

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration
WASHINGTON, D.C. 20210



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Mr. Sarunas S. Mingela
Industrial Hygienist
McCord Corporation
2850 West Grand Boulevard
Detroit, Michigan 48202

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✓	AARD Technical	
	AARD Training	
	Mgt. Officer	
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Dear Mr. Mingela:

Mr. Edward Largent has referred your letter of November 8, 1974, wherein you ask for an explanation of the accuracy requirements for monitoring and measurement presented in Part (d)(4) of the Department of Labor's final Occupational Safety and Health Standard for Exposure to Vinyl Chloride (29 CFR 1910.93q, October 4, 1974), to this office for reply.

Part (d)(4) details the limits of error at the 95% confidence level allowed for measurement of time weighted average exposures that fall in various ranges of concentration. The implied error is the cumulative error incurred in making these measurements of time weighted average exposures. The sampling strategy, sampling mechanism, and quantitative analysis procedure all contribute to the cumulated error. Sampling strategy has the greatest potential influence on the accuracy of measurement of a time weighted average exposure. A sampling strategy that calls for sampling continuously with a personal sampler throughout the duration of exposure in the time period involved (15 minutes or 8 hours) will introduce essentially no error. On the other hand, a sampling strategy that calls for taking a series of grab samples in the breathing zone of an employee can introduce errors up to several hundred percent at the 95% confidence level. This error is due to the variability with time of the vinyl chloride concentration in the work environment. A rather sophisticated statistical treatment of the data is necessary to determine this component of error.

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A 95% confidence level refers to the frequency with which measurements must fall within specified limits of error. In this Standard, for example, if the true 8-hour average exposure were in the range of 0.25 ppm to 0.5 ppm, then the method of measurement of this 8 hour average exposure must have an accuracy such that if a series of measurements were made, then 95% of them would be within plus or minus 50% of the true value.

The error inherent in the sampling mechanism and the error inherent in the quantitative analysis procedure are the only components of error you need to concern yourself with if you employ full-period, continuous sampling strategy. These are best determined as a lump sum in a laboratory by making a large number of measurements of prepared known concentrations of vinyl chloride in air. The plus or minus percent of error at the 95% confidence level is computed by multiplying the product of the standard deviation of a large set of measurements of a given known concentration (s) and the standard normal deviate for 95% confidence limits (1.96) by 100 and then dividing this result by the known concentration (X). In mathematical symbols:

$$\begin{aligned} &+ \text{ percent of error at the 95\% confidence level} = \\ &(1.96) (s) (100) \div (X). \end{aligned}$$

Parts (d)(2)(i), (d)(2)(ii), and (d)(3) specify the frequency with which you must determine each employee's exposures.

I hope this explanation of Part (d)(4) is helpful to you.

Sincerely,

Richard P. Wilson

for Barry J. White
Associate Assistant Secretary
for Regional Programs

INTRODUCTION

The burden of proving noncompliance falls upon OSHA. Since all methods of measurement have inherent errors it is necessary that the results obtained by sampling be greater than the standard in order for it to be certain, beyond reasonable doubt, that noncompliance exists. This chapter applies the classical techniques of statistics to the specific situations which occur in environmental measurements so as to enable decisions of noncompliance to be made at stated levels of certainty.

Sampling and analytical methods have errors which are in general well known. In addition, when it is not possible to sample for the full period for which a standard is defined, environmental variability causes variations among the individual sample results which must be considered in making decisions at stated levels of certainty.

The procedures in this chapter lead to the calculation of the 95% Lower Confidence Limit (LCL) of an occupational environmental sample or the arithmetic average of a group of such samples. This quantity, the LCL, must be greater than the applicable standard in order to be certain, with at least 95% confidence, that noncompliance exists. The LCL is always lower than the sample or mean of samples. Thus, if the sample or mean of samples does not exceed the applicable standard it is not possible to be certain that noncompliance exists and therefore no statistical tests are necessary.

Discussion of the theory underlying the various tests can be found in NIOSH TR-76. It should be noted that the standards used in the examples may not be current and reference should always be made to the most current regulation for the appropriate standard to be used in these statistical tests.

The statistical procedures, presented below will not detect and do not allow for analysis of highly inaccurate results, i.e., systematic (nonrandom) errors or mistakes. The detection and elimination of mistakes, which is primarily a technical rather than a statistical problem is covered in other chapters of the

manual. In general, to assure accurate results it is necessary to have an instrument calibration program and a quality control program for laboratory analysis. Systematic errors must also be known ahead of time whether from the instrument calibration procedure or the laboratory quality control program. If a constant systematic error is known to exist in an instrument or analytical procedure the sample mean of the data should be corrected before analyzing for noncompliance.

Procedures for Data Analysis

One or several consecutive samples taken for the entire time period for which a standard is defined yields an estimate of the true average concentration of the airborne contaminant which is free from the effects of environmental variability. This type of sample is referred to as a "Full-Period Sample". A full-period sample yields an air concentration estimate with the best (narrowest) confidence limits. Typically, a full-period sample would have to be only 10 to 35% above the standard in order to demonstrate noncompliance with 95% confidence. The "Full-Period Sample" procedure is used to calculate the 95% Lower Confidence Limit (LCL) for this type of sample. If several consecutive samples are taken for the entire time period of a standard the "Consecutive Full-Period Samples" procedure is used to calculate the 95% Lower Confidence Limit (LCL) for the arithmetic mean of the samples. The greater the number of consecutive samples, the less the mean of those samples has to be above the standard in order to demonstrate noncompliance. Thus, it is better to take two consecutive 4-hour samples than one 8-hour sample and better yet to take four consecutive 2-hour samples during an 8-hour period for which a standard is defined.

In some cases it isn't possible to take the sample(s) for the entire period of the standard. If one samples for four to almost eight hours for an 8-hour standard, the sample(s) is referred to as a "Partial Period" sample(s). The sample(s) is analyzed in the same manner as a full-period sample(s), but the standard

must be increased by a technique given at the end of the "Consecutive Full-Period Sample" procedure.

Finally, if long term (greater than one hour) samples are not practical one must estimate the average air concentration by several short term or grab samples. The suitable number of grab samples is about four to seven and the mean of these samples typically may have to be as high as 1.8 to 2.8 times the standard in order to demonstrate noncompliance. The "Grab Samples" procedure is used to calculate the LCL of the arithmetic mean of these samples. Samples taken for comparison to a TWA (time weighted average) standard should be taken in a random manner over the period of the standard.

Full-Period Sample Procedure

The following procedure should be used to determine noncompliance with either an 8 hour average, ceiling or excursion standard when only one full period sample has been collected. For an 8 hour average standard the sample must have been taken for the entire period for which the standard is defined. The variability (standard deviation σ or coefficient of variation C.V.) of the sampling and analytical methods used to collect and analyze the sample must be well known from previous measurements. The statistical test given is a one-sided comparison of means test using the t-distribution at the 95% confidence level.

Only if the LCL of the sample exceeds the standard are we at least 95% confident that the true average concentration exceeds the standard and that a condition of noncompliance exists.

$$LCL = \bar{x} - 1.645 \sigma$$

where 1.645 = critical standard normal deviate for 95% confidence.

σ = standard deviation of sampling/analytical method which is well known from prior data.

x = measurement being tested.

If the coefficient of variation (C.V.) is known the LCL is computed from:

$$LCL = x - (1.645) (C.V.) (Standard)$$

Figure 1 can be used to aid this calculation. Some coefficients of variation are available from Table 1.

TABLE 1. COEFFICIENTS OF VARIATION
FOR SOME SAMPLING/ANALYTICAL
PROCEDURES

SAMPLING/ANALYTICAL	C.V.
Colorimetric Detector Tubes	14%
Rotameter on Personal Pumps	5%
Charcoal Tubes (Sampling/Analytical)	10%
Asbestos (Sampling/Counting)	22%
Respirable Dust (Sampling/Weighing)	8%
Gross Dust (Sampling/Weighing)	5%

Consecutive Full-Period Samples Procedure

The following procedure should be used to determine noncompliance with either an 8 hour average ceiling or excursion standard when several consecutive samples are taken for the entire time period for which the standard is defined. The variability (standard deviation or coefficient of variation) of the sampling and analytical methods used to collect and analyze the samples must be well known from previous measurements. The statistical test given is a one-sided comparison of means test using the t-distribution at the 95% confidence level.

Only if the LCL of the mean of the consecutive samples exceeds the standard are we at least 95% confident that the true average concentration exceeds the standard and that a condition of noncompliance exists.

$$LCL = \bar{x} - 1.645 \sigma / (n)^{1/2}$$

where $\bar{x}$ = mean of the consecutive measurements.

n = number of consecutive measurements.

σ = standard deviation of sampling/analytical method which is well known from prior data.

1.645 = critical standard normal deviate for 95% confidence.

If the coefficient of variation (C.V.) is known the LCL is computed from:

$LCL = \bar{x} - [(1.645) (C.V.) (Standard) / (n)^{1/2}]$
Figure 1 can be used to aid this calculation. Some coefficients of variation are available from Table 1.

One or a series of consecutive samples collected over less than the period for which a standard is defined is referred to as a "Partial Period" sample(s). Since it is known with

certainty that the concentration during the period not covered by the sample could not be less than zero, the 8 hour average standard is multiplied by the following factor to obtain a partial period limit. The LCL is then calculated and compared to the partial period limit.

$$\text{Factor} = \frac{(\text{time period of the standard})}{(\text{actual time of the sample(s)})}$$

For an 8-hour standard typical factors would be:

TOTAL TIME OF SAMPLE(S)	FACTOR
8.00 hours	1.000
7.75	1.032
7.50	1.067
7.25	1.103
7.00	1.143
6.75	1.185
6.50	1.231
6.25	1.280
6.00	1.333

See Example #5 for the use of the above technique.

Grab Samples Procedure

The following procedure is used to determine noncompliance with an 8 hour average standard from data based on short period samples collected in an unbiased manner during the period of exposure. The variability (standard deviation) of the data is assumed unknown. The statistical test presented is for determining if the 95% lower confidence limit (LCL) of the arithmetic mean (from a log-normal distribution) exceeds the standard.

Only if the LCL exceeds the standard are we at least 95% confident that the true average concentration exceeds the standard and that a condition of noncompliance exists.

$$\log_{10} \text{ LCL} = \bar{x}_1 - \frac{ts_1}{n} + \text{GM factor}$$

where $\bar{x}_1$ = arithmetic mean of $\log_{10}$ transformation of original data.

s_1 = standard deviation of $\log_{10}$ transformation of original data.

n = number of samples taken at random intervals during the exposure period.

t = the critical Student t-value for 95% confidence as obtained from Table 2. GM factor = correction factor obtained from Fig. 2.

NOTE: when samples are analyzed by this procedure one cannot have a zero in the

data since one cannot take the log of zero. If this occurs the lowest detectable limit for the analytical method must be entered in the data table instead of the zero value.

TABLE 2. STUDENT T-VALUES FOR 95% CONFIDENCE

n	t	n	t	n	t
2	6.314	10	1.833	18	1.740
3	2.920	11	1.812	19	1.734
4	2.353	12	1.796	20	1.729
5	2.132	13	1.782	21	1.725
6	2.015	14	1.771	22	1.721
7	1.943	15	1.761	23	1.717
8	1.895	16	1.753	24	1.714
9	1.860	17	1.746	25	1.711
				30	1.699

The standard deviation of the logarithms of the original data (s_1) can be computed from the following equation:

$$s_1 = \sqrt{\frac{n \sum_{i=1}^n X_{1i}^2 - \left(\sum_{i=1}^n X_{1i} \right)^2}{n(n-1)}}$$

where: x_{1i} = $\log_{10}$ of each measurement

x_{1i}^2 = square of $\log_{10}$ of each measurement.

There are commercial calculators available which are programmed to do the above calculation for the standard deviation.

The following steps are suggested:

a. Arrange the measurements in a column and take $\log_{10}$ of each measurement.

b. If the (s_1) is being calculated by the above equation square each log and place in a third column.

c. Take the sum of the original concentrations ($\sum x_{1i}$) and the sum of the logs ($\sum x_{1i}$) if necessary.

d. Compute the average of the logs ($\bar{x}_1$) and the standard deviation of the logs (s_1).

e. Look up the t-value in Table 2 and calculate GM-factor from Fig. 2.

f. Calculate the LCL or use Fig. 2. Note that on Fig. 2 we may have to add (or subtract) an appropriate power of 10 to $\bar{x}_1$ and divide (or multiply) LCL by the same multiple of 10 in order to fall within the range of the scales on the monogram. See Example 1 for how this is done.