

TECHNICAL APPENDIX A*

CALCULATION OF SAMPLE SIZE FOR A MAXIMUM RISK SUBGROUP FROM A HOMOGENEOUS HIGH RISK GROUP

In some cases it may not be possible to select the *maximum risk worker* from a group of workers with a similar exposure risk. That is, the industrial hygiene considerations of Chapter 2 fail to yield an individual whose exposure is likely to be higher than other employees. This could occur where many employees are involved in work operations with identical exposure potential or the air in the workroom is well mixed, or both. The material in this Appendix was developed to provide guidelines for an adequate sample size for this homogeneous high risk group. This Appendix describes a sampling procedure that can be used by an employer in order to minimize the sampling burden while obtaining a high probability of sampling a *high risk employee*. The number of workers in such a homogeneous risk group is denoted by N , and a random sample of a subgroup $n < N$ is to be taken.

The criterion will be that a high probability will exist that at least one worker from a subgroup with highest exposures should be in this sample. If *highest exposures* is defined as the *top 10%* of all exposures in the parent group, then the sample will have to include (with high probability $[1 - \alpha]$) one worker out of a given subgroup of size $N_0 = \tau N$ where τ is the proportion of the group included as the *high exposures*, $0 < \tau < 1$. In the *top 10%* case, $\tau = 0.1$. The allowed probability of missing all N_0 workers with highest exposure in the sample of n out of N is α .

The expression of the probability of missing all workers from a subgroup of size N_0 from a group of N when sampling n is

$$P_0 = \frac{(N - N_0)!}{(N - N_0 - n)!} \frac{(N - n)!}{N!} \quad (\text{A-1})$$

This expression follows from calculations found in the theory of sampling without replacement treated in reference A-1. Note that

$$P_0 = P_0(N, \tau, n) \quad (\text{A-2})$$

and, to obtain the sample size, the following equation has to be solved

$$P_0(N, \tau, n) = \alpha \quad (\text{A-3})$$

for the sample size n , given N (the size of the parent group under consideration), τ (the desired high exposure subgroup percentage), and α (the allowed probability of missing all of the workers in the top exposure group).

The solution, rounded off to the nearest integer, is presented in Tables A-1-A-4, for the following ranges of values:

- Group size $N = 1, \dots, 50$
- Top 10% and 20% fractions, i.e.,
 $\tau = 0.1, 0.2$
- Confidence levels of 90% and 95%, i.e.,
 $\alpha = 0.1$ and 0.05 .

(When $n \ll N$, the above exact solution is approached by the solution for sampling with replacement.) The procedure in this case is to guarantee with confidence $1 - \alpha$ that, in n trials, the event whose probability of occurring in one trial is τ will not occur. The probability of such an event not occurring in n trials is

$$(1 - \tau)^n = \alpha \quad (\text{A-4})$$

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and

$$n = \frac{\log \alpha}{\log (1 - \tau)} \quad (A-5)$$

For example,

$$n(\tau=0.1, \alpha=0.1) = \frac{\log 0.1}{\log 0.9} = \frac{-1.0}{-0.0458} = 21.9 \text{ or } 22$$

and this is the limit towards which n tends in Table A-1 as $N \rightarrow \infty$.

Note that even for $N=50$, the value of n from Table A-1 is still far from the above limit and, thus, it is advantageous to use the sampling without replacement approach as in equation (A-3).

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TABLE A-1. SAMPLE SIZE FOR TOP 10% ($\tau=0.1$) AND CONFIDENCE 0.90 ($\alpha=0.1$) (USE $n=N$ if $N \leq 7$)

Size of group (N)	8	9	10	11-12	13-14	15-17	18-20	21-24	25-29	30-37	38-49	50	∞
Required No. of measured employees (n)	7	8	9	10	11	12	13	14	15	16	17	18	22

TABLE A-2. SAMPLE SIZE FOR TOP 10% ($\tau=0.1$) AND CONFIDENCE 0.95 ($\alpha=0.05$) (USE $n=N$ if $N \leq 11$)

Size of group (N)	12	13-14	15-16	17-18	19-21	22-24	25-27	28-31	32-35	36-41	42-50	∞
Required No. of measured employees (n)	11	12	13	14	15	16	17	18	19	20	21	29

TABLE A-3. SAMPLE SIZE FOR TOP 20% ($\tau=0.2$) AND CONFIDENCE 0.90 ($\alpha=0.1$) (USE $n=N$ if $N \leq 5$)

Size of group (N)	6	7-9	10-14	15-26	27-50	51- ∞
Required No. of measured employees (n)	5	6	7	8	9	11

TABLE A-4. SAMPLE SIZE FOR TOP 20% ($\tau=0.2$) AND CONFIDENCE 0.95 ($\alpha=0.05$) (USE $n=N$ if $N \leq 6$)

Size of group (N)	7-8	9-11	12-14	15-18	19-26	27-43	44-50	51- ∞
Required No. of measured employees (n)	6	7	8	9	10	11	12	14

TECHNICAL APPENDIX B

EXPOSURE VARIATION IN OCCUPATIONAL GROUPS OF SIMILAR EXPECTED EXPOSURE RISK

In the past it has been accepted industrial hygiene practice to estimate the exposures of a group of workers with similar exposure risk by sampling only a few workers in the group. The measured exposures would be averaged, and this average group exposure was assumed for all employees in the exposure risk group. However, this procedure was an undesirable compromise because there were limited numbers of industrial hygienists and few resources available to measure the exposure of each employee. Also, it was assumed that the variation of exposure averages within a group of similar expected exposure risk would be small, with only small differences between the group average and the low and high exposures in the group.

Ayer and Burg (B-1) made a valuable contribution to industrial hygiene by demonstrating the inaccuracies introduced by the above procedure. Their paper discussed the difference between the maximum 8-hour personal sample that might be obtained on an individual worker and the time-weighted average exposure for a group of workers. Unfortunately, their paper went largely unnoticed. Their work was important because of a requirement established by the Occupational Safety and Health Act of 1970 (B-2). Section 6 (b) 7 of the Act requires the Department of Labor to promulgate standards that "... shall provide for monitoring or measuring employee exposure at such locations and intervals and in such manner as may be necessary for the protection of employees."

Ayer and Burg (B-1) recognized that the distribution of sample results from a given operation is generally lognormal. This distribution and its application to occupational exposure measurements has also been discussed by Leidel and Busch (B-3) and Leidel, Busch, and Crouse (B-4). Recognizing the lognormal dis-

tribution of individual exposure averages in a group has important implications. The exposure averages (for groups with typical geometric standard deviations [GSD]) cover a wide range of values, often an order of magnitude. The ratio of a high exposure, such as that of the 95th-percentile employee (that employee whose exposure average exceeds 95% of all others in the group) to the group arithmetic average exposure can typically be 2 or 3 to 1. That is, the 95th-percentile employee exposure can easily be 200% to 300% of the group average.

In Figure B-1, the distribution of employee exposures within a group for different amounts of exposure variation is graphically shown. The relation between the true arithmetic average exposure μ and the GSD is given by

$$\mu = GM \exp \left[\frac{1}{2} (\ln GSD)^2 \right]$$

where

μ = true arithmetic average exposure of the group

GM = true geometric mean exposure of group (= 50th percentile employee exposure)

GSD = true geometric standard deviation of group exposure distribution

This relation was used to prepare Figure B-1 and Table B-1. In all cases, the true group arithmetic exposure average is fixed at 100 ppm.

Ayer and Burg (B-1) and Leidel et al. (B-4) present tables showing that group GSD's commonly occur in the range 1.5 to 2.5. Table B-1 shows that if the group exposure average was assigned to all employees in the group, the exposure of at least 5% of the employees would be recorded at 56% to 34% (or less) of their true values (for GSD's of 1.5 to 2.5).

TABLE B-1. HIGHER LEVEL EXPOSURES IN A LOGNORMAL DISTRIBUTION

GSD	GM, ppm	90th percentile exposure, ppm	95th percentile exposure, ppm	Ratio 95th/group average	Group avg. as % of 95th percentile
1.1	99.5	112	116	1.16	86%
1.3	97	135	149	1.49	67%
1.5	92	155	179	1.79	56%
1.75	86	175	215	2.15	47%
2.0	79	191	246	2.46	41%
2.5	66	213	297	2.97	34%

Under most situations, it is incorrect to assign the group average exposure to all employees because the group average can significantly underestimate high exposures. Only when the group GSD is very low (about 1.15 or less) could the group average be assigned to all employees with less than about 20% error introduced. However, it takes large sample sizes to determine the group GSD, and in the vast majority of occupational groups, the GSD would exceed 1.15 anyway.

REFERENCES

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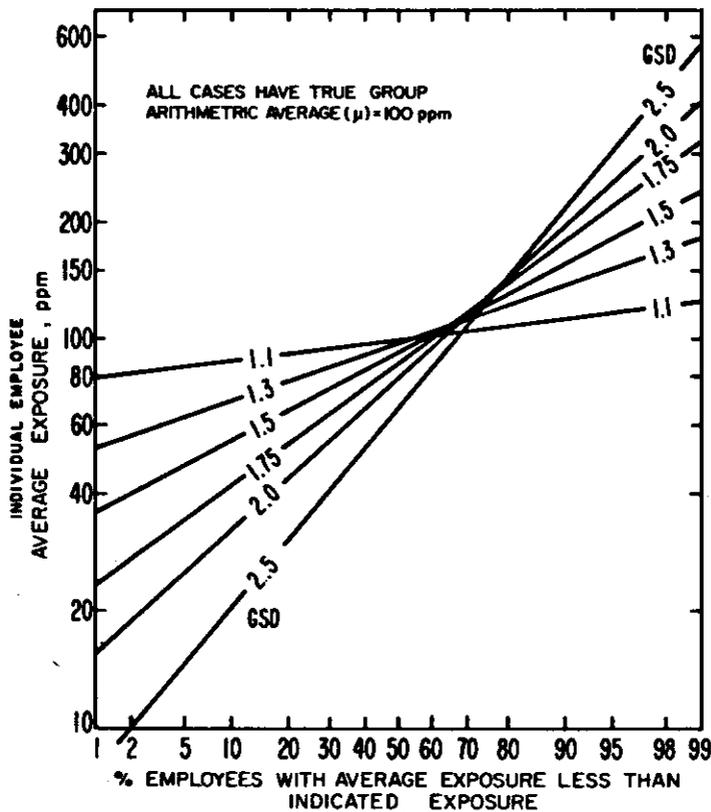


Figure B-1. Lognormal exposure distribution for an occupational group of similar expected exposure. Lines are for differing geometric standard deviations.

TECHNICAL APPENDIX C

THE INADEQUACY OF GENERAL AIR (AREA) MONITORING FOR MEASURING EMPLOYEE EXPOSURES

There are three basic types of occupational environment sample collection techniques:

- Personal — The sampling device is directly attached to the employee and worn continuously during all work and rest operations.
- Breathing Zone — The sampling device is held by a second individual who attempts to sample the air in the "breathing zone" of the employee. The "breathing zone" is that air that would most nearly represent the air inhaled by the employee.
- General Air — The sampler is placed in a fixed location in the work area (this is also referred to as environmental monitoring, area monitoring, static sampling, fixed sampling, and fixed-station monitoring).

Breslin et al. (C-1) is often quoted as "proof" that general air samples yield highly accurate measurements of average daily employee exposure. Breslin, however, shows that the average daily exposures were calculated from a combination of breathing zone and general air samples combined with time-and-motion studies. In addition he states, "The foregoing measurements of average exposure represent the very best accuracy the study team could achieve and were based on far more samples than are collected on a routine survey." Finally, the authors showed (Figure 4 of the article) the approximately 40-fold range the calculated exposure values covered.

Other authors have discussed the problems of general air or static samplers. Sherwood (C-2) concluded that "static samplers may grossly misrepresent the exposure of individual workers who are likely to be exposed to airborne activity of their own making." Sherwood

(C-3) has also shown the very wide variation (typically 100-fold) of air concentrations employees are exposed to at particular work operations. These data contradict the assumption that air concentrations can be expected to be the same everywhere at the work operation. Ayer and Burg (C-4) also present data showing the extreme variation in sampling data. Shulte (C-5) observed a median ratio of four to one (C-4) between personal samplers and fixed (general air) samplers in a uranium graphite processing operation.

Tebbens (C-6) has pointed out that the Act declares as congressional policy the intent "to assure so far as possible every working man and woman in the nation safe and healthful working conditions," and thus the attention in exposure sampling is refocused from groups to individual workers. This concern for individuals appears in the Federal Coal Mine Health and Safety Act of 1969 (C-7) and the MESA Dust Sampling Requirements (C-8). Compliance with dust standards is determined almost exclusively by personal monitoring. Tebbens (C-6) also states, "It is the recognition of the probability of large temporal and spatial measurement errors which had led slowly to the concept of personal sampling or dosimetry, attaching the sensing element of a sampler to the worker himself — he carries it about continuously, often during an entire workday."

Linch and co-workers have compared fixed-station (area) monitors to personal samplers in sampling for tetraalkyl lead (C-9) and carbon monoxide (C-10). In neither case did they find correlation between the area and personal monitors. Regarding the tetraalkyl lead exposures, Linch et al. (C-9) wrote:

"... [the conclusion] that the fixed-station monitors may not disclose the true inhaled

air concentrations of lead in a highly variable ambient work atmosphere appeared to be sufficiently valid to justify the establishment of an extensive personnel monitoring survey."

"... fixed-station air monitoring does not provide valid results required for organic lead exposure control based on air analysis."

"... in those cases where air analysis is required for exposure control, personnel monitoring is the preferred procedure for the collection of the sample."

For the carbon monoxide study of exposure in a large warehouse, in which gasoline-powered trucks were operated, Linch and Pfaff (C-10) concluded that "only by personal monitoring could a true exposure be determined."

A study by Baretta et al. (C-11) concluded that continuous air sampling at fixed locations is valid for estimating an employee's individual daily exposure to vinyl chloride. The study featured multipoint air sampling, analysis using an IR spectrophotometer, and data subsequently analyzed by computer. As was stated in the Breslin et al. article (C-1), this study demonstrated that area samplers provide an inadequate estimate of an employee's exposure. First, a comprehensive job study was required for each of four job classifications to determine the work areas frequented by the workmen and the time they spent in each area. No data were given regarding the variation for individual workers for these time and motion studies or confidence intervals for percent of time spent at each work location. Second, a computer was required for analysis of the vast amount of data and calculation of exposure estimates. Third, no confidence estimates were given for the TWA exposures calculated from the continuous monitoring combined with the comprehensive job study. Fourth, the authors state:

"Continuous monitoring, however, is extremely costly both in time and in the equipment required. The scope of data acquired is limited by the number of sampling probes, and these probes are not always accurately measuring the individual's daily exposure experiences, especially should these involve unusual incidences such as chemical spills or exposures outside the monitored area."

Lastly, a recent NIOSH report (C-12) gives the results of a statistical analysis of a 1973 study in the beryllium industry. The study compared the airborne beryllium exposure estimates obtained with three different sampling techniques: the Atomic Energy Commission (AEC) sampling method, personal total dust, and personal respirable dust. The AEC method uses the results of general area samples (15 to 60 minutes duration) and breathing zone samples (2 to 10 minutes duration) along with a time and motion study of the worker's job to calculate his daily weighted average for a 3-month period. The personal sampling methods differed from the AEC method in that the sampler used was worn by the workers during the work shift. The NIOSH report (C-12) states that no reliable conversion was found to exist between results obtained from the three methods on a single sample basis. However, it appeared that for large numbers of samples taken under the same sampling conditions, when the concentration is $2 \mu\text{gBe}/\text{m}^3$ by the AEC method, the value by the personal total sample will be about $3 \mu\text{gBe}/\text{m}^3$. Thus, the personal sample yielded a value about 50% higher than the general air AEC method on the average.

Therefore, the intent of NIOSH recommendations concerning the proposed OSHA health regulations is that measurements of employee exposure should normally only be based on sampling by the personal or breathing zone methods. It should be necessary to demonstrate that samples taken by the general air method measure employee exposure as accurately as those obtained by the personal or breathing zone methods.

REFERENCES

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TECHNICAL APPENDIX D

COEFFICIENTS OF VARIATION AND ACCURACY REQUIREMENTS FOR INDUSTRIAL HYGIENE SAMPLING AND ANALYTICAL METHODS

The relative variation of a normal distribution (such as the randomly distributed errors occurring in industrial hygiene sampling and analytical procedures) is commonly described by the *coefficient of variation (CV)*. The CV is also known as the *relative standard deviation (RSD)*. The CV is a useful index of dispersion in that limits computed from the true mean of a set of data plus or minus twice the CV will contain about 95% of the data measurements. Thus, if an analytical procedure with a CV of 10% is used to repeatedly measure some constant physical property (such as the concentration of a chemical in a beaker of solution), then about 95% of the measurements will fall within plus or minus 20% (2 times the CV) of the true concentration.

The accuracy required of airborne concentration measurements in the proposed OSHA health standards takes into account (1) random variations in the sampling device (repeatability of the sampling device), (2) random variations in the analytical procedure (repeatability of the replicate analyses of a given sample), (3) systematic errors in the sampling method (determinate errors or bias in the collection technique), and (4) systematic errors in the analytical procedure (determinate error or bias in the analysis).

The term *accuracy* in the proposed OSHA health standards and in this Manual refers to the difference between a measured concentration and the true concentration of the sample. Thus, it includes both the random variation of the method about its own mean (commonly referred to as precision) and the difference between the average result from the method and the true value (commonly referred to as the bias of the method). The term accuracy does not refer to the difference between a measured

concentration and the true employee exposure. There are additional considerations that affect the difference between a measured airborne concentration and the true employee exposure. These include sampler location in relation to the breathing zone of the employee and sampling strategy of exposure measurement — both numbers of samples and duration. (Refer to Chapter 3.)

The proposed OSHA health standards state that the accuracy of a method shall have a *confidence level of 95%*. This means that 95% of the measurements must be as accurate as the standard requires. If one assumes the method is unbiased and errors are normally distributed, the CV (or relative standard deviation) can be used to judge if the method has the required accuracy. The CV in percentage units is defined as the standard deviation of the method, times 100, divided by the true value. The required *total coefficient of variation (CV_T)* of the sampling and analytical method is obtained by dividing the required accuracy by 1.96 (statistical standard normal deviate for 95% two-sided confidence limits, also referred to as z-value). Typical required CV_T's would be:

<u>Concentration</u>	<u>Required accuracy (plus or minus)</u>	<u>Required CV_T</u>
Above permissible exposure	25%	< 12.8%
At or below the permissible exposure and above the action level	35%	< 17.9%
At or below the action level	50%	< 25.5%

The statistical decision techniques in Chapter 4 utilize CV_T. Table D-1 lists some CV_T's for specific NIOSH sampling and analytical procedures. If a specific method is not listed for

TABLE D-1. TOTAL COEFFICIENTS OF VARIATION FOR SOME SPECIFIC NIOSH SAMPLING/ANALYTICAL PROCEDURES

Air contaminant	CV _T	NIOSH method number	Air contaminant	CV _T	NIOSH method number
Acetic anhydride	0.06	S170	Dimethylamine	0.06	S142
Acetone	0.08	S1	Dimethylaniline	0.05	S164
Acetonitrile	0.07	S165	Dimethyl formamide	0.06	S255
Acetylene tetrabromide	0.10	S117	Dioxane	0.05	S360
Acrylonitrile	0.07	S156	Dipropylene glycol methyl ether	0.06	S69
Allyl alcohol	0.11	S52	di-sec-Octyl phthalate		
Allyl chloride	0.07	S116	(see di-2-ethylhexylphthalate)		
Alpha-methyl styrene	0.05	S26	Epichlorohydrin	0.06	S118
n-Amyl acetate	0.05	S51	2-Ethoxyethylacetate	0.06	S41
sec-Amyl acetate	0.07	S31	Ethyl acetate	0.06	S49
Antimony and compounds (as Sb)	0.09	S2	Ethyl acrylate	0.05	S35
Arsenic and compounds (as As)	0.06	S309	Ethyl alcohol	0.06	S56
Arsine	0.06	S229	Ethyl benzene	0.04	S29
Asbestos	0.24-0.38	P&CAM239	Ethyl bromide	0.05	S106
Barium, soluble compounds	0.05	S198	Ethyl butyl ketone	0.09	S16
Benzyl chloride	0.10	S115	Ethyl ether	0.05	S80
Beryllium and beryllium compounds (as Be)	0.06	S339	Ethyl formate	0.08	S36
Butadiene	0.06	S91	Ethyl sec-amyl ketone (see 5-methyl-3-heptanone)		
2-Butanone	0.07	S3	Ethyl silicate	0.06	S264
2-Butoxyethanol	0.06	S76	Ethylamine	0.11	S144
Butyl acetate	0.07	S47	Ethylene chlorohydrin	0.08	S103
sec-Butyl acetate	0.05	S46	Ethylene dichloride (1, 2-dichloroethane)	0.08	S122
tert-Butyl acetate	0.09	S32	Ethylene glycol dinitrate and/or nitroglycerin	0.10	S216
Butyl alcohol	0.07	S66	Ethylene oxide	0.10	S286
sec-Butyl alcohol	0.07	S53	N-ethylmorpholine	0.10	S146
tert-Butyl alcohol	0.08	S63	Glycidol	0.08	S70
n-Butyl glycidyl ether	0.07	S81	Heptane	0.06	S89
p-tert-Butyltoluene	0.07	S22	Hexachloronaphthalene	0.06	S100
Calcium oxide	0.06	S205	Hexane	0.06	S90
Camphor	0.07	S10	2-Hexanone	0.05	S178
Carbaryl (Sevin)	0.06	S273	Hexone (methyl isobutyl ketone)	0.06	S18
Carbon tetrachloride	0.09	S314	Hydrazine	0.09	S237
Chlorinated camphene	0.08	S67	Hydrogen bromide	0.07	S175
Chlorobenzene	0.06	S133	Hydrogen chloride	0.06	S246
Chlorobromomethane	0.06	S113	Hydrogen fluoride (HF)	0.06	S176
Chlorodiphenyl (54% chlorine)	0.06	S121	Hydrogen sulfide (aqueous)	0.12	S4
Chloroform	0.06	S351	Isoamyl acetate	0.06	S45
Chromic acid and chromates	0.08	S317	Isoamyl alcohol	0.08	S58
Chromium, metal, and insoluble compounds	0.08	S352	Isobutyl acetate	0.07	S44
Chromium, soluble chromic, and chromous salts (as Cr)	0.08	S323	Isobutyl alcohol	0.07	S64
Copper dusts and mists	0.05	S186	Isophorone	0.06	S367
Cresol (all isomers)	0.07	S167	Isopropyl acetate	0.07	S50
Cumene	0.06	S23	Isopropyl alcohol	0.06	S65
Cyanide (as Cn)	0.10	S250	Isopropylamine	0.07	S147
Cyclohexane	0.07	S28	Isopropyl glycidyl ether	0.07	S77
Cyclohexanol	0.08	S54	Ketene	0.06	S92
Cyclohexanone	0.06	S19	Lead and inorganic lead compounds	0.07	S341
Cyclohexene	0.07	S82	LPG (liquefied petroleum gas)	0.05	S93
Diacetone alcohol	0.10	S55	Magnesium oxide fume	0.06	S369
Diazomethane	0.08	S137	Manganese and compounds (as Mn)	0.06	S5
Dibutyl phthalate	0.05	S33	Mesityl oxide	0.07	S12
o-Dichlorobenzene	0.07	S135	Methyl acetate	0.06	S42
p-Dichlorobenzene	0.05	S281	Methyl acrylate	0.07	S38
1, 1-Dichloroethane	0.06	S123	Methyl alcohol	0.06	S59
1, 2-Dichloroethylene	0.05	S110	Methyl (n-amyl) ketone	0.07	S1
1, 1-Dichloro-1-nitroethane	0.05	S213	Methyl "Cellosolve"	0.07	S79
Diethylamine	0.07	S139	Methyl "Cellosolve" acetate	0.07	S39
Di-2-ethylhexylphthalate	0.06	S40	Methyl chloroform (1, 1, 1-trichloroethane)	0.05	S328
Difluorodibromomethane	0.09	S107	Methyl cyclohexane	0.05	S94
Diisobutyl ketone	0.07	S358	5-Methyl-3-heptanone	0.10	S13
Dimethyl acetamide	0.07	S254			

TABLE D-1. TOTAL COEFFICIENTS OF VARIATION FOR SOME SPECIFIC NIOSH SAMPLING/ANALYTICAL PROCEDURES (cont.)

Air contaminant	CV _T	NIOSH method number	Air contaminant	CV _T	NIOSH method number
Methyl iodide	0.07	S98	Propylene oxide	0.08	S75
Methyl isoamyl acetate	0.06	S37	n-Propyl nitrate	0.05	S227
Methyl isobutyl carbinol	0.08	S60	Pyridine	0.06	S161
Methyl isobutyl ketone (see Hexone)			Rhodium, metal fume and dust	0.08	S188
Methyl methacrylate	0.13	S43	Rhodium, soluble salts	0.07	S189
Methylal (dimethoxymethane)	0.06	S71	Selenium compounds	0.09	S190
alpha-Methylstyrene	0.05	S26	Stoddard solvent	0.05	S382
Molybdenum, soluble compounds	0.09	S193	Styrene	0.06	S30
Monomethyl aniline (N-methylaniline)	0.09	S153	Sulfuric acid	0.08	S174
Morpholine	0.06	S150	Tellurium	0.06	S204
Naphtha, coal tar	0.05	S86	Tellurium hexafluoride	0.05	S187
Naphthalene	0.05	S292	Terphenyls	0.10	S27
Nickel, metal and soluble compounds (as Ni)	0.06	S206	1, 1, 1, 2-Tetrachloro-2, 2-difluoroethane	0.07	S131
Nicotine	0.07	S293	1, 1, 2, 2-Tetrachloro-1, 2-difluoroethane	0.05	S132
Nitrobenzene	0.06	S217	1, 1, 2, 2-Tetrachloroethane	0.06	S124
p-Nitrochlorobenzene	0.10	S218	Tetrahydrofuran	0.06	S78
Nitrotoluene	0.06	S223	Tetranitromethane	0.08	S224
Octachloronaphthalene	0.07	S97	Tetryl	0.06	S225
Octane	0.06	S378	Thallium, soluble compounds (as Tl)	0.06	S306
Ozone (alkaline MI)	0.08	S8	Tin, inorganic compounds except oxides	0.06	S185
Parathion	0.08	S295	Titanium dioxide dust	0.11	S385
Pentane	0.05	S379	o-Toluidine	0.06	S168
2-Pentanone	0.06	S20	Tributyl Phosphate	0.08	S208
Petroleum distillate (naptha)	0.05	S380	1, 1, 2-Trichloroethane	0.06	S134
2-Pentyl acetate (see sec-amyl acetate)			Trichloroethylene	0.08	S336
Phenol	0.07	S330	1, 2, 3-Trichloropropane	0.07	S126
Phenyl ether	0.07	S72	1, 1, 2-Trichloro-1, 2, 2-trifluoroethane	0.07	S129
Phenyl ether-biphenyl mixture	0.09	S73	Trifluoromonobromethane	0.06	S125
Phenylglycidyl ether	0.06	S74	Triorthocresyl phosphate	0.07	S209
Phenylhydrazine	0.06	S160	Triphenyl phosphate	0.07	S210
Phosphoric acid	0.06	S333	Turpentine	0.05	S88
Phthalic anhydride	0.09	S179	Vinyl chloride	0.08	—
Platinum, soluble salts	0.06	S191	Vinyl toluene	0.06	S25
Propane	0.05	S87	Xylidine	0.06	S162
n-Propyl acetate	0.06	S48	Yttrium	0.05	S200
Propyl alcohol	0.08	S62	Zirconium compounds (as Zr)	0.05	S185
Propylene dichloride	0.06	S95			

a chemical, then the general coefficients of variation in Table D-2 may be used with care. Tables D-1 and D-2 apply only to laboratories with adequate maintenance and calibration facilities for sampling equipment (such as pumps) and a quality control program for the analytical laboratory.

The CV_T 's in Table D-1 were reported by the NIOSH Measurement Research Branch and obtained from NIOSH Contract CDC-99-74-45, Laboratory Validation of Air Sampling Methods Used to Determine Environmental Concentrations in Work Places, June 26, 1974 to July 30, 1976. Additional work in this area was performed by Reckner and Sachdev (D-1) under NIOSH Contract HSM 99-72-98.

TABLE D-2. GENERAL COEFFICIENTS OF VARIATION FOR SOME SAMPLING/ANALYTICAL PROCEDURES

Sampling/analytical procedure	CV	Data sources*
Colorimetric detector tubes	0.14	A
Rotameter on personal pumps (sampling only)	0.05	B
Charcoal tubes (sampling/analytical)	0.10	C
Asbestos (sampling/counting)	0.24-0.38	D
Respirable dust, except coal mine dust (sampling/weighing)	0.09	E
Gross dust (sampling/analytical)	0.05	E

*Data source references

- A. Leidel, N. A., and K. A. Busch: Statistical Methods for the Determination of Noncompliance with Occupational Health Standards, NIOSH Technical Information, HEW Pub. No. (NIOSH) 75-159, Cincinnati, Ohio 45226, 1975.
- B. NIOSH Engineering Branch estimate of typical calibrated pumps capable of the range 1.5 to 3.0 lpm.
- C. Conservative estimate by the authors. Recent work under NIOSH Contract CDC-99-74-45 have shown typical CV_T 's (precision only) of 0.05 to 0.09 for charcoal tubes.
- D. Leidel, N. A., S. G. Bayer, R. D. Zumwalde, and K. A. Busch: USPHS/NIOSH Membrane Filter Method for Evaluating Airborne Asbestos Fibers, NIOSH Technical Information Report, Cincinnati, Ohio 45226 (to be published, 1977).
- E. NIOSH Engineering Branch estimate based on the use of pumps in the flow range 1.5 to 3.0 lpm and a collected mass of at least 1.0 milligram.

If an analytical coefficient of variation different from that given in Tables D-1 and D-2 is available from a laboratory, it is better to use a computed total coefficient of variation. It is important to realize that CV 's are not directly additive, but that the CV_T increases as the square root of the sum of the squares of component CV 's. In general there are only two component CV 's: the CV_P for the sampling pump and the CV_A for the analytical method. Thus, the CV_T would be calculated from

$$CV_T = \sqrt{(CV_P)^2 + (CV_A)^2}$$

where

CV_P = pump CV, generally taken as 0.05

CV_A = analytical CV

Example:

Charcoal tubes were used to sample for acetone and were taken to a local laboratory for analysis. The laboratory reported that its CV_A for acetone on charcoal tubes was 0.09. The CV_T is calculated as

$$CV_T = \sqrt{(0.05)^2 + (0.09)^2} = 0.10$$

Another example dealing with coal mine dust samples was given by Leidel and Busch (D-2).

REFERENCES

- D-1. Reckner, L. R., and J. Sachdev: Collaborative Testing of Activated Charcoal Sampling Tubes for Seven Organic Solvents. NIOSH Technical Information, HEW Pub. No. (NIOSH) 75-184, Cincinnati, Ohio 45226, 1975.
- D-2. Leidel, N. A., and K. A. Busch: Comments — Statistical Methods for Determination of Noncompliance. American Industrial Hygiene Association Journal, 36: 839-840, 1975.

TECHNICAL APPENDIX E

GENERAL EFFECT OF SAMPLE SIZE ON REQUIREMENTS FOR DEMONSTRATION OF COMPLIANCE AND NONCOMPLIANCE

COMPLIANCE DEMONSTRATION

Full Period Consecutive Samples Measurement and Partial Period Consecutive Samples Measurement

The effect of the number of samples on requirements for demonstrating compliance can be found by using the equation for the 95% upper confidence limit (UCL) given in section 4.2.2. The standardized exposure average \bar{x} , needed to demonstrate compliance, is plotted versus sample size n and shown as Figure E-1.

$$\bar{x} = 1 - \frac{(1.645) (CV_T)}{\sqrt{n}}$$

where

CV_T = coefficient of variation of sampling and analytical method (see Technical Appendix D)

n = number of consecutive samples

Note: for a true concentration equal to this decision point of the test, the power of the test ($1 - \beta$) equals 50% (see Technical Appendix J).

Figure E-1 can also be used to show the effect of partial period consecutive sample size, if it is assumed the exposure average of the unsampled period is equal to the one calculated for the sampled period. However, refer to sections 3.3.3 and 3.4 before using this procedure.

Grab Samples Measurement

The definition and application of the Grab Samples Measurement strategy is given in sections 3.3.4 and 3.4. The effect of grab sample size on the requirements for compliance demonstration can be found by using Figure 4.3 in section 4.2.3. The lower family of curves (between the Possible Overexposure and Compliance Regions) is used to calculate the maximum

average exposure that would yield a compliance exposure decision. One assumes several different data geometric standard deviations (GSD) (intraday), and these are converted to the standard deviations of the logarithmic concentration values:

$$s = \log_{10} (GSD)$$

A \bar{y} is read from Figure 4.3, section 4.2.3, for each chosen sample size n . Then \bar{y} is converted to the standardized arithmetic mean exposure \bar{x} :

$$\bar{x} = [\text{antilog}_{10}(\bar{y})] [\exp(\frac{1}{2} (\ln GSD)^2)]$$

The above holds only if the *true* GSD equals the *sample* GSD, but the approximation is useful for estimating the effect of sample size shown in Figure E-2.

NONCOMPLIANCE DEMONSTRATION

The effect of sample size on requirements for noncompliance demonstration has been discussed previously (E-1). (Figures E-3, E-4, and E-5 are taken from Leidel and Busch (E-1). Equations similar to those given previously in this Appendix were used to calculate and draw Figures E-3 and E-4.)

Full Period Consecutive Samples Measurement

For full period consecutive samples, Figure E-3 shows that, based on statistical consideration alone, a suitable number of samples is from four to seven. However, practicality and costs of sampling and analysis must be considered. Most long duration sampling methods cannot be run for longer than about 4 hours per sample. Thus, most full period consecutive sampling strategies would obtain at least two samples

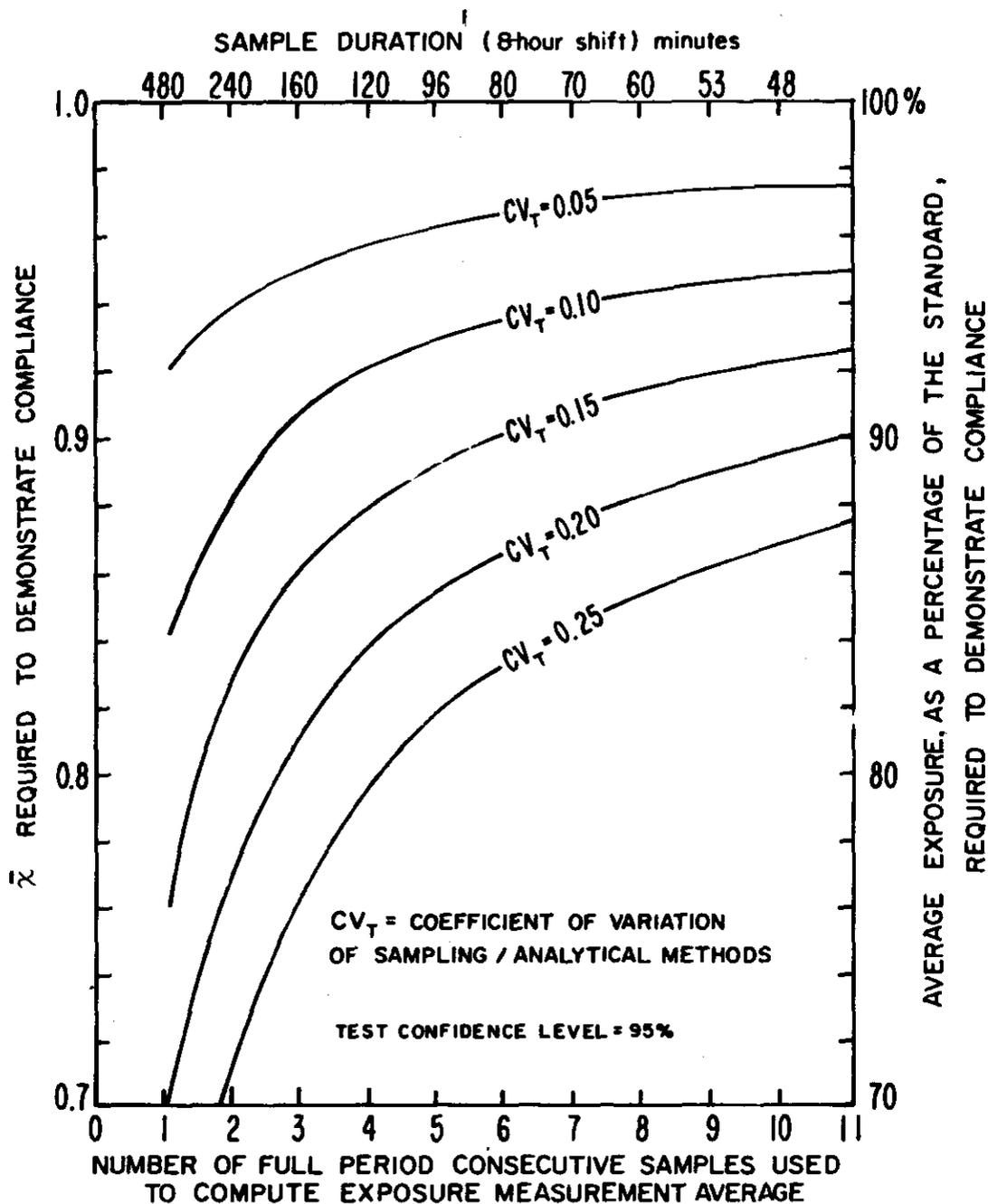


Figure E-1. Effect of full period consecutive sample size on compliance demonstration when test power is 50%.

when an 8-hour average standard is sampled for.

If one had a sampling/analytical technique with a CV_T of 10%, Figure E-3 shows that the standardized exposure average \bar{x} required to demonstrate noncompliance decreases from about 1.12 for two samples to about 1.06 for seven samples. Or, for two samples, we can demonstrate noncompliance when the mean

of the two samples is 12% above the standard. But with seven samples, we can demonstrate noncompliance when the mean of the seven samples is 6% above the standard. The uncertainty of the TWA measurement can be further reduced by taking more than seven samples; however, the additional sampling effort is not usually justified.

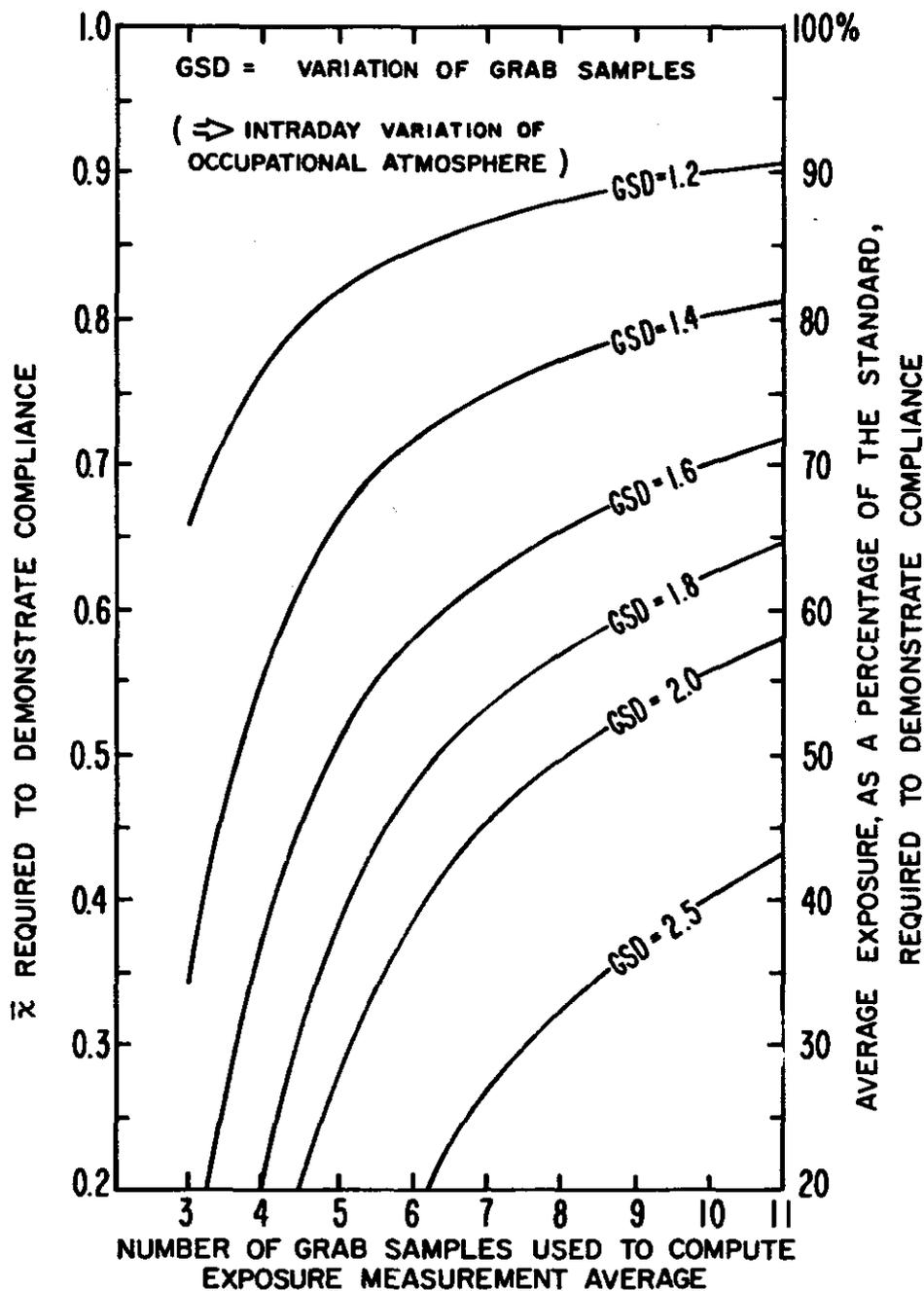


Figure E-2. Effect of grab sample size on compliance demonstration.

There are theoretical benefits with larger sample sizes, but in relation to the large additional costs involved (especially from extra analyses), the benefits are usually negligible. Thus, we can conclude that two consecutive full period samples (about 4 hours each for an 8-hour TWA standard) is usually the "best" number to use, as discussed in section 3.4.

Grab Samples Measurement

For grab samples, fewer than four samples requires unreasonably large values of \bar{x} to demonstrate noncompliance. As with consecutive full period samples, Figure E-4 shows there is a point of diminishing returns in attempting to reduce uncertainty in the measured mean by

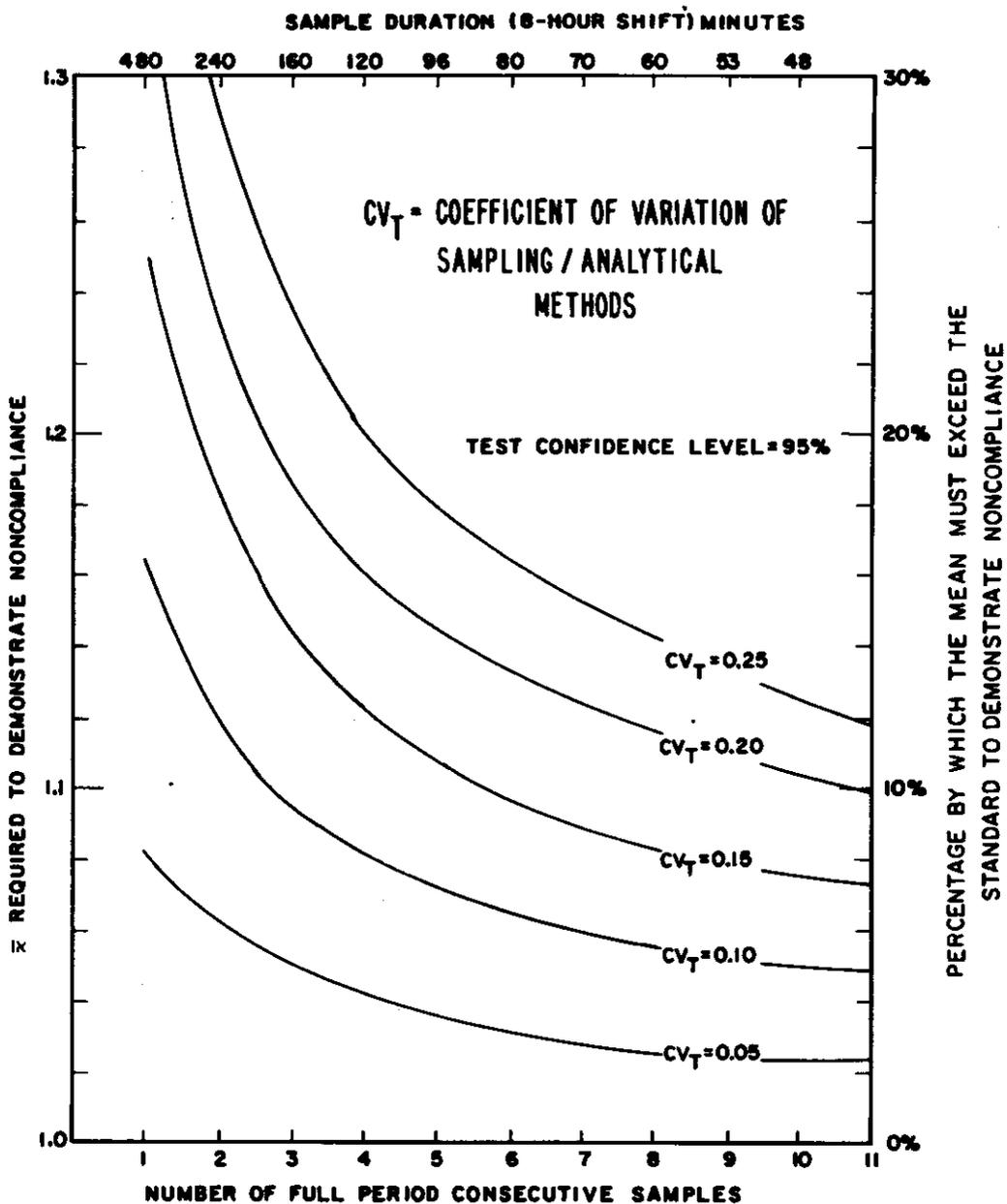


Figure E-3. Effect of full period consecutive sample size on noncompliance demonstration when test power is 50%.

taking more than about seven grab samples. However, since the random variation in a grab sample average is usually much greater than for the same number of full period samples, one might have to take many times more than seven grab samples to approach the low variation of four or fewer full period consecutive samples. Thus, we have a statistical criterion that can lead to a reduced sampling effort, but with a predictable level of confidence. For non-

compliance, the best number of grab samples to take over the specified time period is between four and seven. Note that this is less than the recommended 8 to 11 grab samples for compliance demonstration.

Partial Period Consecutive Samples Measurement

Figure E-5 demonstrates the effect of sample size on the Partial Period Consecutive Samples Procedure, when demonstrating compliance.

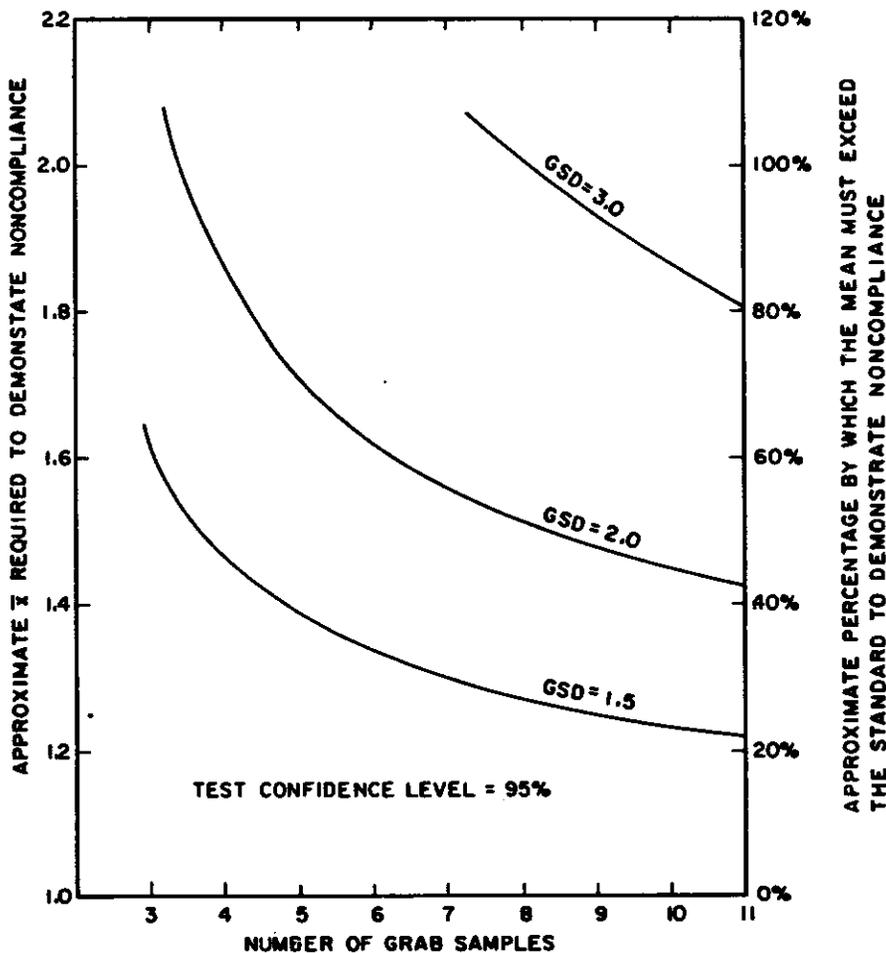


Figure E-4. Effect of grab sample size on noncompliance demonstration. Three different data geometric standard deviations (GSD) are shown that reflect the amount of intraday variation in the environment.

(Note: This procedure is not applicable when demonstrating compliance, as discussed in section 3.4(3).) A typical sampling/analytical CV_T of 0.10 is used for all curves. The bottom curve (for 8-hour total sample time) is the same curve as the $CV_T=0.10$ curve of Figure E-3. Partial period consecutive samples are a compromise between the preferred full period sample(s) and grab samples, which are least desirable. Note that a GSD curve of 2.5 on Figure E-4 is roughly equivalent to a 5.5-hour curve on Figure E-5. Therefore, if one cannot sample

for at least 70% of the time period required by the standard (such as 5.5 hours for an 8-hour standard), it is better to use grab sampling for demonstrating noncompliance.

REFERENCES

- E-1. Leidel, N. A., and K. A. Busch: Statistical Methods for the Determination of Non-compliance with Occupational Health Standards. NIOSH Technical Information, HEW Pub. No. (NIOSH) 75-159, Cincinnati, Ohio 45226, April 1975.

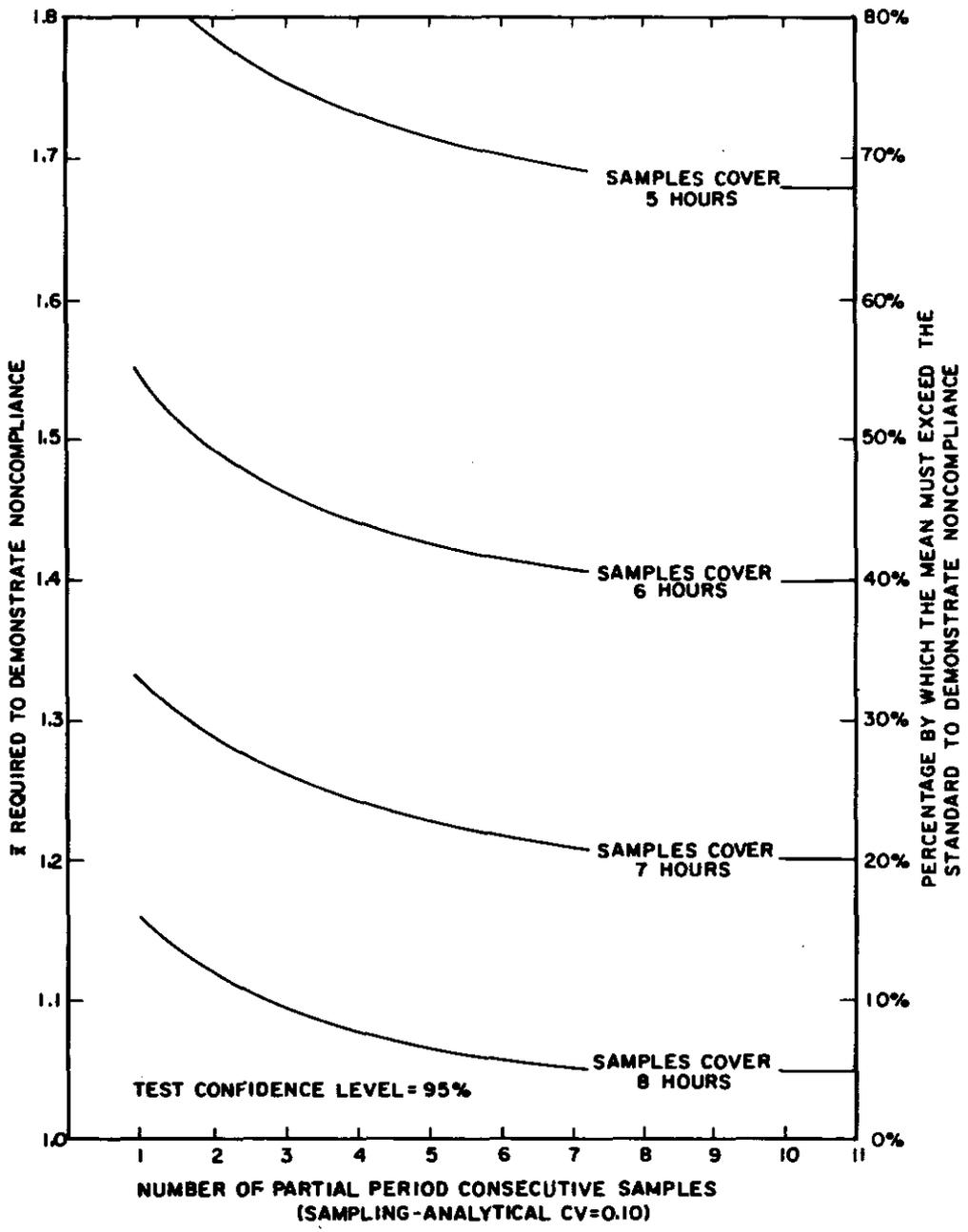


Figure E-5. Effect of partial period consecutive sample size and total time covered by all samples on noncompliance demonstration when test power is 50%.

TECHNICAL APPENDIX F*

SELECTION OF RANDOM SAMPLING PERIODS DURING AN 8-HOUR WORKSHIFT

To select a random sample, proceed as follows:

1. Divide the total period over which the standard is defined into n mutually exclusive (non-overlapping) intervals whose collective lengths equal the period for the standard. The number n is equal to P/s , where P is the period of the standard and s is the length of sampling intervals.

For example, if 15-minute samples are taken and the standard is a time-weighted average (TWA) over an 8-hour period, there would be $n=32$ possible sampling intervals from which a random sample could be selected.

2. Number the possible sampling intervals consecutively: 1, 2, 3, . . . , n . For example, for an 8-hour standard over a workday from 8:00 a.m. to 4:30 p.m. with 12:00 noon to 12:30 p.m. spent outside the work area for lunch, we would assign the following code numbers for 15-minute sampling intervals.

Code #	Interval
1	8:00 - 8:15 a.m.
2	8:15 - 8:30 a.m.
3	8:30 - 8:45 a.m.
.	
.	
.	
15	11:30 - 11:45 a.m.
16	11:45 - 12:00 noon
17	12:30 - 12:45 p.m.
18	12:45 - 1:00 p.m.

.	
.	
.	
31	4:00 - 4:15 p.m.
32	4:15 - 4:30 p.m.

3. If n random samples are to be taken, use a table of random numbers such as Table F-1. Select an arbitrary starting point, and from there, list the first n different integers between 1 and n .

For example, suppose five random 15-minute sampling periods from 32 possible periods are to be selected. Arbitrarily choose the first column and the eleventh row (where the integer 67 appears) from the first page of Natrella's Table A-36 as our starting point (Table F-1, Reference F-2). By moving vertically downward in the table, the five periods would be 24, 6, 29, 16, and 4 since all integers greater than 32 would be ignored. We would then sample during the time periods given below.

Period	Interval
4	8:45 - 9:00 a.m.
6	9:15 - 9:30 a.m.
16	11:45 - 12:00 noon
24	2:15 - 2:30 p.m.
29	3:30 - 3:45 p.m.

Small deviations in the starting times shown of up to 10 minutes (either earlier or later) would probably not significantly affect their randomness. Juda and Budzinski (F-3) give a similar procedure.

*This material originally appeared in Leidel and Busch (F-1).

46	96	85	77	27	92	86	26	45	21	89	91	71	42	64	64	58	22	75	51	74	91	48	46	18
44	19	15	32	63	55	87	77	33	29	45	00	31	34	84	05	72	90	44	27	78	22	07	62	17
34	39	80	62	24	33	81	67	28	11	34	79	26	35	34	23	09	94	00	80	55	31	63	27	91
74	97	80	30	65	07	71	30	01	84	47	45	89	70	74	13	04	90	51	27	61	34	63	67	44
22	14	61	60	86	38	33	71	13	33	72	08	16	13	50	56	48	51	29	48	30	93	45	66	29
40	03	96	40	03	47	24	60	09	21	21	18	00	05	86	52	55	40	73	73	57	68	36	33	91
52	33	76	44	56	15	47	75	78	73	78	19	87	06	98	47	48	02	62	03	42	05	32	55	02
37	59	20	40	93	17	82	24	19	90	80	87	32	74	59	84	24	49	79	17	23	75	83	42	00
11	02	55	57	48	84	74	36	22	67	19	20	15	92	53	37	13	75	54	89	56	73	23	39	07
10	33	79	26	34	54	71	33	89	74	68	48	23	17	49	18	81	05	52	85	70	05	73	11	17
67	59	28	25	47	89	11	65	65	20	42	23	96	41	64	20	30	89	87	64	37	93	36	96	35
93	50	75	20	09	18	54	34	68	02	54	87	23	05	43	36	98	29	97	93	87	08	30	92	98
24	43	23	72	80	64	34	27	23	46	15	36	10	63	21	59	69	76	02	62	31	62	47	60	34
39	91	63	18	38	27	10	78	88	84	42	32	00	97	92	00	04	94	50	05	75	82	70	80	35
74	62	19	67	54	18	28	92	33	69	98	96	74	35	72	11	68	25	08	95	31	79	11	79	54
91	03	35	60	81	16	61	97	25	14	78	21	22	05	25	47	26	37	80	39	19	06	41	02	00
42	57	66	76	72	91	03	63	48	46	44	01	33	53	62	28	30	59	55	05	02	16	13	17	54
06	36	63	06	15	03	72	38	01	58	25	37	66	48	56	19	56	41	29	28	76	49	74	39	50
92	70	96	70	89	80	87	14	25	49	25	94	62	78	26	15	41	39	48	75	64	69	61	06	38
91	08	88	53	52	13	04	82	23	00	26	36	47	44	04	08	84	89	07	44	76	51	52	41	59
68	85	97	74	47	53	90	05	90	84	87	48	25	01	11	05	45	11	43	15	60	40	31	84	59
59	54	13	09	13	80	42	29	63	03	24	64	12	43	28	19	01	65	62	07	79	83	05	59	61
39	18	32	69	33	46	58	19	34	03	59	28	97	31	02	65	47	47	70	39	74	17	30	22	65
67	43	31	09	12	60	19	57	63	73	11	80	10	97	15	70	94	89	81	78	54	84	87	83	42
61	75	37	19	56	90	75	39	03	56	49	92	72	95	27	52	57	47	12	52	54	62	43	23	13
78	10	91	11	00	63	19	63	74	58	69	03	51	38	60	36	53	56	77	06	69	08	89	91	24
93	23	71	58	09	78	08	03	07	71	79	32	25	19	61	04	40	33	12	06	78	91	97	88	95
37	55	48	82	63	89	92	59	14	72	19	17	22	51	90	20	03	64	96	60	48	01	95	44	84
62	13	11	71	17	23	29	25	13	85	33	35	07	69	25	68	57	92	57	11	84	44	01	33	66
29	89	97	47	03	13	20	86	22	45	59	98	64	53	89	64	94	81	55	87	73	81	58	46	42
16	94	85	82	89	07	17	30	29	89	89	80	98	36	25	36	53	02	49	14	34	03	52	09	20
04	93	10	59	75	12	98	84	60	93	68	16	87	60	11	50	46	56	58	45	88	72	50	46	11
95	71	43	68	97	18	85	17	13	08	00	50	77	50	46	92	45	26	97	21	48	22	23	08	32
86	05	39	14	35	48	68	18	36	57	09	62	40	28	87	08	74	79	91	08	27	12	43	32	03
59	30	60	10	41	31	00	69	63	77	01	89	94	60	19	02	70	88	72	33	38	88	20	60	86
05	45	35	40	54	03	98	96	76	27	77	84	80	08	64	60	44	34	54	24	85	20	85	77	32
71	85	17	74	66	27	85	19	55	56	51	36	48	92	32	44	40	47	10	39	22	52	42	29	96
80	20	32	80	98	00	40	92	57	51	52	83	14	55	31	99	73	23	40	07	64	54	44	99	21
13	50	78	02	73	39	66	82	01	28	67	51	75	66	33	97	47	58	42	44	88	09	28	58	06
67	92	65	41	45	36	77	96	46	21	14	39	56	36	70	15	74	43	62	69	82	30	77	28	77
72	56	73	44	26	04	62	81	15	35	79	26	99	57	28	22	25	94	80	62	95	48	98	23	86
28	86	85	64	94	11	58	78	45	36	34	45	91	38	51	10	68	36	87	81	16	77	30	19	36
69	57	40	80	44	94	60	82	94	93	98	01	48	50	57	69	60	77	69	60	74	22	05	77	17
71	20	03	30	79	25	74	17	78	34	54	45	04	77	42	59	75	75	64	99	37	03	18	03	36
89	98	55	98	22	45	12	49	82	71	57	33	28	69	50	58	15	09	25	79	39	42	84	18	70
58	74	82	81	14	02	01	05	77	94	65	57	70	39	42	48	56	84	31	59	18	70	41	74	60
50	54	73	81	91	07	81	26	25	45	49	61	22	88	41	20	00	15	59	93	51	60	65	65	63
49	33	72	90	10	20	65	28	44	63	95	86	75	74	69	24	41	65	86	10	34	10	32	00	93
11	85	01	43	65	02	85	69	56	88	34	29	64	35	48	15	70	11	77	83	01	34	82	91	04
34	22	46	41	84	74	27	02	57	77	47	93	72	02	95	63	75	74	69	69	61	34	31	92	13

TABLE F-1. USE OF A RANDOM NUMBER TABLE FOR SELECTION OF RANDOM SAMPLING PERIODS*

*Reproduced from Table A-36 of Natrella (F-2), with permission of the Rand Corporation, "A Million Random Digits," The Free Press, 1955.

REFERENCES

- F-1. Leidel, N. A., and K. A. Busch: Statistical Methods for the Determination of Non-compliance with Occupational Health Standards. NIOSH Technical Information, HEW Pub. No. (NIOSH) 75-159, Cincinnati, Ohio 45226, 1975.
- F-2. Natrella, M. G.: Experimental Statistics. National Bureau of Standards Handbook 91. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, 1963.
- F-3. Juda, J., and K. Budzinski: Determining the Tolerance Range of the Mean Value of Dust Concentration, Staub, 27:12-16, (English translation), April 1967.

TECHNICAL APPENDIX G*

TEMPERATURE AND PRESSURE CORRECTIONS OF INDUSTRIAL HYGIENE SAMPLE VOLUMES AND CALCULATION OF CONCENTRATIONS (ppm)

The objective of industrial hygiene sampling is to obtain the best estimate of the true concentration the employee is exposed to at the sampling site. This is because Federal health standards such as 29 CFR 1910, Subpart Z, are exposure standards. Analytical laboratories generally report the mass of contaminant found on a filter, charcoal tube, or in an impinger sample. To calculate the original airborne concentration at the time of sampling, the true volume of air that passed through the sampling device must be calculated. Suppose a pump rotameter is calibrated for a specific flow rate (such as 2.0 lpm) at Cincinnati, OH (elevation, 575 feet; temperature, 75°F) and this pump is then used at a higher altitude (such as 5000 feet) or another temperature. If, at the time of sampling the pump rotameter float is set to the 2.0 lpm calibration mark (indicated flow rate), the actual flow through the pump will not be 2.0 lpm.

The indicated flow rate at the time of sampling must be corrected to determine the actual flow rate at the time of sampling. This correction is a function of the basic flow equation for the particular flow meter used (rotameter, limiting orifice, or critical orifice) and IS NOT A SIMPLE GAS LAW CORRECTION.

TEMPERATURE AND PRESSURE CORRECTIONS

These procedures are not necessary for positive displacement pumps. For these devices, see "Calculation of Concentration," below.

*These corrections are based on material prepared by Roper (G-1), and the derivations were prepared by Heitbrink (G-2).

Flow Meter Corrections for Linear Scale Rotameters and Limiting Orifices

$$Q_{\text{actual}} = Q_{\text{indicated}} \sqrt{\frac{P_{\text{cal}} T_{\text{actual}}}{P_{\text{actual}} T_{\text{cal}}}}$$

with

actual = true sample conditions
cal = true calibration conditions
indicated = indicated calibration flow rate on rotameter

and both pressure P and temperature T are in absolute units (as psia, absolute inches Hg, degrees Kelvin or Rankine)

where

psia = psig + 14.7 (psig is gauge pressure)

deg Rankine = deg Fahrenheit + 460

deg Kelvin = deg Celsius + 273

Note that local barometric changes due to weather conditions do not have a significant effect on the average absolute atmospheric pressure at a location. Generally, we know the altitude at both the calibration and sampling locations. Table G-1 can be used to obtain adequate estimates of the average absolute atmospheric pressure at the calibration location (P_{cal}) and at the time of sampling (P_{actual}).

Example:

The rotameter on a battery-operated pump was calibrated and marked for 2.0 lpm in Cincinnati, OH (elevation, 575 feet; temperature, 75°F). The pump was then used to obtain a sample at an elevation of 6000 feet with a temperature of 50°F; with the rotameter ball set at the 2.0 lpm calibration mark.

TABLE G-1. AVERAGE ABSOLUTE ATMOSPHERIC PRESSURE

Altitude, feet	Absolute pressure,	
	psia	inches Hg
sea level	14.7	29.92
Cincinnati, OH (575')	14.4	29.31
1000	14.2	28.87
2000	13.7	27.82
3000	13.2	26.81
4000	12.7	25.85
5000	12.2	24.90
6000	11.7	23.98
7000	11.3	23.10
8000	10.8	22.22
9000	10.5	21.39
10000	10.1	20.58

To obtain the actual flow rate through the pump at time of sampling use

$$Q_{\text{actual}} = 2.0 \text{ lpm} \sqrt{\frac{(14.4 \text{ psia})}{(11.7 \text{ psia})} \cdot \frac{(460 + 50) \text{ }^\circ\text{R}}{(460 + 75) \text{ }^\circ\text{R}}}$$

$$= (2.0 \text{ lpm}) (1.083) = 2.17 \text{ lpm}$$

An error of about -8% would have resulted if the correction had not been made.

Critical Orifices

We are assured of critical orifice conditions if the orifice is operated with at least 15 inches Hg downstream suction. Generally, it is best to operate the downstream vacuum pump at about 20 inches suction pressure. The correction for a critical orifice is

$$Q_{\text{actual}} = Q_{\text{indicated}} \sqrt{T_{\text{actual}} / T_{\text{cal}}}$$

where temperature *T* is in absolute units.

Example:

A 9 lpm (nominal) critical orifice was calibrated at 9.1 lpm in Cincinnati, OH (temperature, 75°F). This critical orifice was then used in a sampling train to collect an area silica sample at 35°F. To obtain the actual flow rate through the critical orifice, use

$$Q_{\text{actual}} = 9.1 \text{ lpm} \sqrt{(460 + 35) / (460 + 75)}$$

$$= (9.1 \text{ lpm}) (0.962) = 8.75 \text{ lpm}$$

An error of about +4% would have resulted if the correction had not been made.

CALCULATION OF CONCENTRATION

When calculating the mass concentration (mg/m³) of a contaminant, the actual air volume sampled (as determined by the flow meter correction factors discussed above) must be used for the calculation.

All gas or vapor concentrations must be converted to ppm (parts per million) before they are analyzed for noncompliance. Only the ppm values of the Federal health standards (29 CFR 1910, Subpart Z) should be used because the mass concentration values of the standards are only approximate and some contain significant round-off errors.

Most equations for converting to ppm use the factor 24.45. This is the number of liters a gram-mole (gmole) of gas occupies at OSHA/ACGIH standard temperature and pressure (STP: 25°C and 760 mm Hg), which is also known as the STP gram-molecular volume. What the conversion equation actually does is calculate the gram-molecular volume at the sampled temperature and pressure. However, the equation can also be interpreted as calculating the volume occupied at STP by the amount of gas in the actual sampled volume. The equation is

$$\text{ppm} = \frac{(C) (24.45) (T + 460) (14.7)}{(MW) (537) (P)}$$

where

- C = concentration in mg/m³ at the sampled *T* and *P*
- MW = contaminant molecular weight (g/gmole)
- T* = actual sampling temperature (degrees Fahrenheit)
- P* = actual sampling pressure (psia)

Or the nomogram given as Figure G-1 can be used for a quick approximate conversion. It is important to realize that, in effect, it is the actual sampled volume that is being converted to an STP volume in the above equation. One does not correct ppm to STP. Once a ppm concentration is calculated, it remains the same regardless of temperature and pressure.

Example: SO₂ gas was sampled at an elevation of 2000 feet and a temperature of 60°F.

The mass concentration at these conditions was 4.0 mg/m³.

Read: 1.6 ppm

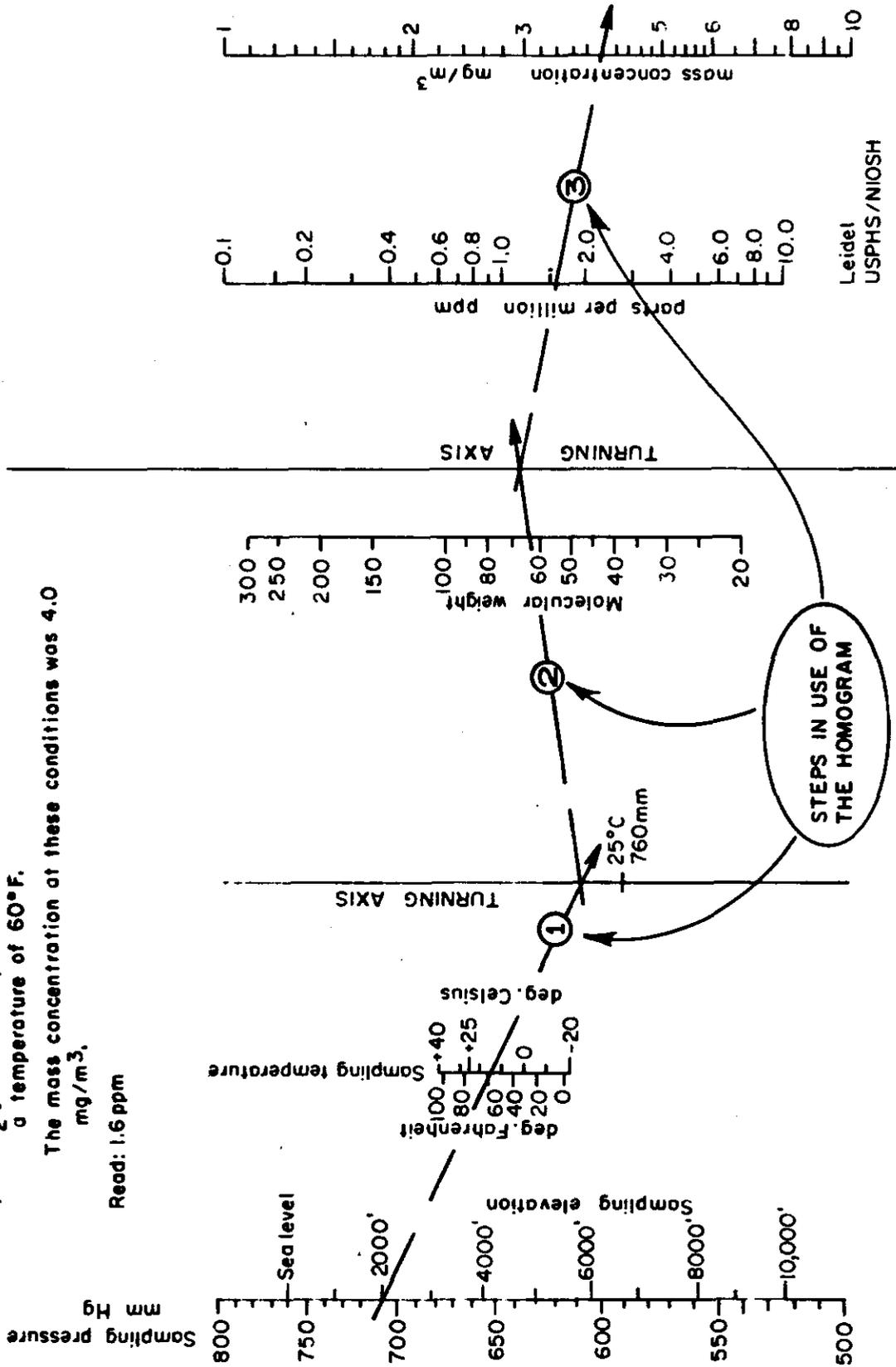


Figure G-1. Nomogram relating mg/m³ to ppm.

SUMMARY OF PROCEDURE

1. The altitude, temperature, calibration location, and indicated flow rate should be recorded when a sample is taken.
2. Using the flow meter altitude/temperature correction factors, the actual volume sampled should be calculated. This is necessary only for rotameter, limiting orifices, or critical orifices.
3. When calculating mass concentration (mg/m³), the actual sample volume should be used. The mass concentration should be reported at the actual temperature and pressure (or altitude) conditions at the time of sampling.
4. The ppm concentration must be calculated before the exposure data are examined for non-compliance with the Federal ppm standards (29 CFR 1910, Subpart Z).

DERIVATION OF CORRECTION FACTORS

Source of Correction Factor for Flow Rate Indicated by a Calibrated Rotameter

In Perry's Chemical Engineers' Handbook (G-3), the ratio of the flow rates for two different fluids in the same rotameter is given by equation 5-24 on page 5-13:

$$\frac{W_a}{W_b} = \frac{K_A}{K_B} \sqrt{\frac{(\rho_f - \rho_a) \rho_a}{(\rho_f - \rho_b) \rho_b}} \quad (G-1)$$

where

- W = mass flow rate
- ρ_f = density of float
- K = flow parameter
- ρ = gas density
- a, b = subscript for different gases or gas at two conditions

Because we are only concerned with air under two different conditions, two assumptions can be made:

$$\begin{aligned} K_a &= K_b \\ \rho_f - \rho_a &= \rho_f - \rho_b \end{aligned}$$

As a result, equation G-1 can be expressed as

$$\frac{W_a}{W_b} = \sqrt{\rho_a / \rho_b}$$

But, $W = \rho q$ where q = volumetric flow rate. Applying this relation, we have

$$\frac{q_a}{q_b} \sqrt{\rho_b / \rho_a}$$

From the ideal gas law,

$$\rho = MP/RT$$

- where M = molecular weight
- P = ambient pressure
- R = gas law constant
- T = temperature

Now equation G-1 can be expressed as

$$\frac{q_a}{q_b} = \sqrt{\frac{P_b}{T_b} \cdot \frac{T_a}{P_a}}$$

The subscript a now refers to ambient conditions during sampling, and b refers to conditions at the time of calibration.

Source of Correction for Flow Rate of a Calibrated Critical Orifice

On Page 5-9 of Perry's Handbook (G-3), the equation for the flow rate of air through a critical orifice is given as

$$W_a = \frac{0.533 (C) (A) (P)}{\sqrt{T}}$$

where

- W_a = mass flow rate
- C = coefficient of discharge
- A = cross sectional area of orifice
- P = upstream pressure
- T = upstream temperature

When the same orifice is used under different conditions of temperature and pressure, different mass flow rates result. The ratio of these flow rates is

$$\frac{W_a}{W_b} = \frac{P_a / \sqrt{T_a}}{P_b / \sqrt{T_b}} \quad (G-2)$$

where a and b refer to different conditions of fluid temperature and pressure. Mass flow rate can be converted to volumetric flow rate by using this expression:

$$W = q\rho \quad (G-3)$$

where

- q = volumetric rate (liters/minute)
- ρ = gas density

The air's density can be computed from

$$\rho = (M) (P) / (R) (T) \quad (G-4)$$

where

M = molecular weight

P = pressure

R = gas law constant

T = temperature

After applying equations G-3 and G-4 to equation G-2, the correction equation is obtained:

$$q_a / q_b = \sqrt{T_a / T_b}$$

The subscript a now refers to ambient conditions during sampling, and b refers to conditions at the time of calibration.

REFERENCES

- G-1. Roper, P.: Calibration of Orifices. NIOSH in-house report, Cincinnati, Ohio 45226, 1972.
- G-2. Heitbrink, W. A.: NIOSH memorandum. Measurement Research Branch, Division of Physical Sciences and Engineering, Cincinnati, Ohio 45226, September 14, 1976.
- G-3. Perry, J. H., ed.: Chemical Engineers' Handbook, 4th ed. McGraw-Hill Book Company, New York, N.Y. 1963.

TECHNICAL APPENDIX H

TIME-WEIGHTED AVERAGE (TWA) EXPOSURE CALCULATION

In a typical work environment, the employee may be exposed to several different average concentrations during the workshift (due to changes in job assignment, workload, ventilation conditions, processes, etc.). The time-weighted average (TWA) exposure evolved as a method of calculating daily average exposure by weighting the different average concentrations by exposure time. It is the equivalent of integrating the concentration values over the total time base of the TWA. It may be determined by the following formula:

$$TWA = \frac{T_1 X_1 + T_2 X_2 + T_3 X_3 + \dots + T_n X_n}{T_t}$$

where $T_1, T_2, T_3, \dots, T_n$ are the incremental exposure times at average concentrations $X_1, X_2, X_3, \dots, X_n$ and T_t is the total time in a workday. This formula appears in Federal regulations 29 CFR 1910.1000(d) (1). For example suppose a worker is exposed as follows:

<i>Time of exposure (T_i)</i>	<i>Average exposure concentration (ppm)</i>
1 hour	250
3 hours	100
4 hours	50

Total $T = 8$ hours

Then the TWA for the 8-hour workday will be

$$TWA = \frac{(1)(250) + (3)(100) + (4)(50)}{8} = 94 \text{ ppm}$$

For most of the substances listed in 29 CFR 1910, Subpart Z, the maximum permissible average exposure over an 8-hour period is specified. Even though the standards are referred to as TWA's, the time-weighted average expo-

sure calculation is not the preferred method of determining the 8-hour average exposure because of the uncertainties in determining the component average concentrations.

The sampling method and the time available for sampling will determine the way an 8-hour average exposure is calculated. When possible, it is most desirable to take a single sample over the full period for which the standard is defined, such as the full 8 hours. The advantage is that in this case the sample is a direct integrated measure of the exposure over the entire period and eliminates the need for TWA calculations. Even if it is not possible to collect one single sample over a full period of 8 hours, it may be possible to collect a series of consecutive samples that cover the full period or partial period of the standard. Note that an exposure concentration calculated from one sample is a time-weighted concentration even though the time-weighted average calculations in this section may not be used.

FULL PERIOD CONSECUTIVE AND PARTIAL PERIOD CONSECUTIVE SAMPLE MEASUREMENTS

For these exposure measurement strategies, the duration of each sample and the reported (ppm) sample concentration are used in the equation, above. For a partial period strategy, an example would be:

<i>Sample</i>	<i>Time Period</i>	<i>Duration</i>	<i>Sample Results</i>
A	0915 - 1030 hr	75 min	320 ppm
B	1100 - 1210 hr	70 min	250 ppm
C	1320 - 1540 hr	140 min	350 ppm

Then the TWA exposure for the 4.75-hour period sampled is

TWA =

$$\frac{(75 \text{ min}) (320 \text{ ppm}) + (70 \text{ min}) (250 \text{ ppm}) + (140 \text{ min}) (350 \text{ ppm})}{(285 \text{ min})}$$

= 318 ppm for the 4.75-hour period.

Refer to section 4.2.1 for analysis of these data. Note this example *does not* meet the recommendations of section 3.4(3) that the sampled portion of the period cover at least 70% to 80% of the total 8-hour period.

GRAB SAMPLE MEASUREMENT

If the employee's operation and work exposure can be assumed relatively constant during the workshift, then all samples can be directly averaged. If the duration of each sample is relatively short compared with the period of the standard (such as each sample is less than 5% of that period), then the times can be omitted in the TWA calculation.

Sample	Time period	Sample results
A	0830 - 0835	20 ppm
B	0940 - 0945	45
C	1105 - 1110	10
D	1250 - 1255	15
E	1430 - 1435	30
F	1550 - 1555	25

The TWA for the 8-hour workday would be

$$TWA = \frac{(20 + 45 + 10 + 15 + 30 + 25)}{6} = 24 \text{ ppm}$$

Refer to section 4.2.3 for analysis of these data.

However, if the employee was at several work locations or operations during the 8-hour shift and several grab samples were taken during each of the operations with different expected

exposures (see section 3.4(4)), then the results are analyzed as follows:

Operation	Duration	Sample	Results (of each 5-min sample)
Solvent room	0800-1030	A	110 ppm
		B	180
		C	90
		D	120
		E	150
Printer feed	1030-1630	F	50
		G	35
		H	60
		I	40

The solvent room average exposure is

$$\bar{x}_1 = \frac{(110 + 180 + 90 + 120 + 150)}{5} = 130 \text{ ppm}$$

The printer feed average exposure is

$$\bar{x}_2 = \frac{(50 + 35 + 60 + 40)}{4} = 46 \text{ ppm}$$

Then the TWA exposure for the 8-hour shift (excluding 30 minutes for lunch) is

$$TWA = \frac{(2.5 \text{ hr}) (130 \text{ ppm}) + (5.5 \text{ hr}) (46 \text{ ppm})}{8 \text{ hr}} = 72 \text{ ppm}$$

Note that data analysis and decision procedures are not presented in Chapter 4 for this sampling strategy. They would be too complex for a manual at this level. The preferred approach would be to use the Full Period Consecutive Samples procedure.

TECHNICAL APPENDIX I

LOGNORMAL PROBABILITY PLOTS OF EXPOSURE MEASUREMENT DATA AND EXPOSURE AVERAGES

The utility and convenience of lognormal probability paper for plotting industrial hygiene exposure measurement data have been discussed previously by Hounam (I-1), Gale (I-2, I-3), Coenen (I-4), Jones and Brief (I-5), and Sherwood (I-6). This appendix will address the practical aspects of using lognormal probability paper. First, the "how to" of using this paper will be given. Then, two examples using exposure measurement data and exposure averages of individual employees in an occupational group will be shown.

Figures I-1 and I-2 show examples of commercially available lognormal probability paper (2-cycle and 3-cycle, respectively). Generally, these papers will cover the usual range of exposure measurement. If additional cycles are required, the "cut and paste" method for creating 4- or 5-cycle paper can be used.

The first step in plotting data is to rank the data by increasing exposure measurement value. The smallest measurement becomes ordinal value 1, and the largest value becomes ordinal value n where there are n measurements or exposure averages to be plotted. The ranked values are then assigned plotting positions on the probability scale. No universal agreement exists among statisticians as to the correct way of plotting sample data on probability paper. Santner (I-7) has provided a table of plotting positions that has wide acceptance. Santner's table is given as Table I-1. The table covers sample sizes of $n=2$ to 50 and an equation is given for larger sample sizes.

After the data have been plotted and subjectively decided to be linear, the regression line of best fit is drawn. It is very important to realize that the common analytic technique of minimizing the squared deviations from the fitted line (least squares regression line) *cannot*

be used with lognormal probability paper. Kottler (I-8) has pointed out the reasons for this.

If the line is fitted visually to the plotted data points, one must resist the tendency to give equal weight to all data points. The data points in the central region of the plot should have greater influence on the fitted line. Any deviation in percentage probability occurring at low and high probabilities (such as below 5% and above 95%) will appear much exaggerated on the lognormal probability paper, particularly when compared with a deviation of the same absolute magnitude in percentage in the central region of the paper (approximately the 20% and 80% probability region). For example, compared with the 50% plot position, the deviation is exaggerated 15 times at the 99% plot position and 28 times at the 99.5% position. It is impossible to even approximate the size of the deviations by mere inspection because the lognormal probability paper distorts. An example of a similar distortion occurs in cartography. Mercator's projection of the Earth onto a plane tends to exaggerate the distances along the vertical lines, especially near the poles.

Lognormal probability paper should only be used to plot data and make preliminary judgments about the suitability of a lognormal model. It is also useful for providing quick estimates of the geometric mean (*GM*) and the geometric standard deviation (*GSD*) of a fitted lognormal model. But lognormal probability paper cannot be used to make statistically definitive judgments about the goodness-of-fit to a straight line representing the fitted lognormal model. In fitting a straight line to the data points observe the following:

- disregard all data outside the bounds of 1% and 99% probability;

K-E PROBABILITY \bar{X} & LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 8040

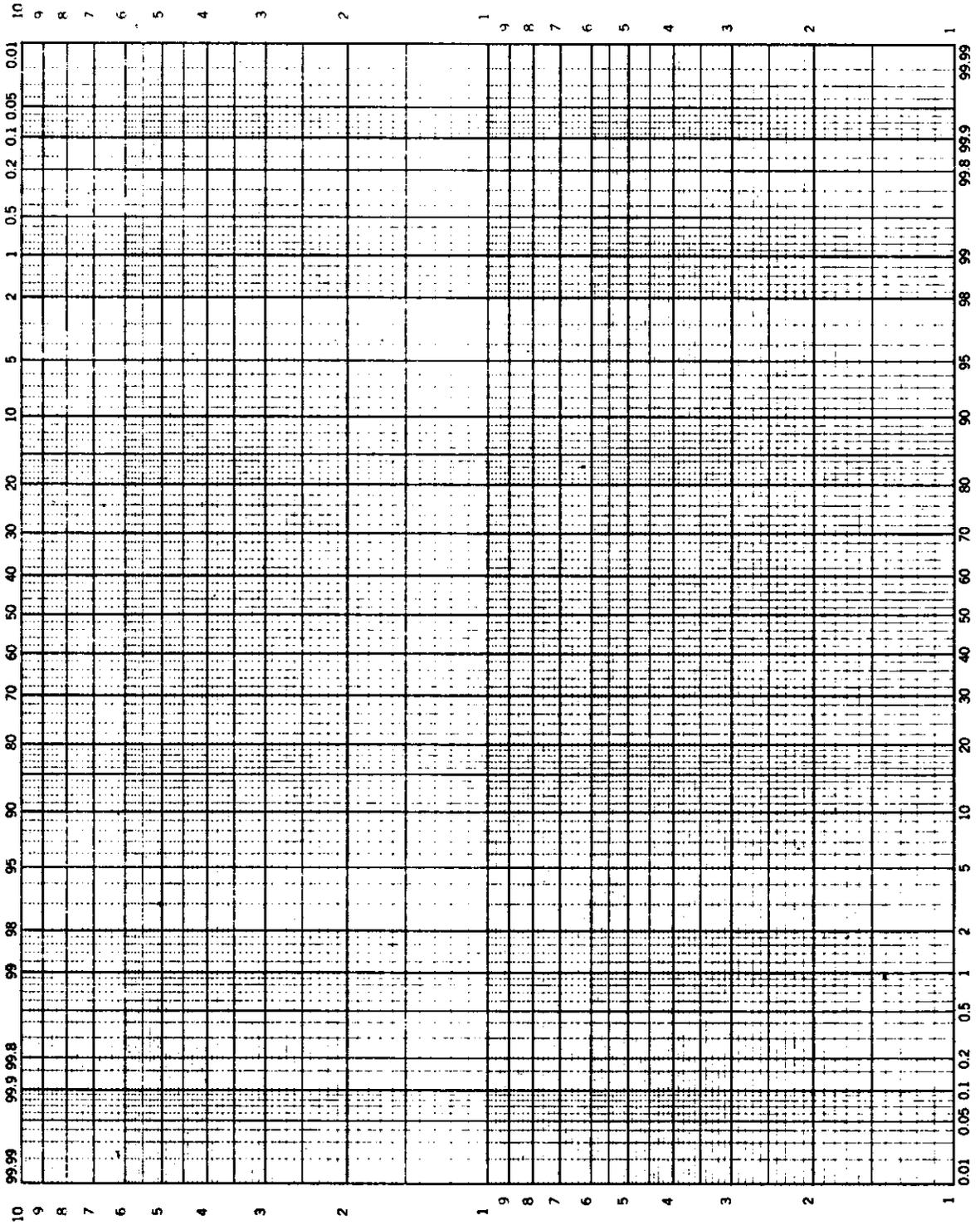


Figure I-1. Lognormal probability paper — 2 cycle.

K&E PROBABILITY
X 3 LOG CYCLES
HEUFFEL & ESSER CO.
46 8082
MADE IN U. S. A.

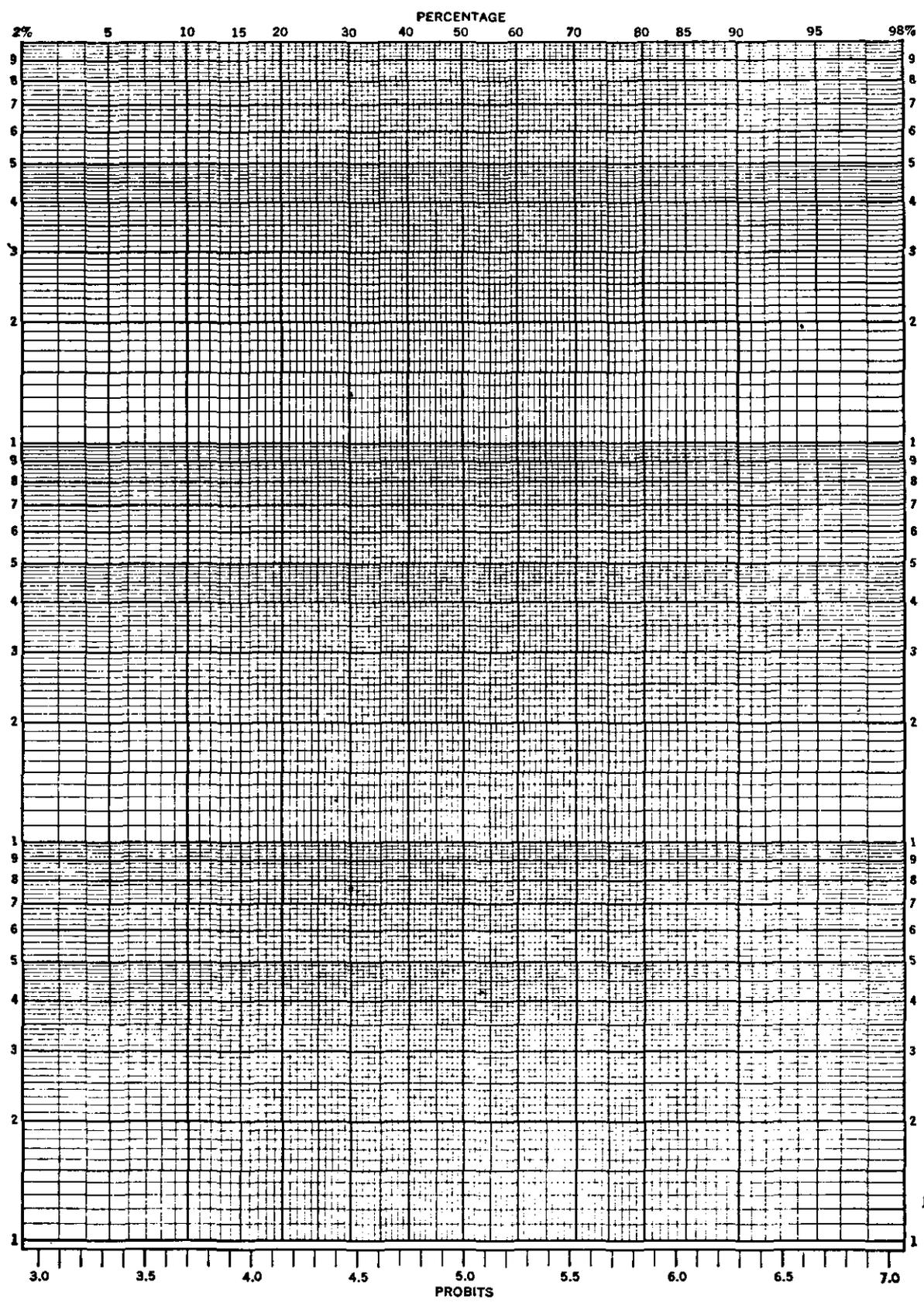


Figure I-2. Lognormal probability paper — 3 cycle.

TABLE 1-1. PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER

Ordinal No.	Sample Size																Ordinal No.														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	28.6	19.9	15.2	12.2	10.3	8.8	7.7	6.9	6.2	5.6	5.2	4.8	4.4	4.1	3.9	3.6	3.4	3.3	3.1	2.9	2.8	2.7	2.6	2.4	2.4	2.3	2.2	2.1	2.1	2.0	1
2	71.4	50.0	38.3	31.0	26.0	22.5	19.7	17.6	15.8	14.4	13.2	12.2	11.4	10.6	9.9	9.4	8.9	8.4	8.0	7.7	7.2	6.8	6.7	6.4	6.2	5.9	5.7	5.5	5.3	5.2	2
3	80.1	61.7	50.0	42.0	36.2	31.8	28.4	25.6	23.3	21.4	19.8	18.4	17.2	16.1	15.2	14.3	13.6	12.9	12.3	11.7	11.3	10.7	10.4	9.9	9.5	9.1	8.9	8.7	8.4	3	
4	84.8	69.0	58.0	50.0	43.9	39.2	35.3	32.2	29.6	27.3	25.4	23.7	22.3	21.0	19.8	18.8	17.9	17.1	16.4	15.6	14.9	14.2	13.8	13.3	12.7	12.3	11.9	11.5	4		
5	87.8	74.0	63.8	56.1	50.0	45.1	41.1	37.8	34.9	32.4	30.3	28.4	26.8	25.3	24.0	22.8	21.8	20.6	19.8	18.9	18.1	17.6	16.9	16.4	15.9	15.2	14.7	5			
6	89.7	77.5	68.2	60.8	54.9	50.0	45.9	42.5	39.5	36.5	34.6	32.6	30.8	29.2	27.8	26.4	25.1	24.2	23.3	22.4	21.5	20.6	19.8	19.2	18.7	17.9	6				
7	91.2	80.3	71.6	64.7	58.9	54.1	50.0	46.5	43.4	40.7	38.4	36.3	34.4	32.7	31.2	29.8	28.4	27.4	26.1	25.1	24.2	23.3	22.4	21.8	21.2	7					
8	92.3	82.4	74.4	67.8	62.2	57.5	53.5	50.0	46.9	44.2	41.8	39.6	37.6	35.9	34.1	32.6	31.6	30.2	29.1	28.1	27.1	26.1	25.1	24.6	8						
9	93.1	84.2	76.7	70.4	65.1	60.5	56.6	53.1	50.0	47.2	44.8	42.6	40.5	38.6	37.1	35.6	34.1	33.0	31.6	30.5	29.5	28.4	27.4	9							
10	93.8	85.6	78.6	72.7	67.6	63.1	59.3	55.8	52.8	50.0	47.5	45.2	43.3	41.3	39.7	38.2	36.7	35.2	34.1	33.0	31.9	30.9	10								
11	94.4	86.8	80.2	74.6	69.7	65.4	61.6	58.2	55.2	52.5	50.0	47.6	45.6	43.6	42.1	40.5	39.0	37.4	36.3	35.2	34.1	11									
12	94.8	87.8	81.6	76.3	71.6	67.4	63.7	60.4	57.4	54.8	52.4	50.0	48.0	46.0	44.4	42.5	41.3	39.7	38.6	37.1	12										
13	95.2	88.6	82.8	77.7	73.2	69.2	65.6	62.4	59.5	56.7	54.3	52.0	50.0	48.0	46.4	44.8	43.3	41.7	40.5	13											
14	95.6	89.4	83.9	79.0	74.7	70.8	67.3	64.1	61.4	58.7	56.4	54.0	52.0	50.0	48.4	46.4	45.2	43.6	14												
15	95.9	90.1	84.8	80.2	76.0	72.2	68.8	65.9	62.9	60.3	57.9	55.6	53.6	51.6	50.0	48.4	46.8	15													
16	96.1	90.6	85.7	81.2	77.2	73.6	70.2	67.4	64.4	61.8	59.5	57.5	55.2	53.6	51.6	50.0	16														
17	96.4	91.1	86.4	82.1	78.2	74.9	71.6	68.4	65.9	63.3	61.0	58.7	56.7	54.8	53.2	17															
18	96.6	91.6	87.1	82.9	79.4	75.8	72.6	69.8	67.0	64.8	62.6	60.3	58.3	56.4	18																
19	96.7	92.0	87.7	83.6	80.2	76.7	73.9	70.9	68.4	65.9	63.7	61.4	59.5	19																	
20	96.9	92.3	88.3	84.4	81.1	77.6	74.9	71.9	69.5	67.0	64.8	62.9	20																		
21	97.1	92.8	88.7	85.1	81.9	78.5	75.8	72.9	70.5	68.1	65.9	63.1	61.1	59.2	21																
22	97.2	93.2	89.3	85.8	82.4	79.4	76.7	73.9	71.6	69.1	66.8	64.4	62.1	60.1	58.1	56.1	54.1	52.1	22												
23	97.3	93.3	89.6	86.2	83.1	80.2	77.3	74.9	72.6	70.3	68.1	65.8	63.5	61.2	59.1	57.1	55.1	53.1	23												
24	97.4	93.6	90.1	86.7	83.6	80.8	78.2	75.4	72.9	70.5	68.1	65.8	63.5	61.2	59.1	57.1	55.1	53.1	24												
25	97.6	93.8	90.5	87.3	84.1	81.3	78.8	75.8	73.1	70.5	68.1	65.8	63.5	61.2	59.1	57.1	55.1	53.1	25												
26	97.6	94.1	90.8	87.7	84.8	82.1	79.6	76.8	74.1	71.6	69.1	66.8	64.4	62.1	60.1	58.1	56.1	54.1	26												
27	97.7	94.3	91.1	88.1	85.3	82.7	79.9	77.1	74.4	71.9	69.5	67.0	64.8	62.9	27																
28	97.8	94.5	91.3	88.5	85.8	83.2	80.4	77.6	74.9	72.4	70.0	67.6	65.2	62.9	28																
29	97.9	94.7	91.6	88.9	86.2	83.6	80.9	78.1	75.4	72.9	70.5	68.1	65.8	63.5	61.2	59.1	57.1	55.1	29												
30	97.9	94.8	91.8	89.1	86.4	83.8	81.1	78.3	75.6	72.9	70.5	68.1	65.8	63.5	61.2	59.1	57.1	55.1	30												
31	98.0	31																													

References:

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- (4) Hartar, H. Leon, Expected Values of Normal Order Statistics, ARL Technical Report 60-292, Wright-Patterson Air Force Base, July '60

TABLE I-1. PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER (CONT.)

Ordinal No.	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	Ordinal No.
1	1.92	1.88	1.83	1.74	1.70	1.66	1.62	1.58	1.54	1.50	1.46	1.43	1.39	1.36	1.32	1.32	1.29	1.25	1.22	1
2	4.9	4.8	4.6	4.6	4.5	4.3	4.2	4.1	4.0	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.3	3.2	3.2	2
3	8.1	7.8	7.6	7.4	7.2	6.9	6.8	6.7	6.4	6.3	6.2	6.1	5.8	5.7	5.6	5.5	5.4	5.3	5.2	3
4	11.1	10.9	10.6	10.2	10.0	9.7	9.4	9.2	9.0	8.7	8.5	8.4	8.1	7.9	7.8	7.6	7.5	7.4	7.2	4
5	16.2	13.8	13.3	13.1	12.7	12.3	12.1	11.7	11.5	11.1	10.9	10.6	10.4	10.2	10.0	9.7	9.5	9.3	9.2	5
6	17.4	16.9	16.4	15.9	15.4	15.2	14.7	14.2	14.0	13.6	13.3	12.9	12.7	12.3	12.1	11.9	11.7	11.3	11.1	6
7	20.6	19.8	19.2	18.7	18.1	17.9	17.4	16.9	16.4	16.1	15.6	15.4	14.9	14.7	14.2	14.0	13.8	13.3	13.1	7
8	23.6	23.0	22.4	21.5	20.9	20.3	19.8	19.5	18.9	18.4	18.1	17.6	17.1	16.9	16.4	16.1	15.9	15.4	15.2	8
9	26.8	25.8	25.1	24.5	23.6	23.3	22.7	22.1	21.5	20.9	20.3	20.0	19.5	18.9	18.7	18.1	17.9	17.4	17.1	9
10	29.8	28.8	28.1	27.4	26.4	25.8	25.1	24.5	23.9	23.3	22.7	22.4	21.8	21.2	20.9	20.3	20.0	19.5	19.2	10
11	33.0	31.9	30.9	30.2	29.5	28.4	27.8	27.1	26.4	25.8	25.1	24.5	23.9	23.6	23.0	22.4	22.1	21.5	21.2	11
12	35.9	34.8	34.1	33.0	31.9	31.2	30.5	29.5	28.8	28.1	27.4	26.8	26.1	25.8	25.1	24.5	24.2	23.6	23.0	12
13	39.0	37.8	36.7	35.9	34.8	33.7	33.0	32.3	31.2	30.5	29.8	29.1	28.4	27.8	27.4	26.7	26.1	25.5	25.1	13
14	42.1	40.9	39.7	38.6	37.4	36.7	35.6	34.8	33.7	33.0	32.3	31.6	30.9	30.2	29.5	28.8	28.1	27.8	27.1	14
15	45.2	44.0	42.9	41.3	40.5	39.4	38.2	37.1	36.3	35.6	34.5	33.7	33.0	32.3	31.6	30.9	30.2	29.8	29.1	15
16	48.4	46.8	45.6	44.4	43.3	42.1	40.9	39.7	39.0	37.8	37.1	35.9	35.2	34.5	33.7	33.0	32.3	31.6	31.2	16
17	51.6	50.0	48.4	47.2	46.0	44.4	43.6	42.5	41.3	40.1	39.4	38.6	37.4	36.7	35.9	35.2	34.5	33.7	33.0	17
18	54.8	53.2	51.6	50.0	48.8	47.2	46.0	44.8	43.6	42.9	41.7	40.9	39.7	39.0	38.2	37.4	36.7	35.9	35.2	18
19	57.9	56.0	54.4	52.8	51.2	50.0	48.8	47.6	46.4	45.2	44.0	43.3	42.1	41.3	40.1	39.4	38.6	37.8	37.1	19
20	61.0	59.1	57.1	55.6	54.0	52.8	51.2	50.0	48.8	47.6	46.4	45.2	44.4	43.3	42.5	41.7	40.5	39.7	39.0	20
21	64.1	62.2	60.3	58.7	56.7	55.6	54.0	52.4	51.2	50.0	48.8	47.6	46.4	45.6	44.4	43.6	42.9	41.7	40.9	21
22	67.0	65.2	63.3	61.4	59.5	57.9	56.4	55.2	53.6	52.4	51.2	50.0	48.8	47.6	46.8	45.6	44.8	44.0	42.9	22
23	70.2	68.1	65.9	64.1	62.6	60.6	59.1	57.5	56.4	54.8	53.6	52.4	51.2	50.0	48.8	48.0	46.8	46.0	44.8	23
24	73.2	71.2	69.1	67.0	65.2	63.3	61.8	60.3	58.7	57.1	56.0	54.8	53.6	52.4	51.2	50.0	48.8	48.0	46.8	24
25	76.4	74.2	71.9	69.8	68.1	66.3	64.4	62.9	61.0	59.9	58.3	56.7	55.6	54.4	53.2	52.0	51.2	50.0	48.8	25
26	79.4	77.0	74.9	72.6	70.5	68.8	67.0	65.2	63.7	62.2	60.6	59.1	57.9	56.7	55.6	54.4	53.2	52.0	51.2	26
27	82.6	80.2	77.6	75.5	73.6	71.6	69.5	67.7	66.3	64.4	62.9	61.4	60.3	58.7	57.5	56.4	55.2	54.0	53.2	27
28	85.8	83.1	80.8	78.5	76.4	74.2	72.2	70.5	68.8	67.0	65.5	64.1	62.6	61.0	59.9	58.3	57.1	56.0	55.2	28
29	88.9	86.2	83.6	81.3	79.1	76.7	74.9	72.9	71.2	69.5	67.7	66.3	64.8	63.3	61.8	60.6	59.5	58.3	57.1	29
30	91.9	89.1	86.7	84.1	81.9	79.7	77.3	75.5	73.6	71.9	70.2	68.4	67.0	65.5	64.1	62.6	61.4	60.3	59.1	30
31	95.1	92.2	89.4	86.9	84.6	82.1	80.2	77.9	76.1	74.2	72.6	70.9	69.1	67.7	66.3	64.8	63.3	62.2	61.0	31
32	98.08	95.2	92.4	89.8	87.3	84.8	82.6	80.5	78.5	76.7	74.9	73.2	71.6	69.8	68.4	67.0	65.5	64.1	62.9	32
33	98.12	95.4	92.6	90.0	87.7	85.3	83.1	81.1	79.1	77.3	75.5	73.9	72.2	70.5	69.1	67.7	66.3	64.8	63.3	33
34	98.17	95.4	92.8	90.3	87.9	85.8	83.6	81.6	79.7	77.6	76.1	74.2	72.6	71.2	69.8	68.4	67.0	65.5	64.1	34
35	98.26	95.5	93.1	90.6	88.3	86.0	83.9	81.9	80.0	78.2	76.4	74.9	73.2	71.9	70.2	68.8	67.4	66.0	64.6	35
36	98.30	95.7	93.2	90.8	88.5	86.4	84.4	82.4	80.5	78.8	77.0	75.5	73.9	72.2	70.9	69.5	68.1	66.7	65.3	36
37	98.34	95.8	93.3	91.0	88.9	86.7	84.6	82.9	81.1	79.1	77.6	75.8	74.5	72.9	71.7	70.3	68.9	67.5	66.1	37
38	98.38	95.9	93.6	91.3	89.1	87.1	85.1	83.1	81.3	79.7	77.9	76.4	74.9	73.7	72.3	70.9	69.5	68.1	66.7	38
39	98.42	96.0	93.7	91.4	89.4	87.3	85.3	83.3	81.6	79.9	78.3	76.7	75.2	73.9	72.6	71.2	69.8	68.4	67.0	39
40	98.46	96.1	93.8	91.5	89.5	87.4	85.4	83.4	81.7	80.0	78.4	76.8	75.3	74.0	72.6	71.2	69.8	68.4	67.0	40
41	98.50	96.2	93.9	91.9	89.8	87.9	86.0	84.1	82.4	80.6	79.0	77.4	75.8	74.5	73.2	71.9	70.2	68.8	67.4	41
42	98.54	96.3	94.2	92.1	90.0	88.1	86.2	84.3	82.6	80.8	79.2	77.6	76.0	74.5	73.2	71.9	70.2	68.8	67.4	42
43	98.57	96.4	94.3	92.2	90.1	88.2	86.3	84.4	82.7	80.9	79.3	77.7	76.1	74.6	73.3	72.0	70.2	68.8	67.4	43
44	98.61	96.5	94.4	92.3	90.2	88.3	86.4	84.5	82.8	81.0	79.4	77.8	76.2	74.7	73.4	72.1	70.2	68.8	67.4	44
45	98.64	96.6	94.5	92.4	90.3	88.4	86.5	84.6	82.9	81.1	79.5	77.9	76.3	74.8	73.5	72.2	70.2	68.8	67.4	45
46	98.68	96.6	94.6	92.5	90.4	88.5	86.6	84.7	83.0	81.2	79.6	78.0	76.4	74.9	73.6	72.3	70.2	68.8	67.4	46
47	98.71	96.7	94.7	92.6	90.5	88.6	86.7	84.8	83.1	81.3	79.7	78.1	76.5	75.0	73.7	72.4	70.2	68.8	67.4	47
48	98.75	96.8	94.8	92.7	90.6	88.7	86.8	84.9	83.2	81.4	79.8	78.2	76.6	75.1	73.8	72.5	70.2	68.8	67.4	48
49	98.79	96.8	94.9	92.8	90.7	88.8	86.9	85.0	83.3	81.5	79.9	78.3	76.7	75.2	73.9	72.6	70.2	68.8	67.4	49
50	98.83	96.9	94.9	92.9	90.8	88.9	87.0	85.1	83.4	81.6	80.0	78.4	76.8	75.3	74.0	72.7	70.2	68.8	67.4	50

For sample sizes larger than 50 plotting position is estimated as:

$$100 \left(\frac{\text{Ordinal number} - 0.5}{\text{sample size}} \right)$$

EXAMPLE:

- Sample Size Ordinal number
- 51
- 0.98 = $\frac{100(1-0.5)}{51}$ 1
- 2.94 = $\frac{100(2-0.5)}{51}$ 2
- 99.02 = $\frac{100(51-0.5)}{51}$ 51

- of the remaining data, give preference to those nearest the central 50% position, that is, in the 20% to 80% region.

Santner (I-7) has provided the guidelines (Figure I-3) to aid in the interpretation of data plotted on lognormal probability paper. Other models for linearizing the data plot are considered and suitable plotting paper is suggested.

A useful reference dealing with plotting on probability paper is Hahn and Shapiro (I-9). In their Chapter 8, "Probability Plotting and Testing of Distributional Assumptions," many probability plots are provided. They include plots comparing typical deviations from linearity on normal probability paper, using $n=20$ and $n=50$ samples from two distributions with varying deviations from normality. For samples from a normal distribution (especially $n=20$ samples), the plots can show considerable deviation from linearity due to random variations.

Daniel and Wood (I-10) also show common deviations from linearity due to random sampling variations. In their Appendix 3A probability distribution plots of random normal deviates with sample sizes $n=8, 16, 32, 64,$ and 384 are given. They observe that samples of 8 tell us almost nothing about normality. Sets of 16 from a true normal distribution can still show large deviations from linearity. Sets of 32 and 64 behave much better, but can still bend away from the fitted straight line in the tails of the distribution (less than 10% and greater than 90% probability).

Once the best-fit line has been drawn through the data points, using the guidelines above, the two parameters of the distribution may be estimated. A true lognormal distribution is completely determined by the *GM* and the *GSD*. The *GM* value is the 50% probability value and may be read directly from the plot where the fitted line intersects the 50% probability line. The *GSD* is a measure of the variation or dis-

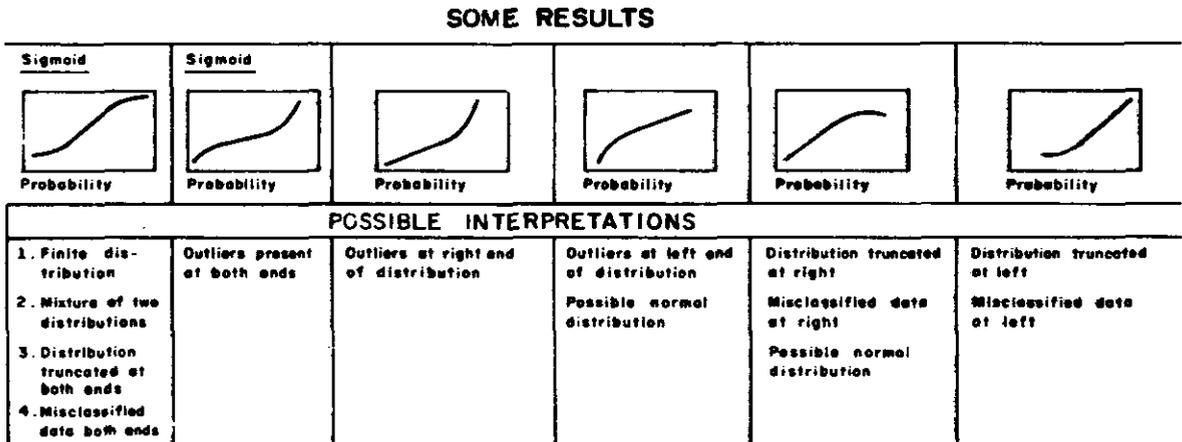
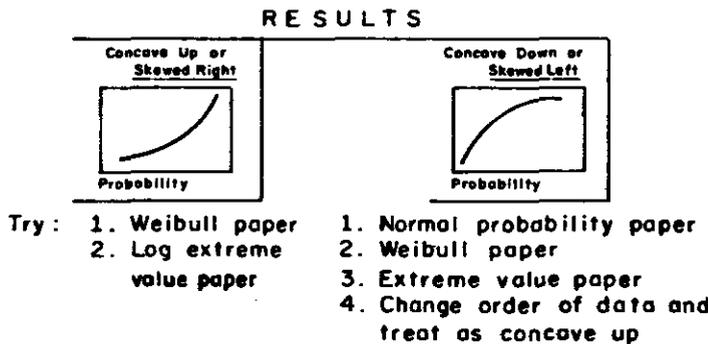


Figure I-3. Interpretation of data plotted on lognormal probability paper. (Adapted from Santner [I-7].)

persion of the data. It can be calculated from the ratio

$$GSD = \frac{84\% \text{ value}}{50\% \text{ value}} = \frac{50\% \text{ value}}{16\% \text{ value}}$$

Finally, there is the problem of how to handle "zero" data values. In industrial hygiene work, "zero" values are generally undetectable values. If large numbers of these occur, another type of data analysis may be required. Berry and Day (I-11) have discussed the use of the gamma distribution. Before the data are manipulated, consider two other possibilities. First, if exposure measurement data for an employee on one workshift is being analyzed, look for a grouping or run of "zero" (undetectable) values during some portion of the workshift. The employee might have changed operations or left the exposure area. These low values are then from another distribution and should not be included in the exposure measurement analysis of the significant values. This elimination of data should be done with great care and knowledge of the employee's movements. Second, the low values may occur in a series of exposure averages for employees in an occupational group of similar exposure risk. Often groups of similar exposure risk are created for survey purposes by using only the employee's job title. Employees may be misclassified by this procedure. One should have actual knowledge of an employee's exposure risk situation before including the employee in the group data analysis.

Undetectable levels do occur, however, and there is no single accepted way to handle them. One method is to obtain the "least detectable amount" of contaminant for the analytical method from the analytical laboratory and use this value to determine the least detectable concentration in the amount of air the pump sampled. The least detectable concentration value is then substituted for all the "zero" values. Another method is to eliminate the zeros by adding a small arbitrary constant to all the data values before they are plotted. Unfortunately, this sometimes must be done by trial and error. Hald (I-12) discusses additions to data that aid in this transformation. Keep in mind that the constant chosen must be small if the location parameter of the distribution is not

to be affected. Start with a constant that is about 5% of the geometric mean of the data.

Example — Exposure Measurement Data:

Hydrogen fluoride (HF) concentrations were sampled with a sequential sampler at a fixed location (near control panel) in an HF production building. The following results were reported:

<u>Collected data</u>		<u>Ranked data</u>	
<u>Start time</u>	<u>ppm</u>	<u>Ranked data</u>	<u>Plot position</u>
1525	0.91	0.11	5.2%
1625	1.3	0.11	13.2
1725	10.0	0.12	21.4
1825	0.8	0.14	29.6
1925	2.6	0.14	37.8
2025	0.12	0.21	45.9
2125	0.14	0.33	54.1
2225	0.11	0.8	62.2
2325	0.14	0.91	70.4
0025	0.11	1.3	78.6
0125	0.33	2.6	86.8
0225	0.21	10.0	94.8

The plot positions for the $n=12$ values were obtained from Table I-1. The plotted results are shown in Figure I-4. The data seem to show a lack of lognormality in the left tail. Such a distribution would result if there were log-normal random additive variations in addition to a fixed background level. The data plot can be linearized by going to a 3-parameter log-normal model where a constant is subtracted from each concentration value before plotting. An appropriate constant can be estimated from the initial plot by noting the concentration the data approach asymptotically. For Figure I-4, the data appear to converge to a value of about 0.1 ppm. Thus, 0.1 ppm was subtracted from each concentration before it was replotted on Figure I-4. The resulting geometric mean is read as 0.16, which corresponds to a concentration of $(0.16+0.1)$ or 0.26 ppm. The GSD of the transformed variable (concentration -0.1) is calculated as

$$GSD = \frac{84\% \text{ value}}{50\% \text{ value}} = \frac{2.05 \text{ ppm}}{0.16 \text{ ppm}} = 12.8.$$

By direct calculation (see section 4.2.3), the mean of \log_{10} (concentration -0.10) is -0.739 and the corresponding concentration is 0.28. The

calculated *GSD* of (concentration - 0.10) is 9.8. Thus, the graphic determinations are close to the calculated values. Although the latter are preferred for objectivity and accuracy, the graphic estimates would be good enough for most practical purposes. The distribution corresponding to the calculated *GM* and *GSD* of (concentration - 0.10) is shown as a dotted line in Figure I-4.

Example — Exposure averages of individual employees in an occupational exposure group:

The following exposure averages were obtained for 24 employees in the job category

“mix men” at a facility using methyl methacrylate (MMA) in ppm:

26, 53, 8.8, 37, 19, 31, 45, 56, 15,
49, 16, 44, 96, 39, 63, 90, 23, 16,
31, 24, 30, 24, 116, 49

The plotted data are shown in Figure I-5. Following the previous procedures, the *GM* is 34 ppm and the *GSD* is

$$GSD = \frac{65 \text{ ppm}}{34 \text{ ppm}} = 1.9$$

For this set of data, calculated values were almost the same as graphic values: *GM* = 34.5 ppm and *GSD* = 1.89.

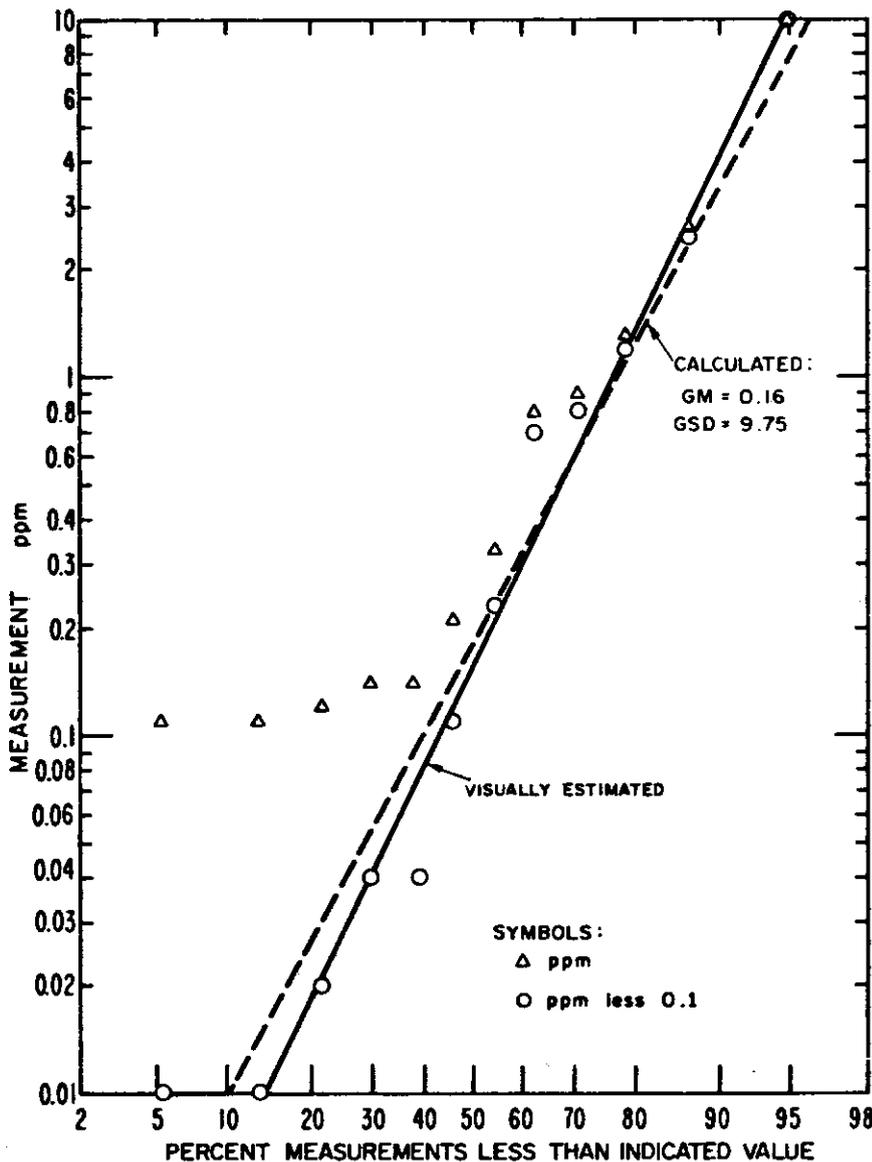


Figure I-4. Hydrogen fluoride measurement distribution.

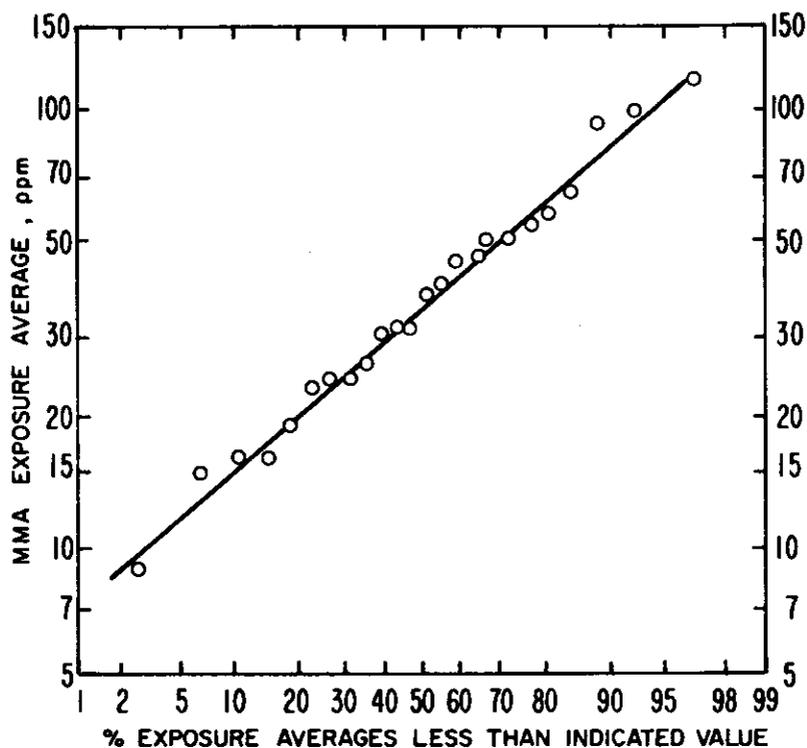


Figure I-5. MMA exposure average distribution in mix men classification.

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