Appendix A

Statistical Techniques Employed in Atmospheric Sampling

A.1 Introduction

Proper use of statistics and statistical techniques is necessary for assessing the quality of ambient air sampling data. For a comprehensive discussion of the subject of data quality assessment (DQA), review EPA's technical assistance document, Guidance for Data Quality Assessment, Practical Methods of Data Analysis, EPA QA/G-9 (EPA/600/R-96/084), January 1998. This reference document provides practical demonstrations on how to use the data quality assessment (DQA) technique in evaluating environmental data sets and shows how to apply some graphic and statistical tools for performing DQA.

This chapter is intended as an introduction to statistics and statistical concepts and their use in analyzing ambient air sampling data. Topics addressed include: (a) Data Quality Objectives (DQO), (b) Data Plotting, (c) Measures of Central Tendency, (d) Measures of Dispersion, and (e) Distribution Curves. Although these topics are not simple, they can be understood and used by non-statisticians. If a detailed statistical analysis of data is required, it is recommended that an experienced statistician be consulted.

Students who could benefit from a review of basic mathematics in ambient monitoring are encouraged to access the EPA Air Pollution Training Institute course, SI 100: Mathematics Review for Air Pollution Control. This self-instruction course can be found at:

http://yosemite.epa.gov/oaqps/EOGtrain.nsf/DisplayView/SI_100_0-5?OpenDocument

In addition, the University of Illinois-Chicago, School of Public Health-Environmental and Occupational Health Division, has developed an Internet-based program entitled "Introduction to Environmental Statistics." This program is presented as a video series in three modules on topics which include interpreting monitoring data, sampling and analytical limitations and sample detection limits, and quality assurance and quality control. This program can be found at: http://www.uic.edu/sph/eohs_webcasts.htm.

It is important to note that the statistical calculations discussed in this Appendix are best and more easily performed by employing one of many commercially available computer-based statistical software packages.

A.2 The Data Quality Objectives (DQO) Process

While the Data Quality Objectives (DQO) Process is not a statistical technique *per se*, it is important because it helps to establish criteria for data quality and the development of data collection designs. DQOs provide the appropriate context for understanding the purpose of the ambient air sampling and analysis data collection effort. Also, they establish the qualitative and quantitative criteria for assessing the quality of the collected data set, based on the predefined intended use of data. Specific information on the Data Quality Objectives Process can be found in EPA document, "Guidance on Systematic Planning Using the Data Quality Objective Process" (EPA QA/G-4), at: http://www.epa.gov/quality/qs-docs/g4-final.pdf.

DQOs are qualitative and quantitative statements derived from the outputs of the first six steps of the DQO Process that encompass the following:

- Clarify the study objective.
- Define the most appropriate type of data to collect.
- Determine the most appropriate conditions from which to collect the data.
- Specify tolerable limits on decision errors which will be used as the basis for establishing the quantity and quality of data needed to support the decision.

The DQOs are then used to develop a scientific and resource-effective data collection design.

The Seven Steps of the DQO Process

Step 1: *State the Problem*. Concisely describe the problem to be studied. Review prior studies and existing information to gain a sufficient understanding to define the problem.

Step 2: *Identify the Goal of the Study*. Identify what questions the study will attempt to answer.

Step 3: *Identify Information Inputs*. Identify the information that needs to be obtained and the measurements that need to be taken to resolve the decision statement.

Step 4: *Define Boundaries of the Study*. Specify the time periods and spatial area to which decisions will apply. Determine when and where data should be collected.

Step 5: *Develop the Analytical Approach*. Define the statistical parameters of interest, specify the action level, and integrate the previous DQO outputs into a single statement that describes the logical basis for choosing among alternative actions.

Step 6: *Specify the Performance or Acceptance Criteria*. Define the decision maker's tolerable decision error rates based on a consideration of the consequences of making an incorrect decision.

Step 7: *Develop the Plan for Obtaining Data*. Evaluate information from the previous steps and generate alternative data collection designs. Choose the most resource-effective design that meets all DQOs.

Outputs of the DQO Process

The DQO Process leads to the development of a quantitative and qualitative framework for a study. Each step of the Process derives valuable criteria that will be used to establish the final data collection design. The first five steps of the DQO Process identify mostly qualitative criteria, such as what problem has initiated the study and what decision it attempts to resolve. These steps also define the type of data that will be collected, where and when the data will be collected, and a decision rule that specifies how the decision will be made.

The sixth step defines quantitative criteria expressed as limits on decision errors that the decision maker can tolerate.

The final step is used to develop a data collection design based on the criteria developed in the first six steps. The final product of the DQO Process is a data collection design that meets the quantitative and qualitative needs of the study.

A.3 Data Collection Design

A data collection design specifies the final configuration of the environmental monitoring or measurement effort required to satisfy the DQOs. It designates:

- the types and quantities of samples or monitoring information to be collected;
- where, when, and under what conditions they should be collected;
- what variables are to be measured; and
- QA/QC procedures to ensure that sampling design and measurement errors are controlled sufficiently to meet the tolerable decision error rates specified in the DQOs.

Data Plotting

Data is usually uninterpretable in the form in which it is collected. In this section, we shall consider the graphical techniques of summarizing such data so that the meaningful information can be extracted from it. There are two kinds of variables to which we assign data: continuous variables and discrete variables.

A continuous variable is one that can assume any value in some interval of values. Examples of continuous variables are weight, volume, length, time, and temperature. Most air pollution data are taken from continuous variables. Discrete variables, on the other hand, are those variables whose possible values are integers. Therefore, they involve counting rather than measuring. Examples of discrete variables are the number of sample stations, number of people in a room, and number of times a control standard is violated. Since any measuring device is of limited accuracy, measurements in real life are actually discrete in nature rather than continuous, but this should not keep us from regarding such variables as continuous. When a weight is recorded as 165 pounds, it is assumed that the actual weight is somewhere between 164.5 and 165.5 pounds.

A.4 Graphical Analysis

Frequency Tables

Let us consider the set of data in Table A-1, which represents SO_2 levels for a given hour for 25 days. The first step in summarizing the data is to form a frequency table. A frequency table is a table prepared by dividing a data set into selected units or class intervals, then counting and inserting the number of points (frequency of occurrences) within the units or class intervals. Table A-2 is a frequency table prepared from the SO_2 data set given in Table A-1.

In constructing the frequency table, we have divided the 25 points in the data set into 11 class intervals with each interval being 15 units in length. The choice of dividing the data into 11 intervals was purely arbitrary. However, in dealing with data it is best to choose the length of the class interval such that 8 to 15 intervals will include all of the data under consideration. Deriving the frequency of occurrence column involves nothing more than counting the number of values in each interval. The relative frequency column is obtained by dividing the number of points or frequency of occurrences within a unit by the total number of events within the data set, which in this example is 25.

From observation of the frequency table, we can now see the data taking form. The values appear to be clustered between 25 and 85 ppb. In fact, nearly 80% are in this interval.

Table A-1. SO_2 levels.

Days	SO_2 Concentration (ppb)*
1	53
2	72
3	59
4	45
5	44
6	85
7	77
8	56
9	157
10	83
11	120
12	81
13	35
14	63
15	48
16	180
17	94
18	110
19	51
20	47
21	55
22	43
23	28
24	38
25	26

*ppb = parts per billion collected SO_2 levels.

Table A-2. Frequency table.

Class Interval (ppb)	Frequency of Occurrence (total 25)	Relative Frequency
25 - 40	4	4/25 = 0.16
40 - 55	7	7/25 = 0.28
55-70	4	4/25=0.16
70-85	4	4/25=0.16
85 - 100	2	2/25 = 0.08
100-115	1	1/25=0.04
115-130	1	1/25=0.04
130 - 145	0	0.00
145 - 160	1	1/25 = 0.04
160 - 175	0	0.00
175 - 190	1	0.04

The Frequency Polygon

The next step is to graph the information in the frequency table. One way of doing this would be to plot the frequency for the midpoint of each class interval. The solid line connecting the points of Figure A-1 forms a frequency polygon.

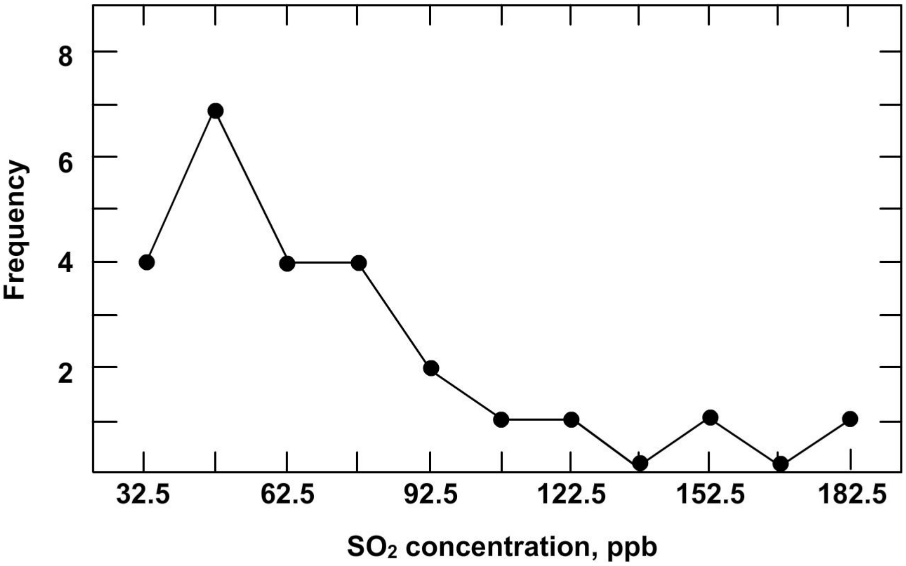

Figure A-1. Pollution concentration (midpoint of class interval) frequency polygon.

The Histogram

Another method of graphing the information would be by constructing a histogram as shown in Figure A-2. The histogram is a two-dimensional graph in which the length of the class interval is taken into consideration. The histogram can be a very useful tool in statistics, especially if we convert the given frequency scale to a relative scale so that the sum of all the ordinates equals one. This is shown in Figure A-3. Thus, each ordinate value is derived by dividing the original value by the number of observations in the sample, in this case, 25.

The advantage in constructing a histogram like this one is that we can read probabilities from it, if we can assume a scale on the abscissa such that a given value will fall in any one interval in the area under the curve in that interval. For example, the probability that a value will fall between 55 and 70 is equal to its associated interval's portion of the total area of intervals, which is 0.16.

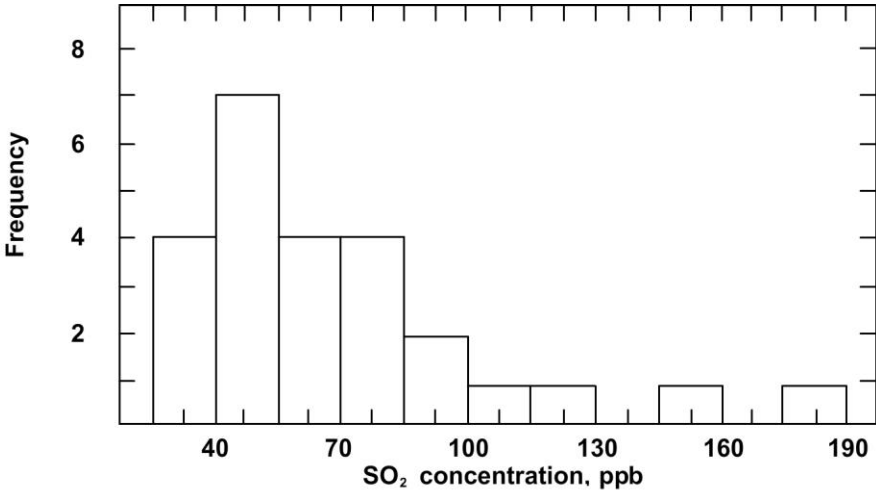

Figure A-2. Pollutant concentration histogram of frequency distribution curve.

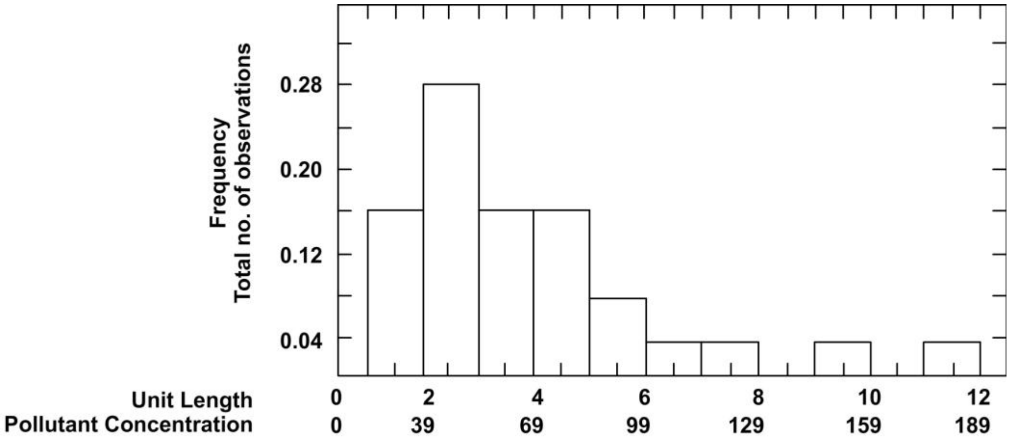

Figure A-3. Histogram of percent frequency distribution curve.

The Cumulative Frequency Distribution

Using the frequency table and histogram discussed above, we can construct a cumulative frequency table and curve as shown in Table A-3 and Figure A-4.

Table A-3. Cumulative frequency table.

SO_2 level		Cumulative frequency	Relative cumulative frequency
Under	40	4	0.16
”	55	11	0.44
”	70	15	0.60
”	85	19	0.76
”	100	21	0.84
”	115	22	0.88
”	130	23	0.92
”	145	23	0.92
”	160	24	0.96
”	175	24	0.96
”	190	25	1.00

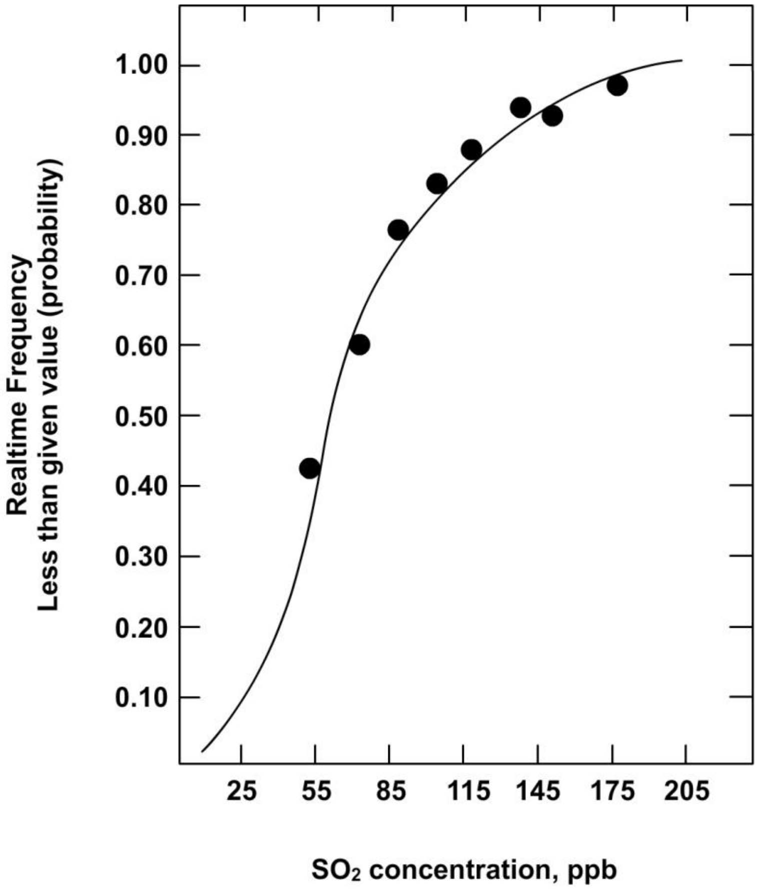

Figure A-4. Cumulative frequency distribution curve.

The cumulative frequency table gives the number of observations less than a given value. Probabilities can be read from the cumulative frequency curve or cumulative frequency table. For example, to find the probability that a value will be less than 85, we read up to the curve at the point $x = 85$ and across to the value 0.76 on the y-axis. An alternative way to use the table is to go to the row where the SO_2 level shows under 85, then go across to the relative cumulative frequency value of 0.76.

Distribution of Data

When we draw a histogram for a set of data, we are representing the distribution of the data. Different sets of data will vary in relation to one another and, consequently, their histograms will look different. In this chapter, we identify three characteristics that will distinguish the distributions of different sets of data. These are central location, dispersion, and skewness. These are characterized in Figure A-5. Curves A and B have the same central location, but B is more dispersed. However, both A and B are symmetrical and are, therefore, said not to be skewed. Curve C is skewed to the right and has a different central location than A and B. Mathematical measures of central location and dispersion will be discussed later.

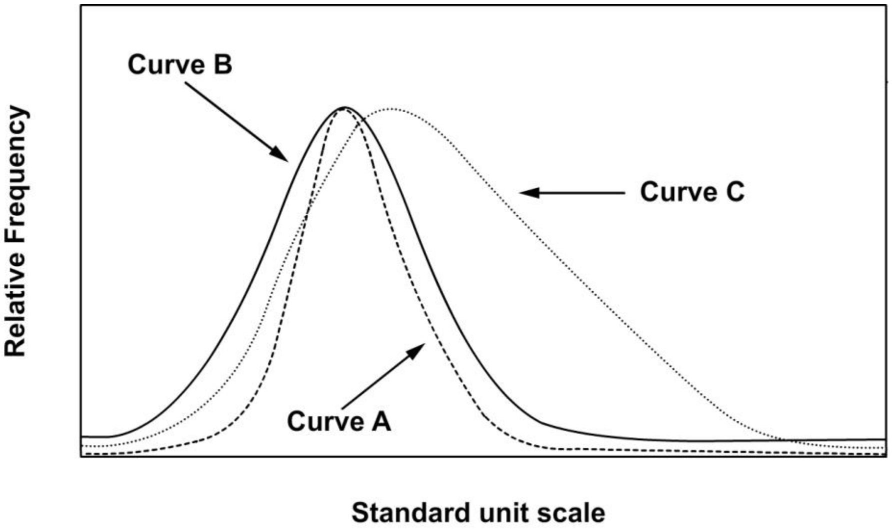

Figure A-5. Relative frequency distribution showing: Curve A and B both centrally located, Curve B being more dispersed than Curve A, and the skewness of Curve C.

Transformation of Data

In most statistical work, data that closely approximate a particular symmetrical curve, called the normal curve, are required. Both curves A and B in Figure A-5 are examples of normal curves. In dealing with skewed curves, such as C in the same figure, it is desirable to transform the data in some way so that a symmetrical curve resembling the normal curve is obtained. Referring to the frequency table (Table A-2) and histogram (Figure A-2) of the data used earlier, it can be seen that for this set of data, the distribution is skewed (in the opposite direction as Curve C above), hence the data are not normally distributed.

The Logarithmic Transformation

One of the most successful ways of deriving a symmetrical distribution from a skewed distribution is by expressing the original data in terms of logarithms. The logarithms of the original data are given in Table A-4.

Arbitrarily dividing the logarithmic data into nine class intervals, each of 0.1 unit in length, we can prepare the logarithmic frequency table in Table A-5. As can be seen in Figure A-6, a frequency plot of the log transformed data more closely approximates a symmetrical curve than the arithmetic plot of the original data.

Table A-4. Logarithmic transformation.

Day	Pollutant conc. X	$\mathrm{Log}_{10}X$
1	53	1.724
2	72	1.857
3	59	1.771
4	45	1.653
5	44	1.644
6	85	1.929
7	77	1.887
8	56	1.748
9	157	2.196
10	83	1.919
11	120	2.079
12	81	1.909
13	35	1.544
14	63	1.799
15	48	1.681
16	180	2.255
17	94	1.973
18	110	2.041
19	51	1.708
20	47	1.672
21	55	1.740
22	43	1.634
23	28	1.447
24	38	1.580
25	26	1.415

Table A-5. Logarithmic frequency table.

Class interval	Frequency of occurrence	Cumulative frequency	Relative cumulative frequency
1.4 - 1.5	2	2	0.08
1.5 - 1.6	2	4	0.16
1.6 - 1.7	5	9	0.36
1.7 - 1.8	6	15	0.60
1.8 - 1.9	2	17	0.68
1.9 - 2.0	4	21	0.84
2.0 - 2.1	2	23	0.92
2.1 - 2.2	1	24	0.96
2.2 - 2.3	1	25	1.00

Probability Graph Paper

Probability graph paper is used in the analysis of cumulative frequency curves; for example, the graph paper can be used as a rough test of whether the arithmetic or the logarithmic scale best approximates a normal distribution. The scale, arithmetic or logarithmic, on which the cumulative frequency distribution of the data is more nearly a straight line, is the one providing the better approximation to a normal distribution. Plotting the cumulative distribution curve of the data above on the two scales shows that the logarithmic scale yields the better fit (Figure A-6).

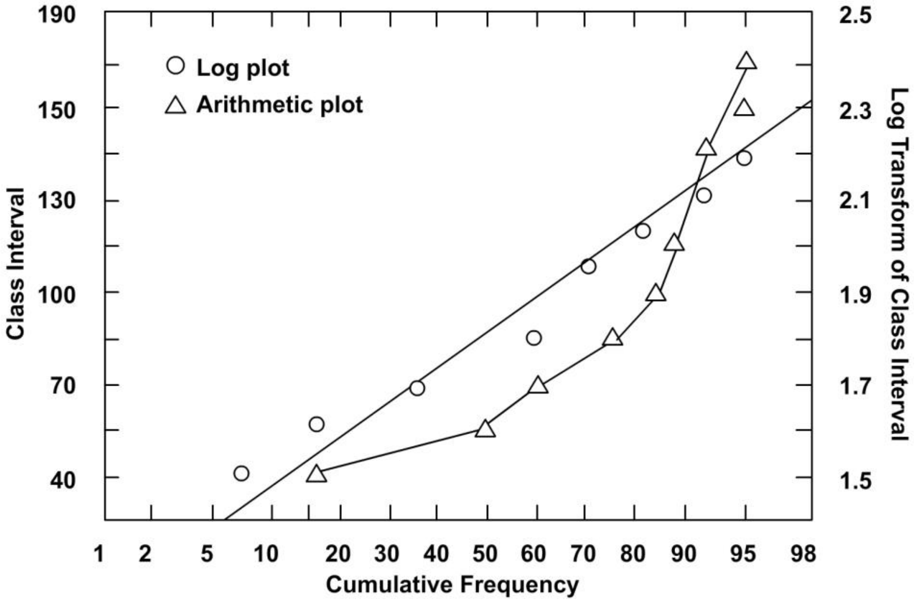

Figure A-6. Normalized data plot vs. non-transformed data.

These probability plots can be used, if the data are normally distributed, to estimate the mean and standard deviation of the data. The estimate of the mean, as will be shown later, is the 50th percentile point, and the estimation of the standard deviation is the distance from the 50th percentile to the 16th percentile. A percentile is a measure of the relative position of one of several observations in relation to all of the observations, and provides a measure of relative standing that is useful for summarizing data.

Least-Square Linear Regression

If the linear relationship between two variables is significant, a least-square linear regression line, or line of "best fit," may be drawn to represent the data. This relationship can then be used to determine the value of an unknown variable. For example, if the ambient air concentration is unknown, but linearly related to the response of an ambient air monitor, we can estimate the ambient air concentration based on an observed response from the air monitor. Algebraically, a straight line has the following form:

(Eq. A-1)
$$y = mx + b$$

Where:
y = *dependent variable plotted on the ordinate (y-axis)*
x = *explanatory variable (independent variable) plotted on the abscissa (x-axis)*
b = *the point at which the line intercepts the y-axis at $x = 0$*
m = *slope, which shows how much of a change of 1 unit of x affects y*

Linear regression minimizes the vertical distance between all data points and the straight line (Figure A-7).

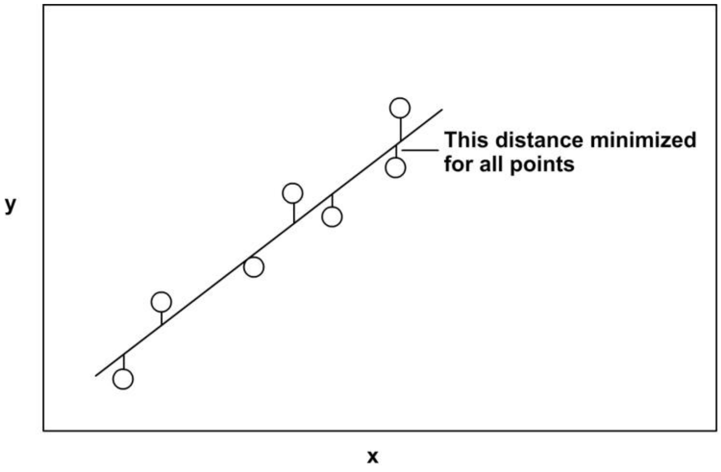

Figure A-7. Linear regression curve.

The constants *m* and *b* for the "least-square" line can be determined using the following equations:

(Eq. A-2)

$$m = \frac{\sum xy - \frac{\left(\sum x\right)\left(\sum y\right)}{n}}{\sum x^2 - \frac{\left(\sum x\right)^2}{n}}$$

(Eq. A-3)

$$b = \bar{y} - m\bar{x}$$

Where: n = *number of observations*

$\bar{y} = \sum y/n; \bar{x} = \sum x/n$

Example Problem

Calibration of an ambient air analyzer is required before it can be used to provide reliable ambient air concentration measurements. A typical calibration consists of the introduction of known and certified standard concentrations, typically in parts per million (ppm) over the linear operational range of the instrument, and the recording of the corresponding response of the instrument in units such as volts. Based on the recorded responses and the known concentrations, a least-square linear relationship between the variables can be calculated and subsequently used to determine ambient concentrations based on the response of the analyzer. The following data were collected during a calibration of a chemiluminescent NO_X analyzer.

x = Concentration NO_x (ppm)	0.05	0.10	0.20	0.30	0.45
y = Instrument response (volts)	1.20	2.15	3.90	6.20	9.80

Values for m and b for the least-square or "best fit" line can be calculated from: $\sum x$, $\sum y$, $\sum x^2$, $\sum xy$, n, $\bar{y}$, and $\bar{x}$.

Solution:

$$\sum x = 0.05 + 0.10 + 0.20 + 0.30 + 0.45 = 1.1$$

$$\sum y = 1.20 + 2.15 + 3.90 + 6.20 + 9.80 = 23.25$$

$$\sum x^2 = (0.05)^2 + (0.10)^2 + (0.20)^2 + (0.30)^2 + (0.45)^2 = 0.345$$

$$\sum xy = (0.05)(1.20) + (0.10)(2.15) + (0.20)(3.90) + (0.30)(6.20) + (0.45)(9.80) = 7.33$$

$$n = 5$$

$$\bar{x} = \frac{\sum x}{n} = \frac{1.1}{5} = 0.22$$

$$\bar{y} = \frac{\sum y}{n} = \frac{23.25}{5} = 4.65$$

$$m = \frac{7.33 - \frac{(1.1)(23.25)}{5}}{0.345 - \frac{(1.1)^2}{5}} = \frac{2.22}{0.103} = 21.6$$

$$b = 4.65 - (21.6)(0.22) = -0.102$$

The equation for this calibration curve would be y = 21.6x – 0.102, where y (the instrument response in volts) is equal to the ambient concentration in ppm times the slope of the line which is 21.6, plus the y-intercept of x, which is 0.102.

To calculate ambient concentrations in ppm, we solve the equation for x:

$$x(ppm) = \frac{y - b}{m}$$

$$x(ppm) = \frac{y + 0.102}{21.6}$$

A.5 Measures of Central Tendency

Arithmetic Average, or Mean

A basic way of summarizing data is by the computation of a central value. The most commonly used central value statistic is the arithmetic average, or the mean. This statistic is particularly useful when applied to a set of data having a fairly symmetrical distribution. The mean is an efficient statistic in that it summarizes all the data in the set, and because each piece of data is taken into account in its computation. The formula for computing the mean is:

(Eq. A-4)

$$\overline{X} = \frac{X_1 + X_2 + X_3 ... + X_n}{n} = \frac{\sum X_i}{n}$$

Where:

$\overline{X}$ = *arithmetic mean*

X_i = *i^{th} measurement*

n = *total number of observations*

The arithmetic mean is not a perfect measure of the true central value of a given data set. Arithmetic means overemphasize the importance of one or two extreme data points. Many measurements of a normally distributed data set will have an arithmetic mean that closely approximates the true central value.

Example Problem
Calculate the mean of 3.0, 2.5, 2.2, 3.4, 3.2.

Solution:

$$\overline{X} = \frac{X_1 + X_2 + X_3 ... + X_n}{n} = \frac{\sum X_i}{n}$$

$$\overline{X} = \frac{3.0 + 2.5 + 2.2 + 3.4 + 3.2}{5}$$

$$\overline{X} = \frac{14.3}{5} = 2.86$$

Median

When a distribution of data is asymmetrical, such as that of Figure A-8, it is sometimes desirable to compute a different measure of central value. This second measure, known as the median, is simply the middle value of a distribution, or the quantity above which half the data lie and below which the other half of the data lie.

If *n* data are listed in their *order of magnitude* (from lowest to highest), the median is the [(*n*+1)/2] value. If the number of data is even, then the numerical data of the median is the value midway between the two data nearest the middle. The median, being a positional value, is less influenced by extreme values in a distribution than the mean.

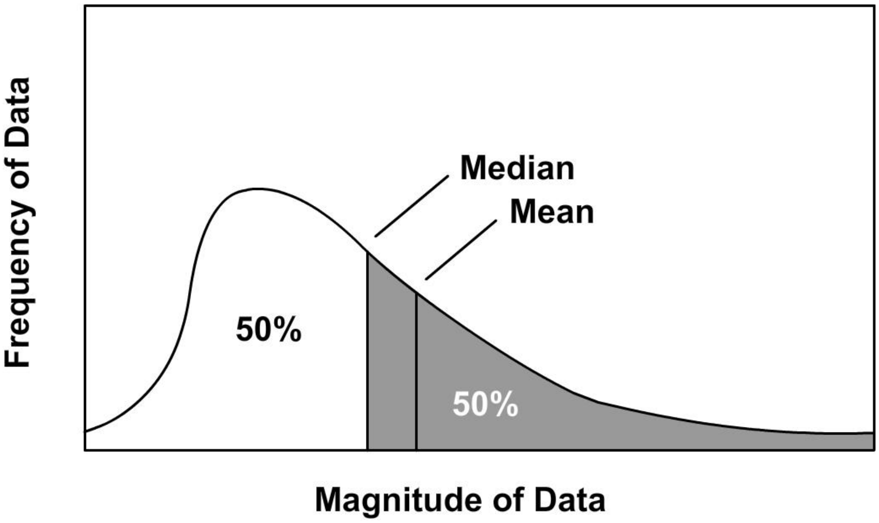

Figure A-8. Example of an asymmetrical distribution of data (median vs. mean).

Example Problem
Find the median of 22, 10, 15, 8, 13, 18.

Solution: The data must first be arranged in order of magnitude, such as:

8, 10, 13, 15, 18, 22

Since $n = 6$, the median is the 7/2 = 3.5 value, thus the median is 14, or the value halfway between 13 and 15, since this data set has an even number of measurements.

Geometric Mean

Another measure of central tendency used in more specialized applications is the geometric mean (X_g). The geometric mean is defined by using the following equation:

(Eq. A-5)
$$\bar{X}_g = \sqrt[n]{(X_1)(X_2)\ldots(X_n)}$$

If scientific calculators are not available, a formula that more readily lends itself to a four-function calculator is:

$$Log_{10}\bar{X}_g = \frac{1}{n}\sum Log_{10}X_i$$

The formula is derived as follows.

$$Log_{10}\bar{X}_g = Log\left[\sqrt[n]{(X_1)(X_2)\ldots(X_n)}\right] = Log[(X_1)(X_2)\ldots(X_n)]^{1/n}$$

Where: *log is to base 10*

$$\text{but } LogX^{1/n} = \frac{1}{n}LogX$$

$$\text{and } Log(X \times Y) = LogX + LogY$$

Therefore:
$$Log\bar{X}_2 = \frac{1}{n}Log[(X1)(X2)(Xn)]^{1/n}$$

$$= \frac{1}{n}(Log\,X_1 + Log\,X_2 \ldots + Log\,X_n)$$

$$= \frac{1}{n}\sum_i Log\,X_i$$

The geometric mean is most often used for data whose causes behave exponentially rather than linearly, such as in the growth of bacteria, measurements that are ratios, or lognormal distributions.

In a distribution shaped like that of Figure A-8, the geometric mean, like the median, will yield a value closer to the main cluster of values than will the mean. The arithmetic mean is always higher than the geometric mean.

Example Problem

Calculate the geometric mean of 3.0, 2.5, 2.2, 3.4, 3.2.

Solution:

$$\overline{X}_z = \sqrt[5]{(3.0)(2.5)(2.2)(3.4)(3.2)} = 2.8$$

or

$$Log_{10}\overline{X}_z = \frac{1}{5}(0.477 + 0.398 + 0.342 + 0.531 + 0.505)$$

$$Log_{10}\overline{X}_z = 0.4506$$

$$\overline{X}_z = 10^{0.4506} = 2.8$$

A.6 Measures of Dispersion

Measures of central tendency are more meaningful if accompanied by information on measures of dispersion. Measures of dispersion describe how the data spread out from the center. Examples of measures of dispersion in a data set include the range, sample standard deviation, coefficient of variation, and the standard geometric deviation.

The Range

The easiest measure of dispersion of a set of data is the difference between the maximum and the minimum values in the set, termed the *range*. The range does not make full use of the information contained in the data, since only two of the data points are taken into account. Thus the range is a useful measure of variability for data sets of 10 or less.

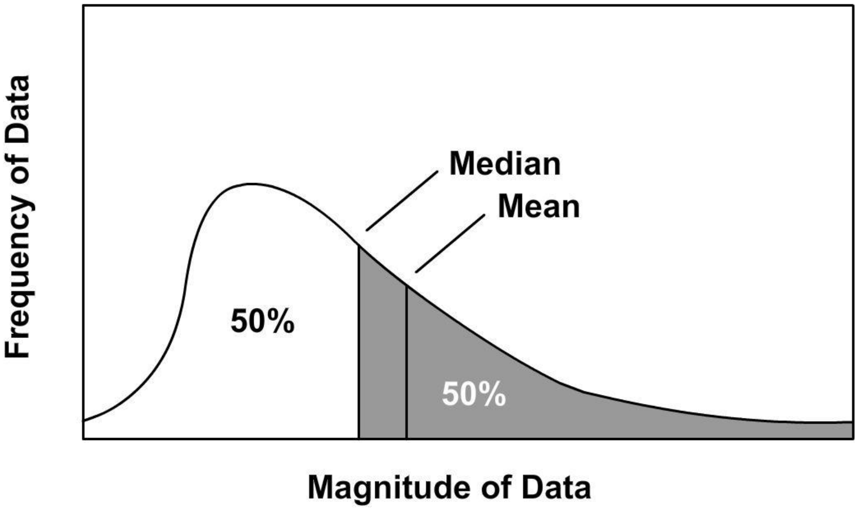

Figure A-9. Dispersion characteristic curves.

Standard Deviation

The most commonly used measure of dispersion, or variability, of sets of data is the standard deviation. Its defining formula is given by the expression:

(Eq. A-6)

$$s = +\sqrt{\frac{\sum (X_i - \overline{X})^2}{n-1}}$$

Where:

s = *the standard deviation (always positive)*
X_i = *i^{th} measurement*
$\overline{X}$ = *the mean of the data sample*
n = *the number of observations*

The expression $(X_i - \overline{X})$ shows how the deviation of each measurement from the overall mean is incorporated into the standard deviation.

An algebraically equivalent formula that makes computation much easier is:

$$s = +\sqrt{\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}}$$

where the variables are defined as above.

Example Problem: Standard Deviation

Using the data provided in the following table, calculate the standard deviation:

X_i	X_i^2
3.00	9
2.5	6.25
2.2	4.84
3.4	11.56
3.2	10.24
------	------
$14.31 \sum X_i$	$41.89 \sum X_i^2$

Solution:

$$s = +\sqrt{\frac{\sum X_i^2 - \frac{\left(\sum X_i\right)^2}{n}}{n-1}}$$

$$s = +\sqrt{\frac{41.89 - \frac{(14.30)^2}{5}}{5-1}}$$

$$s = +\sqrt{\frac{41.89 - \frac{204.49}{5}}{5-1}}$$

$$s = +\sqrt{\frac{41.89 - 40.90}{4}}$$

$$s = +\sqrt{\frac{0.990}{4}}$$

$$s = +\sqrt{.248}$$

$$s = 0.498$$

Coefficient of Variation

The coefficient of variation (CV) is a unitless measure that allows the comparison of dispersion across several sets of data. It is the standard deviation divided by the sample mean. The CV is often used in environmental applications because variability (expressed as standard deviation) is often proportional to the mean.

(Eq. A-7) $$CV = s/\overline{X}$$

Where:
s = *standard*
$\overline{X}$ = *sample mean*

Example Problem: Coefficient of Variation
Use the data presented in the previous example problem to solve for the CV.

$$CV = s/\overline{X}$$
$$CV = 0.498/2.86$$
$$CV = 0.174$$

Standard Geometric Deviation

Dispersion of skewed data such as lognormal distributions is measured by the standard geometric deviation. The standard geometric deviation is very similar to the standard deviation. The dispersion in the log of the measurements is measured by the *geometric* standard deviation instead of the dispersion of the measurements which would provide an *arithmetic* standard deviation. The log calculation normalizes the data to better approximate a normal distribution. The formula for calculating the standard geometric deviation is:

(Eq. A-8) $$s_z = antilog\left[\frac{\sum(logX_i) - \frac{\left(\sum logX_i\right)}{n}}{n-1}\right]^{1/2}$$

Where:
log is to the base 10
s_z = *standard geometric deviation*
X_i = i^{th} *measurement*
X = *the mean of the sample*

The following formula is mathematically identical, yet it is much easier to use in calculation:

$$s_z = antilog\left[\frac{\sum(logX_i) - \frac{\left(\sum logX_i\right)}{n}}{n-1}\right]^{1/2}$$

Example Problem: Standard Geometric Deviation

Using the data provided in the following table, calculate the standard geometric deviation:

X_i	$\log X_i$	$(\log X_i)^2$
3.0	0.4771	.2276
2.5	0.3979	.1584
2.2	0.3424	.1173
3.4	0.5315	.2825
3.2	0.5051	.2552

$$\sum logX_i = 2.2541$$

$$\sum (logX_i)^2 = .0409$$

$$\left(\sum logX_i\right)^2 = 5.0810 \qquad \text{[i.e. } (2.2541)^2\text{]}$$

$$s_z = antilog\left[\frac{\sum (logX_i) - \frac{\left(\sum logX_i\right)}{n}}{n-1}\right]^{1/2}$$

$$s_z = antilog\left[\frac{1.0409 - \frac{5.0810}{5}}{5-1}\right]^{1/2}$$

$$s_z = antilog\left[\frac{1.0409 - 1.0162}{4}\right]^{1/2}$$

$$s_z = antilog\left[\frac{0.0247}{4}\right]^{1/2}$$

$$s_z = antilog[0.0062]^{1/2}$$

$$s_z = antilog[0.0786]^{1/2}$$

$$s_z = 1.1984 \text{or } 1.20$$

A.7 Distribution Curves

Distribution curves are graphical displays of the individual data points in a data set and are important because they can identify patterns and trends in data that might go unnoticed if the data were not plotted.

Many types of distribution curves exist: binomial, t, chi, F, normal, and lognormal are just a few of the existing distributions. However, in air pollution measurements, the normal and lognormal are the most commonly occurring ones. Thus, only these two will be discussed.

The Normal Distribution

One reason the normal (Gaussian) distribution is so important is that a number of natural phenomena are normally distributed or closely approximate it. In fact, many experiments when repeated a large number of times will approach the normal distribution curve. In its pure form, the normal curve is a continuous symmetrical, smooth curve shaped like the one shown in Figure A-10. Naturally, a finite distribution of discrete data can only approximate this curve. The normal curve has the following definite relations to the descriptive measures of a distribution.

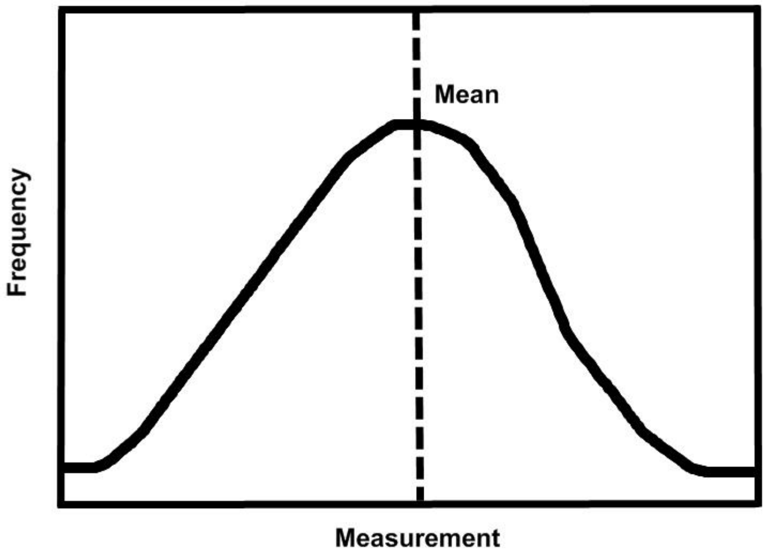

Figure A-10. Normal distribution curve.

The Mean and Median
The normal distribution curve is symmetrical; therefore, the mean and the median are equal and are found at the center of the curve. Recall that, in general, the mean and median of an asymmetrical distribution do not coincide.

The Range
The normal curve ranges along the x-axis from minus infinity to plus infinity. Therefore, the range of a normal distribution is infinite.

The Standard Deviation
The standard deviation, *s*, becomes a most meaningful measure when related to the normal curve. A total of 68.2% of the area lying under a normal curve is included by the part ranging from 1 standard deviation below to 1 standard deviation above the mean. A total of 95.4% lies $\pm$ 2 standard deviations from the mean and 99.7% lies within 3 standard deviations (Figure A-11). By using tables found in statistics texts and handbooks, one can determine the area lying under any part of the normal curve.

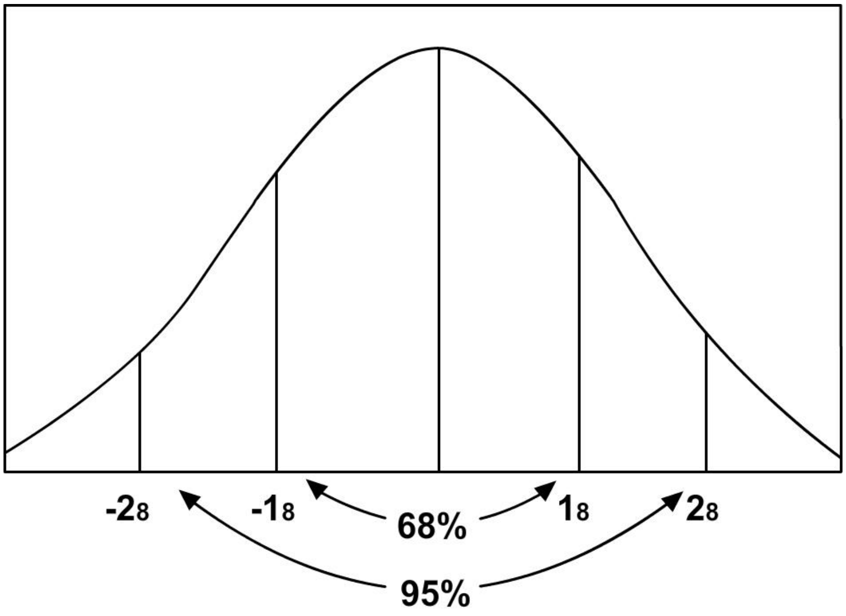

Figure A-11. Characteristics of the normal distribution.

These areas under the normal distribution curve can be given probability interpretations. For example, if an experiment yields a nearly normal distribution with a mean equal to 30 and a standard deviation of 10, we can expect about 68% of a large number of experimental results to range from 20 to 40, so that the probability of any particular experimental result's having a value between 20 and 40 is about 0.68.

In applying the properties of the normal curve to the testing of data readings, one can determine whether a change in the conditions being measured is shown or whether only chance fluctuations in the readings are represented. For a well-established set of criterion data, a frequently used set of control limits is ± 3 standard deviations. That is, a special investigation of data readings trying these limits can be used to determine whether the conditions under which the original data were taken have changed. Since the limits of 3 standard deviations on either side of the mean include 99.7% of the area under the normal curve, it is very unlikely that a reading outside these limits is due to the conditions producing the criterion set of data. The purpose of this technique is to separate the purely chance fluctuations from the other causes of variation. For example, if a long series of observations of an environmental measurement yield a mean of 50 and a standard deviation of 10, then control limits will be set up as 50 ± 30 - in other words, ± 3 standard deviations, or from 20 to 80. So, a value of 81 would suggest that the underlying conditions have changed, and that a large number of similar observations at this time would yield a distribution of results with a mean different (larger) than 50.

This process of determining whether a value represents a significant change is closely related to the use of control charts. In setting up control limits, it is often necessary to divide the available data into subgroups and calculate the mean and standard deviations of each of these groups, making careful note of the conditions prevailing under each subgroup. In collecting data to establish control limits, as much information as possible should be gathered about the causes and conditions in effect during the period of obtaining a criterion set of data. Generally, the conditions during this period should be “normal,” or as much in control as possible.

In the situation where one takes readings of some environmental quantity, the appearance of data beyond the control limits might suggest the starting of a new data grouping to further ascertain whether the underlying environmental variable has changed.

It should be kept in mind that the limits of ± 3 standard deviations are traditional rather than absolute. They have been found through experience to be very useful in many control situations, but each experimenter must decide what limits would be most suitable for a given purpose by determining what levels of probability would be needed to quantify acceptance and rejection bounds.

Lognormal Distributions

Lognormal distributions can best be demonstrated by means of an example:

If hourly sulfur dioxide concentrations are plotted against frequency of occurrence as in the Data Plotting Section, a skewed distribution would exist similar to the one in Figure A-12. Such a curve indicates that many concentrations are close to zero and that few are very high. Unlike temperature, sulfur dioxide concentrations are blocked on the left because values less than zero do not exist. Because numerous aids exist for normal distributions, it is desirable to normalize this type of distribution. By plotting the log of hourly SO_2 concentrations against the frequency of occurrence, a “bell-shaped” curve similar to Figure A-10 is obtained. By making this ample normalizing feature, all existing normal distribution tables can be used to make probability interpretations.

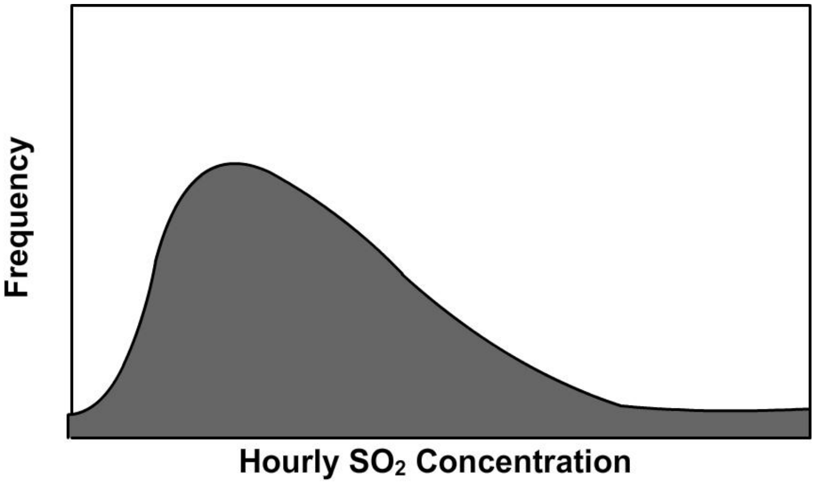

Figure A-12. Frequency vs. concentration of SO_2.

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Appendix

B

Glossary and Acronyms

B.1 Glossary

A

Abscissa. The x-axis on a graph.

Absolute Filter. A filter or filter medium of ultra-high collection efficiency for very small particles (submicrometer size), so that essentially all particles of interest or of concern are collected. Commonly, the efficiency is 99.95% or higher for a standard aerosol of 0.3 μm diameter.

Absolute Pressure. A pressure scale that starts with a value of zero for an absolute vacuum.

Absolute Temperature. A temperature scale that starts with zero at absolute zero temperature.

Absolute Zero Temperature. The temperature at which molecular kinetic energy is negligible.

Absorption. The transfer of molecules from the bulk of the gas to a liquid surface, followed by diffusion of these molecules to the bulk of the liquid.

ACFM. The acronym for actual cubic feet per minute, which is the actual gas flow rate expressed in the American Engineering system of units. ACFM is a measure of the volume of gas that passes a given point during a one-minute period.

Accuracy. A measure of the closeness of an individual measurement or the average of a number of measurements to the true value. Accuracy includes a combination of random error (precision) and systematic error (bias) components that are due to sampling and analytical operations; the EPA recommends using the terms *precision* and *bias* rather than *accuracy*, to convey the information usually associated with accuracy (see Bias).

Acute Exposure. One dose (or exposure) or multiple doses (or exposures) occurring within a short time relative to the life of a person or other organism (e.g., approximately 24 hours or less for humans).

Adsorbs. The adhesion of a substance to the surface of a solid or liquid.

Adsorption. The process whereby vapor phase compounds in the gas stream pass through a bed or layer of highly porous material (adsorbent). The vapor phase compounds diffuse to the surface of the adsorbent and are retained due to weak attractive forces.

Aerodynamic Diameter (a.d.). The diameter of a unit density sphere having the same terminal settling velocity as the particle in question. Operationally, the size of a particle as measured by an inertial device.

Aerodynamic Diameter. The diameter of a spherical particle having a density of 1 gm/cm^3 that has the same inertial properties (i.e., settling velocity) in the gas as the particle of interest.

Aerosol. Suspended solid or liquid particles in the atmosphere.

Air at EPA Standard Conditions. Air at 25°C and 760 mm Hg (29.92 in. Hg).

Air Pollution. The presence of unwanted material in the air. The term *unwanted material* here refers to material concentrations present for a sufficient time and under such circumstances as to interfere significantly with comfort, health, or welfare of persons, or with the full use and enjoyment of property.

Air Toxic. Any air pollutant that causes or may cause cancer, respiratory, cardiovascular, or developmental effects, reproductive dysfunctions, neurological disorders, heritable gene mutations, or other serious or irreversible chronic or acute health effects in humans. See "Hazardous Air Pollutant."

Ambient Measurement. A measurement (usually of the concentration of a chemical or pollutant) taken in an ambient medium, normally with the intent of relating the measured value to the exposure of an organism that contacts that medium.

Anion. An atom or molecule with a negative charge.

Approved Regional Method (ARM). A continuous $PM_{2.5}$ method that has been approved specifically within a state or local air monitoring network for purposes of comparison to EPA's National Ambient Air Quality Standards (NAAQS) and to meet other monitoring objectives.

Aqueous Liquid. A liquid whose main component is water, but which can also contain significant concentrations of other dissolved solids and liquids (usually <15% by weight) and/or low-to-moderate levels of suspended solids (usually <2% by weight).

Area Source (in the context of the Clean Air Act, Air Toxics Provisions). Any stationary source that falls below a major source threshold of emissions (see "Major Source"), such as a dry cleaner or gas station. The term generally excludes motor vehicles (both road and nonroad).

Aspirator. Any apparatus, such as a squeeze bulb, fan, pump, or venturi, that produces a movement of a fluid by suction.

Atmosphere, The. The whole mass of air surrounding the earth, composed largely of oxygen and nitrogen.

Atmosphere, An. A specific gaseous mass, occurring either naturally or artificially, containing any number of constitutents and in any proportion.

Attainment Area. An area that meets the air quality standard for a criteria pollutant (under NAAQS).

Audit (quality). A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements, and whether these arrangements are implemented effectively and are suitable to achieve objectives.

B

Background Levels. Two types of background levels may exist for chemical substances: (a) naturally occurring levels, or ambient concentrations of substances present in the environment without human influence; and (b) anthropogenic levels, or concentrations of substances present in the environment due to human-made, non-site sources (e.g., automobiles, industries) [IRIS, 1999: Glossary of IRIS Terms].

Baghouse. This term is often used interchangeably with the term *filtration systems*. However, it is applicable only to pulse jet, cartridge, reverse air, and shaker-type filtration systems. The term *baghouse* does not have any clear meaning for HEPA filtration systems.

Barometric Pressure. The total pressure exerted by the atmosphere. This term is synonymous with *atmospheric pressure*.

Bias. The systematic or persistent distortion of a measurement process that causes errors in one direction (i.e., the expected sample measurement is different from the sample's true value).

Bottom Ash. Incombustible matter resulting from combustion that does not leave as fly ash.

Brake Horsepower. The horsepower required to drive a fan. This includes the energy losses in the fan but does not include the drive losses between motor and fan.

Breathing Zone. The location in the atmosphere where persons breathe.

Brownian Diffusion. The slight deflection of very small particles in a gas stream that occurs when rapidly moving gas molecules strike them.

BTU (British Thermal Unit). The quantity of heat that must be transferred to a one pound mass of water to raise the temperature by 1°F.

C

Calibration. The process of comparing a standard or instrument with one of greater accuracy (small uncertainty) to obtain quantitative estimates of the actual values of the standard being calibrated, the deviation of the actual value from a nominal value, or the difference between the value indicated by an instrument and the actual value.

Calibration Standards. Devices that are specifically designed to be placed in a monitoring location and can be used to calibrate air monitoring instruments. These devices are commercially available from a number of vendors. These units usually are permeation devices or mass flow calibrators (MFC). The flow rates of these devices are verified by the transfer standard on a set schedule.

Cancer. A disease of heritable, somatic mutations affecting cell growth and differentiation, characterized by abnormal, uncontrolled growth of cells.

Carbon Bed Adsorber. An air pollution control system that is used to collect and concentrate organic compounds on an activated carbon adsorbent.

Cascade Impactor. A sampling device used to determine the particle size distribution. Particles are separated and deposited on a series of stages that correspond to different aerodynamic diameters.

Catalyst. A substance, usually present in small amounts compared to the reactants, that speeds up the chemical reaction rate without being consumed in the process.

Catalytic Oxidizer. An air pollution control device that uses a catalyst to accelerate the oxidation reaction at lower temperatures than possible in gas phase thermal oxidation.

Certification. A certification is the process of checking a transfer standard against a primary standard and establishing a mathematical relationship that is used to adjust the transfer standard values back to the primary standard.

Chemical Abstracts Service Registry Number (CAS No.). A unique, chemical-specific number used in identifying a substance. The registry numbers are assigned by the Chemical Abstract Service, a division of the American Chemical Society.

Chimney Effect. A phenomenon consisting of a vertical movement of a localized mass of air or other gases due to temperature/pressure differences.

Chronic Exposure. Multiple exposures occurring over an extended period of time, or a significant fraction of the animal's or the individual's lifetime.

Class I Areas. Class I areas are protected by the PSD program and include national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historical value.

Class II Areas. Attainment areas that are neither industrialized nor meet the specific requirements for classification as Class I areas. They are protected by the PSD program.

Class III Areas. Industrialized attainment areas. They are protected by the PSD program.

Cloud. A visible dispersion occupying a discrete portion of space, with apparent boundaries.

Coarse Particles. EPA classification of particles having aerodynamic diameters ranging from 2.5 to 10μm ($PM_{10-2.5}$).

Collection Efficiency. A ratio of pollutants entering a control device versus pollutants leaving the device expressed as a percent.

Collector. A device for removing and retaining contaminants from air or other gases. Usually this term is applied to cleaning devices in exhaust systems.

Collocated Samples. Two or more portions collected at the same point in time and space so as to be considered identical. These samples are also known as field replicates and should be identified as such.

Combustion. The production of heat and light energy through a chemical process, usually oxidation. Products of complete combustion include water and carbon dioxide, while incomplete combustion can yield partially oxidized organic compounds and carbon monoxide. Factors that promote complete combustion include the proper fuel-air ratio, temperature range, and adequate amount of time for the fuel and its by-products to complete the combustion reactions.

Condensable Particulate Matter. Particulate matter, contained almost entirely within the $PM_{2.5}$ classification, that forms from condensing gases or vapors. It forms by chemical reactions as well as by physical phenomena.

Condensate. Liquid or solid matter formed by condensation from the vapor phase. In sampling, the term is applied to the components of an atmosphere that have been isolated by simple cooling.

Condensation. The process of converting a material in the gaseous phase to a liquid or solid state by decreasing temperature, increasing pressure, or both. Usually in air sampling only cooling is used.

Condenser. A simple, relatively inexpensive device that normally uses water or air to cool and condense a vapor stream.

Condensoid. The particles of a dispersion formed by condensation.

Conductivity. A measure of the ability of a material to conduct an electric charge.

Conservation of Matter. A general principle of non-nuclear reactions and processes where matter is neither created nor destroyed.

Contaminant. Unwanted material.

Count Median Size. A measurement of particle size for samples of particulate matter, consisting of that diameter of particle such that one half of the number of particles is larger and half is smaller.

Criteria Air Pollutant. One of six common air pollutants determined to be hazardous to human health and regulated under the EPA's National Ambient Air Quality Standards (NAAQS). The six criteria air pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, sulfur dioxide, and particulate matter. The term *criteria pollutants* derives from the requirement that the EPA must describe the characteristics and potential health and welfare effects of these pollutants. It is on the basis of these criteria that standards are set or revised.

Cryogenic Sampling. See "Sampling, Condensation."

Cyclonic Separator. A mechanical collector that uses centrifugal force to drive particles to the wall of the device.

D

Dalton's Law of Partial Pressures. The law stating that the total pressure of a gas is the sum of the pressures exerted by each component gas.

Data Acquisition System. A strip chart recorder, analog computer, or digital computer for recording measurement data from the analyzer output.

Data Quality Objectives (DQOs). The qualitative and quantitative statements derived from the DQO Process that clarify a study's technical and quality objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

Density. The quantity of mass contained in a specific volume.

Denuder. A device designed to remove gases from an air sampling stream by the process of molecular diffusion to a collecting surface.

Desorption. The process of using low pressure steam or hot nitrogen gas to remove compounds from an adsorbent bed.

Dew Point. The temperature at which the partial pressure of a substance (in vapor form) equals the equilibrium vapor pressure of the substance. At this temperature, a vapor begins to condense at a constant pressure.

Differential Pressure Meter. Any flow measuring device that operates by restricting air flow and measuring the pressure drop across the restriction.

Diffusion. The random motion of small particles suspended in a gas or liquid, also known as Brownian Movement. It can also be described as a process by which the molecules of two or more substances gradually mix.

Diffusitivity. Measure of the extent to which very small particles are influenced by molecular collisions which cause the particles to move in a random manner across the direction of gas flow.

Dimensions. Units of measure used to express the magnitude of mass, distance, force, and time.

Dimensional Calculations. A form of mathematical calculation in which the units applying to each value are stated explicitly and are handled algebraically.

Dispersion. The most general term for a system consisting of particulate matter suspended in air or other gases.

Dispersoid. The particles of a dispersion.

Diurnal. Recurring daily. Applied to (variations in concentration of) air contaminants, diurnal indicates variations following a distinctive pattern and recurring from day to day.

Dose-Response Assessment. A determination of the relationship between the magnitude of an administered, applied, or internal dose and a specific biological response. Response can be expressed as measured or observed incidence, percent response in groups of subjects (or populations), or as the probability of occurrence within a population [IRIS, 1999: Glossary of IRIS Terms].

Droplet. A small liquid particle of such size and density as to fall under still conditions, but which may remain suspended under turbulent conditions.

Dry Scrubber. An air pollution control device used to remove an acid gas pollutant from a gas stream. The pollutant is collected on or in a solid or liquid material, which is injected into the gas stream. A dry scrubber produces a dry product that must be collected downstream from this control device.

Dust. A loose term applied to solid particles predominantly larger than colloidal and capable of temporary suspension in air or other gases. Dusts do not tend to flocculate except under electrostatic forces; they do not diffuse but settle under the influence of gravity. Derivation from larger masses through the application of physical force is usually implied.

Dust Fall. See “Particle Fall.”

Dust Loading. An engineering term for “dust concentration,” usually applied to the contents of collection ducts and the emission from stacks.

E

Ecological Risk Assessment. A process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. Stressors are defined as any chemical, biological, or physical entity that can induce an adverse response on ecological individuals, populations, communities, or ecosystems.

Efficiency. The ratio of attained performance to absolute performance, commonly expressed in percent.

Efficiency, Fractional. The mean collection efficiency for specific size fractions of a contaminant. Commonly this term has been applied to the performance of air cleaning equipment toward particulate matter in various size ranges.

Ejector. A device that uses a fluid under pressure, such as steam, air, or water, to move another fluid by developing suction. Suction is developed by discharging the fluid under pressure through a venturi.

Electrostatic Attraction. An affinity or attraction between oppositely charged particles and/or collection media.

Electrostatic Precipitator. A type of air pollution control system that uses high voltage fields to electrically charge and collect particulate matter. The charged particles approach an electrically grounded collection plate and accumulate as a dust layer, which is partially removed by mechanical rapping (hammers) on a routine basis.

Emissions. The total of substances discharged into the air from a stack, vent, or other discrete source.

Emission Mixture. The total mixture in the outside atmosphere of emission from all sources.

Emission Sampling Train. Equipment usually consisting of (1) a sampling nozzle and probe, (2) filter and impingers for collection of gaseous and/or particulate components, (3) flow meter and flow regulation devices, and (4) a vacuum pump for collecting a representative sample of a gas stream.

Entrainment. The process in which material, such as water droplets or particulate matter, is picked up and carried along by a gas or liquid stream.

Entry Loss. The loss of pressure that occurs when airflow moves into a system.

Equilibrium. A steady state condition. The amount of mass transferred in one direction is exactly balanced by the amount of mass transferred in the reverse direction.

Evaporative Cooling Tower. Equipment used to reduce the temperature of a gas stream. Fine droplets, injected into a vessel, are evaporated as they absorb heat from the gas stream.

Exposure. Contact made between a chemical, physical, or biological agent and the outer boundary of an organism. Exposure is quantified as the amount of an agent available at the exchange boundaries of the organism (e.g., skin, lungs, gut).

Exposure Assessment. An identification and evaluation of the human population exposed to a toxic agent, describing its composition and size, as well as the type magnitude, frequency, route and duration of exposure.

F

Fabric Filter. A filtration device using one or more filter bags, sheets, or panels to remove particles from a gas stream.

Fan Drive. The way in which the motor shaft is linked to the fan wheel to transmit power and control speed.

Federal Equivalent Method. A method for measuring the concentration of an air pollutant in the ambient air that has been designated as an equivalent method in accordance with 40 CFR Part 53.

Federal Reference Method. A method of sampling and analyzing the ambient air for an air pollutant that is specified as a reference method in an appendix to 40 CFR Part 50.

Fine Particles. EPA classification of particles having aerodynamic diameters greater than 0.1 micrometer and less than or equal to 2.5 micrometers.

Flocculation. Synonymous with agglomeration.

Flowmeter. An instrument for measuring the rate of flow of a fluid moving through a pipe or duct system. The instrument is calibrated to give volume or mass rate of flow.

Flow Rate (Actual). The volume of gas moving through a system or stack per unit time expressed at actual conditions of temperature and pressure.

Flow Rate (Standard). The volume of gas moving through a system or stack per unit time expressed at standard conditions of temperature and pressure.

Flow Rate (Volumetric). The volume of gas moving through a ventilation system, stack, or air pollution control system per unit time.

Fly Ash. Uncombusted particulate matter in the combustion gases resulting from the burning of coal and other material.

Fog. A loose term applied to visible aerosols in which the dispersed phase is liquid. Formation by condensation is usually implied; in meteorology, a dispersion of water or ice.

Force. An influence on a physical object that causes a change in movement and/or shape.

Freezing Out. See "Sampling, Condensation."

Fugitive Emissions. Emissions that escape from industrial processes and equipment.

Fume. Properly, the solid particles generated by condensation from the gaseous state, generally after volatilization from melted substances, and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce. Popularly, the term is used in reference to any of all types of contaminant, and in many laws or regulations, with the added qualification that the contaminant has some unwanted action.

G

Gas. One of the three states of aggregation of matter, having neither independent shape nor volume and tending to expand indefinitely.

Gauge Pressure. The relative pressure inside a vessel or container (the difference between the inside pressure and atmospheric pressure).

Grab Sample. See "Sampling, Instantaneous."

Gravimetry/Gravimetric. A weight-based measurement.

Gravitational settling/sedimentation. A process by which suspended particles in air settle to the bottom.

H

Hazardous Air Pollutants. See "Air Toxics."

Heterogeneous Nucleation. The accumulation of material from the vapor phase onto an existing particle.

High-Volume Air Sampler (Hi-Vol). A device for sampling large volumes of an atmosphere for collecting the contained particulate matter by filtration. Consists of a high-capacity blower, a filter to collect suspended particles, and a means for measuring the flow rate.

Homogeneous Nucleation. The formation of a particle from the vapor phase involving only one compound.

Hood. A shaped inlet designed to capture contaminated air and conduct it into the exhaust duct system.

Hood Capture Velocity. The air velocity at any point in front of the hood or at the hood opening necessary to overcome opposing air currents and to capture the contaminated air at that point by pulling it into the hood.

Human Health Inhalation Assessment. A process that evaluates the likelihood of an adverse impact of a chemical or group of chemicals on human health for people that are exposed through the inhalation of the chemical(s). Inhalation can be defined as drawing of air (and pollutants) into the lungs via the nasal or oral respiratory passages.

Human Health Multipathway Assessment. A process that evaluates the likelihood of an adverse impact of a chemical or group of chemicals on human health for people that are exposed through multiple exposure pathways. These pathways could include inhaling the chemical(s), eating food that the chemical(s) has deposited on, accidently eating dirt or dust that contains the chemical(s), or skin contact with dirt or water that contains the chemical(s).

Hydrometer. An instrument for measuring the specific weight of a liquid by utilizing the principle of buoyancy.

Hygroscopic. Characterized by readily absorbing moisture.

I

Impaction. A forcible contact of particles of matter. A term often used synonymously with impingement.

Impactor. A sampling device that employs the principle of impaction (impingement).

Impingement. The act of bringing matter forcibly in contact. When used in air sampling, refers to a process for the collection of particulate matter in which the gas being sampled is directed forcibly against a surface.

Impingement, Dry. The process of impingement carried out so that particulate matter carried in the gas stream is retained upon the surface against which the stream is directed. The collecting surface may be treated with a film of adhesive.

Impingement, Wet. The process of impingement carried out within a body of liquid, the latter serving to retain the particulate matter.

Impinger. Broadly, a sampling instrument employing impingement for the collection of particulate matter. Commonly, this term is applied to specific instruments, the *midget impinger* and *standard impinger*.

Impinger, Midget. A specific instrument employing wet impingement, using a liquid volume of 10 ml and a gas flow of 0.1 ft^3 per minute.

Impinger, Standard. A specific instrument employing wet impingement, using a liquid volume of 75 ml and a gas flow of 1 ft^3 per minute (e.g., Greenberg-Smith Impinger).

Individual Exposure or Risk Assessment. A process that evaluates the likelihood of an adverse impact on human health (risk), or amount of exposure, of a chemical or group of chemicals for an actual or hypothetical person.

Inertial Impaction. The process whereby a particle moving in a gas stream strikes slowly moving or stationary obstacles or targets (e.g. liquid droplets) directly in its path. Compare with Interception.

Inhalable Particles. Particles with aerodynamic diameters of <10 µm that are capable of being inhaled into the human lung.

Inorganic. A term that applies to compounds that contain no carbon-hydrogen bonds.

Interception. The process whereby a particle moving in a gas stream is offset slightly from directly impacting a moving or stationary obstacle or target. As the particle tries to move past the obstacle, the obstacle intercepts (and collects) the particle. Compare with "Inertial Impaction."

Interference. An undesired positive or negative output caused by a substance other than the one being measured.

Isokinetic. A term describing a condition of sampling in which the flow of gas into the sampling device (at the opening or face of the inlet) has the same flow rate and direction as the gas stream being sampled.

J

K

Kinematic Viscosity. See "Viscosity (Kinematic)."

L

Lognormal Distribution. A frequency distribution that is symmetric (i.e. bell shaped) when plotted on a logarithmic abscissa.

Lower Explosive Limit. The lowest concentration at which a gas or vapor is flammable or explosive at ambient conditions.

M

Major Source (in the context of the Clean Air Act, Air Toxics Provisions). Any stationary source or group of stationary sources located within a contiguous area and under common control that emits, or has the potential to emit considering controls in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants [Section 112(a)(1)].

Manometer. An instrument used for measuring the pressure of liquids and gases. An open-tube manometer consists of a U-shaped tube that usually contains a liquid such as mercury or water. One end of the tube is open to the atmosphere and the other end of the tube is connected to the container where the pressure is to be measured.

Mass. The measure of the magnitude of a physical object that is related directly to the atoms in the object.

Mass Concentration. Concentration expressed in terms of mass of substance per unit volume of gas or liquid.

Mass Flowmeter. Device that measures the mass flow rate of air passing a point, usually using the rate of cooling or heat transfer from a heated probe.

Mass Flow Controller. A device that works on the principle of heat loss. The mass flow meter within the MFC has a small thermister that is sensitive to heat loss. A potential voltage is applied to the thermister. As the air flow increases across the thermister, the resistance of the thermister changes. This change in resistance can be measured very accurately by electronic circuitry. The mass flow circuitry can then be integrated with a controlling loop circuit that can control/monitor the flow instantaneously. Usually, MFCs have two channels, gas and diluent or air flow. The gas portion of the unit allows for gases from compressed cylinders to be allowed in and metered. The air flow side of the unit blends down the high concentration from the compressed cylinders to the desired working concentration. The flow rate of both portions of the unit must be measured accurately. It is important when purchasing a MFC calibrator that it meet the 40 CFR 50 requirements of having an accuracy within +/- 2%.

Mass Median Particle Diameter. The particle diameter at which half the particulate mass is composed of particles larger than this diameter and half the mass is composed of particles smaller than this diameter.

Mass Transfer. A natural phenomenon in which a component travels from a region of high concentration to one of low concentration in order to minimize concentration differences in a mixture.

Master Flow-Rate Standard. A flow-rate measuring device, such as a standard orifice meter, that has been calibrated against a primary standard.

Matter. The substance of which a physical object is composed.

Maximum Achievable Control Technology (MACT). EPA standards mandated by the 1990 CAAA for the control of toxic emissions from various industries.

Mean. The arithmetic average of distribution.

Method Detection Limit (MDL). The minimum concentration of an analyte that can be reported with 95% confidence that the value is above zero, based on a standard deviation of at least seven repetitive measurements of the analyte in the matrix of concern at a concentration near the low standard.

Micrograms. A unit of measurement for mass. One microgram equals 10^{-6} grams.

Milligrams. A unit of measurement for mass. One milligram equals 10^{-3} grams.

Mist. A loose term applied to dispersions of liquid particles, the dispersion being of low concentration and the particles of large size. In meteorology, a light dispersion of water droplets of sufficient size to be falling.

Mode. The value that occurs the most frequently in a distribution.

Mole. The mass of a material equal to the combined mass of 6.023 10^{23} atoms or molecules of the material.

Mole Fraction. An expression of the number of moles of a compound divided by the total number of moles of all compounds present.

Momentum. The product of the mass of an object times its velocity.

N

Nanograms. A unit of measurement for mass. One nanogram equals 10^{-9} grams.

National Ambient Air Quality Standards (NAAQS). Enforced air quality standards established by EPA that apply to outdoor air throughout the country.

Natural Logarithm (Napierian). The exponent applied to the base number of 2.718 to equal a given value. For example, 2 is the natural logarithm that is equal to a value of 7.389. $(2.718)^2=7.389$

Negative Pressure. A relative pressure that is below atmospheric pressure.

Nucleate. To form a central part around which other parts can attach.

Non-Attainment Areas. A geographic area that does not meet one or more of the federal air quality standards (NAAQS) for the criteria pollutants.

O

Odor. That property of a substance affecting the sense of smell; any smell; scent; perfume.

Odor Concentration. The number of unit volumes that a unit volume of sample will occupy when diluted to the odor threshold.

Odor Unit. Unit volume of air at the odor threshold.

Odorant. Odorous substance.

Operating Permit (Permit). Document required by EPA under Title V for any major stationary source. Potential-to-emit limits defining a major source are determined by the air quality of the geographical region where the facility is located. A permit contains the specific information about how the facility will comply with established emission standards and guidelines set forth by EPA.

Ordinate. The y-axis on a graph.

Organic. A term that applies to compounds that contain carbon-hydrogen bonds.

Orifice Meter. A flowmeter, employing as the measure of flow rate the difference between the pressures measured on the upstream and downstream sides of the orifice (that is, the pressure differential across the orifice) in the conveying pipe or duct.

Ozone Season. The ozone season from May 1 to September 30 (Northern Hemisphere) when ground-level ozone formation concentrations tend to be highest.

P

Partial Pressure. The fraction of the total static pressure in a gas stream caused by one of the constituents of the mixture.

Particle. A small discrete mass of solid or liquid matter.

Particle Concentration. Concentration expressed in terms of number of particles per unit volume of air or other gas. (Note: On expressing particle concentration, the method of determining the concentration should be stated.)

Particle Fall. A measurement of air contamination consisting of the mass rate at which solid particles deposit from the atmosphere. A term used in the same sense as the older terms Dust Fall and Soot Fall, but without any implication as to nature and source of the particles.

Particle Size. An expression for the size of liquid or solid particles expressed as the average or equivalent diameter.

Particle Size Distribution. The relative percentage by weight or number of each of the different size fractions of particulate matter.

Particulate. Solids or liquids existing in the form of separate particles.

Particulate Matter. Solid or liquid matter that is dispersed in a gas, or insoluble solid matter dispersed in a liquid, that gives a heterogeneous mixture.

Penetration. The ratio of the amount of pollutants leaving an air pollution control device versus the amount of pollutants entering the device.

Penetration Efficiency. The ratio of the amount of pollutants leaving an air pollution control device versus the amount of pollutants entering the device, expressed as a percent.

Permeation Devices. Calibration units that pass a known volume of air over a permeation tube. The permeation tube is a small cylinder (usually steel) that has a permeable membrane at one end. Usually the tube is filled with a liquid that permeates out through the membrane at a given rate at a very narrow temperature range. By knowing the permeation rate and the air flow rate, a NIST-traceable concentration in parts per million can be calculated.

Photochemical Reaction. Any chemical reaction that is initiated as a result of absorption of light.

Photochemical Smog. Air pollution resulting from photochemical reactions.

Physical Attrition. The act of wearing or grinding down by friction.

$PM_{2.5}$. EPA defines $PM_{2.5}$ as particulate matter with a diameter of 2.5 micrometers collected with 50% efficiency by a $PM_{2.5}$ sampling collection device. However, for convenience in this manual, the term $PM_{2.5}$ includes all particles having an aerodynamic diameter of less than or equal to 2.5 micrometers.

PM_{10}. EPA defines PM_{10} as particulate matter with a diameter of 10 micrometers collected with 50% efficiency by a PM_{10} sampling collection device. However, for convenience in this manual, the term PM_{10} includes all particles having an aerodynamic diameter of less than or equal to 10 micrometers.

Pollutant Ranking Assessment. An assessment used to rank chemicals with respect to their impact on human health and the environment. Often used to select a subset of the most important chemicals on which to focus further risk assessments. For example, the 33 air toxics highlighted as priority pollutants in EPA's Urban Strategy were selected based on a number of factors, including toxicity-weighted emissions, monitoring data, past air quality modeling analysis, and a review of existing risk assessment literature.

Population Exposure or Risk Assessment. A process that evaluates the likelihood of an adverse impact on human health (risk), or amount of exposure, of a chemical or group of chemicals, for groups of actual or hypothetical people. For cancer-causing chemicals, population risk can be expressed as the number of people estimated to be exposed to specific risk levels or as the number of excess cancer cases expected to occur.

Potential-to-Emit. The total emissions that a facility would release by operating at maximum load for 24 hours per day and 365 days per year.

PPBV [or PPB(V/V)]. A unit of measure of the concentration of gases in air expressed as parts of the gas per billion (10^9) parts of the air-gas mixture, normally both by volume.

PPMV [or PPM(V/V)]. The part per million concentration that is determined by comparing the volume of one constituent with the total volume of the substance. Gas concentrations are always expressed in a ppm(v/v) format as opposed to the ppm(w/w) format often used for liquids. Throughout APTI courses, the term ppm when applied to gases means ppm(v/v).

PPMVD. The part per million concentration that is determined by comparing the volume of one constituent with the volume of the other constituents with the exception of moisture.

PPM(W/W). The part per million concentration that is determined by comparing the mass of one constituent with the total mass of the sample. Liquid concentrations are often expressed in a ppm(w/w) format as opposed to the ppm(v/v) format used for gases. Throughout APTI courses, the term ppm when applied to liquids means ppm(w/w). Note that the abbreviation "w/w" is used despite the fact that the ppm concentration is based on a ratio of masses.

Precipitation, Electrostatic. A process consisting of the separation of particulate matter from air or other gases under the influence of an electrostatic field.

Precipitation, Meteorological. The precipitation of water from the atmosphere in the form of hail, mist, rain, sleet, and snow. Deposits of dew, fog, and frost are excluded.

Precipitation, Thermal. A process consisting of the separation of particulate matter from air and other gases under the influence of a relatively large temperature gradient extending over a short distance. In the *thermal precipitator* (a sampling instrument), the air or gas is drawn through a narrow chamber across which extends a heated wire, particulate matter being deposited upon the adjacent collecting surface.

Precipitation, Ultrasonic. A process consisting of the separation of particulate matter from air and other gases following agglomeration induced by an ultrasonic field.

Precipitator, Electrostatic. Apparatus employing electrostatic precipitation for the separation of particles from a gas stream. The apparatus may be designed either for sampling or for cleaning large volumes of gas.

Precision. The degree of mutual agreement between individual measurements, namely repeatability and reproducibility.

Preconcentration. The process of removing organic vapors from a gas stream and transferring them to a smaller, more concentrated gas stream.

Pressure Drop. A measure of the resistance the gas stream encounters as it flows through an air control device or other piece of equipment.

Pressure Static. The pressure of a fluid at rest, or in motion, exerted perpendicularly to the direction of flow.

Pressure, Velocity. That pressure caused by and related to the velocity of the flow of fluid; a measure of the kinetic energy of the fluid.

Pressure, Total. The pressure representing the sum of static pressure and velocity pressure at the point of measurement.

Pressure Gauge. The difference in pressure existing within a system and that of the atmosphere. Zero gauge pressure is equal to atmospheric pressure.

Primary Flow-Rate Standard. A device or means of measuring flow rate based on direct primary observations such as time and physical dimensions.

Primary Standard. This is a flow device that is certified to be directly traceable to the NIST-SRM. These devices usually provide paperwork that proves that the device is traceable. Bubble meters, volumetric burettes, and some piston devices can be considered to be primary standards. Check with the vendor for certification of a primary standard. The primary standard should remain in the central laboratory and not be moved.

Probe. A tube used for sampling or for measuring pressures at a distance from the actual collection or measuring apparatus. It is commonly used for reaching inside stacks and ducts.

Promulgate. To put a law into effect by formal public announcement.

Q

Quality. The totality of features and characteristics of a product or service that bears on its ability to meet the stated or implied needs and expectations of the user.

Quality Assurance (QA). An integrated system of management activities involving planning, implementation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the client.

Quality Assurance Project Plan (QAPP). A formal document describing in comprehensive detail the necessary quality assurance (QA), quality control (QC), and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria. The QAPP components are divided into four classes: 1) Project Management, 2) Measurement/Data Acquisition, 3) Assessment/Oversight, and 4) Data Validation and Usability. Guidance and requirements on preparation of QAPPs can be found in EPA QA/R-5 and QA/G-5.

Quality Control (QC). The overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated Operational techniques and activities that are used to fulfill requirements for quality. The system of activities and checks used to ensure that measurement systems are maintained within prescribed limits, providing protection against “out of control” conditions and ensuring the results are of acceptable quality.

R

°R. Rankine is an absolute temperature scale often used in engineering. Using this scale, the freezing point of water is 492°R and the boiling point of water is 672°R.

Receptor. The entity which is exposed to the stressor (U.S. EPA, 1997: Guidance on Cumulative Risk Assessment, Planning and Scoping).

Reference Concentration (RfC). An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a no-observed-adverse-effect level (NOAEL), lowest-observed-adverse-effect level (LOAEL), or benchmark concentration, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer human health risk assessments.

Reference Dose (RfD). An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral dose exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a NOAEL, LOAEL, or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. Generally used in EPA's noncancer human health risk assessments.

Relative Pressure. The difference in pressure between a point in a ventilation system or air pollution control system and the atmospheric pressure.

Relative Temperature. The difference between the measured temperature value and an arbitrarily selected value, such as the freezing point of water.

Resistivity. A measure of a particle's ability to conduct electricity (expressed in units of ohm-cm). Resistivity is very important in the efficient operation of electrostatic precipitators.

Reynolds Number, Gas or Flow. A dimensionless number corresponding to the ratio of the fluid inertial force to the fluid viscous force in a flow system. It is used as an index for turbulence.

Reynolds Number, Particle. A dimensionless number corresponding to the ratio of the inertial force of a particle to the viscous force of the surrounding fluid in a flow system. It is used as an index for turbulence.

Risk (in the context of human health). The probability of injury, disease, or death from exposure to a chemical agent or a mixture of chemicals. In quantitative terms, risk is expressed as values ranging from zero (representing the certainty that harm will not occur) to one (representing the certainty that harm will occur).

Risk Assessment (in the context of human health). The determination of potential adverse health effects from exposure to chemicals, including both quantitative and qualitative expressions of risk. The process of risk assessment involves four major steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization.

Risk-Based Concentrations (RBCs). An estimate of a health-based air concentration of a chemical that a person or ecosystem could be exposed to that would not result in a risk of cancer or other adverse health effects above a specified level of concern. The risk-based concentration is developed from toxicological dose response values (for human health, usually selecting the most protective of both cancer toxicological dose response values and noncancer toxicological dose response values) and assumptions about exposure rates. It is a tool used to identify which chemicals may pose a threat to human or ecological receptors without conducting an exposure or risk assessment.

Risk-Based Doses (RBDs). An estimate of a health-based, media-specific concentration (e.g., soil or water) of a chemical that a person or ecosystem could be exposed to that would not result in a risk of cancer or other adverse health effects above a specified level of concern. The risk-based dose is developed from toxicological dose response values (for human health, usually selecting the most protective of both cancer toxicological dose response values and noncancer toxicological dose response values) and assumptions about exposure rates. It is a tool used to identify which chemicals may pose a threat to human or ecological receptors without conducting an exposure or risk assessment.

Risk Characterization. The final, summarizing step of a risk assessment. The risk characterization integrates information from the proceeding components of the risk assessment and synthesizes an overall conclusion about risk that is complete, informative, and useful for decision makers. It conveys the risk assessor's judgment as to the nature and existence of (or lack of) human health or ecological risks.

Risk Management (in the context of human health). A decision making process that accounts for political, social, economic, and engineering implications together with risk-related information in order to develop, analyze, and compare management options and select the appropriate managerial response to a potential chronic health hazard.

Rotameter. A device, based on the principle of Stoke's law, for measuring rate of fluid flow. It consists of a tapered vertical tube having a circular cross section, and containing a flow that is free to move in a vertical path to a height dependent upon the rate of fluid flow upward through the tube.

S

Sample, Integrated. A sample obtained over a period of time with (1) the collected atmosphere being retained in a single vessel, or (2) with a separated component accumulating into a single whole. Examples are particle sampling, in which all the particles separated from the air are accumulated in one mass of fluid; the absorption of acid gas in an alkaline solution; and collection of air in a plastic bag. Such a sample does not reflect variations in concentration during the period of sampling.

Sample, Continuous. Withdrawal of a portion of the atmosphere over a period of time with continuous analysis or with separation of the desired material continuously and in a "linear" form. Examples are continuous withdrawal of the atmosphere accompanied by absorption of a component in a flowing stream of absorbent or by filtration on a moving strip or paper. Such a sample may be obtained with a considerable concentration of the contaminant, but it still indicates fluctuations in concentration that occur during the period of sampling.

Sampling. A process consisting of the withdrawal or isolation of a fractional part of a whole. In air or gas analysis, the separation of a portion of an ambient atmosphere with or without the simultaneous isolation of selected components.

Sampling, Condensation. A process consisting of the collection of one or several components of a gaseous mixture by the simple cooling of the gas stream in a device that retains the condensate.

Sampling, Continuous. Sampling without interruptions throughout an operation or for a predetermined time.

Sampling, Instantaneous. Obtaining a sample of an atmosphere in a very short period of time such that this sampling time is insignificant in comparison with the duration of the operation or the period being studied.

Sampling, Intermittent. Sampling successively for limited periods of time throughout an operation or for a predetermined period of time. The duration of sampling periods and of the intervals between are not necessarily regular and are not specified.

SCFM. The acronym for standard cubic feet per minute, which is the gas flow rate at standard conditions expressed in the American Engineering system of units.

Scrubbing Liquid. A liquid used to remove particulate or gaseous pollutants by absorption or chemical reaction through contact with the gas stream.

Series Collection. An operation involving the use of two or more collectors joined in a series.

Settling Velocity. The terminal rate of fall of a particle through a fluid as induced by gravity or other external force; the rate at which frictional drag balances the accelerating force (or the external force).

Sheaves. Part of the drive system that supports the belt that extends from the drive shaft to the fan shaft.

Sieving. A process that occurs in fabric filters whereby the dust cake, which has accumulated on the fabric surface, acts as a filter for collecting particles.

Silica Gel. A regenerative adsorbent consisting of amorphous silica (SiO_2) with OH surface groups, making it a polar material and enhancing surface reactions.

Smog. A term derived from smoke and fog, applied to extensive atmospheric contamination by aerosols which arise partly through natural processes and partly from the activities of human subjects. Now sometimes used loosely for any contamination of air. (See also "Smog, Photochemical.")

Smog, Photochemical. Air contamination caused by chemical reactions of pollutants formed primarily by the action of sunlight on oxides of nitrogen and hydrocarbons.

Smoke. Small gas-borne particles resulting from incomplete combustion, consisting predominantly of carbon and other combustible material, and present in sufficient quantity to be observable independently of the presence of other solids.

Solute. The substance distributed (i.e., dissolved or suspended) in a solvent.

Solution. A substance (usually a liquid) that dissolves a solute to form a solution.

Sorbent. A liquid or solid medium in or upon which materials are retained by absorption or adsorption.

Sorption. A process consisting of either absorption or adsorption or both.

Specific Gravity. A ratio of the density of a liquid and the density of pure water at a specific temperature.

Spirometer. A displacement gasometer consisting of an inverted bell resting upon or sealed by liquid (or other means) and capable of showing the amount of gas added to or withdrawn from the bell by the displacement (rise or fall) of the bell.

Standard. A concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quantity of the establishment of a practice or procedure.

Standard Conditions (EPA-defined). EPA-defined standard conditions of temperature and pressure are 68°F (20°C) and 14.7 psia (760 mm Hg).

Standard Deviation. A measure of the dispersion of a set of numbers.

Standard Operating Procedure (SOP). A written document that details the method for an operation, analysis, or action with thoroughly prescribed techniques and steps and that is officially approved as the method for performing certain routine or repetitive tasks.

State Implementation Plan (SIP). A complex and voluminous document that contains comprehensive emission inventories, proposed control strategies, demonstration of modeling/calculation results, summaries of regulatory authority, description of monitoring programs, and enforcement procedures.

Static Pressure. A measure of the resistance to airflow through a system.

Stationary Source. Any building, structure, facility, or installation which emits or may emit any air pollutant.

Stratosphere. The atmospheric layer just above the troposphere, which starts at approximately 7.5 miles (12 km) above the Earth and rises to approximately 31.1 miles (50 km). The beneficial ozone layer resides in the stratosphere.

Stressors. Physical, chemical, or biological entities that can induce adverse effects on ecosystems or human health [EPA/OA/Office of Communications, Education, and Media Relations: Terms of Environment: Glossary, Abbreviations, and Acronyms (Revised December 1997)].

Sulfates. Inorganic salts of sulfuric acid (H_2SO_4) containing the divalent, negative ion.

Sulfites. Inorganic salts of sulfurous acid (H_2SO_3) containing the divalent, negative ion.

T

Terminal Settling Velocity. The velocity of a falling particle when the gravitational force downward is balanced by the air resistance (or drag) force upward.

Total Filterable Particulate Matter. Particulate matter of all sizes is regulated as total filterable particulate matter. This category of air pollutants was the first one that was subject to air pollution control regulations.

Total Suspended Particulates (TSP). Particulate matter collected by the high-volume sampler, usually particles of up to 100 micrometers in aerodynamic diameter.

Traceability. According to 40 CFR Parts 50 and 58, this term means "that a local standard has been compared and certified, either directly or via not more than one intermediate standard, to a primary standard such as a National Institute of Standards and Technology Standard Reference material (NIST-SRM)."

Traceability to NIST. Documented procedure by which a standard is related to a more reliable standard verified by the National Institute of Standards Technology (NIST).

Transfer Standard. A device that is certified against a primary standard. These standards usually travel to monitoring stations. Transfer standards can be volumetric, electronic flow meters, wet test meters, pressure gauges, or pressure/flow transducers. These devices usually have a certain amount of error involved in their operation and can drift with time. Therefore they must be verified against a primary standard on a known set schedule.

Troposphere. The lowest layer of the Earth's atmosphere, which rises to a height of approximately 7.5 miles (12 km). Air masses, fronts, and storms reside in this layer.

U

Ultrafine Particles. EPA classification of particles having aerodynamic diameters less than or equal to 0.1 micrometer.

Uncertainty. An allowance assigned to a measured value to take into account two major components of error. The systematic error and the random error attributed to the imprecision of the measurement process.

Unit Risk Estimate or Factor (URE or URF). The upper-bound excess lifetime cancer risk estimated to result for continuous exposure to an agent at a concentration of 1 Fg/L in water, or 1 Fg/m^3 in air. The interpretation of unit risk would be as follows: if unit risk = 1.5 x 10-6 Fg/L, 1.5 excess tumors are expected to develop per 1,000,000 people if exposed daily for a lifetime to 1 Fg of the chemical in 1 liter of drinking water.

V

Van der Waal Forces. Weak attraction forces (1 to 10 Kcal/gm-mole) between molecules such as in gases and liquids.

Vapor. The gaseous phase of matter which normally exists in a liquid or solid state.

Vapor Pressure. In a closed system at a constant temperature, the pressure exerted by gaseous molecules that are in equilibrium with molecules of the same kind in the liquid or solid state.

Velocity Pressure. The pressure required to accelerate air from zero velocity to a greater velocity. It is proportional to the kinetic energy of the air stream.

Venturi Scrubber. A type of wet scrubber that is usually highly efficient but requires a large amount of energy to operate. (Wet scrubbers are air pollution control devices.) In venturi scrubbers, a scrubbing liquid is introduced into the gas stream, which then passes through a contracted area of the scrubber at a high velocity creating a high dispersion of fine droplets. These fine droplets capture the gaseous and particulate pollutants.

Verification. Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled. In design and development, verification concerns the process of examining a result of a given activity to determine conformance to the stated requirements for that activity.

Viscosity (Absolute). The resistance of a fluid to shear stress.

Viscosity (Kinematic). The value obtained when the absolute viscosity is divided by the density of the fluid.

Volume Concentration. Concentration expressed in terms of gaseous volume of substance per unit volume of air or other gas, usually expressed in percent or parts per million.

Volume Percent. Percentage of the total volume of a gas sample that is comprised of the volume of a single gaseous constituent.

W

Working Flow-Rate Standard. A flow-rate measuring device, such as a standard orifice meter, that has been calibrated against a master flow-rate standard. The working flow-rate standard is used to calibrate a flow measuring or flow rate indicating instrument.

X

Y

Z

B.2 Acronyms

ACFM	Actual Cubic Feet per Minute
AIRS	Aerometric Information Retrieval System
ADBA	AIRS Data Base Administrator
AIRMoN	Atmospheric Integrated Research Monitoring Network
ALAPCO	Association of Local Air Pollution Control Officials
AMTIC	Ambient Monitoring Technical Information Center
APTI	Air Pollution Training Institute
AQI	Air Quality Index
AQS	Air Quality (data) System
AQSSD	Air Quality Strategies and Standards Division
ARM	Approved Regional Method
AWMA	Air and Waste Management Association
BAM	Beta Attenuation Monitor
BTU	British Thermal Unit
CAA	Clean Air Act
CAC	Correlating Acceptable Continuous (monitor)
CAIR	Clean Air Interstate Rule
CASAC	Clean Air Science Advisory Committee
CBI	Confidential Business Information
CBSA	Core Based Statistical Area
CENR	Committee for Environment and Natural Resources
CEU	Continuing Education Unit
CFR	Code of Federal Regulations
CMAQ	Community Model Air Quality (system)
CO	Carbon Monoxide
CO	Contracting Officer
CRPAQS	Central Valley (California) Regional Particulate Air Quality Study
CSA	Consolidated Statistical Area
CV	Coefficient of Variance
CY	Calendar Year
DC	Direct Current
DCO	Document Control Officer
DD	Division Director
DHS	Department of Homeland Security
DMC	Data Management Center
DOE	Department of Energy
DOI	Department of Interior
DQA	Data Quality Assessment
DQAO	Deputy QA Officers

DQI	Data Quality Indicator
DQOs	Data Quality Objectives
EC	Elemental Carbon
EDO	Environmental Data Operation
EMAD	Emissions, Monitoring, and Analysis Division
EPA	U.S. Environmental Protection Agency
EPAAR	EPA Acquisition Regulations
ESAT	Environmental Services Assistance Team
ESD	Emission Standards Division
ETSD	Enterprise Technology Services Division
FAR	Federal Acquisition Regulations
FEM	Federal Equivalent Method
FIPS	Federal Information Processing Standards
FLM	Federal Land Manager
FPD	Flame Photometric Detection
FRM	Federal Reference Method
FY	Fiscal Year
GAO	General Accounting Office
GC	Gas Chromatograph
GFC	Gas Filter Correlation
GIS	Geographical Information Systems
GLP	Good Laboratory Practice
HAP	Hazardous Air Pollutants
HCN	Hydrogen Cyanide
HEI	Health Effects Institute
IACET	International Association for Continuing Education and Training
IADN	Interagency Deposition Network
IAG	Interagency Agreement
IC	Ion Chromatography
IDP	Individual Development Plans
IMPROVE	Interagency Monitoring of Protected Visual Environments
IR	Infrared
IT	Information Technology
ITEP	Institute of Tribal Environmental Professionals
ITPID	Information Transfer and Program Integration Division
ITT	Information Transfer Technology
K	Thousand
LAN	Local Area Network
LDL	Lower Detectable Limit
M	Million
MACT	Maximum Achievable Control Technology
MANE-VU	Mid-Atlantic/Northeast Visibility Union
MDL	Method Detection Limit
MDN	Mercury Disposition Network
MQAG	Monitoring and Quality Assurance Group
MQOs	Measurement Quality Objectives
MPA	Monitoring Planning Area

Mo	Molybdenum
MSA	Metropolitan Statistical Area
MSR	Management System Review
N_2	Nitrogen
NAAMS	National Ambient Air Monitoring Strategy
NADP	National Atmospheric Deposition Program
NAAQS	National Ambient Air Quality Standards
NAMS	National Air Monitoring Station
NAPAP	National Acid Precipitation Assessment Program
NARSTO	North American Research Strategy for Tropospheric Ozone
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration
NAU	Northern Arizona University
NCore	National Core Monitoring Network
NDIR	Non-Dispersive Infrared
NECMSA	New England County Metropolitan Statistical Area
NESHAP	National Emission Standards for Hazardous Air Pollutants
NH_3	Ammonia
NH_4^+	Ammonium
NIST	National Institute of Standards and Technology
NMHC	Non-Methane Hydrocarbons
NMSC	National Monitoring Strategy (or Steering) Committee
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
NO_y	Reactive Nitrogen Oxides
NOAA	National Oceanic and Atmospheric Administration
NPAP	National Performance Audit Program
NPEP	National Performance Evaluation Program
NPN	Non-Propyl Nitrate
NPS	National Parks Service
NSPS	New Source Performance Standard
NTN	National Trends Network
O_3	Ozone
OAP	Office of Atmospheric Programs
OAQPS	Office of Air Quality Planning and Standards
OARM	Office of Administration and Resources Management
OC	Organic Carbon
OEI	Office of Environmental Information
OIRM	Office of Information Resources Management
OMB	Office of Management and Budget
ORD	Office of Research and Development
ORIA	Office of Radiation and Indoor Air
PAMS	Photochemical Assessment Monitoring Stations
P&A	Precision and Accuracy
Pb	Lead
PBT	Persistent Bioaccumulative Toxics
PBMS	Performance Based Measurement System

PC	Personal Computer
PE	Performance Evaluation
PEP	Performance Evaluation Program
Pt	Platinum
PM	Particulate Matter
PM_{10}	Particulate Matter with aerodynamic diameter less than 10 micrometers
$PM_{2.5}$	Particulate Matter with aerodynamic diameter less than 2.5 micrometers
PMT	Photomultiplier Tube
POP	Persistent Organic Pollutants
ppb	part per billion
ppm	part per million
PR	Procurement Request
PMSA	Primary Metropolitan Statistical Area
PSD	Prevention of Signification Deterioration
PDW	Primary Wind Direction
QA	Quality Assurance
QC	Quality Control
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
QMP	Quality Management Plan
RADM	Regional Acid Deposition Model
REM	Regional Equivalent Monitor
RCRA	Resource Conservation and Recovery Act
RO	EPA Regional Office
ROM	Regional Oxidant Model
RPO	Regional Planning Organization
RTP	Research Triangle Park (North Carolina)
S&T	Science and Technology
SAMWG	Standing Air Monitoring Workgroup
SCFM	Standard Cubic Feet per Minute
SCG	Source Characterization Group
SIPS	State Implementation Plans
SIRMO	Servicing Information Resources Management Officer
SLAMS	State and Local Air Monitoring Station
SLTs	State and Local Agencies and Tribes
SO_2	Sulfur Dioxide
SOP	Standard Operating Procedure
SOW	Statement or Scope Of Work
SPM	Special Purpose Monitor
SPMS	Special Purpose Monitoring Stations
SRP	Standard Reference Photometer
SS	Supersite
STAG	State and Tribal Air Grant
STAPPA	State and Territorial Air Pollution Program Administrators
STN	Speciation Trend Network
Strategy	The National Air Monitoring Strategy

SVOC	Semi-Volatile Organic Compound
SYSOP	System Operator
TAD	Technical Assistance Document
TAMS	Tribal Air Monitoring Support (Center)
TAR	Tribal Authority Rule
TBD	To Be Determined
TEOM	Tapered Element Oscillation Monitor
TIP	Tribal Implementation Plan
TNMOC	Total Non-Methane Organic Compound
TSA	Technical System Audit
TSP	Total Suspended Solids
TSP	Total Suspended Particulates
USB	Universal Serial Bus
VOC	Volatile Organic Compound
UV	Ultraviolet
WAM	Work Assignment Manager
XML	Extensible Markup Language

Appendix C

Conversion Factors and Useful Information

International Metric System – Le Systeme International d'Unites (SI Units)

Base Units of the International Metric System (SI)		
Quantity	**Name of the Unit**	**Symbol**
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	Kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cd
Amount of substance	mole	mol

Recommended Decimal Multiples and Submultiples with Corresponding Prefixes and Names

Factor	Prefix	Symbol	Meaning
10^{12}	tera	T	One trillion times
10^{9}	giga	G	One billion times
10^{6}	mega	M	One million times
10^{3}	kilo	k	One thousand times
10^{2}	hecto	h	One hundred times
10	deca	da	Ten times
10^{-1}	deci	d	One tenth of
10^{-2}	centi	c	One hundredth of
10^{-3}	milli	m	One thousandth of
10^{-6}	micro	μ	One millionth of
10^{-9}	nano	n	One billionth of
10^{-12}	pico	p	One trillionth of
10^{-15}	femto	f	One quadrillionth of
10^{-18}	atto	a	One quintillionth of

Pressure

From/to	**mm Hg**	**in. Hg**	**in. H_2O**	**ft H_2O**	**atm**	**lb/in.^{2}**	**Kg/cm^2**
mm Hg	1	0.03937	0.5553	0.04460	0.00132	0.01934	0.00136
in. Hg	25.40	1	13.60	1.133	0.03342	0.4912	0.03453
in. H_2O	1.868	0.07355	1	0.08333	0.00246	0.03613	0.00254
ft. H_2O	22.42	0.8826	12	1	0.02950	0.4335	0.03048
atm	760	29.92	406.8	33.90	1	14.70	1.033
lb/in.^{2}	51.71	2.036	27.67	2.301	0.06805	1	0.07031
kg / cm^2	735.6	28.96	393.7	32.81	0.9678	14.22	1

Volume

From/to	cm^3	liter	m^3	in.^{3}	ft^3
cm^3	1	0.001	1×10^{-6}	0.06102	3.53×10^{-5}
liter	1000	1	0.001	61.02	0.03532
m^3	1×10^{6}	1000	1	6.10×10^{4}	35.31
in.^{3}	16.39	0.01639	1.64×10^{-5}	1	5.79×10^{-4}
ft^3	2.83×10^{4}	28.32	0.02832	1728	1

Temperature

$°C = 5/9(°F - 32)$	$°F = 9/5(°C - 32)$
$K = °C + 273.2$	$°R = °F + 459.7$

Conversion Factors – Flow

Desired units / Given units	$\frac{m^3}{sec}$	$\frac{m^3}{min}$	$\frac{m^3}{hour}$	$\frac{ft^3}{sec}$	$\frac{ft^3}{min}$	$\frac{ft^3}{hour}$	$\frac{L}{sec}$	$\frac{L}{min}$	$\frac{cm^3}{sec}$	$\frac{cm^3}{min}$
$\frac{m^3}{sec}$	1	60	3600	35.3144	21.1887 x 10^{2}	12.7132 x 104	999.973	59.998 x 10^{3}	1 x 10^{5}	6 x 10^{7}
$\frac{m^3}{min}$	0.0167	1	60	0.5886	35.3144	21.189 x 10^{2}	16.667	999.973	16.667 x 10^{3}	1 x 10^{4}
$\frac{m^3}{hour}$	2.778 x 10^{-3}	16.667 x 10^{-3}	1	98.90 x 10^{-6}	0.5886	35.3144	27.777 x 10^{-2}	16.667	2.777 x10^{2}	1.666 x 10^{4}
$\frac{ft^3}{sec}$	28.317 x 10^{-3}	1.699	101.94	1	60	3600	28.316	16.9896 x 10^{2}	2.8317 x 10^{4}	1.699 x 10^{6}
$\frac{ft^3}{min}$	4.7195 x 10^{-6}	28.317 x 10^{-3}	1.699	16.667 x 10^{-2}	1	60	47.193 x 10^{-2}	28.316	4.7195 x 10^{3}	2.8317
$\frac{ft^3}{hour}$	7.8658 x 10^{-6}	4.7195 x 10^{-4}	28.317 x 10^{-3}	2.778 x 10^{-4}	16.667 x 10^{-2}	1	7.866 x 10^{-3}	0.4719	78.658	4.7195 x 10^{2}
$\frac{L}{sec}$	1.000027 x 10^{-3}	6.00016 x 10^{-2}	3.6	35.316 x 10^{-3}	2.11896	127.138	1	60	1000.027	16.667
$\frac{L}{min}$	1.6667 x 10^{-6}	1.000027 x 10^{-3}	6.00016 x 10^{-2}	5.886 10^{-6}	35.316 x 10^{-3}	2.11896	1.6667 x 10^{-2}	1	16.667	1000.027
$\frac{cm^3}{sec}$	6 x 10^{-6}	6 x 10^{-6}	3.6 x 10^{-3}	3.5314 x 10^{-6}	2.1189 x 10^{-3}	1.271 x 10^{-3}	9.99973 x 10^{-4}	5.9998 x 10^{-2}	1	16.667 x 10^{-2}
$\frac{cm^3}{min}$	1 x 10^{-6}	1 x 10^{-4}	6 x 10^{-6}	5.886 x 10^{-7}	0.3531 x 10^{-6}	2.11887 x 10^{-3}	5.9998 x 10^{-2}	9.99973 x 10^{-6}	60	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given unit and beneath the desired unit.

Conversion Factors – ppm vs. μg/m^3

Desired units / Given units	Parts per million by volume – ppm					
	O_3	NO_2	SO_2	H_2S	CO	HC as methane
μg/m^3	5.10 x 10^{-4}	5.32 x 10^{-4}	3.83 x 10^{-4}	7.19 x 10^{-4}	-	-
mg/m^3	-	-	-	-	0.875	1.53

Desired units / Given units	μg/m^3				mg/m^3	
	O_3	NO_2	SO_2	H_2S	CO	HC
ppm	1960	1880	2610	1390	1.14	0.654

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Atomic Weight and Numbers

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	-	Mercury	Hg	80	200.59
Aluminum	Al	13	26.9815	Molybdenum	Mo	42	95.94
Americium	Am	95	-	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.183
Argon	Ar	18	39.948	Neptunium	Np	93	-
Arsenic	As	33	74.9216	Nickel	Ni	28	58.71
Astatine	At	85	-	Niobium	Nb	41	92.906
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067
Berkelium	Bk	97	-	Nobelium	No	102	-
Beryllium	Be	4	9.0122	Osmium	Os	75	190.2
Bismuth	Bi	83	208.980	Oxygen	O	8	15.9994
Boron	B	5	10.811	Palladium	Pd	46	106.4
Bromine	Br	35	79.904	Phosphorus	P	15	30.9738
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	-
Californium	Cf	98	-	Polonium	Po	84	-
Carbon	C	6	12.01115	Potassium	K	19	39.102
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.907
Cesium	Cs	55	132.905	Promethium	Pm	61	-
Chlorine	Cl	17	35.453	Protactinium	Pa	91	-
Chromium	Cr	24	51.996	Radium	Ra	88	-
Cobalt	Co	27	58.9332	Radon	Rn	86	-
Copper	Cu	29	63.546	Rhenium	Re	75	186.2
Curium	Cm	96	-	Rhodium	Rh	45	102.905
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	84.57
Einsteinium	Es	99	-	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.35
Europium	Eu	63	151.96	Scandium	Sc	21	44.956
Fermium	Fm	100	-	Selenium	Se	34	78.96
Fluorine	F	9	18.9984	Silicon	Si	14	28.086
Francium	Fr	87	-	Silver	Ag	47	107.868
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.9898
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.064
Gold	Au	79	196.967	Tantalum	Ta	73	180.946
Hafnium	Hf	72	178.49	Technetium	Tc	43	-
Helium	He	2	4.0026	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930	Terbium	Tb	65	158.924
Hydrogen	H	1	1.00797	Thallium	TI	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.038
Iodine	I	53	126.9044	Thulium	Tm	59	168.934
Iridium	Ir	77	196.2	Tin	Sn	50	118.69
Iron	Fe	26	55.847	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.91	Uranium	V	92	238.03
Lawrencium	Lr	103	-	Vanadium	V	23	50.942
Lead	Pb	82	207.19	Xenon	Xe	54	131.30
Lithium	Li	3	6.939	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.905
Magnesium	Mg	12	24.312	Zinc	Zn	30	65.37
Manganese	Mn	25	54.9380	Zirconium	Zr	40	91.22
Mendelevium	Md	101	-				

Saturation Vapor Pressure Over Water (°C, mm Hg)*

Values for fractional degree between 50 and 89 were obtained by interpolation

Temp. °C	0.0	0.2	0.4	0.6	0.8
-15	1.436	1.414	1.390	1.368	1.345
-14	1.560	1.534	1.511	1.485	1.460
-13	1.691	1.665	1.637	1.611	1.585
-12	1.834	1.804	1.776	1.748	1.720
-11	1.987	1.955	1.924	1.893	1.863
-10	2.149	2.116	2.084	2.050	2.018
-9	2.326	2.289	2.254	2.219	2.184
-8	2.514	2.475	2.437	2.399	2.362
-7	2.715	2.674	2.635	2.593	2.553
-6	2.931	2.887	2.843	2.800	2.757
-5	3.163	3.115	3.069	3.022	2.976
-4	3.410	3.359	3.309	3.259	3.211
-3	3.673	3.620	3.567	3.514	3.461
-2	3.956	3.898	3.841	3.785	3.730
-1	4.258	4.196	4.135	4.075	4.016
-0	4.579	4.513	4.448	4.385	4.320
0	4.579	4.647	4.715	4.785	4.855
1	4.926	4.998	5.070	5.144	5.219
2	5.294	5.370	5.447	5.525	5.605
3	5.685	5.766	5.848	5.931	6.015
4	6.101	6.187	6.274	6.363	6.453
5	6.543	6.635	6.728	6.822	6.917
6	7.013	7.111	7.209	7.309	7.411
7	7.513	7.617	7.722	7.828	7.936
8	8.045	8.155	8.267	8.380	8.484
9	8.609	8.727	8.845	8.965	9.086
10	9.209	9.333	9.458	9.585	9.714
11	9.844	9.976	10.109	10.244	10.380
12	10.518	10.658	10.799	10.941	11.085
13	11.231	11.379	11.528	11.680	11.833
14	11.987	12.144	12.302	12.462	12.624
15	12.788	12.953	13.121	13.290	13.461
16	13.634	13.809	13.987	14.166	14.347
17	14.530	14.715	14.903	15.092	15.284
18	15.477	15.673	15.871	16.071	16.272
19	16.477	16.685	16.894	17.105	17.319
20	17.535	17.853	17.974	18.197	18.422
21	18.650	18.880	19.113	19.349	19.587
22	19.827	20.070	20.312	20.565	20.815
23	21.068	21.324	21.583	21.845	22.110
24	22.377	22.648	22.922	23.198	23.476
25	23.756	24.039	24.326	24.617	24.912
26	25.209	25.509	25.812	26.117	26.426
27	26.739	27.055	27.374	27.696	28.021
28	28.349	28.680	29.015	29.354	29.697
29	30.043	30.392	30.745	31.102	31.461
30	31.824	32.191	32.561	32.934	33.312
31	33.695	34.082	34.471	34.864	35.261
32	35.663	36.068	36.477	36.891	37.308
33	37.729	38.155	38.584	39.018	39.457
34	39.898	40.344	40.796	41.251	41.710
35	42.175	42.644	43.117	43.595	44.078
36	44.563	45.054	45.549	46.050	46.556
37	47.067	47.582	48.102	48.627	49.157
38	49.692	50.231	50.774	51.323	57.879
39	52.442	53.009	53.580	54.156	54.737
40	55.324	55.91	56.51	57.11	57.72
41	58.34	58.96	59.58	60.22	60.86
42	61.50	62.14	62.80	63.46	64.12
43	64.80	65.48	66.16	66.86	67.56
44	68.26	68.97	69.69	70.41	71.14
45	71.88	72.62	73.36	74.12	74.88
46	75.65	76.43	77.21	78.00	78.80
47	79.60	80.41	81.23	82.05	82.87
48	83.71	84.56	85.42	86.28	87.14
49	88.02	88.90	89.79	90.69	91.59
50	92.51	93.5	94.4	95.3	96.3
51	97.20	98.2	99.1	100.1	101.1
52	102.09	103.1	104.1	105.1	106.2
53	107.20	108.2	109.3	110.4	111.4
54	112.51	113.6	114.7	115.8	116.9
55	118.04	119.1	120.3	121.5	122.6
56	123.90	125.0	126.2	127.4	128.6
57	129.82	131.0	132.3	133.5	134.7
58	136.08	137.3	138.5	139.9	141.2
59	142.60	143.9	145.2	146.6	148.0
60	149.38	150.7	152.1	153.5	155.0
61	156.43	157.8	159.3	160.8	162.3
62	163.77	165.2	166.8	168.3	169.8
63	171.38	172.9	174.5	176.1	177.7
64	179.31	180.9	182.5	184.2	185.8
65	187.54	189.2	190.9	192.6	194.3
66	196.09	197.8	199.5	201.3	203.1
67	204.96	206.8	208.6	210.5	212.3
68	214.17	216.0	218.0	219.9	221.8
69	223.78	225.7	227.7	229.7	231.7
70	233.7	235.7	237.7	239.7	241.8
71	243.9	246.0	248.2	250.3	252.7
72	254.6	256.8	259.0	261.2	263.4
73	265.7	268.0	270.2	272.6	274.8
74	277.2	279.4	281.8	284.2	286.6
75	289.1	291.5	294.0	296.4	298.8
76	301.4	303.8	306.4	308.9	311.4
77	314.1	316.6	319.2	322.0	324.6
78	327.3	330.0	332.8	335.6	338.2
79	341.0	343.8	346.6	349.4	352.2
80	355.1	358.0	361.0	363.8	366.8
81	369.7	372.6	375.6	378.8	381.8
82	384.9	388.0	391.2	394.4	397.4
83	400.6	403.8	407.0	410.2	413.6
84	416.8	420.2	423.6	426.8	430.2
85	433.6	437.0	440.4	444.0	447.5
86	450.9	454.4	458.0	461.6	465.2
87	468.7	472.4	476.0	479.8	483.4
88	487.1	491.0	494.7	498.5	502.2
89	506.1	510.0	513.9	517.8	521.8
90	525.76	529.77	533.90	537.86	541.95
91	546.05	550.18	554.35	558.53	562.75
92	566.99	571.26	575.55	579.87	584.22
93	588.60	593.00	597.43	601.89	606.38
94	610.90	615.44	620.01	624.61	629.24
95	633.90	638.59	643.30	648.05	652.82
96	657.62	662.45	667.31	672.20	677.12
97	682.07	687.04	692.05	697.10	702.17
98	707.27	712.40	717.56	722.75	727.98
99	733.24	738.53	743.85	749.20	754.58
100	760.00	765.45	770.93	776.55	782.00
101	787.57	793.18	798.82	804.50	810.21

* Handbook of chemistry and physics, 45th edition. 1965. Chemical Rubber Publishing Company.

Appendix D

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

U. S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Center for Environmental Research Information
Cincinnati, Ohio 45268

January 1999

Disclaimer

The information in this document has been compiled wholly or in part by the United States Environmental Protection Agency under contract No. 68-C3-0315, W.A. 3-10 to Eastern Research Group (ERG). The work was performed by Midwest Research Institute (MRI) under subcontract to ERG. It has been subjected to Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

It is further noted that the test methods compiled here are working compilations subject to on-going review and update. It is recommended that the reader refer to the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network web site at http:/www.epa.gov/ttn/amtic/airtox.html to obtain the latest updates, corrections, and/or comments to these test methods.

FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

Measurement of organic pollutants in ambient air is often difficult, in part because of the variety of organic substances of potential concern, the variety of potential techniques for sampling and analysis, and the lack of standardized and documented methods. Consequently, NRMRL has developed a Second Edition of the *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air* to assist Federal, State, and local regulatory personnel in developing and maintaining necessary expertise and up-to-date monitoring technology for characterizing organic pollutants in the ambient air. The Compendium contains a set of 17 peer reviewed, standardized methods for the determination of volatile, semi-volatile, and selected toxic organic pollutants in the air. The 17 methods in the Second Edition have been compiled from the best elements of methods developed or used by various research or monitoring organizations and of which EPA has experience in use of the methodology during various field monitoring programs over the last several years. As with the previous Compendia of methods, these methods are provided only for consideration by the user for whatever potential applications for which they may be deemed appropriate. In particular, these methods are not intended to be associated with any specific regulatory monitoring purpose and are specifically offered with no endorsement for fitness or recommendation for any particular application.

This publication has been prepared in support of NRMRL's goal to provide technical support and information transfer. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director

National Risk Management Research Laboratory

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Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-1

Method for the Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Tenax® Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)

Summary of Method

Compendium Method TO-1 involves drawing ambient air through a cartridge containing ~1-2 grams of Tenax®. Selected VOCs are trapped on the resin, while highly volatile organic compounds and most inorganic atmospheric constituents pass through the cartridge. The cartridge is then transferred to the laboratory and analyzed.

For analysis, the cartridge is placed in a heated chamber and purged with an inert gas, which transfers the VOCs from the cartridge onto a cold trap and subsequently onto the front of the GC column. The column is first held at low temperature (e.g., -70°C), then the column temperature is uniformly increased (temperature programmed). The components eluting from the column are identified and quantified by mass spectrometry. Component identification is normally accomplished using a library search routine on the basis of the GC retention time and mass spectral characteristics. Less sophisticated detectors (e.g., electron capture or flame ionization) may be used for certain applications, but their suitability for a given application must be verified by the user. Due to the complexity of ambient air samples, only high resolution (i.e., capillary) GC techniques are considered to be acceptable in this method.

Sources of Methodology

Method TO-1 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-1 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-13 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe ®, free of charge, at:

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EPA/625/R-96/010b

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-2

Method for the Determination of Volatile Organic Compounds (VOCs) in Ambient Air by Carbon Molecular Sieve Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)

Summary of Method

Compendium Method TO-2 is similar to Compendium Method TO-1 except the adsorbent is a carbon molecular sieve (CMS) rather than Tenax®. The use of CMS allows some of the more volatile organics (i.e., vinyl chloride) to be captured and analyzed.

Method TO-2 is suitable for the determination of certain nonpolar VOCs having boiling points in the range of -15°C to 120°C. The analytical detection limit varies with the analyte. Detection limits of 0.01 to 1 ppbv are achievable using a 20-liter sample.

Sampling involves drawing ambient air through a cartridge containing ~0.4 g of a CMS adsorbent. Volatile organic compounds are captured on the adsorbent while major inorganic atmospheric constituents pass through (or are only partially retained). After sampling, the cartridge is returned to the laboratory for analysis. Prior to analysis the cartridge is purged with 2 to 3 liters of pure, dry air (in the same direction as sample flow) to remove adsorbed moisture.

Similar to Compendium Method TO-1, the cartridge is heated to 350° to 400°C, under helium purge, and the desorbed organic compounds are collected in a specially designed cryogenic trap. The collected organics are then flash evaporated onto a capillary column GC/MS system (held at -70°C). The individual components are identified and quantified during a temperature programmed chromatographic run.

Similar to Compendium Method TO-1, contamination of the CMS, breakthrough, and antifact formation are potential weaknesses of the methodology. Method TO-2 also involves a single analysis.

Sources of Methodology

Method TO-2 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-2 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

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EPA/625/R-96/010b

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-3

Method for the Determination of Volatile Organic Compounds in Ambient Air Using Cryogenic Preconcentration Techniques and Gas Chromatography with Flame Ionization and Electron Capture Detection

Summary of Method

Compendium Method TO-3 involves the *in situ* collection of VOCs having boiling points in the range of -10° to 200°C in a cryogenic trap constructed of copper tubing packed with glass beads. The collection trap is submerged in either liquid nitrogen or liquid argon. Liquid argon is highly recommended because of the safety hazard associated with liquid oxygen. With the sampling valve in the fill position, an air sample is admitted into the trap by a volume measuring apparatus. In the meantime, a GC column oven is cooled to a subambient temperature (-50°C) for sample analysis. Once sample collection is completed, the value is switched so that the carrier gas sweeps the VOCs in the trap onto the head of the cooled GC column. Simultaneously, the liquid cryogen is removed, and the trap is heated to assist the sample transfer process. The GC column is temperature programmed, and the component peaks eluting from the columns are identified and quantified using flame ionization and/or electron capture detection. Alternative detectors (e.g., photoionization) can be used as appropriate. An automated system incorporating these various operations as well as the data processing function is described in the method. Due to the complexity of ambient air samples, high resolution (capillary column) GC techniques are recommended. However, when highly selective detectors (such as the electron capture detector) are employed, packed column technology without cryogenic temperature programming can be effectively used in some cases.

Sources of Methodology

Method TO-3 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium.* Method TO-3 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

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Compendium of Methods
for the Determination of
Toxic Organic Compounds
in Ambient Air

Second Edition

Compendium Method TO-5

Determination of Aldehydes and Ketones in Ambient Air Using High Performance Liquid Chromatography (HPLC)

Summary of Method

Compendium Method TO-5 involves drawing ambient air through a midget impinger containing 10 mL of 2N HCl/0.05% 2,4-dinitrophenylhydrazine (DNPH reagent) and 10 mL of isooctane. Aldehydes and ketones readily form stable 2,4-dinitrophenylhydrazones (DNPH derivatives).

After sampling, the impinger solution is placed in a screw-capped vial having a Teflon®-lined cap and returned to the laboratory for analysis. The DNPH derivatives are recovered by removing the isooctane layer, extracting the aqueous layer with 10 mL of 70/30 hexane/methylene chloride, and combining the organic layers.

The combined organic layers are evaporated to dryness under a steam of nitrogen and the residue dissolved in methanol. The DNPH derivatives are determined using reversed phase HPLC with an ultraviolet (UV) adsorption detector operated at 370 nm.

Sources of Methodology

Method TO-5 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium.* Method TO-5 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

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Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-6

Determination of Phosgene in Ambient Air Using High Performance Liquid Chromatography (HPLC)

Summary of Method

Compendium Method TO-6 involves drawing an air sample through a midget impinger containing 10 mL of 2% aniline/toluene (2/98 by volume). Phosgene readily reacts with aniline to form carbanilide (1,3-diphenylurea), which is stable indefinitely. After sampling, the impinger contents are transferred to a screw-capped vial having a Teflon-lined cap and returned to the laboratory for analysis. The solution is taken to dryness by heating to 60°C on an aluminum heating block under a gentle stream of pure nitrogen gas. The residue is dissolved in 1 mL of acetonitrile. Carbanilide is determined in the acetonitrile solution using reverse-phase HPLC with an ultraviolet (UV) absorbance detector operating at 254 nm. Precision for phosgene spiked into a clean air stream is ±15-20% relative standard deviation. Recovery is quantitative within that precision, down to less than 3 ppbv.

Sources of Methodology

Method TO-6 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-6 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

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EPA/625/R-96/010b

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-7

Method for the Determination of N-nitrosodimethylamine (NDMA) in Ambient Air Using Gas Chromatography

Summary of Method

Compendium Method TO-7 involves drawing ambient air through a Thermosorb/N adsorbent cartridge at a rate of approximately 2 L per minute for an appropriate period of time. Breakthrough has been shown not to be a problem with total sampling volumes of 300 L (i.e., 150 minutes at 2 L per minute) or less. The selection of Thermosorb/N adsorbent over Tenax® GC, was due, in part, to recent laboratory studies indicating artifact formation on Tenax® from the presence of oxides of nitrogen in the sample matrix.

After sampling, the cartridge is plugged and returned to the laboratory for analysis. In the laboratory, the cartridge is pre-eluted with 5 mL of methylene chloride (in the same direction as sample flow) to remove interferences. Residual methylene chloride is removed by purging the cartridge with air in the same direction. The cartridge is then eluted, in the reverse direction, with 2 mL of acetone. This eluate is collected in a screw-capped vial and refrigerated until analysis. NDMA is determined by GC/MS using a Carbowax 20M capillary column. NDMA is quantified from the response of the m/e 74 molecular ion using an external standard calibration method.

Sources of Methodology

Method TO-7 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium.* Method TO-7 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

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EPA/625/R-96/010b

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-8

Method for the Determination of Phenol and Methylphenols (Cresols) in Ambient Air Using High Performance Liquid Chromatography

Summary of Method

Compendium Method TO-8 involves drawing ambient air through two midget impingers, each containing 15 mL of 0.1 N NaOH. The phenols are trapped as phenolates. The impinger solutions are placed in a vial with a Teflon®-lined screw cap and returned to the laboratory for analysis. The solution is cooled in an ice bath and adjusted to a pH <4 by addition of 1 mL of 5% sulfuric acid (V/V). The sample is adjusted to a final volume of 25 mL with distilled water. The phenols are determined using reverse-phase HPLC with either ultraviolet (UV) absorption detection at 274 nm, electrochemical detection, or fluorescence detection. In general, the UV detection approach should be used for relatively clean samples.

Sources of Methodology

Method TO-8 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium*. Method TO-8 is contained in the original *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

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EPA/625/R-96/010b

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air

Second Edition

Compendium Method TO-12

Method for the Determination of Non-Methane Organic Compounds (NMOC) in Ambient Air Using Cryogenic Preconcentration and Direct Flame Ionization Detection (PDFID)

Summary of Method

Compendium Method TO-12 combines a cryogenic concentration technique for trapping organics in the ambient air (similar to Compendium Method TO-3) coupled to a highly sensitive and simple flame ionization detector (FID) to determine non-speciated total NMOC concentrations in the ambient air.

In Compendium Method TO-12, a whole air sample is either extracted directly from the ambient air and analyzed on-site by the GC system or collected into a precleaned specially-treated canister and analyzed off-site.

The analysis requires drawing a fixed-volume portion of the extracted sample air, at a low flow rate, through a glass-bead filled trap that is cooled to approximately -186°C with liquid argon. The cryogenic trap simultaneously collects and concentrates the NMOC (either via condensation or adsorption) while allowing the methane, nitrogen, oxygen, etc. to pass through the trap without retention. The system is dynamically calibrated so that the volume of sample passing through the trap does not have to be quantitatively measured, but must be precisely repeatable between the calibration and the analytical phases.

After the fixed-volume air sample has been drawn through the trap, a helium carrier gas flow is diverted to pass through the trap, in the opposite direction to the sample flow, and into an FID. When the residual air and methane have been flushed from the trap and the FID baseline restabilizes, the cryogen is removed and the temperature of the trap is raised to approximately 90°C.

The NMOC previously collected in the trap revolatilize due to the increase in temperature and are carried into the FID, resulting in a response peak or peaks from the FID. The area of the peak or peaks is integrated, and the integrated value is translated to concentration units via a previously obtained calibration curve relating integrated peak areas with known concentrations of propane.

By convention, concentrations of NMOC are reported in units of parts per million carbon (ppmC), which, for a specific compound, is the concentration by volume (ppmv) multiplied by the number of carbon atoms in the compound.

Sources of Methodology

Method TO-12 has not been revised. Therefore, the original method is not repeated in the Second Edition of the *Compendium.* Method TO-12 is contained in the original supplement of *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA-600/4-89-017, which may be purchased in hard copy from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; Telephone: 703-487-4650; Fax: 703-321-8547; E-Mail: info@ntis.fedworld.gov; Internet: www.ntis.gov. Order number: **PB90-116989.** The TO-methods may also be available from various commercial sources.

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United States
Environmental Protection Agency
Center for Environmental Research Information
Research and Development
EPA-625/SR-96/010b
January 1999

EPA

Project Summary[1]

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air--Second Edition

This Project Summary is the announcement of the availability of the Second Edition of the Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air. This Second Edition of the Compendium has been prepared to provide regional, state and local environmental regulatory agencies with step-by-step sampling and analysis procedures for the determination of selected toxic organic pollutants in ambient air. It is designed to assist those persons responsible for sampling and analysis of hazardous air pollutants (HAPs) in complying with the requirements of Title III of the Clean Air Act.

Determination of pollutants in ambient air is a complex task, primarily because of the wide variety of compounds of interest coupled with the lack of standardized sampling and analysis procedures. Many toxic organics can be sampled and analyzed by several techniques, often with different interferences and detection limitations. This revised Compendium presents a set of 17 methods in a standardized format with a variety of applicable sampling methods, as well as several analytical techniques, for specific classes of organic pollutants, as appropriate to the specific pollutant compound, its level, and potential interferences. Consequently, this treatment allows the user flexibility in selecting alternatives to complement his or her background and laboratory capability. These methods may be modified from time to time as advancements are made.

This Project Summary was developed jointly by the U. S. Environmental Protection Agency (EPA) Center for Environmental Research Information (CERI), National Risk Management Research Laboratory (NRMRL), Office of Research and Development (ORD), Cincinnati, OH and ORD's National Exposure Research Laboratory (NERL) at Research Triangle Park, NC to alert potential users of the availability of the updated Compendium that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Clean Air Act Amendments of 1990 (CAAA of 1990) have significantly increased the responsibilities of both federal and state agency programs for evaluating and maintaining air emissions compliance. In turn, this increased responsibility has generated a need for more

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personnel trained to interpret, enforce, and respond to regulatory initiatives. Consequently, the Agency has restructured its technology transfer program to more effectively provide technical assistance in the form of publication of technical documents, presentations and workshops, and development of tools to assist Agency personnel in keeping their skills up-to-date so that they may efficiently cope with the many changes evolving in new programs, equipment, sampling and analytical methodology, and available enforcement tools.

Limited guidance has been available to state and local agencies or to other organizations concerned with the determination of toxic organic compounds in ambient air. As a result, state and local agencies and others responding to air pollution problems have had to develop their own monitoring strategies, including selection of monitoring methods, sampling plan design, and specific procedures for sampling, analysis, logistics, calibration and quality control. For the most part, these procedures were based on professional judgments rather than adherence to any documented uniform guidelines. Many governmental agencies and professional or research organizations have developed ambient air monitoring methods and procedures, mostly to respond to specialized needs. But these methods and procedures have, *in general,* been neither standardized nor readily available to other agencies involved with ambient air monitoring for organic hazardous air pollutants (HAPs).

To meet these needs, EPA's ORD, through CERI and NERL has supported technology transfer programs involving standardized, peer reviewed monitoring methods for regulatory and industrial personnel via publications of Compendia methods. Other recent or upcoming documents in this series are:

- *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air,* EPA 625/R-96/010a, January 1999. (This publication is scheduled for release during the first half of 1999).
- *Compendium of Methods for the Determination of Air Pollutants in Indoor Air,* EPA 600/4-90-010, April 1990.

These Compendia have historically assisted Federal, State, and local regulatory personnel in developing and maintaining necessary expertise and up-to-date technology involving sampling and analysis of both inorganic and organic HAPs. However, since the publication of these documents, new technology has been introduced to cope with the monitoring requirements identified in the Amendments, thus creating the need for updating many of the methods in the existing Organic Compendium.

The methods in the Second Edition have been compiled from the best elements of methods developed or used by various research or monitoring organizations. They are presented in a standardized format, and each one has been extensively reviewed by several technical experts having expertise in the methodology presented.

Structure of the Second Edition of the Compendium

This Second Edition has been prepared to provide regional, state and local environmental regulatory agencies, as well as other interested parties, with specific guidance on the determination of selected toxic organic compounds in ambient air. A visual guide to the organization of the Compendium for specific methods covering a variety of organic compounds is illustrated in Figure 1.

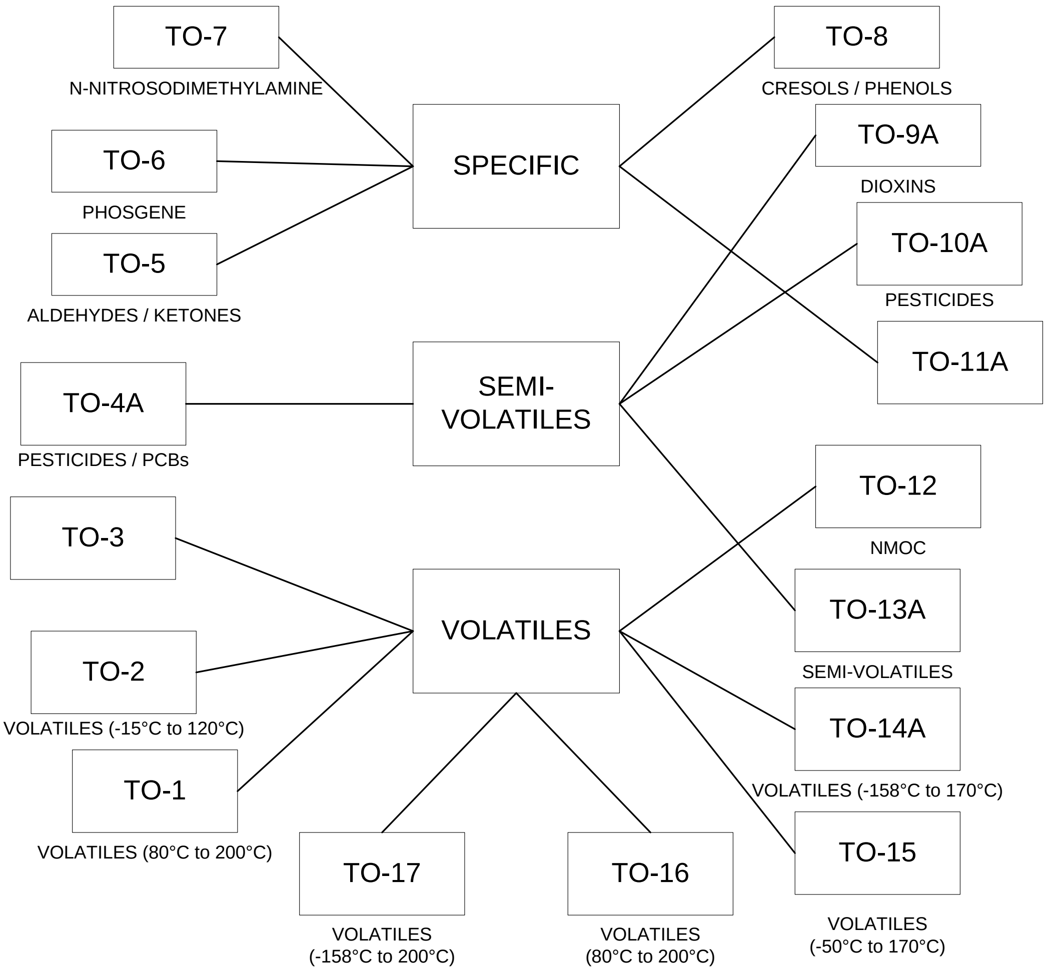

Figure D-1. A visual guide to the organization of the Second Edition of the Organic Compendium.

Those methods assigned the "A" notation are methods which were published in the First Edition (Compendium Methods TO-1 through TO-14) of the Compendium and have now been updated due to technological advances in either the sampling or analysis methodology. In addition, three new methods (Compendium Methods TO-15 through TO-17) have been added to make the complete Second Edition of the Compendium. These methods were added due to their advanced technology application involving specially treated canisters (Compendium Method TO-15), long-path (open-path) fourier transform infrared spectroscopy (Compendium Method TO-16), and multibed sorbent techniques (Compendium Method TO-17). The methods which are neither new or modified are not reproduced in the Second Edition in order to save space. This decision was based on the fact that they are not as likely to be used as the revised or new methods.

A list of methods contained in the Second Edition of the Compendium is presented in Table 1. This listing provides a brief indication of the type of compounds to which the method is applicable, the type of sample collection device used, and the type of analytical methodology for which the sample collection system was designed for compatibility. Finally, a listing of the advantages and disadvantages of the methods in the Second Edition of the Compendium are documented in Table 2.

TABLE 1. LIST OF METHODS IN SECOND EDITION OF THE COMPENDIUM

Compendium Method No.	Type of Compounds Determined	Sample Collection Device	Analytical Methodology[1]
TO-1[2]	Volatile organic compounds	Tenax® solid sorbent	GC/MS
TO-2[2]	Volatile organic compounds	Molecular sieve sorbent	GC/MS
TO-3[2]	Volatile organic compounds	Cryotrap	GC/FID
TO-4A	Pesticides/PCBs	Polyurethane foam	GC/MD
TO-5[2]	Aldehydes/Ketones	Impinger	HPLC
TO-6[2]	Phosgene	Impinger	HPLC
TO-7[2]	Anilines	Adsorbent	GC/MS
TO-8[2]	Phenols	Impinger	HPLC
TO-9A	Dioxins	Polyurethane foam	HRGC/HRMS
TO-10A	Pesticides/PCBs	Polyurethane foam	GC/MD
TO-11A	Aldehydes/ketones	Adsorbent	HPLC
TO-12[2]	Non-methane organic compounds (NMOC)	Canister or on-line	FID
TO-13A	Polycyclic aromatic hydrocarbons	Polyurethane foam	GC/MS
TO-14A	Volatile organic compounds (nonpolar)	Specially-treated canister	GC/MS and GC/MD
TO-15	Volatile organic compounds (polar/nonpolar)	Specially-treated canister	GC/MS
TO-16	Volatile organic compounds	Open path monitoring	FTIR
TO-17	Volatile organic compounds	Single/multi-bed adsorbent	GC/MS, FID, etc.

[1] GC/MS = Gas chromatography/mass spectrometry.

GC/FID = Gas chromatography/flame ionization detector.

HPLC = High performance liquid chromatography.

GC/MD = Gas chromatography/multi-detector.

GC/IT = Gas chromatography/ion trap detector.

FTIR = Fourier transform infrared spectroscopy.

HRGC/HRMS = High resolution gas chromatography/high resolution mass spectrometry.

[2] Methods denoted by “2” have not been changed since their publication in the First Edition of the Compendium, so the full content of these methods is not repeated in this Second Edition. Therefore, the full content of these methods must be obtained from the original Compendium (EPA 600/4-89-017).

TABLE 2. COMPENDIUM METHODS CHARACTERISTICS

Method Design.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-1 (See also Methods TO-14A, TO-15, and TO-17)	VOCs (80° to 200°C) [e.g., benzene, toluene, xylenes]	**TENAX-GC ADSORPTION AND GC/MS OR GC/FID ANALYSIS** Ambient air is drawn through organic polymer sorbent where certain compounds are trapped. The cartridge is transferred to the laboratory, thermally desorbed and analyzed using GC/MS or GC/FID.	0.01-100 ppbv	• Good data base. • Large volume of air can be sampled. • Water vapor is not collected. • Wide variety of compounds collected. • Low detection limits. • Standard procedures available. • Practical for field use.	• Highly volatile compounds and certain polar compounds are not collected. • Rigorous clean-up of adsorbent required. • No possibility of multiple analysis. • Low breakthrough volumes for some compounds. • Desorption of some compounds difficult. • Structural isomers are the most common interferences. • Contamination of adsorbent and blank contaminants may be a problem. • Artifact formation.
TO-2 (See also Methods TO-14A, TO-15, and TO-17)	Highly volatile VOCs (-15° to +120°C) [e.g., vinyl chloride, chloroform, chlorobenzene]	**CARBON MOLECULAR SIEVE ADSORPTION AND GC/MS OR GC/FID ANALYSIS** Selected volatile organic compounds are captured on carbon molecular sieve adsorbents. Compounds are thermally desorbed and analyzed by GC/MS or GC/FID techniques.	0.1-200 ppbv	• Trace levels of volatile organic compounds are collected and concentrated on sorbent material. • Efficient collection of polar compounds. • Wide range of application. • Highly volatile compounds are adsorbed. • Easy to use in field.	• Some trace levels of organic species are difficult to recover from the sorbent. • Structural isomers are common interferences. • Water is collected and can de-activate adsorption sites. • Thermal desorption of some compounds may be difficult.
TO-3 (See also Methods TO-14A, TO-15, and TO-17)	VOCs nonpolar (-10° to +200°C) [e.g., vinyl chloride, methylene chloride, acrylonitrile]	**CRYOGENIC PRECONCENTRATION AND GC/FID/ECD ANALYSIS** Vapor phase organics are condensed in a cryogenic trap. Carrier gas transfers the condensed sample to a GC column. Adsorbed compounds are eluted from the GC column and measured by FID or ECD.	0.1-200 ppbv	• Collects wide variety of volatile organic compounds. • Standard procedures are available. • Contaminants common to adsorbent materials are avoided. • Low blanks. • Consistent recoveries. • Large data base.	• Moisture levels in air can cause freezing problems with cryogenic trap. • Difficult to use in field. • Expensive. • Integrated sampling is difficult. • Compounds with similar retention times will interfere.
TO-4 (See also Method TO-10A)	Pesticides/PCBs [e.g., PCBs, 4,4-DDE, DDT, DDD]	**HIGH VOL FILTER AND PUF ADSORBENT FOLLOWED BY GC/FID/ECD OR GC/MS DETECTION** Pesticides/PCBs trap on filter and PUF adsorbent trap. Trap returned to lab, solvent extracted and analyzed by GC/FID/ECD or GC/MS.	0.2pg/m^3-200 ng/m^3	• Low detection limits. • Effective for broad range of pesticides/PCBs • PUF reusable. • Low blanks. • Excellent collection and retention efficiencies for common pesticides • and PCBs.	• Breakdown of PUF adsorbent may occur with polar extraction solvents. • Contamination of glassware may limit detection limits. • Loss of some semi-volatile organics during storage. • Extraneous organics may interfere. • Difficulty in identifying individual pesticides and PCBs if using ECD.

TABLE 2. (CONTINUED)

Method Design.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-5 (See also Method TO-11A)	Aldehydes and ketones [e.g., formaldehyde, acetaldehyde, acrolein]	**DNPH LIQUID IMPINGER AND HPLC/UV ANALYSIS** Air sample is drawn through dinitrophenylhydrazine (DNPH) impinger solution using a low volume pump. The solution is analyzed using HPLC with a UV detector.	1-50 ppbv	• Specific for aldehydes and ketones. • Good stability for derivative compounds formed in the impingers. • Low detection limits.	• Sensitivity limited by reagent purity. • Potential for evaporation of liquid over long term sampling. • Isomeric aldehydes and ketones may be unresolved by the HPLC system.
TO-6	Phosgene	**ANILINE/TOLUENE LIQUID IMPINGER AND HPLC/UV ANALYSIS** Ambient air is drawn through a midget impinger containing 10 mL of 2/98 aniline/toluene (v/v). The phosgene reacts with aniline to form 1,3-diphenylurea and is analyzed using reverse-phase HPLC with a UV absorbance detector operating at 254 nm.	1-50 ppbv	• Good specificity. • Good stability for derivative compounds formed in the impingers. • Low detection limits.	• Chloroformates and acidic materials may interfere. • Contamination of aniline reagents may be a source of interference. • Use of midget impingers in field application may not be practical.
TO-7	N-Nitroso dimethylamine	**THERMOSORB/N CARTRIDGE WITH GC/MS ANALYSIS** Ambient air is drawn through a cartridge containing Thermosorb/N adsorbent to trap N-nitrosodimethylamine. The cartridge is then returned to the lab and eluted with 5 mL of dichloromethane. The cartridge is then eluted in reverse direction with 2 mL of acetone. The N-nitrosodimethylamine is then determined by GC/MS.	1-50 ppbv	• Good specificity. • Good stability for derivative compounds formed on the cartridge. • Low detection limit for n-nitrosodimethylamine. • Placement of sorbent as first component in sample train minimizes contamination. • Sampling system portable and lightweight.	• Compounds with similar GC retention times and detectable MS ions may interfere. • Specificity is a limiting factor if looking for other organic amines.
TO-8	Cresol/Phenol	**SODIUM HYDROXIDE LIQUID IMPINGER AND HPLC/UV DETECTION** Ambient air is drawn through two midget impingers. Phenols are trapped as phenolates in NaOH solution which is returned to the lab and analyzed by HPLC.	1-250 ppb	• 4,6-dinitro-2-methylphenol specific to class of compounds. • Good stability. • Detects non-volatile as well as volatile phenol compounds.	• Compounds having the same HPLC retention times will interfere with this method. • Phenolic compounds of interest may be oxidized during sampling. • Limited sensitivity.

TABLE 2. (CONTINUED)

Method Design.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-9A	Dioxin/ Furan/PCBs	**PUF ADSORBENT CARTRIDGE AND HRGC/HRMS ANALYSIS** Ambient air is drawn through a glass fiber filter and a polyurethane foam (PUF) adsorbent cartridge by means of a high volume sampler. The filter and PUF cartridge are returned to the laboratory and extracted using toluene. The extract is concentrated using the Kuderna-Danish technique, diluted with hexane, and cleaned up using column chromatography. The cleaned extract is then analyzed by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS).	0.25-5000 pg/m^3	• Cartridge is reusable. • Excellent detection limits. • Easy to preclean and extract. • Excellent collection and retention efficiencies. • Broad database. • Proven methodology.	• Analytical interferences may occur from PCBs, methoxybiphenyls, chlorinated hydroxydiphenylethers, naphthalenes, DDE, and DDT with similar retention times and mass fractions. • Inaccurate measurement Ds/Fs are retained on particulate matter and may chemically change during sampling and storage. • Analytical equipment required (HRGC/HRMS) is expensive and not readily available. • Operator skill level important. • Complex preparation and analysis process. • Can't separate particles from gaseous phase.
TO-10A	Pesticides [e.g., heptachlor, chlordane, dieldrin, aldrin]	**PUF ADSORBENT CARTRIDGE AND GC/ECD/PID/FID ANALYSIS** A low-volume sample (1-5 L/min) is pulled through a polyurethane foam (PUF) plug to trap organochlorine pesticides. After sampling, the plug is returned to the laboratory, extracted and analyzed by GC coupled to multi-detectors (ECD, PID, FID, etc.).	1-100 ng/m^3	• Easy field use. • Proven methodology. • Easy to clean. • Effective for broad range of compounds. • Portability. • Good retention of compounds.	• ECD and other detectors (except the MS) are subject to responses from a variety of compounds other than target analytes. • PCBs, dioxins and furans may interfere. • Certain organochlorine pesticides (e.g., chlordane) are complex mixtures and can make accurate quantitation difficult. • May not be sensitive enough for all target analytes in ambient air.

TABLE 2. (CONTINUED)

Method Design.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-11A	Formaldehyde (other aldehydes/ ketones) [e.g., formaldehyde, acetaldehyde, acrolein]	**DNPH-CARTRIDGE AND HPLC/UV DETECTION** An ambient air sample is drawn through a commercially-coated DNPH cartridge at a rate of 500-1200 mL/minute. The cartridges are returned to the laboratory in screw-cap glass vials. The cartridges are then removed from the vials and washed with acetonitrile by gravity feed elution. The eluate is diluted volumetrically and an aliquot is removed for determination of the DNPH-formaldehyde derivative by isocratic reverse phase HPLC with UV detection at 350 nm.	0.5-100 ppbv	• Placement of sorbent as first element in the sampling train minimizes contamination. • Large database. • Proven technology. • Sampling system is portable and light weight.	• Isometric aldehydes and ketones and other compounds with the same HPLC retention time as formaldehyde may interfere. • Carbonyls on the DNPH cartridge may degade if an ozone denuder is not employed. • Liquid water captured on the DNPH cartridge during sampling may interfere. • O_3 and UV light deteriorates trapped carbonyls on cartridge.
TO-12	NMOC (non-methane organic compounds)	**CANISTER SAMPLING—CRYOGENIC PRECONCENTRATION AND FID DETECTION** Ambient air is drawn into a cryogenic trap where the non-methane organic compounds 9NMOCs) are concentrated. The trap is heated to move the NMOCs to the FID. Concentration of NMOCs is determined by integrating under the broad peak. Water correction is necessary.	0.1-200 ppmvC	• Standard procedures are available. • Contaminants common to absorbent materials are avoided. • Low blanks. • Consistent recoveries. • Large data base. • Good sensitivity. • Useful for screening areas or samples. • Analysis much faster than GC.	• Moisture levels in air can cause freezing problems. • Non-speciated measurement. • Precision is limited.

TABLE 2. (CONTINUED)

Method Design.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-13A	PAHs [e.g., benzo(a)pyrene, naphthalene, flourene]	**PUF OR XAD-2 ADSORBENT CARTRIDGE AND GC/MS ANALYSIS** Ambient air is drawn through a glass fiber filter and a polyurethane foam (PUF) or XAD-2 adsorbent cartridge by means of a high volume sampler. The filter and PUF cartridge are extracted using 10% diethyl ether. The extract is concentrated using Kuderna-Danish technique, diluted, and cleaned up using column chromatography. The cleaned extract is then analyzed by gas chromatography/mass spectrometry (GC/MS).	0.5-500 ng/m^3	• Allows for sample dilution if concentration is too high during analysis. Repeated analysis is possible. • High-volume sampling provides for lower detection limits. • Filter and PUF are low cost.	• Method has interferences due to contamination of solvents, reagents, glassware, and sampling hardware. • Coeluting contaminants may cause interference with target analytes. • Heat, ozone, NO_2, and ultraviolet light may cause sample degradation.
TO-14A	VOCs (non-polar) [e.g., toluene, benzene, chlorobenzene]	**SPECIALLY-PREPARED CANISTER AND GC/FID/ECD OR GC/MS DETECTION** Whole air samples are collected in an evacuated stainless steel canister. VOCs are concentrated in the laboratory with cryogen trap. VOCs are revolatilized, separated on a GC column, and passed to one or more detectors for identification and quantitation.	0.2-25 ppbv	• Best method for broad speciation of unknown trace volatile organics. • Simple sampling approach.. • Good QA/QC database. • Proven field and analytical technology.	• Limited to non-polar compounds due to use of permeation type dryer. • Sample components may be adsorbed or decompose through interaction with container walls. • Water condensation at high humidity may be a problem at high concentrations (ppm). • Complex equipment preparation required. • Expensive analytical equipment.
TO-15	VOCs (polar/non-polar) [e.g., methanol, benzene, xylene, nitrobenzene]	**SPECIALLY-PREPARED CANISTER AND GC/MS ANALYSIS** Whole air samples are collected in a specially-prepared canister. VOCs are concentrated on a solid sorent trap or other arrangement, refocused on a second trap, separated on a GC column, and passed to an MS detector for identification and qualification.	0.2-25 ppbv	• Incorporates a multisorbent/dry purge technique or equivalent for water management thereby addressing a more extensive set of compounds. • Establishes method performance criteria for acceptance of data. • Provides enhanced provisions for quality control. • Unique water management approach allows analysis for polar VOCs.	• Expensive analytical equipment. • Operator skill level important.

TABLE 2. (CONTINUED)

Method Design.	Types of Compounds Determined[1]	Sampling and Analysis Approach	Detection Limit	Advantages	Disadvantages
TO-16	VOCs (polar/non-polar) [e.g., alcohols, ketones, benzene, toluene, o-xylene, chlorobenzene]	**FTIR OPEN PATH SPECTROSCOPY** VOCs are monitored using real-time long-path open-path fourier transform infrared spectroscopy (FTIR).	25-500 ppbv	• Open path analysis maintains integrity of samples. • Multi-gas analysis saves money and time. • Path-integrated pollutant concentration measurement minimizes possible sample contamination, and provides real-time pollutant concentration. • Applicability for special survey monitoring. • Monitoring at inaccessible areas possible using open-path FTIR.	• High level of operator skill level required. • Requires spectra interpretation. • Limited spectra library available. • Higher detection limits than most alternatives. • Must be skilled in computer operation. • Substantial limitations from ambient CO_2 and humidity levels associated with spectral analysis.
TO-17	VOCs (polar/non-polar) [e.g., alcohols, ketones, benzene, toluene, o-xylene, chlorobenzene]	**MULTI-BED ADSORBENT TUBE FOLLOWED BY GC/MS** Ambient air is drawn through a multi-bed sorbent tube where VOCs are trapped. The cartridge is returned to the laboratory, thermally desorbed and analyzed by GC/MS or other methods.	0.2-2.5 ppbv	• Placement of the sorbent as the first element minimizes contamination from other sample train components. • Large selection of sorbents to match with target analyte list. • Includes polar VOCs. • Better water management using hydrophobic sorbents than Compendium Method TO-14A. • Large database, proven technology. • Size and cost advantages in sampling equipment.	• Distributed volume pairs required for quality assurance. • Rigorous clean-up of sorbent required. • No possibility of multiple analysis. • Must purchase thermal desorption unit for analysis. • Desorption of some VOCs is difficult. • Contamination of adsorbent can be a problem.

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[1] Number in parenthesis is the boiling point range of the organics applicable to that Compendium Method.

The following is a brief overview of important technical changes/additions that have been made to those methods which have been updated or added to comprise the Second Edition of the Organic Compendium.

Compendium Method TO-4A
(Pesticides/PCBs)

- Incorporates an extensive update of quality assurance (QA) requirements involving the sampling mechanism.
- Allows a multi-detector approach for quantifying analytes on the target compound list (TCL).
- Establishes method performance criteria for acceptance of data, allowing the use of alternative but equivalent sampling and analytical equipment.
- Provides specific procedures for sample clean-up, employing solid phase extraction using silica, alumina or florisil.
- A detailed discussion associated with method performance criteria involving surrogate recoveries, laboratory method blanks, GC column performance and minimum detection limits is provided.

Compendium Method TO-9A (Dioxins/Furans)

- Includes guidance associated with the use of benzene or toluene as the extraction solvent.
- Provides extensive guidance associated with field operation and quality assurance checks involving the high-volume sampler.
- Presents extracted ion current profiles (EICP) for selected dioxins and furans.
- Discusses method performance criteria involving surrogate recoveries, laboratory method blanks, GC column performance, laboratory control spikes, matrix spikes, and minimum detection limits determination.
- Provides specific procedures for sample clean-up employing solid phase extraction using silica, alumina, and carbon adsorbents.

Compendium Method TO-10A
(Pesticides/PCBs)

- Provides guidance on determining sampling efficiency (SE), retention efficiency (RE), and dynamic retention efficiency (RE_d)
- Recommends specific detectors for common pesticides and PCBs.
- Gives construction specifications for both PUF and PUF/XAD-2 adsorbent cartridges.
- Includes recent laboratory evaluation of sampling efficiencies for organochlorine pesticides, PCBs, ureas, triazines and pyethrins.
- Describes generator used in determining sampling efficiencies.

Compendium Method TO-11A
(Formaldehyde)

- Includes new material from EPA's Technical Assistance Document (TAD) on enhanced ozone monitoring.
- Adds design and construction specifications for an ozone denuder and scrubber.
- Reviews commercially-prepared low pressure drop adsorbent cartridges.
- Discusses sampler design for sequential sampling and heated inlet.

- Provides guidance on sorbent selection (C_{18} vs. silica gel).
- Illustrates the application of ozone denuder or scrubber to the field sampling system.
- Updates of HPLC procedures for column alternatives to quantitate up to 14 carbonyl compounds.

Compendium Method TO-13A
(Semi-volatiles)

- Incorporates an extensive update of quality assurance (QA) requirements involving sampling mechanism.
- Allows only gas chromatography/mass spectrometry (GC/MS) approach specified for quantifying analytes on the target compound list (TCL).
- Establishes method performance criteria for acceptance of data, allowing the use of alternative but equivalent sampling and analytical equipment.
- Provides specific procedures for sample clean-up, employing solid phase extraction.
- Provides detailed discussion of method performance evaluation (PE) standard and recoveries, laboratory method blanks, GC column performance and minimum detection limits requirements.

Compendium Method TO-14A
(VOCs - non-polar)

- Excludes alternative “water management” technique in lieu of permeation dryers.
- Expands canister requirements to include specially-prepared canisters.
- Provides for gas chromatography coupled to an ion trap detector.

Compendium Method TO-15
(VOCs - polar/non-polar)

- Addresses a more extensive set of compounds (the VOCs mentioned in Title III of the CAAA of 1990).
- The analytical methodology emphasizes GC/MS as the means to identify and quantitate target compounds.
- Establishes method performance criteria for acceptance of data, allowing the use of alternate but equivalent sampling and analytical equipment.
- Uses a multisorbent/dry purge technique or equivalent for water management.

Compendium Method TO-16
(VOCs - polar/non-polar)

- Describes the use of an FT-IR system to measure pollutants using a long, open air path.
- Provides measurement of the path-average atmospheric concentrations of various organic gases.
- Methodology discussed in Compendium Method TO-16 provides the following advantages for field application:
  -- The integrity of the sample is assured, since no sampling actually occurs.
  -- Multi-gas analysis is possible with a single field spectrum.
  -- Path-integrated pollutant concentrations are obtained.
  -- Spatial survey monitoring of industrial facilities is possible if scanning optics are used.

-- Coadding of spectra to improve detection capabilities is easily performed.
-- Rapid temporal scanning of line-of-site or multiple lines-of-sight is possible.
-- Monitoring of otherwise inaccessible areas is possible.

Compendium Method TO-17
(VOCs - polar/non-polar)

- The use of solid adsorbents in multisorbent tubes for concentrating VOCs from the ambient air is presented as part of EPA's program for methods development of automated gas chromatographs.
- Uses sorbent tubes with single or multisorbent packings.
- Compendium Method TO-17, collection of VOCs in ambient air samples by passage through solid sorbent packings, provides numerous advantages, including:

-- The small size and light weight of the sorbent packing and attendant equipment allows for field application.
-- The placement of the sorbent packing as the first element (with the possible exception of a filter or chemical scrubber for ozone) in the sampling train reduces the possibility of contamination from upstream elements.
-- The availability of a large selection of sorbents enables matching sorbents with a target set of compounds, including polar VOC.
-- The method provides for the possibility of water management using a combination of hydrophobic sorbents (to cause water breakthrough while sampling), dry gas purge of water from the sorbent after sampling, and splitting of the sample during analysis.
-- Technology is based on a large amount of literature associated with the use of sorbent sampling and thermal desorption for monitoring of workplace air, particularly from the Health and Safety Executive in the United Kingdom.

Ordering Information

The First Edition of the Compendium was published over a period of four years in four separate EPA documents. They are:

- Original Compendium (Methods TO-1 through TO-5), EPA 600/4-84-041, April 1984.
- First Supplement (Methods TO-6 through TO-9), EPA 600/4-87-006, September 1986.
- Second Supplement (Methods TO-10 through TO-14), EPA 600/4-89-018, June 1988.
- Full Compendium (Methods TO-1 through TO-14), EPA 600/4-89-017, June 1988.

Please Note: The Second Edition of the Compendium does not contain Methods TO-1, 2, 3, 5, 6, 7, 8, and 12. These methods, which were not updated because there were no significant technological advances made in them, can be found in their entirety in the First Edition only. The Second Edition contains only: a) the updated methods (methods assigned with an "A" in Table 1 from the First Edition which includes Compendium Methods TO-4A, TO-9A, TO-10A, TO-11A, TO-13A, and TO-14A); and b) the three new methods, Compendium Methods TO-15, TO-16, and TO-17.

These documents, including the Second Edition, may be purchased in hard copy from:

National Technical Information Service (NTIS) 5285
Port Royal Road, Springfield, VA 22161 Telephone: 703-
487-4650; FAX: 703-321-8547 E-mail:Info @
NTIS.FEDWORLD.GOV
INTERNET: http://www.ntis.gov.

U.S. EPA: Office of Air Quality Planning and Standards (OAQPS)

Electronic versions of the individual unrevised Compendium (TO-) Methods are available for downloading from the "AMTIC, Air Toxics" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTNWeb:

http://www.epa.gov/ttn/amtic/airtox.html

Methods TO-1 to TO-17 are now posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe ®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

and are required to read Acrobat (PDF) files. Readers are available for Windows, MacIntosh, and DOS.

U.S. EPA: Office of Research and Development (ORD),
Center for Environmental Research Information (CERI)

New technology transfer documents may be ordered on-line through the CERI Technology Transfer web site - "http://www.epa.gov/ttbnrmrl/". Once the web site has been accessed, click on the publication list and follow the menu-driven ordering instructions.

Acknowledgements

The Second Edition of the **Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air** (EPA/625/R-96/010b) was prepared under Contract No. 68-C3-0315, WA No. 3-10, by Midwest Research Institute (MRI), as a subcontractor to Eastern Research Group, Inc. (ERG), and under the sponsorship of the EPA. Justice A. Manning, John O. Burckle, Scott Hedges, Center for Environmental Research Information, and Frank F. McElroy, National Exposure Research Laboratory , all in EPA's Office of Research and Development, were responsible for overseeing the preparation of the Second Edition of the Compendium. Invaluable support was also provided by the following members of the Compendium Workgroup:

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Appendix E

Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air

Project Summary

This Project Summary is the announcement of the availability of a collection of methods for measurement of inorganic pollutants of interest in ambient air. These methods have been prepared to provide regional, state and local environmental regulatory agencies and other users with step-by-step sampling and analysis procedures for the determination of selected inorganic pollutants in ambient air. The methods comprise the *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air,* which is intended to assist those persons responsible for sampling and analysis of ambient inorganic pollutants.

Determination of pollutants in ambient air is a complex task, primarily because of the wide variety of compounds of interest coupled with the lack of standardized sampling and analysis procedures. Many inorganic compounds can be sampled and analyzed by several techniques, often with different interferences and detection limitations. This Compendium contains a set of 17 methods (in 5 categories) presented in a standardized format, with a variety of applicable sampling methods and various analytical techniques for specific classes of inorganic pollutants, as appropriate to their ambient levels and potential interferences. Consequently, this treatment allows flexibility in selecting alternatives to complement the user's background and laboratory capability. These methods may be modified from time to time as advancements are made.

This Project Summary was developed by EPA's Center for Environmental Research Information (CERI), National Risk Management Research Laboratory (NRMRL), Office of Research and Development (ORD), U.S. EPA, Cincinnati, OH, with assistance from the ORD's National Exposure Research Laboratory (NERL) at Research Triangle Park, NC. Its purpose is to announce key findings of the research project, which is fully documented in a separate report of the same title (see Project Report ordering information on the last page).

Introduction

The Clean Air Act Amendments of 1990 (CAAA of 1990) have significantly increased the responsibilities of both federal and state agency programs for evaluating and maintaining air pollutant emissions compliance. In turn, this increased responsibility has generated a need for more personnel trained to interpret, enforce, and respond to regulatory initiatives. Consequently, the Agency has restructured its technology transfer program to more effectively provide technical assistance in the form of publication of technical documents, presentations and workshops, and development of tools to assist Agency personnel in keeping their skills up-to-date so that they may efficiently cope with the many changes evolving in new programs, equipment, sampling and analytical methodology, and available enforcement tools.

Limited guidance has been available to state and local agencies or to other organizations concerned with the determination of inorganic pollutant concentrations in ambient air. As a result, state and local agencies and others responding to air pollution problems have had to develop their own monitoring strategies, including selection of monitoring methods, sampling plan designs, and specific procedures for sampling, analysis, logistics, calibration and quality control. For the most part, these procedures were based on professional judgments rather than adherence to any documented uniform guidelines. Many governmental agencies and professional or research organizations have developed ambient air monitoring methods and procedures, mostly to respond to specialized needs. But these methods and procedures have, *in general,* been neither standardized nor readily available to other agencies involved with ambient air monitoring for various pollutants.

To meet these needs, EPA's ORD, through CERI and NERL has supported technology transfer programs involving standardized, peer reviewed monitoring methods for regulatory and industrial personnel via publications of a series of methods Compendia. Other Compendia in this series, reflecting EPA's commitment to technology transfer, are:

- *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* EPA 600/4-89-017, June 1988.
- *Compendium of Methods for the Determination of Air Pollutants in Indoor Air,* EPA 600/4-90-010, April 1990.
- *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition,* EPA 625/R-96/010b, January 1999.

These Compendia have historically assisted Federal, State, and local regulatory personnel in developing and maintaining necessary expertise and up-to-date technology involving sampling and analysis of both indoor and organic hazardous air pollutants (HAPs). The objective of this project was to develop and standardize methods for measuring inorganic pollutants of interest in ambient air and publish them in this *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air.* This fourth Compendium adds much needed methods for measurement of inorganic pollutants in ambient air to the series.

Consistent with past practices, the Compendium methods are provided as guidance only in appropriate monitoring situations. In particular, these methods are not intended to be used as specific regulatory guidance for measurement or monitoring purposes and are offered with no endorsement for suitability or recommendation for any specific application; rather, this is merely to document the methods and to make them more widely available.

Structure and Content of the Inorganic Compendium

This Compendium has been prepared to provide regional, state and local environmental regulatory agencies, as well as other interested parties, with specific guidance on the determination of selected inorganic compounds and pollutants in ambient air. A visual guide to the organization of the Inorganic Compendium is illustrated in Figure 1, while Table 1 lists the 17 methods which comprise the 5 chapters of the Compendium. The 17 methods have been compiled from the best elements of methods developed or used by various research or monitoring organizations. They are presented in a standardized format, and each one has been extensively reviewed by several technical experts having expertise in the methodology presented.

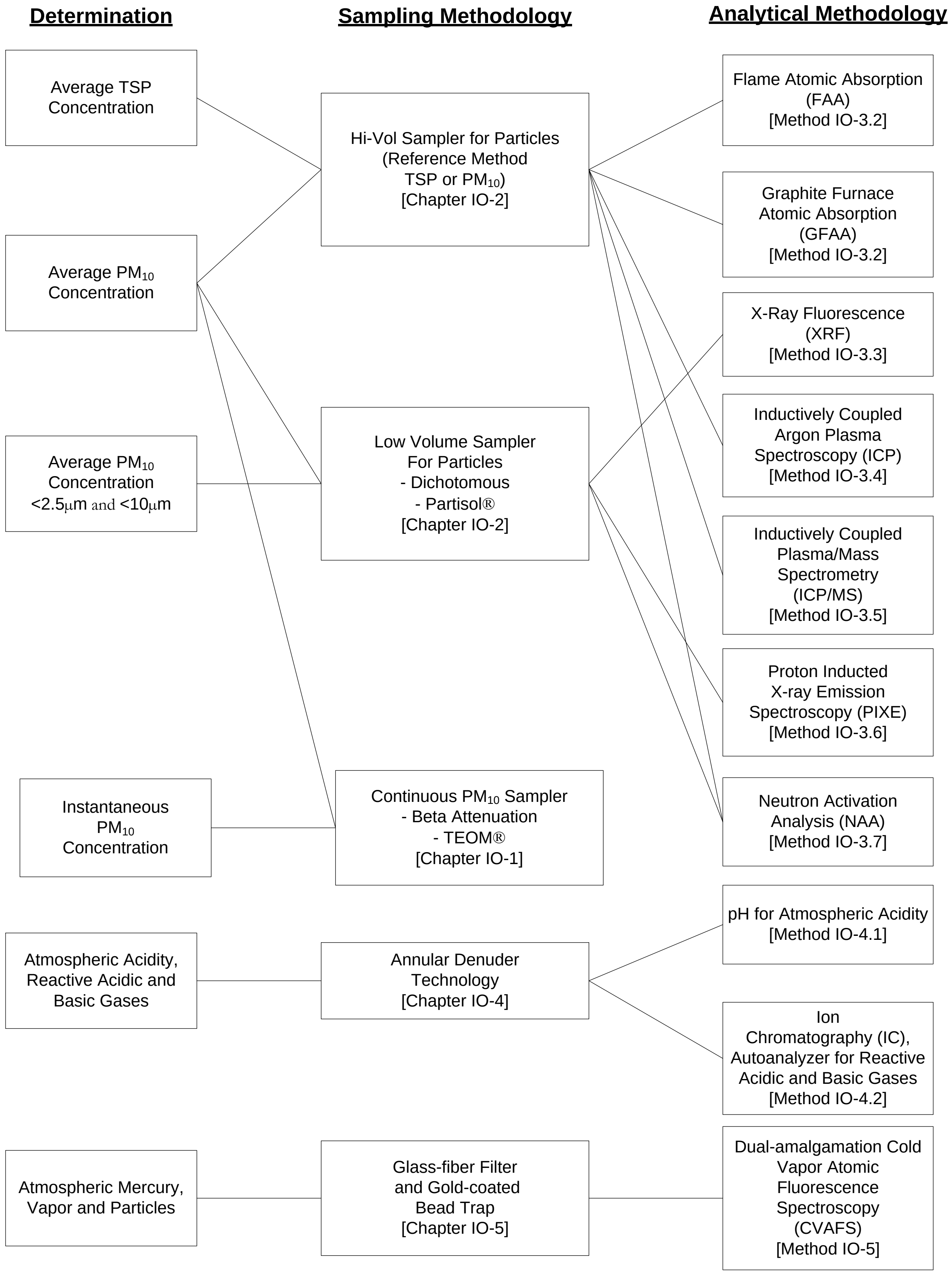
Determination
Sampling Methodology
Analytical Methodology
Average TSP Concentration
Average PM$_{10}$ Concentration
Average PM$_{10}$ Concentration <2.5µm and <10µm
Instantaneous PM$_{10}$ Concentration
Atmospheric Acidity, Reactive Acidic and Basic Gases
Atmospheric Mercury, Vapor and Particles
Hi-Vol Sampler for Particles (Reference Method TSP or PM$_{10}$) [Chapter IO-2]
Low Volume Sampler For Particles - Dichotomous - Partisol® [Chapter IO-2]
Continuous PM$_{10}$ Sampler - Beta Attenuation - TEOM® [Chapter IO-1]
Annular Denuder Technology [Chapter IO-4]
Glass-fiber Filter and Gold-coated Bead Trap [Chapter IO-5]
Flame Atomic Absorption (FAA) [Method IO-3.2]
Graphite Furnace Atomic Absorption (GFAA) [Method IO-3.2]
X-Ray Fluorescence (XRF) [Method IO-3.3]
Inductively Coupled Argon Plasma Spectroscopy (ICP) [Method IO-3.4]
Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) [Method IO-3.5]
Proton Inducted X-ray Emission Spectroscopy (PIXE) [Method IO-3.6]
Neutron Activation Analysis (NAA) [Method IO-3.7]
pH for Atmospheric Acidity [Method IO-4.1]
Ion Chromatography (IC), Autoanalyzer for Reactive Acidic and Basic Gases [Method IO-4.2]
Dual-amalgamation Cold Vapor Atomic Fluorescence Spectroscopy (CVAFS) [Method IO-5]

Table 1. Methods in the Inorganic Compendium

Chapter IO-1 Continuous Measurement of PM_{10} Suspended Particulate Matter (SPM) in Ambient Air

Method IO-1.1	Determination of PM_{10} in Ambient Air Using the Andersen Continuous Beta Attenuation Monitor
Method IO-1.2	Determination of PM_{10} in Ambient Air Using the Thermo Environmental Inc. (formerly Wedding and Associates) Continuous Beta Attenuation Monitor
Method IO-1.3	Determination of PM_{10} in Ambient Air Using a Continuous Rupprecht and Patashnick (R&P) TEOM® Particle Monitor

Chapter IO-2 Integrated Sampling of Suspended Particulate Matter (SPM) In Ambient Air

Method IO-2.1	Sampling of Ambient Air for Total Suspended Particulate Matter (SPM) and PM_{10} Using High Volume (HV) Sampler
Method IO-2.2	Sampling of Ambient Air for PM_{10} Using an Andersen Dichotomous Sampler
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The 17 specific methods, covering a variety of inorganic pollutants and compounds, are categorized into 5 chapters. Nearly all the procedures have considerable flexibility and assume that the analyst has a substantial air monitoring background and expertise. Consequently, users are responsible for preparing a specific standard operating procedure (SOP) when incorporating the Inorganic Compendium methods into their air monitoring program.

Ordering Information

The *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air,* EPA-625/R-96/010a, may be purchased in hard copy from:

National Technical Information Service (NTIS)
5285 Port Royal Road, Springfield, VA 22161
Telephone: 703-487-4650; Fax: 703-321-8547 E-mail: Info@NTIS.FEDWORLD.GOV
Internet: http://www.ntis.gov

➔ U.S. EPA: Office of Air Quality Planning and Standards (OAQPS)

Electronic versions of the individual Compendium (IO-) Methods are available for downloading from the "AMTIC" section of EPA's OAQPS Technology Transfer Network via the Internet at the "AMTIC, Air Toxics" section of the TTN Web:

http://www.epa.gov/ttn/amtic/

Methods IO-1 to IO-5 are posted in the portable document format (PDF). The downloaded files can be read using an Acrobat Reader. Acrobat readers are available from Adobe®, free of charge, at:

http://www.adobe.com/prodindex/acrobat/readstep.html

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Acknowledgments

The *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air* (EPA/625/R-96/010a) was prepared under Contract No. 68-C3-0315, Work Assignments Nos. 2-10 and 3-10, by Midwest Research Institute (MRI), as a subcontractor to Eastern Research Group, Inc. (ERG), and under the sponsorship of the U.S. Environmental Protection Agency (EPA). Final revisions were performed by Science Applications International Corporation (SAIC) under Contract No. 68-C7-0011, W.A. 1-82. Justice A. Manning, John O. Burckle, and Scott Hedges, Center for Environmental Research Information (CERI), and Frank F. McElroy, National Exposure Research Laboratory (NERL), all in the EPA Office of Research and Development, were responsible for overseeing the preparation of the Compendium. Further support was provided by other members of the Compendia Workgroup, which included:

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EPA/625/R-96/010a
June 1999

COMPENDIUM OF METHODS FOR THE DETERMINATION OF INORGANIC COMPOUNDS IN AMBIENT AIR

U. S. Environmental Protection Agency
Office of Research and Development
Center for Environmental Research Information
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

DISCLAIMER

The information in this document has been compiled wholly or in part by the United States Environmental Protection Agency (EPA) under Contract No. 68-C3-0315, W.A. 2-10 to Eastern Research Group (ERG). The work was performed by Midwest Research Institute (MRI) under subcontract to ERG. Final revisions were performed by Science Applications International Corporation (SAIC) under Contract No. 68-C7-0011, W.A. 1-82. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Acknowledgments

These Methods were prepared for publication in the *Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air* (EPA/625/R-96/010a), which was prepared under Contract No. 68-C3-0315, WA No. 2-10, by Midwest Research Institute (MRI), as a subcontractor to Eastern Research Group, Inc. (ERG), and under the sponsorship of the U. S. Environmental Protection Agency (EPA). Final revisions were performed by Science Applications International Corporation (SAIC) under Contract No. 68-C7-0011, W.A. 1-82. Justice A. Manning, John O. Burckle, and Scott Hedges, Center for Environmental Research Information (CERI), and Frank F. McElroy, National Exposure Research Laboratory (NERL), all in the EPA Office of Research and Development, were responsible for overseeing the preparation of this Compendium. Other support was provided by the following members of the Compendia Workgroup:

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These Methods are the result of the efforts of many individuals. Gratitude goes to each person involved in the preparation and review of this methodology.

Chapter IO-1: CONTINUOUS MEASUREMENT OF PM$_{10}$ SUSPENDED PARTICULATE MATTER (SPM) IN AMBIENT AIR

Method IO-1.1: Determination of PM$_{10}$ in Ambient Air Using the Andersen Continuous Beta Attenuation Monitor

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Chapter IO-2: INTEGRATED SAMPLING OF SUSPENDED PARTICULATE MATTER (SPM) IN AMBIENT AIR

Method IO-2.1: Sampling of Ambient Air for Total Suspended Particulate Matter (SPM) and PM_{10} Using High Volume (HV) Sampler

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Method IO-2.2: Sampling of Ambient Air for PM_{10} Using an Anderson Dichotomous Sampler

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Method IO-2.3: Sampling of Ambient Air for PM_{10} Concentration Using the Rupprecht and Patashnick (R&P) Low Volume Partisol® Sampler

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Method IO-2.4: Calculations for Standard Volume

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Chapter IO-3: CHEMICAL SPECIES ANALYSIS OF FILTER-COLLECTED SUSPENDED PARTICULATE MATTER

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Method IO-3.5: **Determination of Metals in Ambient Particulate Matter Using Inductively Coupled Plasma/Mass Spectrometry (ICP/MS)**

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Method IO-3.6: **Determination of Metals in Ambient Particulate Matter Using Proton Induced X-Ray Emission (PIXE) Spectroscopy**

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Method IO-3.7: **Determination of Metals in Ambient Particulate Matter Using Neutron Activation Analysis (NAA) Gamma Spectrometry**

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Chapter IO-4: DETERMINATION OF REACTIVE ACIDIC AND BASIC GASES AND STRONG ACIDITY OF ATMOSPHERIC FINE PARTICLES IN AMBIENT AIR USING THE ANNULAR DENUDER TECHNOLOGY

Method IO-4.1: Determination of the Strong Acidity of Atmospheric Fine-Particles (<2.5 • m)

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Method IO-4.2: Determination of Reactive Acidic and Basic Gases and Strong Acidity of Atmospheric Fine Particles (<2.5 • m)

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Chapter IO-5: SAMPLING AND ANALYSIS FOR ATMOSPHERIC MERCURY

Method IO-5: Sampling and Analysis for Vapor and Particle Phase Mercury in Ambient Air Utilizing Cold Vapor Atomic Fluorescence Spectrometry (CVAFS)

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FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

Measurement of inorganic pollutants in ambient air is often difficult, in part because of the variety of inorganic substances of potential concern, the variety of potential techniques for sampling and analysis, and lack of standardized and documented methods. This Compendium is one of three Compendia of methods which provide documented and technically reviewed methodology for determining concentrations of selected pollutants of frequent interest in ambient and indoor air. The methods contained in this Compendium provide sampling and analysis procedures for a variety of inorganic pollutants and suspended particulate matter in ambient air. As with the previous Compendia methods, these methods are provided only for consideration by the user for whatever potential applications for which they may be deemed appropriate. In particular, these methods are not intended to be associated with any specific regulatory monitoring purpose and are offered with no specific endorsement for fitness or recommendation for any particular application, other than for an attempt at standardization.

This publication has been prepared by the Center for Environmental Research Information (CERI) with support from the National Exposure Research Laboratory (NERL) to continue NRMRL's goal of providing technical support and information transfer. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Appendix F

Theory and Calibration Procedures for the Use of a Rotameter

F.1 Nomenclature

A_f = cross-sectional area of the float
A_m = annular area between the circumference of the float and the inside circumference of the meter tube at that position
C = drag coefficient
C_m = length which is characteristic of the physical system under study (used to calculate Reynolds Number)
d = length which is characteristic of the physical system under study
D_f = diameter of the float
D_t = diameter of the tube at the float position
g = local acceleration due to gravity
g_c = dimensional constant
m_f = mass of the float
M_m = molecular weight of the metered gas
M_1, M_2, M_3...etc.= value of molecular weight of the metered gas at conditions 1, 2, 3...etc.
Re = Reynolds Number
Re/C_m = dimensionless factor defined by Equation F-14
P_m = absolute pressure of the metered gas
P_1, P_2, P_3...etc. = values of absolute pressure at conditions 1, 2, 3...etc.
Q_m = volumetric flow rate through the meter at conditions of pressure (P_m), temperature (T_m), and molecular weight (M_m)
R = universal gas constant
T_m = absolute temperature of the metered gas
T_1, T_2, T_3...etc. = values of absolute temperature at conditions 1, 2, 3...etc.
v = average gas velocity through the annular area of the meter
V_f = volume of the float
μ = viscosity of flowing fluid (used to calculate Reynolds Number)

μ_m = viscosity of the metered gas
ϱ = density of flowing fluid (used to calculate Reynolds Number)
ϱ_f = density of the float
ϱ_m = density of the metered gas

F.2 Description of a Rotameter

The rotameter (Figure F-1) is a variable area meter which consists of a vertical, tapered, transparent tube containing a float. The float moves upward as the fluid flow increases. A variable ring or annulus is created between the outer diameter of the float and the inner wall of the tube. As the float moves upward in the tube, the area of the annulus increases. The float will continue to move upward until a pressure drop across the float, which is unique for each rotameter, is reached. This pressure drop across the float is constant regardless of the flow rate. Graduations are etched on the side of the tube so that an instantaneous reading may be observed.

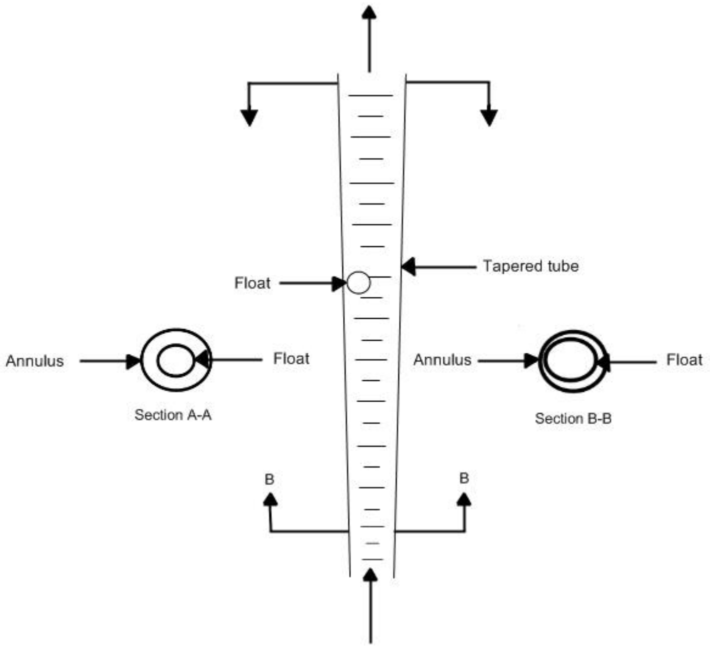


Figure F-1. Rotameter.

F.3 Development of Flow Equations

General Flow Rate Equations

A free body diagram of the forces acting upon the rotameter float is shown in Figure F-2. The weight of the float is equal to the force of gravity acting on the float. The buoyant force is equal to the weight of the gas that is displaced by the float. The drag force is equal to the frictional forces acting between the float and the moving gas stream.

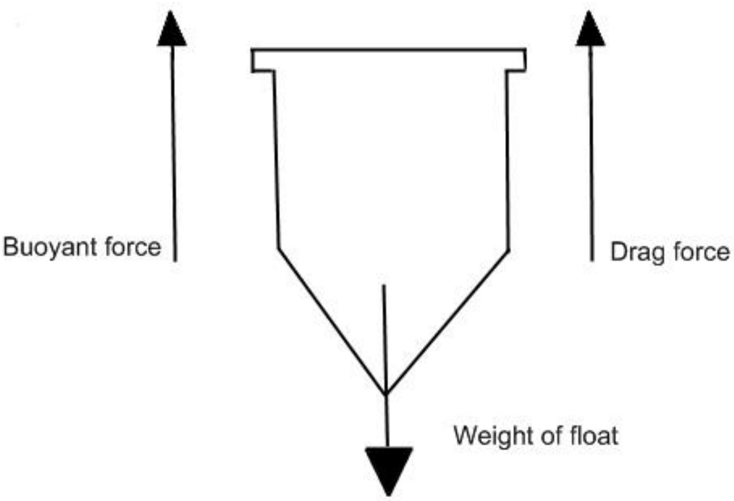


Figure F-2. Forces acting upon a rotameter float.

Mathematically, these forces are as follows:

$$Drag\ force = \frac{CA_f \varrho_m v^2}{2g_c}$$

$$Weight\ of\ float = \frac{V_f \varrho_f g}{g_c}$$

$$Buoyant\ force = \frac{V_f \varrho_m g}{g_c}$$

Where:
A_f = *cross sectional area of the float*
C = *drag coefficient*
g = *local acceleration due to gravity*
g_c = *dimensional constant*

v = *average gas velocity through the annular area of the meter*
V_f = *volume of the float*
ϱ_f = *density of the float*
ϱ_m = *density of the metered gas*

When the forces acting in an upward direction exactly equal the force acting in a downward direction, the float will remain stationary in the tube. Equating these forces yields:

$$\frac{CA_f\varrho_m v^2}{2g_c}+\frac{V_f\varrho_m g}{g_c}=\frac{V_f\varrho_f g}{g_c}$$

Cancelling like terms (g_c) and rearranging yields:

$$V_f\varrho_f g - V_f\varrho_m g=\frac{CA_f\varrho_m v^2}{2}$$

Solving for v and factoring out V_f and g from the first two terms yields:

(Eq. F-1)
$$v=\left[\frac{2V_f g(\varrho_f-\varrho_m)}{CA_f\varrho_m}\right]^{1/2}$$

The area of the float is equal to $\pi D_f^{\,2}/4$, where D_f is the diameter of the float. Substituting $\pi D_f^{\,2}/4$ for A_f in Equation F-1 yields:

(Eq. F-2)
$$v=\left[\frac{8V_f g(\varrho_f-\varrho_m)}{C\pi D_f^{\,2}\varrho_m}\right]^{1/2}$$

Let C_m equal $(8/C\pi)^{1/2}$, where C_m is called a meter coefficient and is dependent on the drag coefficient. Substituting C_m for $(8/C\pi)^{1/2}$ in Equation F-2 yields:

(Eq. F-3)
$$v=C_m\left[\frac{V_f g(\varrho_f-\varrho_m)}{D_f^{\,2}\varrho_m}\right]^{1/2}$$

Because the drag coefficient C is dependent on Reynolds Number, C_m must also be a function of Reynolds Number. Because the density of the gas flowing in the rotameter is very small compared to the density of the float, it can be ignored in the $(\varrho_f - \varrho_m)$ term. Modifying the $(\varrho_f - \varrho_m)$ term in Equation F-3 yields:

(Eq. F-4)

$$v = C_m \left[\frac{V_f g \varrho_f}{D_f^{\,2} \varrho_m} \right]^{1/2}$$

The volumetric flow rate (*Q*,.) through the rotameter is equal to the product of the velocity (*v*) and the annular area of the meter (A_m). Substituting Q_m / A_m for *v* in Equation F-4 yields:

$$\frac{Q_m}{A_m} = C_m \left[\frac{V_f g \varrho_f}{D_f^{\,2} \varrho_m} \right]^{1/2}$$

Rearranging terms and removing $D_f^{\,2}$ from the radical yields:

(Eq. F-5)

$$Q_m = \frac{C_m A_m}{D_f} \left[\frac{V_f g \varrho_f}{\varrho_m} \right]^{1/2}$$

The density of the float ϱ_f is equal to the mass of the float (m_f) divided by the volume of the float. Substituting m_f / V_f for ϱ_f in Equation F-5 and cancelling the V_f's yields:

(Eq. F-6)

$$Q_m = \frac{C_m A_m}{D_f} \left[\frac{g m_f}{\varrho_m} \right]^{1/2}$$

The density of the gas mixture passing through the meter (ϱ_m) is equal to $P_m M_m / R T_m$, where P_m is the absolute pressure at the meter, M_m is the apparent molecular weight of the gas mixture passing through the meter, *R* is the universal gas constant, and T_m is the absolute temperature of the gas mixture. Substituting $P_m M_m / R T_m$ for ϱ_m in Equation F-6 yields the general flow rate equation for a rotameter:

(Eq. F-7)

$$Q_m = \frac{C_m A_m}{D_f} \left[\frac{g m_f R T_m}{P_m M_m} \right]^{1/2}$$

Computation of Reynolds Number

Reynolds Number is defined as $vd\varrho/\mu$, where *v* is the velocity flow, *d* is a length which is characteristic of the physical system under study, ϱ is the density of the flowing fluid, and μ is the viscosity of the flowing fluid. When calculating Reynolds Number for a gas flowing through a rotameter, the length characteristic of the physical system *(d)* is the difference between the tube diameter (D_f) and the diameter of the float (D_r). Therefore, Reynolds Number may be calculated by using the following equation:

(Eq. F-8)

$$Re = \frac{v\left(D_r - D_f\right)\rho}{\mu}$$

The average velocity of flow through the rotameter is given by Q_m / A_m where Q_m is the volumetric flow rate through the meter and A_m is the annular area between the inside circumference of the tube at the float position.

Substituting Q_m / A_m for v in Equation F-8 yields:

(Eq. F-9)

$$Re = \frac{Q_m\left(D_r - D_f\right)\rho}{A_m \mu}$$

The density of the flowing fluid ρ is equal to $P_m M_m / RT_m$, where P_m is the absolute pressure of the metered gas, M_m is the apparent molecular weight of the metered gas, R is the universal gas constant, and T_m is the absolute temperature of the metered gas.

Substituting $P_m M_m / RT_m$ for ρ in Equation F-9 yields:

(Eq. F-10)

$$Re = \frac{Q_m\left(D_r - D_f\right)P_m M_m}{A_m \mu R T_m}$$

Adding the subscript *m* to the viscosity term μ in Equation F-10 to denote the viscosity of the metered gas yields the following equation, which is used to calculate Reynolds Number for gas flow in a rotameter.

(Eq. F-11)

$$Re = \frac{Q_m\left(D_r - D_f\right)P_m M_m}{A_m \mu_m R T_m}$$

F.4 Common Practices in the Use of a Rotameter for Gas Flow Measurement

It can be seen from Equation F-7 that the volumetric flow rate through a rotameter can be calculated when such physical characteristics as the diameter and the mass of the float and the annular area of the meter at each tube reading are known, providing measurements are made of the temperature, pressure, and molecular weight of the metered gas. Before these calculations of the volumetric flow rate can be made, data must be known about the meter coefficient, C_m. The meter coefficient being a function of Reynolds Number is ultimately a function of the conditions at which the meter is being used. To obtain data on the meter coefficient, the meter must be calibrated. However, because of the ease involved in using calibration curves, common practice is to use calibration curves to determine volumetric flow rates instead of calculating the flow rates from raw data.

Procedures for the Calibration of a Rotameter

A common arrangement of equipment for calibrating a rotameter is shown in Figure F-3.

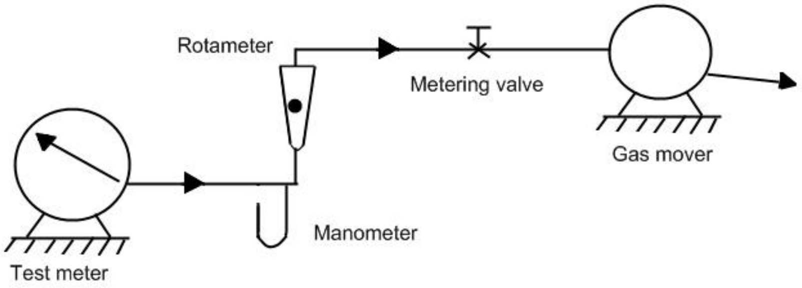


Figure F-3. Test setup for calibrating a rotameter.

Flow through the calibration train is controlled by the metering valve. At various settings of the rotameter float, measurements are made of the flow rate through the train and of the pressure and temperature of the gas stream at the rotameter. The temperature of the gas stream is usually assumed to be the same as the temperature of the ambient air. If the test meter significantly affects the pressure or temperature of the gas stream, measurements should also be made of the actual pressure and temperature at the test meter. A typical rotameter calibration curve is illustrated in Figure F-4.

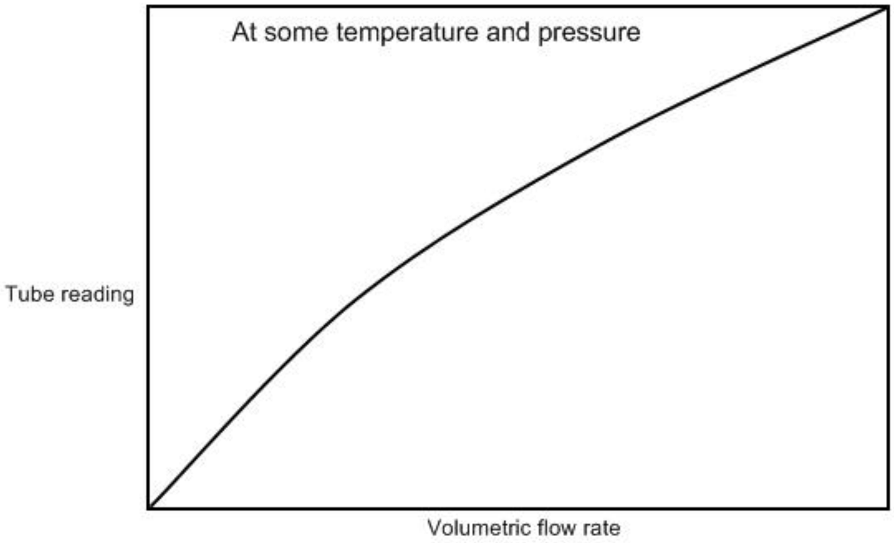


Figure F-4. Rotameter calibration curve.

To make the calibration curve useful, the temperature and pressure of the volumetric flow rate must be specified.

A Universal Calibration Curve

The normal arrangement of the components in a sampling train is shown in Figure F-5. Since the meter is usually installed downstream from the pollutant collector, it can be expected to operate under widely varying conditions of pressure, temperature, and molecular weight. This requires a different calibration curve for each condition of pressure, temperature, and molecular weight. This can be facilitated by drawing a family of calibration curves, which would bracket the anticipated range of pressures, temperatures and molecular weights, as shown in Figure F-6.

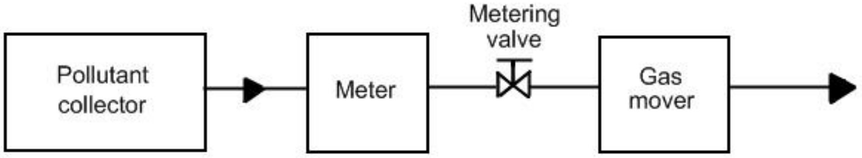


Figure F-5. Arrangement of sampling components.

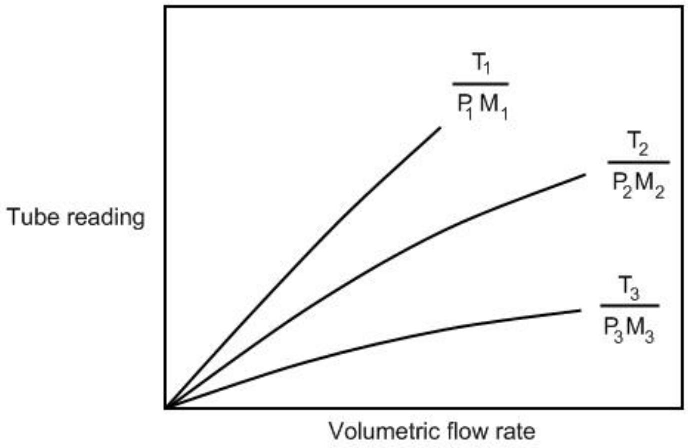


Figure F-6. Family of rotameter calibration curves.

Operation of a rotameter under extreme sampling conditions, particularly extreme temperatures, complicates the calibration setup. It is difficult, if not impossible, for most laboratories to be able to calibrate flow metering devices at high temperatures or unusual gas mixtures (especially where toxic gases are involved). For these reasons, it is desirable to develop a calibration curve which is independent of the actual expected sampling conditions. As previously mentioned, the flow through a rotameter is dependent upon the value of C_m, the meter coefficient (see Equation F-7), which is a function of the Reynolds Number for the flow in the rotameter. Therefore, to be independent of the sampling conditions, the calibration curve must be in terms of C_m and *Re*.

Development of a Universal Calibration Curve

Solving Equation F-7 for C_m gives the following relationship:

(Eq. F-12)

$$C_m = \frac{Q_m D_f}{A_m}\left(\frac{P_m M_m}{g m_f R T_m}\right)^{1/2}$$

Dividing Equation F-11 by Equation F-12 yields:

$$\frac{Re}{C_m} = \frac{\dfrac{Q_m\left(D_r - D_f\right)P_m M_m}{A_m \mu_m R T_m}}{\dfrac{Q_m D_f}{A_m}\left(\dfrac{P_m M_m}{g m_f R T_m}\right)^{1/2}}$$

Cancelling the like terms Q_m and A_m yields:

$$\frac{Re}{C_m} = \frac{\dfrac{(D_r - D_f)P_m M_m}{\mu_m R T_m}}{D_f\left(\dfrac{P_m M_m}{gm_f R T_m}\right)^{1/2}}$$

Simplifying:

$$\frac{Re}{C_m} = \left[\frac{(D_r - D_f)P_m M_m}{\mu_m R T_m}\right]\left[\frac{1}{D_f}\left(\frac{gm_f R T_m}{P_m M_m}\right)^{1/2}\right]$$

Combining the like terms P_m, M_m, and T_m yields:

(Eq. F-13)

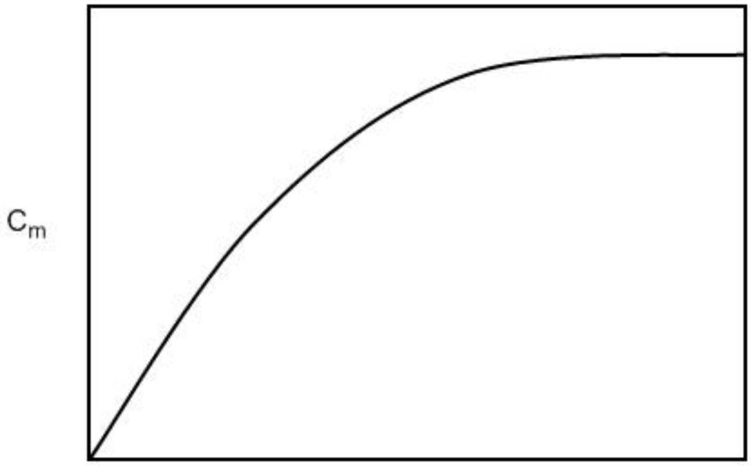
$$\frac{Re}{C_m} = \left[\frac{(D_r - D_f)}{\mu_m D_f}\right]\left(\frac{gm_f P_m M_m}{R T_m}\right)^{1/2}$$

Simplifying the $(D_r - D_f)$ and D_f relationship in Equation F-13 yields a dimensionless factor which has no limitations on either Reynolds Number or the meter coefficient C_m.

(Eq. F-14)

$$\frac{Re}{C_m} = \frac{1}{\mu_m}\left[\frac{D_r}{D_f}\right]\left(\frac{gm_f P_m M_m}{R T_m}\right)^{1/2}$$

A plot of the dimensionless factor Re/C_m defined by Equation F-14 versus the meter coefficient C_m as calculated from Equation F-12 on regular graph paper will yield a universal calibration curve which is independent of the sampling conditions. Such a plot is illustrated in Figure F-7.



$$\frac{Re}{C_m} = \frac{1}{\mu_m}\left[\left(\frac{D_r}{D_f}\right) - 1\right]\left(\frac{gm_f P_m M_m}{RT_m}\right)^{1/2}$$

Figure F-7. A universal calibration curve for a rotameter.

F.5 Use of the Universal Calibration Curve for a Rotameter

To Determine an Existing Flow Rate

To determine an existing flow rate, measurements must be made of the gas temperature and pressure as well as the float position. Data from the manufacturer of the rotameter will yield information on the diameter of the tube at the various float positions and on the diameter and mast of the float. The apparent molecular weight of the gas being metered can be calculated if the composition of the gas stream is known. The viscosity of the gas stream can be determined if the temperature of the gas stream is known (see Perry's *Chemical Engineer's Handbook)*. From this data the Re/C_m factor (see Equation F-14) can be calculated. The universal calibration curve is then entered at the calculated value of Re/C_m and the corresponding C_m is noted. Q_m is then calculated from Equation F-7.

To Establish a Required Sampling Rate

To establish a required sampling rate, estimates are made of the metered gas pressure (P_m), the metered gas temperature (T_m), the apparent molecular weight of the metered gas (M_m), and the area of the meter (A_m) which will exist at the desired sampling rate. Using these estimated values, the meter coefficient, C_m, is calculated (see Equation F-12) for the desired sampling rate Q_m. The universal calibration curve (see Figure F-7) is entered at this value of C_m and the corresponding factor is noted. $\lfloor (D_r/D_f) - 1 \rfloor$ is solved by using the following equation which is a rearrangement of Equation F-14:

(Eq. F-15)

$$\left[\left(\frac{D_r}{D_f}\right) - 1\right] = \mu_m \left(\frac{Re}{C_m}\right)\left(\frac{RT_m}{gm_f P_m M_m}\right)^{1/2}$$

The float position can be determined from the value $\lfloor (D_r/D_f) - 1 \rfloor$. For some rotameters the value of $\lfloor (D_r/D_f) - 1 \rfloor$ is the tube reading divided by 100. If the area of the meter corresponding to this float position is not equal to the original estimated value for the meter area, the new value of area is used as an estimate and the entire procedure is repeated until the estimated area and the calculated area are equal. Then upon setting the float position at this tube reading, T_m, P_m, and M_m, are noted. If they are different from the original estimates, the procedure is repeated using the observed values of T_m, P_m, and M_m as estimates. Experience will aid in selecting original estimates that are nearly accurate so that the required sampling rate may be set fairly rapidly.

To Predict Calibration Curves

The above techniques are very cumbersome to apply in the field and, as a result, the universal calibration curve should not be used in such a manner.

The real utility of the universal calibration curve is that it can be used to predict calibration curves at any set of conditions. This results in a great reduction in laboratory work in that the rotameter need only be calibrated once and not every time the conditions at which the meter is operated change.

The first step in predicting calibration curves from the universal calibration curve of a rotameter is to ascertain the anticipated meter operating range for the sampling application of concern. Once this operating range is established, an arbitrary selection of a point on the universal calibration curve is made (see point in Figure F-8). The coordinates of point a, point b (Re/C_m), and point c (C_m) are determined. Values of T_1, P_1, and M_1 and the value of Re/C_m are used to calculate a value for $(D_r/D_f) - 1$ by means of the following equation:

(Eq. F-15)

$$\left[\left(\frac{D_r}{D_f}\right) - 1\right] = \mu_m \left(\frac{Re}{C_m}\right)\left(\frac{RT_m}{gm_f P_m M_m}\right)^{1/2}$$

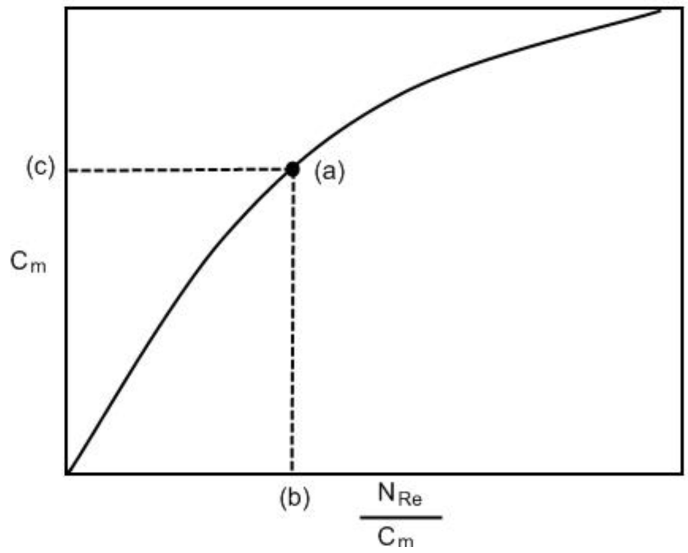


Figure F-8. Predicting calibration curves from the universal calibration curve (N_{Re}=Re, or Reynolds Number).

The area of the meter (A_m) is calculated from this value of $\lfloor (D_r/D_f) - 1 \rfloor$ and is used along with the assumed values of T_1, P_1, and M_1 and the value of C_m from the universal calibration curve to calculate a volumetric flow rate by means of the following equation:

(Eq. F-7)

$$Q_m = \left(\frac{C_m A_m}{D_f}\right)\left[\frac{g m_f R T_m}{P_m M_m}\right]^{1/2}$$

This procedure is repeated until enough points are available to plot a normal calibration curve. The entire procedure is repeated using new values for temperature, pressure, and molecular weight until a family of calibration curves is plotted. Of course, this family of curves should bracket the anticipated meter operating conditions for the sampling application of concern. The volumetric flow rate (Q_m) is plotted versus either the area of the meter (A_m) or the tube reading that corresponds to the meter area.

Field operation is greatly simplified if the tube reading is used. A typical family of calibration curves is shown in Figure F-9.

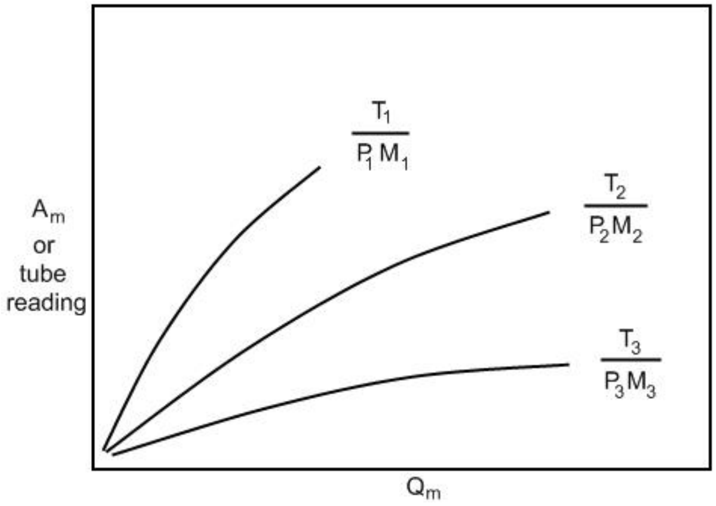


Figure F-9. Calibration curves predicted from universal calibration curve.

Notice that these curves are similar to the calibration curves illustrated in Figure F-6. The difference between them is the manner in which they were obtained. The curves of Figure F-6 were obtained by an actual laboratory calibration run for each set of conditions illustrated, whereas the curves of Figure F-9 were obtained by mathematical manipulation of data from only one calibration run. This can, of course, save considerable laboratory time. In addition, it may not be possible to ascertain, in the laboratory, calibration data at extreme conditions, particularly at high temperatures.

Appendix G

Significant Figures and Rounding Off[1]

G.1 Working with Numbers

In most cases, rather than using paper and pencil, you will be performing math calculations using a handheld calculator, a personal computer, or a mainframe computer. However, whether you use an electronic tool or paper and pencil, you are often required to make decisions based on certain basic rules and principles of mathematics. In addition, when a calculator or computer is used, you have the additional responsibility for ensuring that the tool (hardware or software) is, in fact, providing accurate and reliable results.

In this initial lesson some of the most basic mathematical concepts are reviewed. These concepts, though basic and supposedly simple, often lead to periods of frustration and hair pulling when ignored or overlooked. The basics to be presented in this lesson deal with determining how many figures to keep (where to truncate) and how or when to round off.

The number of digits displayed as the answer on most calculators and computers is governed by the physical properties of the instrument (e.g., many handheld calculators display only 10 digits). Determining how many digits to keep (where to truncate, or which digits to throw away), and when and how to round are decisions that you must make. On the next page you will be asked to solve 12 problems requiring you to determine which digits to keep and when to round.

Using your calculator, provide your answers in two forms, the *complete* answer, and the *corrected* answer. In the first column (Complete) supply the complete answer obtained by performing the required function (probably an answer with 10 digits on many calculators). In the second column (Corrected), supply the answer retaining the *correct* number of digits, rounded where necessary.

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[1] The information in this appendix is extracted from the EPA's APTI Self Instruction Course (SI:100) found at: http://yosemite.epa.gov/oaqps/EOGtrain.nsf/DisplayView/SI_100_2?OpenDocument.

Intro Problems

	Problem	Complete	Corrected
1.	3.5 + 2.075 =		
2.	3.49 - 2.0075 =		
3.	2.0 x 307 =		
4.	2.49 x 3.07 =		
5.	2.074 x 4.700 =		
6.	4.1 x 3.29875 =		
7.	50 ÷ 3.0069=		
8.	9.4 ÷ 334 =		
9.	9.4000 ÷ 0.02=		
10.	0.052 ÷ 0.0026 =		
11.	0.00791 ÷ 0.52 =		
12.	0.0025 x 0.00025 =		

Now, compare your answers with those provided on page G-10.

G.2 Approximate Numbers

Any number may be classified as exact or as approximate. An exact number is derived from the use of specific numbering systems and arithmetic rules. (For example, 12 is an exact number.) Approximate numbers are derived from measurements and calculations where rounding has been, or may be, applied. When it is stated that 12 eggs are consumed by five people, or that each person consumed 2.4 eggs, 2.4 eggs represents an approximate number. Even if the eggs were scrambled, we have no way of ensuring that each person consumed exactly 2.4 eggs.

With air pollution problems, we deal primarily with measurements. Therefore, we are dealing primarily with approximate numbers. Another way of considering approximate numbers is to acknowledge that an approximate number has some degree of error associated with it. Since the numbers being used are approximate and contain some degree of error at the outset, care must be taken to avoid introducing any more error into problems and their solutions. The following general rules are useful in remembering the rules and calculating the values associated with approximate numbers.

Rule 1 (General)

In most cases, mathematical rules governing the results of an addition or subtraction operation are quite similar to one another, if not the same. Also, the rules governing the results of a multiplication or division operation are similar to one another, or the same. But the rules governing the results of addition and subtraction operations are generally quite different from the rules governing the results of multiplication and division operations.

Rule 2 (General)

When performing calculations with approximate numbers, carry as many digits as possible until the final result is calculated. Once the final result is calculated, apply the appropriate rules for truncating and rounding.

Since the rule for rounding approximate numbers applies to addition, subtraction, multiplication, and division, and is easy to remember, we will look at it first.

G.3 Rounding Approximate Numbers

For the moment, we will not concern ourselves with where and how to truncate numbers. We will simply assume that the appropriate number of digits to be retained are givens in the following examples. When truncating (removing final, unwanted digits), rounding is normally applied to the last digit to be kept.

Rule for Rounding Approximate Numbers

If the value of the first digit to be discarded is less than 5, retain the last kept digit with no change. If the value of the first digit to be discarded is 5 or greater, increase the last kept digit's value by one.

Example: 25.0847

Assume only the first two decimal places are to be kept (the 4 and 7 are to be dropped). Round to 25.08. Since the first digit to be discarded (4) is less than 5, the 8 is not rounded up.

Example: 25.0867

Assume only the first two decimal places are to be kept (the 6 and 7 are to be dropped). Round to 25.09. Since the first digit to be discarded (6) is 5 or more, the 8 is rounded up to 9.

G.4 Adding and Subtracting Approximate Numbers

When adding or subtracting approximate numbers, a rule based upon precision determines how many digits are kept. In general, precision relates to the decimal significance of a number. When a measurement is given as 1.005 cm, we can say that the number is precise to the *thousandth* of a centimeter. If the decimal is removed (1005 cm) we have a number that is precise to *thousands* of centimeters.

You may make a measurement in gallons or liters. Although a gallon or a liter may represent an exact quantity, the measuring instruments that are used are capable of producing approximations only. Using a standard graduated flask as an example, can you determine whether there is exactly one liter? Likely not. In fact you would be hard pressed to verify that there was a liter to within ±1/10 of a liter. Therefore, depending upon the instruments used, the precision of a given measurement may vary.

If a measurement is given to us as 16.0 L, the zero after the decimal indicates that the measurement is precise to within 1/10 L. Given a measurement of 16.00 L, we have precision to 1/100 L. In short, the digits following the decimal indicate how precise the measurement is. Precision is used to determine where to truncate when approximate numbers are added or subtracted.

Truncating Approximate Numbers Following Addition or Subtraction

When approximate numbers are added or subtracted the results are expressed in terms of the least precise number in the problem.

Since this is a relatively simple rule to master, just one problem will be used to illustrate it. Calculate the following and express the result in precise terms:

$$6.04\text{L} + 2.8\text{ L} - 4.173\text{ L} = 4.7\text{ L}$$

The complete result is 4.667 L. The answer follows the rule of precision. The expressions in the problem have two, one, and three decimal places respectively. The least precise number (least decimal places) in the problem is 2.8, a value carried only to the tenths position. Therefore, the answer must be calculated to the tenths position only. Thus the correct answer is 4.7 L. (The last 6 and the 7 are dropped from 4.667 L, and the first 6 is rounded up to provide 4.7 L.)
Intro Problems 1 and 2 represent addition and subtraction of approximate numbers.

Problem 1: 3.5 + 2.075 = 5.575 = 5.6
The least precise number (3.5) is provided to one decimal place. The answer must therefore contain only one decimal and the second 5 is rounded up to 6.

Problem 2: 3.49 - 2.0075 = 1.4825 = 1.48
Two decimal places are represented by the least precise number (3.49). The answer is given to two decimals and the 8 is not rounded up.

G.5 Multiplying and Dividing Approximate Numbers

In multiplication and division of approximate numbers, finding the number of significant digits is used to determine how many digits to keep (where to truncate). We must first understand significant digits in order to determine the correct number of digits to keep or remove in multiplication and division problems.

Significant Digits

Generally, the digits 1 through 9 are considered to be significant. Thus, the numbers 123, 53, 7492, and 5 contain three, two, four, and one significant digits respectively.

The digit 0 must be considered separately.

Zeros are significant when they occur between significant digits. In the following examples, all zeros are significant: 10001, 402, 1.1001, 50.09 (five, three, four, and four significant digits respectively).

Zeros are not significant when they are used as place holders. When used as a place holder, a zero simply identifies where a decimal is located. For example. each of the following numbers has only one significant digit: 1000, 500, 60, 0.09, 0.0002. In the numbers 1200, 540, and 0.0032, there are two significant digits, and the zeros are not significant.

When zeros follow a decimal and are preceded by a significant digit, the zeros are significant. In the following examples, all zeros are significant: 1.00, 15.0, 4.1000, 1.90, 10.002, 10.0400. In the example 10.002, the zeros are significant because they fall between two significant digits. In the last example, 10.0400, the first two zeros are significant because they fall between two significant digits; the last two zeros are significant because they follow a decimal and are preceded by a significant digit.

Additional illustrations of significant digits are provided in the following chart. The significant digits are underlined.

Example		Number of Significant Digits
1.	123	3
2.	12300	3
3.	12003	5
4.	123.000	6
5.	12300.0	6
6.	1.0004	5
7.	0.0004	1
8.	0.005003	4
9.	0.005300	4
10.	1000.0001	8

Example 1 is pretty easy. There are three non-zero digits and no decimal places; therefore, three significant digits. Example 2 uses two zeros as "place holders" to locate the decimal. The two zeros are not significant; thus, only three digits are significant. In example 3 the two zeros are not place holders, but part of a five-digit number; hence, five significant digits. Example 4 contains three zeros after the decimal. The zeros follow a decimal and are preceded by three significant digits. (The zeros show precision, which is explained later.) Example 5 is similar to the previous example. By the presence of the zero after the decimal preceded by significant digits, the last zero becomes significant. Now the two zeros before the decimal become significant since they fall between significant digits.

The three zeros in example 6 follow the rule described in examples 4 and 5. The zeros in example 7 establish the position of the decimal only; therefore, they are not significant and the 4 is the lone significant digit. Example 8 uses four zeros. The first two zeros (place holders) are not significant; the other two are significant digits. In example 9, the two trailing zeros are significant because they follow a significant digit that follows a decimal. In the last example, all six zeros are significant since they all fall between significant digits.

Having determined how to count significant digits, we can now apply this information to determine where to truncate the results from multiplying or dividing approximate numbers.

Truncating Approximate Numbers Following Multiplication or Division

When approximate numbers are multiplied or divided, the result is expressed as a number having the same number of significant digits as the expression in the problem having the least number of significant digits.

In other words, if you multiply a number having four significant digits by a number having two significant digits, the correct answer will be expressed to two significant digits.

Let's consider a measurement of 200 ft. Not knowing how the measurement was made, we can only know for certain that the measurement represents a distance of 200 ft or greater but less than 300 ft. There is one significant digit, and no matter what computation this measurement enters, the result is good to only one significant digit. Thus, if the problem 200 ft x 13.6 is solved, the complete answer is 2720.0 ft. The two numbers, 200 and 13.6, represent one and three significant digits, respectively. One significant digit is less than three; therefore the correct answer will be rendered to one significant digit. Thus, after rounding, the correct answer is 3000 ft.

If the measurement were made to two significant digits, such as 290 ft, we know that the measurement represents a distance of 290 ft or greater, but less than 300 ft. Again using the measurement, 290 ft x 13.6, the complete result yields 3944.0, and the correct result is 3900 ft. In this case, two significant digits are used (39). Since the first discarded digit is 4, the 39 remains.

Now let's reconsider the answers to problems 3 through 12 (on page 9) for the problems you worked.

Problem 3: 2.0 x 307 = 614 = 610
The number 2.0 represents two significant digits since the zero following the decimal follows a significant digit. The number 307 has three significant digits. The *least* number of significant digits is two. Therefore, the 4 in the answer is not significant and it is less than 5, so the answer, properly rounded to two significant digits, is 610. The 4 is dropped.

Problem 4: 2.49 x 3.07 = 7.6443 = 7.64
There are three significant digits in each number of the problem. The answer, expressed to three significant digits, is 7.64, keeping the decimal and dropping the two nonsignificant digits (43).

Problem 5: 2.074 x 4.700 = 9.7478 = 9.748
Again, both numbers in the problem have the same number of significant digits (four). By keeping four significant digits (9.747), truncating the 800 and rounding, we have 9.748.

Problem 6: 4.1 x 3.29875 = 13.524875 = 14
The numbers in this problem represent two and six significant digits, respectively. Using the fewest significant digits (two) the 13 is kept. By dropping and rounding 0.524875, the correct result is 14.

Problem 7: 50 ÷ 3.0069 = 16.6284213 = 20
The first number, 50, has one significant digit. Therefore, the results will be expressed with the accuracy of one significant digit. The first digit to be truncated is the first 6. So, rounding the 1, the only significant digit becomes 2. The correct answer is then 20.

Problem 8: 9.4 ÷ 3.34 = 2.814371257 = 2.8
Two significant digits divided by three significant digits means the answer must be calculated to two significant digits. The first digit to be discarded is the 1. The 8 remains unchanged, and the answer is 2.8.

Problem 9: 9.4000 ÷ 0.02 = 470 = 500
The 0.02 in the problem contains the least number of significant digits, one. Remember that zeros used as place holders are not significant digits. Therefore, the 4 in the answer must be retained as the only significant digit. By dropping the 7 and rounding, the 4 becomes 5 and the answer is 500.

Problem 10: 0.052 ÷ 0.0026 = 20 = 20
Here, both numbers in the problem are comprised of two significant digits. As it happens, the calculated number and the correct number are the same.

Problem 11: 0.00791 ÷ 0.52 = 0.015211538 = 0.015
Again, the least number of significant digits is two (0.52). Since the first digit to be discarded is a 2, the 5 remains unchanged and the answer is 0.015.

Problem 12: 0.0025 x 0.00025 = 0.000000625 = 0.00000063
Once again, the least number of significant digits is two. The answer yielded three significant digits, 625. The 5 is discarded, the 2 is rounded up to 3, and the answer is 0.00000063.

G.6 Reasonability

The rules for handling approximate numbers are used when there is no overriding rule or condition to be met. In all measurement work, deriving correct answers must be considered in context of the conditions that exist. For example, suppose you are provided numeric data to be processed. The results of your calculations are to be given to a technician who will adjust the airflow through a system. The calculation and raw results are as follows. What value should you give to the technician?

20.067 cfm x 12.9362 cfm + 18.00782 cfm = 14.41544426 cfm

You probably arrived at the value 14.415 cfm, which is a correct value using the rules provided. However, if the gauge that the technician uses to adjust the airflow is calibrated in whole cubic feet per minute, what value should you provide? The numbers following the decimal are of no value so you should give the technician the value of 14 cfm. So now things are all set, or are they? With the piece of equipment being used, the manufacturer states that it is better to be on the high side rather than on the low side. So, since the mathematical results are actually more than 14 cfm, you had better give the technician a value of 15 cfm.

At this point you should see that even though 14.415 cfm is the correct mathematical result, the solution must be modified by reasonability to meet the environment and the operating conditions.

Rule to Meet the Conditions of Reasonability

This rule of common sense may be stated as follows: *Keep only those results that are reasonable (meaningful) in the context of the work being done and the equipment being used.*

Remember, generally you are not dealing with exact numbers, you are working with approximate numbers. With approximate numbers you must always be careful not to introduce undesirable errors into the final results. When multiple calculations are performed on approximate numbers, errors may become so large that the final results are of no value.

G.7 Practice Exercises

Answers are located on page G-11.

1. Give the number of significant digits for each of the following:

   a. 3.7 = ____________
   b. 2.06 = ____________
   c. 17.41 = ____________
   d. 0.114 = ____________
   e. 0.00134 = ____________
   f. 12000.0 = ____________
   g. 12000 = ____________
   h. 1200.001 = ____________

2. Give the most accurate/precise number for the following calculations:

   a. 1.50 + 2.317 = ____________
   b. 1.50 - 2.317 = ____________
   c. 1500 x 3.94 = ____________
   d. 1500 + 3.94 = ____________
   e. 1.500 + 394 = ____________

G.8 Answers to Intro Problems

	Problem	Complete	Corrected
1.	3.5 + 2.075 =	5575	5.6
2.	3.49 - 2.0075 =	1.4825	1.48
3.	2.0 x 307=	614.0	610
4.	2.49 x 3.07 =	7.6443	7.64
5.	2.074 x 4.700 =	9.7478	9.748
6.	4.1 x 3.29875 =	13.524875	14
7.	50 ÷ 3.0069 =	16.6284213	20
8.	9.4 ÷ 334 =	2.814371257	2.8
9.	9.4000 ÷ 0.02 =	470	500
10.	0.052 ÷ 0.0026 =	20	20
11.	0.00791÷ 0.52 =	0.015211538	0.015
12.	0.0025 x 0.00025 =	0.000000625	0.00000063

The numbers given in the preceding chart represent the answers obtained when the correct rules for truncating and rounding are applied.

G.9 Answers to Practice Exercises

1. Give the number of significant digits for each of the following:

   a. 3.7 = **2**
   b. 2.06 = **3**
   c. 17.41 = **4**
   d. 0.114 = **3**
   e. 0.00134 = **3**
   f. 12000.0 = **6**
   g. 12000 = **2**
   h. 1200.001 = **7**

2. Give the most accurate/precise number for the following calculations:

   a. 1.50 + 2.317 = **3.82**
   b. 1.50 - 2.317 = **-0.82**
   c. 1500 x 3.94 = **5900**
   d. 1500 ÷ 3.94 = **380**
   e. 1.500 ÷ 3.94 = **0.381**