 where *meas* is the value indicated by the mass measurement and *audit* is the actual lead mass on the audit strip.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

The absolute "mass bias" upper bound is then calculated using Equation 3 of this chapter where n is the number of lead strip audits being aggregated; $t_{0.95,n-1}$ is the 95th percentile of a t-distribution with *n-1* degrees of freedom;

Equation 3:

$$|bias| = AB + t_{0.95,n-1} \cdot \frac{AS}{\sqrt{n}}$$

Where *n* is the number of mass pairs being aggregated; $t_{0.95,n-1}$ is the 95th of a t-distribution with n-1 degrees of freedom. The quantity *AB* (Equation 4) is the mean of the absolute values of the d_i's (Equation 1), while AS is calculated using Equation 5:

Equation 4:

$$AB = \frac{1}{n} \cdot \sum_{i-1}^{n} |d_i|$$

The quantity *AS* is the standard deviation of the absolute value of the d_i's and is calculated using Equation 5 as follows:

Equation 5:

$$AS = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} |d_i|^2 - \left(\sum_{i=1}^{n} |d_i|\right)^2}{n(n-1)}}$$

Since the bias statistic as calculated in Equation 3 of this document using absolute values, it does not have an associated sign direction (negative or positive bias). A sign will be designated by rank ordering the percent differences of the mass pairs from a given site for a particular assessment interval. Calculate the 25th and 75th percentiles of the percent differences for each site. The absolute bias upper bound should be flagged as positive if both percentiles are positive or negative if both percentiles are negative. The absolute bias upper bound would not be flagged if the 25th and 75th percentiles are of different signs (i.e. straddling zero).

5.0 Site-level and Aggregated Monitors

The USEPA recommends all reporting agencies calculate parameter precision, bias, and other statistical analysis on a continuing basis. Calculate upgraded statistics after each audit for each analyzer/pollutant, and for PM_{10}, $PM_{2.5}$, and Pb, as soon as analytical results become available. Precision and bias is aggregated at the PQAO level quarterly, annually, and at the 3-year level.

Once 1-point QC checks and flow rate verification/audits are submitted to AQS, the precision and bias estimators are calculated by the AQS database and the results can be found in the AMP 256 report (see Section 1.4 of this chapter).

In addition, USEPA has prepared a Microsoft Excel spreadsheet, the Data Assessment Statistical Calculator (DASC), which calculates the precision and bias estimators at the site level, and the aggregated monitors for the quarterly, annual, and 3-year periods. The spreadsheet can be downloaded from the following USEPA website:

https://www3.epa.gov/ttn/amtic/qareport.html

6.0 NPAP and PEP Bias Assessments

6.1 NPAP Through-the-Probe (TTP) Bias Assessments

NPAP performance evaluation calculations depend on the percent difference (d_i) for each audit concentration level using Equation 1.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

Where, *meas* is the concentration indicated by the monitoring organization's analyzer and *audit* is the audit concentration of the standard used in the TTP audit.

The bias estimator is based on the mean percent difference calculated using equation 8.

Equation 8:

$$D = \frac{1}{n_j} \cdot \sum_{i-1}^{n_j} d_i$$

Where n_j is the number of audit level comparisons.

6.2 PEP $PM_{2.5}$ Bias Assessment

PEP $PM_{2.5}$ bias estimator is based on the mean percent differences using Equation 1 to calculate the percent difference (d_i) for each mass concentration.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

Where, *meas* is the concentration indicated by the monitoring organization's $PM_{2.5}$ instrument and *audit* is the $PM_{2.5}$ concentration obtained using the PEP instrument.

The bias estimator is based on the mean percent difference calculated using equation 8.

Equation 8:

$$D = \frac{1}{n_j} \cdot \sum_{i-1}^{n_j} d_i$$

Where n_j is the number of $PM_{2.5}$ mass concentration comparisons.

6.3 PEP Pb Bias Assessment

The PEP Pb bias estimate is based upon the Pb concentration differences, using Equation 1 to calculate the percent differences between the Pb concentration collected by the site Pb instrument and the PEP Pb instrument.

Equation 1:

$$d_i = \frac{meas - audit}{audit} \times 100$$

Where, *meas* is the Pb concentration collected by the site-level particulate matter instrument and *audit* is the actual Pb concentration collected by the PEP Pb particulate monitor.

The absolute bias estimator is an upper bound on the mean absolute value of the percent differences as described in Equation 3:

Equation 3:

$$|bias| = AB + t_{0.95,n-1} \cdot \frac{AS}{\sqrt{n}}$$

Where *n* is the number of paired Pb concentrations being aggregated; $t_{0.95,n-1}$ is the 95th percentile of a t-distribution with *n-1* degrees of freedom. The quantity *AB* (Equation 4) is the mean of the absolute values of the flow rate differences d_i's (Equation 1), while AS is calculated using Equation 5:

Equation 4:

$$AB = \frac{1}{n} \cdot \sum_{i-1}^{n} |d_i|$$

The quantity *AS* is the standard deviation of the absolute value of the Pb concentration differences d_i's and is calculated using Equation 5 as follows:

Equation 5:

$$AS = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} |d_i|^2 - \left(\sum_{i=1}^{n} |d_i|\right)^2}{n(n-1)}}$$

Since the bias statistic as calculated in Equations 3 of this chapter uses absolute values, it does not have an associated sign direction (negative or positive bias). A sign will be designated by rank ordering the percent differences of the Pb concentration pairs from a given site for a particular assessment interval and determining the values of the 25th and 75th percentiles of the percent differences. The absolute bias upper bound should be flagged as positive if both percentiles are positive or negative if both percentiles are negative. The absolute bias upper bound would not be flagged if the 25th and 75th percentiles are of different signs (i.e. straddling zero).

7.0 Reporting Organization Submittal of Data to AQS

Ambient data must be submitted to the IDEM Ambient Monitoring Section within 60 days after the end of the quarter. This will allow sufficient time for review before the AQS submittal deadline of 90 days after the end of each reporting calendar quarter

The IDEM, OAQ, Quality Assurance Section (IDEM, OAQ, QAS), must submit to the USEPA - AQS, within 90 days after the end of each quarter, the results of all required valid 1-point QC checks, PE audits, and flow rate audits/verifications conducted within the state during that quarter. This data is from monitoring networks operated by industries, consultants, local agencies, and IDEM. In order to meet the 90-day deadline, all QA/QC evaluation data from each reporting agency in Indiana must be submitted to the OAQ, QAS within 60 days after the end of each quarter.

All ambient and QA/QC data submittals to AQS are done electronically via the internet.

APPENDIX A - EQUATIONS

Equation 1(percent difference**):**

$$d_i = \frac{meas - audit}{audit} \times 100$$

Equation 2 (precision estimator**):**

$$CV = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} d_i^2 - \left(\sum_{i=1}^{n} d_i\right)^2}{n(n-1)}} \cdot \sqrt{\frac{n-1}{X^2_{0.1,n-1}}}$$

Equation 3 (absolute bias**):**

$$|bias| = AB + t_{0.95,n-1} \cdot \frac{AS}{\sqrt{n}}$$

Equation 4 (mean of the absolute values of the flow rate differences**):**

$$AB = \frac{1}{n} \cdot \sum_{i-1}^{n} |d_i|$$

Equation 5 (standard deviation of the absolute value**):**

$$AS = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} |d_i|^2 - \left(\sum_{i=1}^{n} |d_i|\right)^2}{n(n-1)}}$$

Equation 6 (the relative percent difference for a collocated data pair**):**

$$d_i = \frac{X_i - Y_i}{(X_i + Y_i)/2} \times 100$$

Equation 7 (Ninety percent upper confidence limit of the coefficient of variation (*CV_{ub}*) of the relative percent differences of the collocated samplers.):

$$CV_{ub} = \sqrt{\frac{n \cdot \sum_{i=1}^{n_j} d_i^2 - \left(\sum_{i=1}^{n} d_i\right)^2}{2n(n-1)}} \cdot \sqrt{\frac{n-1}{X^2_{0.1,n-1}}}$$

Equation 8 (bias estimator**):**

$$D = \frac{1}{n_j} \cdot \sum_{i-1}^{n_j} d_i$$

Appendix B – Chi-square Distribution Table

Lower-tail critical values of chi-square distribution with n-1 degrees of freedom
Probability less than the critical value

n-1	0.10	0.05	0.025	0.01	0.001
1	0.016	0.004	0.001	0.000	0.000
2	0.211	0.103	0.051	0.020	0.002
3	0.584	0.352	0.216	0.115	0.024
4	1.064	0.711	0.484	0.297	0.091
5	1.610	1.145	0.831	0.554	0.210
6	2.204	1.635	1.237	0.872	0.381
7	2.833	2.167	1.690	1.239	0.598
8	3.490	2.733	2.180	1.646	0.857
9	4.168	3.325	2.700	2.088	1.152
10	4.865	3.940	3.247	2.558	1.479
11	5.578	4.575	3.816	3.053	1.834
12	6.304	5.226	4.404	3.571	2.214
13	7.042	5.892	5.009	4.107	2.617
14	7.790	6.571	5.629	4.660	3.041
15	8.547	7.261	6.262	5.229	3.483
16	9.312	7.962	6.908	5.812	3.942
17	10.085	8.672	7.564	6.408	4.416
18	10.865	9.390	8.231	7.015	4.905
19	11.651	10.117	8.907	7.633	5.407
20	12.443	10.851	9.591	8.260	5.921
21	13.240	11.591	10.283	8.897	6.447
22	14.041	12.338	10.982	9.542	6.983
23	14.848	13.091	11.689	10.196	7.529
24	15.659	13.848	12.401	10.856	8.085
25	16.473	14.611	13.120	11.524	8.649
26	17.292	15.379	13.844	12.198	9.222
27	18.114	16.151	14.573	12.879	9.803
28	18.939	16.928	15.308	13.565	10.391
29	19.768	17.708	16.047	14.256	10.986
30	20.599	18.493	16.791	14.953	11.588
31	21.434	19.281	17.539	15.655	12.196
32	22.271	20.072	18.291	16.362	12.811
33	23.110	20.867	19.047	17.074	13.431

Lower-tail critical values of chi-square distribution with n-1 degrees of freedom
Probability less than the critical value

n-1	0.10	0.05	0.025	0.01	0.001
34	23.952	21.664	19.806	17.789	14.057
35	24.797	22.465	20.569	18.509	14.688
36	25.643	23.269	21.336	19.233	15.324
37	26.492	24.075	22.106	19.960	15.965
38	27.343	24.884	22.878	20.691	16.611
39	28.196	25.695	23.654	21.426	17.262
40	29.051	26.509	24.433	22.164	17.916
41	29.907	27.326	25.215	22.906	18.575
42	30.765	28.144	25.999	23.650	19.239
43	31.625	28.965	26.785	24.398	19.906
44	32.487	29.787	27.575	25.148	20.576
45	33.350	30.612	28.366	25.901	21.251
46	34.215	31.439	29.160	26.657	21.929
47	35.081	32.268	29.956	27.416	22.610
48	35.949	33.098	30.755	28.177	23.295
49	36.818	33.930	31.555	28.941	23.983
50	37.689	34.764	32.357	29.707	24.674
51	38.560	35.600	33.162	30.475	25.368
52	39.433	36.437	33.968	31.246	26.065
53	40.308	37.276	34.776	32.018	26.765
54	41.183	38.116	35.586	32.793	27.468
55	42.060	38.958	36.398	33.570	28.173
56	42.937	39.801	37.212	34.350	28.881
57	43.816	40.646	38.027	35.131	29.592
58	44.696	41.492	38.844	35.913	30.305
59	45.577	42.339	39.662	36.698	31.020
60	46.459	43.188	40.482	37.485	31.738
61	47.342	44.038	41.303	38.273	32.459
62	48.226	44.889	42.126	39.063	33.181
63	49.111	45.741	42.950	39.855	33.906
64	49.996	46.595	43.776	40.649	34.633
65	50.883	47.450	44.603	41.444	35.362
66	51.770	48.305	45.431	42.240	36.093
67	52.659	49.162	46.261	43.038	36.826

Lower-tail critical values of chi-square distribution with n-1 degrees of freedom
Probability less than the critical value

n-1	0.10	0.05	0.025	0.01	0.001
68	53.548	50.020	47.092	43.838	37.561
69	54.438	50.879	47.924	44.639	38.298
70	55.329	51.739	48.758	45.442	39.036
71	56.221	52.600	49.592	46.246	39.777
72	57.113	53.462	50.428	47.051	40.519
73	58.006	54.325	51.265	47.858	41.264
74	58.900	55.189	52.103	48.666	42.010
75	59.795	56.054	52.942	49.475	42.757
76	60.690	56.920	53.782	50.286	43.507
77	61.586	57.786	54.623	51.097	44.258
78	62.483	58.654	55.466	51.910	45.010
79	63.380	59.522	56.309	52.725	45.764
80	64.278	60.391	57.153	53.540	46.520
81	65.176	61.261	57.998	54.357	47.277
82	66.076	62.132	58.845	55.174	48.036
83	66.976	63.004	59.692	55.993	48.796
84	67.876	63.876	60.540	56.813	49.557
85	68.777	64.749	61.389	57.634	50.320
86	69.679	65.623	62.239	58.456	51.085
87	70.581	66.498	63.089	59.279	51.850
88	71.484	67.373	63.941	60.103	52.617
89	72.387	68.249	64.793	60.928	53.386
90	73.291	69.126	65.647	61.754	54.155
91	74.196	70.003	66.501	62.581	54.926
92	75.100	70.882	67.356	63.409	55.698
93	76.006	71.760	68.211	64.238	56.472
94	76.912	72.640	69.068	65.068	57.246
95	77.818	73.520	69.925	65.898	58.022
96	78.725	74.401	70.783	66.730	58.799
97	79.633	75.282	71.642	67.562	59.577
98	80.541	76.164	72.501	68.396	60.356
99	81.449	77.046	73.361	69.230	61.137
100	82.358	77.929	74.222	70.065	61.918

Information from the *NIST Engineering Statistics Handbook* http://www.itl.nist.gov/div898/handbook/eda/section3/eda3674.htm

Appendix C – Student's t Distribution Table

Critical values of Student's t distribution with n-1 degrees of freedom
Probability less than the critical value (t_{1-a}, n-1)

n-1	0.9	0.95	0.975	0.99	0.995	0.999
1	3.078	6.314	12.706	31.821	63.657	318.313
2	1.886	2.920	4.303	6.965	9.925	22.327
3	1.638	2.353	3.182	4.541	5.841	10.215
4	1.533	2.132	2.776	3.747	4.604	7.173
5	1.476	2.015	2.571	3.365	4.032	5.893
6	1.440	1.943	2.447	3.143	3.707	5.208
7	1.415	1.895	2.365	2.998	3.499	4.782
8	1.397	1.860	2.306	2.896	3.355	4.499
9	1.383	1.833	2.262	2.821	3.250	4.296
10	1.372	1.812	2.228	2.764	3.169	4.143
11	1.363	1.796	2.201	2.718	3.106	4.024
12	1.356	1.782	2.179	2.681	3.055	3.929
13	1.350	1.771	2.160	2.650	3.012	3.852
14	1.345	1.761	2.145	2.624	2.977	3.787
15	1.341	1.753	2.131	2.602	2.947	3.733
16	1.337	1.746	2.120	2.583	2.921	3.686
17	1.333	1.740	2.110	2.567	2.898	3.646
18	1.330	1.734	2.101	2.552	2.878	3.610
19	1.328	1.729	2.093	2.539	2.861	3.579
20	1.325	1.725	2.086	2.528	2.845	3.552
21	1.323	1.721	2.080	2.518	2.831	3.527
22	1.321	1.717	2.074	2.508	2.819	3.505
23	1.319	1.714	2.069	2.500	2.807	3.485
24	1.318	1.711	2.064	2.492	2.797	3.467
25	1.316	1.708	2.060	2.485	2.787	3.450
26	1.315	1.706	2.056	2.479	2.779	3.435
27	1.314	1.703	2.052	2.473	2.771	3.421
28	1.313	1.701	2.048	2.467	2.763	3.408
29	1.311	1.699	2.045	2.462	2.756	3.396
30	1.310	1.697	2.042	2.457	2.750	3.385
31	1.309	1.696	2.040	2.453	2.744	3.375
32	1.309	1.694	2.037	2.449	2.738	3.365
33	1.308	1.692	2.035	2.445	2.733	3.356
34	1.307	1.691	2.032	2.441	2.728	3.348

Critical values of Student's t distribution with n-1 degrees of freedom
Probability less than the critical value (t_{1-a}, n-1)

n-1	0.9	0.95	0.975	0.99	0.995	0.999
35	1.306	1.690	2.030	2.438	2.724	3.340
36	1.306	1.688	2.028	2.434	2.719	3.333
37	1.305	1.687	2.026	2.431	2.715	3.326
38	1.304	1.686	2.024	2.429	2.712	3.319
39	1.304	1.685	2.023	2.426	2.708	3.313
40	1.303	1.684	2.021	2.423	2.704	3.307
41	1.303	1.683	2.020	2.421	2.701	3.301
42	1.302	1.682	2.018	2.418	2.698	3.296
43	1.302	1.681	2.017	2.416	2.695	3.291
44	1.301	1.680	2.015	2.414	2.692	3.286
45	1.301	1.679	2.014	2.412	2.690	3.281
46	1.300	1.679	2.013	2.410	2.687	3.277
47	1.300	1.678	2.012	2.408	2.685	3.273
48	1.299	1.677	2.011	2.407	2.682	3.269
49	1.299	1.677	2.010	2.405	2.680	3.265
50	1.299	1.676	2.009	2.403	2.678	3.261
51	1.298	1.675	2.008	2.402	2.676	3.258
52	1.298	1.675	2.007	2.400	2.674	3.255
53	1.298	1.674	2.006	2.399	2.672	3.251
54	1.297	1.674	2.005	2.397	2.670	3.248
55	1.297	1.673	2.004	2.396	2.668	3.245
56	1.297	1.673	2.003	2.395	2.667	3.242
57	1.297	1.672	2.002	2.394	2.665	3.239
58	1.296	1.672	2.002	2.392	2.663	3.237
59	1.296	1.671	2.001	2.391	2.662	3.234
60	1.296	1.671	2.000	2.390	2.660	3.232
61	1.296	1.670	2.000	2.389	2.659	3.229
62	1.295	1.670	1.999	2.388	2.657	3.227
63	1.295	1.669	1.998	2.387	2.656	3.225
64	1.295	1.669	1.998	2.386	2.655	3.223
65	1.295	1.669	1.997	2.385	2.654	3.220
66	1.295	1.668	1.997	2.384	2.652	3.218
67	1.294	1.668	1.996	2.383	2.651	3.216

Critical values of Student's t distribution with n-1 degrees of freedom

Probability less than the critical value (t_{1-a}, n-1)

n-1	0.9	0.95	0.975	0.99	0.995	0.999
68	1.294	1.668	1.995	2.382	2.650	3.214
69	1.294	1.667	1.995	2.382	2.649	3.213
70	1.294	1.667	1.994	2.381	2.648	3.211
71	1.294	1.667	1.994	2.380	2.647	3.209
72	1.293	1.666	1.993	2.379	2.646	3.207
73	1.293	1.666	1.993	2.379	2.645	3.206
74	1.293	1.666	1.993	2.378	2.644	3.204
75	1.293	1.665	1.992	2.377	2.643	3.202
76	1.293	1.665	1.992	2.376	2.642	3.201
77	1.293	1.665	1.991	2.376	2.641	3.199
78	1.292	1.665	1.991	2.375	2.640	3.198
79	1.292	1.664	1.990	2.374	2.640	3.197
80	1.292	1.664	1.990	2.374	2.639	3.195
81	1.292	1.664	1.990	2.373	2.638	3.194
82	1.292	1.664	1.989	2.373	2.637	3.193
83	1.292	1.663	1.989	2.372	2.636	3.191
84	1.292	1.663	1.989	2.372	2.636	3.190
85	1.292	1.663	1.988	2.371	2.635	3.189
86	1.291	1.663	1.988	2.370	2.634	3.188
87	1.291	1.663	1.988	2.370	2.634	3.187
88	1.291	1.662	1.987	2.369	2.633	3.185
89	1.291	1.662	1.987	2.369	2.632	3.184
90	1.291	1.662	1.987	2.368	2.632	3.183
91	1.291	1.662	1.986	2.368	2.631	3.182
92	1.291	1.662	1.986	2.368	2.630	3.181
93	1.291	1.661	1.986	2.367	2.630	3.180
94	1.291	1.661	1.986	2.367	2.629	3.179
95	1.291	1.661	1.985	2.366	2.629	3.178
96	1.290	1.661	1.985	2.366	2.628	3.177
97	1.290	1.661	1.985	2.365	2.627	3.176
98	1.290	1.661	1.984	2.365	2.627	3.175
99	1.290	1.660	1.984	2.365	2.626	3.175
100	1.290	1.660	1.984	2.364	2.626	3.174
∞	1.282	1.645	1.960	2.326	2.576	3.090

Information from the *NIST Engineering Statistics Handbook* http://www.itl.nist.gov/div898/handbook/eda/section3/eda3672.htm