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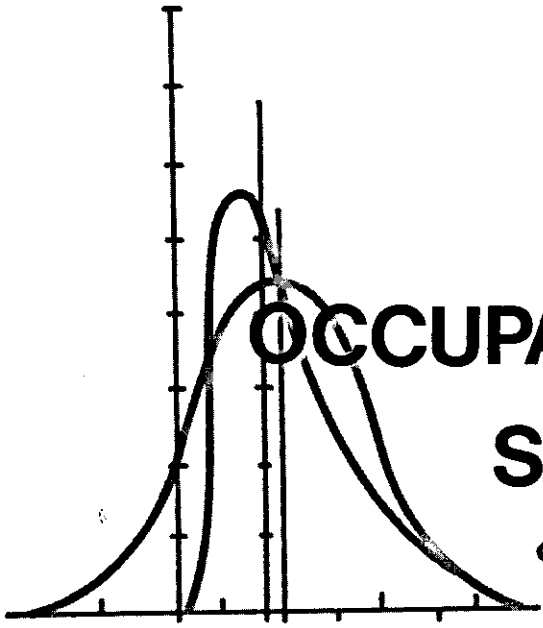
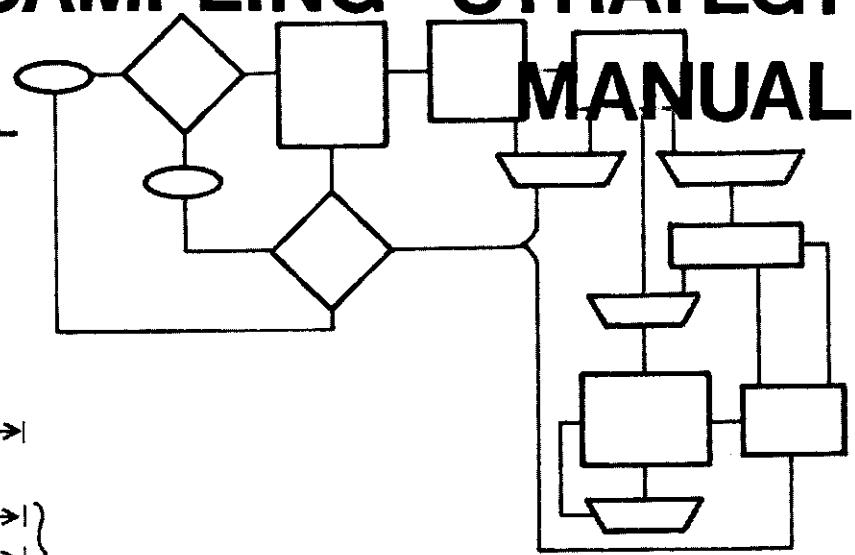
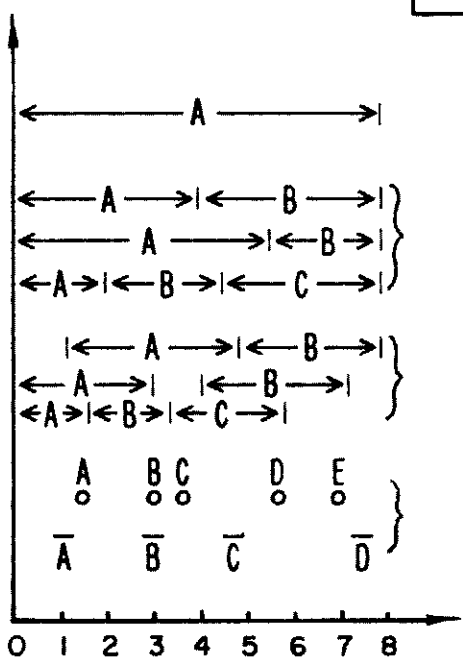
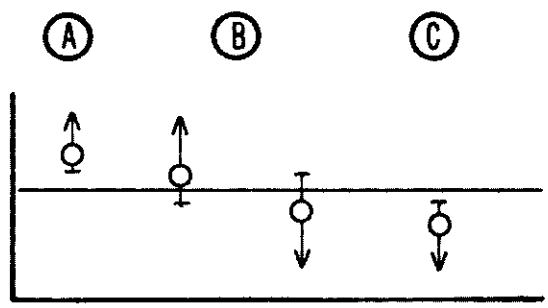
OCCUPATIONAL EXPOSURE SAMPLING STRATEGY MANUAL









U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

OCCUPATIONAL EXPOSURE SAMPLING STRATEGY MANUAL

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Center for Disease Control
National Institute for Occupational Safety and Health
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This manual is the fourth NIOSH report oriented toward use of predictive and analytical statistical methods in the field of industrial hygiene. The three previous works are:

Statistical Methods for the Determination of Noncompliance with Occupational Health Standards, NIOSH Report 75-159 (April 1975).

A handbook-type report treating noncompliance statistics and oriented toward the governmental compliance officer. The background material and conclusions are, however, also applicable to employers and industry industrial hygienists. Available for $1.30 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, as GPO #1733-00062.

Handbook for Statistical Tests for Evaluating Employee Exposure to Air Contaminants, NIOSH Report 75-147 (April 1975).

A research report containing a handbook and statistical theory for sampling time-varying industrial atmosphere contaminant levels. Sophisticated procedures are given for fitting trend curves to grab sample data. Available for $3.95 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, as GPO #1733-00058.

Exposure Measurement Action Level and Occupational Environmental Variability, NIOSH Report 76-131 (December 1975).

A research report explaining the necessity and technical basis for an exposure measurement action level of one-half an occupational health standard. Statistical theory is given for tolerance limits on TWA daily exposures. Employee risk curves presented show the varying probability (risk) that at least 5% of an employee's unmeasured daily 8-hour exposure averages will exceed the standard, given the fact that 1 day's measured 8-hour TWA exposure happened to fall below the standard by a specified amount. Available for $1.10 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, as GPO # 1733-00112-0.

DHEW (NIOSH) Publication No. 77-173

FOREWORD

One of the most important steps toward reducing the risk of impaired health resulting from inhalation of toxic chemicals is the measurement and evaluation of employee exposure to these chemicals. The Occupational Safety and Health Act of 1970 recognizes the critical importance of employee exposure measurements. Section 6(b)(7) of the Act requires that occupational safety and health standards promulgated by the Secretary of Labor provide for monitoring or measuring employee exposure at such locations and in such a manner as may be necessary for the protection of employees. Section 8(c)(3) of the Act directs regulations be issued requiring employers to maintain accurate records of employee exposure to those potentially toxic materials that are required to be monitored under Section 6.

To protect the health of employees, exposure measurements must be unbiased, representative samples of employee exposure. The proper measurement of employee exposures requires more than a token commitment of personnel, sampling equipment, and analytical resources. These resources are not limitless, however, and proper sampling strategy in monitoring programs can produce the best use of exposure measurement resources.

This manual contains the results of almost 5 years of statistical research by personnel and contractors of the National Institute for Occupational Safety and Health. The measurement of exposures and evaluation of the results require the use of statistical procedures that consider variations in exposure concentrations caused by sampling, analysis, and environment. Institute research has provided guidelines for efficient sampling strategies and evaluation of measurement data.

This manual is intended to help employers better understand the spirit and intent of existing and proposed Federal exposure monitoring regulations. It should provide guidance for establishing effective exposure measurement programs to protect the health of employees.

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PREFACE

In January 1974, we assisted in formulating the initial employee exposure monitoring requirements for draft occupational health standards being then written for the joint National Institute for Occupational Safety and Health (NIOSH)/Occupational Safety and Health Administration's (OSHA) Standards Completion Program (SCP). At that time we recognized an obligation to make available to employers and industrial hygienists an informative technical publication detailing the intent and purpose of the proposed employee exposure monitoring regulations. We also envisioned a handbook giving NIOSH recommendations concerning ways of meeting the requirements with minimum burden to the employer while providing adequate protection to the exposed employees. This handbook is aimed at both new and experienced industrial hygienists as well as safety professionals and compliance personnel. This material will assist them to meet the following professional responsibilities:

— devise sampling plans to evaluate occupational exposures to airborne concentrations of chemical substances,
— determine the need for exposure measurements,
— evaluate exposure measurement data, and
— make decisions concerning what action is required by Federal regulations such as 29 CFR 1910 Subpart Z.

A contract (NIOSH #CDC-99-74-75) was let to Systems Control, Inc. (SCI) to develop such a manual. The SCI Final Field Handbook (#SCI 5119-2) was delivered in May 1975. The present manual is an outgrowth of the SCI handbook and incorporates ideas and opinions received from outside reviewers concerning the SCI handbook.

This handbook also attempts to answer additional questions that the authors have received in the last year concerning points of technical intent and purpose of the proposed monitoring requirements. Please keep in mind that most elements of our statistical protocol in Chapter 4 were designed for use by nonstatisticians, and we were sometimes obliged to trade some statistical power or efficiency for simplicity. Also, the statistical procedures given are not regulatory in nature. They are technical recommendations from NIOSH to assist employers in developing efficient monitoring programs and in making better decisions regarding employee exposure measurement results.

The well-intentioned employer will want to use these procedures for the additional protection they will afford his employees. It is possible to develop alternative sampling strategies or decision procedures, or both, that provide equal or increased protection to employees. The authors would welcome additional research in this area.

It is hoped that this is only the first edition of this manual. Field trials of a draft manual would have been most desirable before this handbook was released, but we believe the interests of occupational health are best served by a timely release of this information. We request your comments and ideas concerning how this handbook can be improved, particularly in regard to making it a practical and useful guide for field personnel. Our goals have been simplicity, usefulness, and objectivity.

N.A.L., K.A.B., and J.R.L.

ABSTRACT

The intent and purpose of employee exposure monitoring requirements are explained for employers in this manual. These requirements were proposed in draft occupational health standards written for the joint Standards Completion Program of the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration. NIOSH technical recommendations are given concerning ways of meeting the requirements with minimum burden to the employer while providing adequate protection to the exposed employees. Statistical sampling strategies are given to assist employers in developing efficient programs to monitor occupational exposures to airborne concentrations of chemical substances.

Data analysis methods are given which assist in making better decisions regarding the relation of employee exposure measurement results to standards of safe exposure. Decision criteria are based on assumptions of normal and lognormal distribution models for sampling/analysis errors and for environmental fluctuations, respectively. The manual also discusses topics of industrial hygiene such as determination of the need for exposure measurements, recordkeeping, and the nature of effects and symptoms of toxic agents. Sampling strategies encompass selection of subjects as well as sampling times.

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GLOSSARY*

AL	Action level in a 29 CFR 1910 Subpart Z regulation.
CFR	Code of Federal Regulations.
CSTD	Ceiling standard for occupational health employee exposure such as in Federal Standards 29 CFR 1910 Subpart Z.
CV	Coefficient of variation, a measure of relative dispersion, also known as relative standard deviation (RSD). The sample CV is calculated by dividing the standard deviation by the sample average. Discussed in Technical Appendix D.
GM	Geometric mean, a measure of central tendency for a lognormal distribution. Used in section 4.4 and discussed in Technical Appendix M.
GSD	Geometric standard deviation, a measure of relative dispersion (variability) of a lognormal distribution. Used in section 4.4 and discussed in Technical Appendix M.
K	Number of unsampled intervals of expected high exposure. Used in section 4.3.2.
LCL	Lower confidence limit on a measured exposure average. Unless otherwise specified, LCL is at a 95% (one-sided) confidence level.
LCL (90%)	LCL at a 90% (one-sided) confidence level.
n	Sample size, e.g., number of samples or days being analyzed.
P_c	Probability of compliance with a CSTD for all K unsampled intervals. Used in section 4.3.2.
P_n	Long-term (multiday) estimate of probability of noncompliance for an employee. Calculated in section 4.4.
PEL	Permissible exposure limit in the 29 CFR 1910 Subpart Z Federal regulation.
s	Standard deviation of n values of y_i. A classification variable used in section 4.2.3.
S	Standard deviation of n values of Y_i. Calculated in sections 4.2.3; 4.3; and 4.4.
STD	Standard for TWA exposure, such as Federal Standards 29 CFR 1910.1000. Also known as "permissible exposure limit or level" (PEL).
TLV	Threshold limit value of ACGIH. Refer to section 1.3.
TWA	Time-weighted average exposure concentration. Refer to Technical Appendix H for details of calculation.
UCL	Upper confidence limit on a measured exposure average. Unless otherwise specified, UCL is at a 95% (one-sided) confidence level.

UCL (99%)	UCL at a 99% (one-sided) confidence level.
x	Standardized full period sample concentration calculated by dividing the value X by the STD or CSTD, i.e., $x = X/STD$ or $x = X/CSTD$.
x_i	Standardized sample concentration calculated by dividing the ith sample concentration X_i by the STD or CSTD, i.e., $x_i = X_i/STD$ or $x_i = X_i/CSTD$.
X	Full period sample measurement (exposure average from one cumulative full period sample).
X_i	Exposure concentration calculated from the ith sample within a group of n samples ($i = 1,n$).
$\overline{X}^*$	Best estimate of average exposure concentration calculated from grab samples. Calculated in section 4.2.3.
$\overline{X}^*/STD$	Best estimate of a standardized exposure average calculated from grab samples. Calculated in section 4.2.3.
y_i	Logarithm$_{10}$ of standardized sample concentration. Calculated in section 4.2.3, $y_i = \log_{10}(x_i)$.
$\overline{y}$	Arithmetic mean of n values of y_i. A classification variable used in section 4.2.3.
Y_i	Logarithm$_{10}$ of standardized measured daily exposure average. Calculated in section 4.4 [$Y_i = \log_{10}$ (x_i or $\overline{x}_i$ or $(\overline{X}^*/STD)_i$].
$\overline{Y}$	Arithmetic mean of logarithmic values (Y_i). Calculated in section 4.4.
z	Standard normal variable used in Chapter 4 to obtain probabilities from Table 4.2.
β	Probability of noncompliance with a CSTD during any one unsampled interval. Used in section 4.3.2.
μ	True time-weighted average concentration.

*When an entry is italicized in the text, it is representative of that entry as a variable in an equation.

INTRODUCTION

The American Industrial Hygiene Association (AIHA) has defined Industrial Hygiene as ". . . that science and art devoted to the recognition, evaluation, and control of those environmental factors or stresses, arising in or from the work place, which may cause sickness, impaired health and well being, or significant discomfort and inefficiency among workers or among citizens of the community." Two critical elements for protecting the health of employees in an occupational environment are the recognition and evaluation of employee exposures to toxic airborne chemicals. This Manual presents information that an employer or his representative can use in recognizing toxic substances occurring in the occupational environment and aids in the evaluation of employee exposures to these substances.

Proper evaluation of employee exposures necessitates taking valid quantitative exposure measurements, interpreting these measurements in the light of experience, and exercising professional judgment. The sampling strategy guidelines of Chapter 3 and statistical analysis procedures of Chapter 4 are tools to assist individuals responsible for protecting the health of workers in the design and implementation of occupational exposure monitoring programs. These procedures are a means to an end, not an end in themselves. IN ALL CASES, ONE MUST AVOID THE TRAP OF FALLING INTO A NUMBERS GAME AND KEEP IN PROPER PERSPECTIVE WHAT THE DATA REPRESENT IN RELATION TO WHAT THE WORKER IS EXPOSED TO. Later sections detail existing and proposed legal responsibilities of employers with regard to exposure monitoring of their employees. The purpose of this Manual is to aid the employer to meet his responsibility for providing a safe work environment by implementing a compliance exposure monitoring program. The proposed Occupational Safety and Health Administration (OSHA) employee exposure monitoring requirements detailed in Section 1.4 were developed from the dual principles of recognition and evaluation of hazardous employee exposures that industrial hygienists have followed for many years. Thus the organization of this Manual follows both the sequence of proposed OSHA requirements and the steps an industrial hygienist would follow in evaluating an occupational environment.

0.1 SCOPE OF MANUAL

The sampling strategies and statistical methods of this Manual specifically apply to occupational exposures to airborne concentrations of chemical substances (as dust, fumes, mists, gases, and vapors). The application of normal and lognormal distribution models to occupational exposure concentration measurements is detailed in earlier works by Leidel and Busch (0-1) and Leidel, Busch, and Crouse (0-2), and is discussed in Technical Appendix M. The applicability of these methods to exposure data for physical agents such as noise and heat is unknown at this time because of lack of knowledge concerning suitable distribution models for these types of data. However, if it is found that the normal or lognormal distributions are appropriate for the data in question, then the methods in this manual could be used as appropriate. For those interested in occupational exposures to radiation in mine environments, Misaqi (0-3) has provided an excellent manual on sampling and data analysis for this type of situation.

0.2 HOW TO USE THIS MANUAL

The following checklist is a general guide for the types of questions you should ask yourself when formulating a compliance monitoring program and the appropriate sections of this Manual to refer to. Also refer to the material in section 1.4, particularly the flowchart of Figure 1.1. Keep in mind that the recommended pro-

cedures, particularly the procedures of Chapter 4, go beyond existing and proposed legal minimum requirements.

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0-1. 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, April 1975.

0-2. Leidel, N. A., K. A. Busch, and W. E. Crouse: Exposure Measurement Action Level and Occupational Environmental Variability. NIOSH Technical Information, HEW Pub. No. (NIOSH) 76-131, Cincinnati, Ohio 45226, December 1975.

0-3. Misaqi, F. L.: Application of Statistics to Radiation Surveys in Mines. Mining Enforcement and Safety Administration Informational Report 1020, Washington, D.C. 20240, 1975.

Checklist for Employee Exposure Monitoring

Item		*Refer to*
1. Is there a toxic or hazardous material in the workplace that can be released into the workplace air?	Yes.... No....	Chap. 2
2. If "yes", have you made a written determination for each toxic material that states whether any employee may be exposed to airborne concentrations of each material?	Yes.... No....	Chap. 2
3. If "yes" to 2, does the written determination include at least the following:		
a. Any information, observations, or calculations that would indicate employee exposure?	Yes.... No....	
b. If employees are exposed to toxic material, statement that exposure is at or above the action level?	Yes.... No....	
c. Any employee complaints of symptoms attributable to exposures?	Yes.... No....	Chap. 2
d. Date of determination, work being performed, location within the worksite, names and social security numbers of employees possibly exposed?	Yes.... No....	
e. Any concentration measurements (area or personal) taken?	Yes.... No....	
f. Any comments from medical examinations that may point to possible exposures?	Yes.... No....	
4. Is there any reasonable possibility of any employee being exposed above the action level according to the written determination?	Yes.... No....	Chap. 2
5. If "yes", have you measured the exposure of the employee(s) most likely to have the greatest exposure (maximum risk employees)?	Yes.... No....	Chap. 3
6. If "no", have you repeated Step 2 and succeeding steps each time there has been a change in production, process, or control measures that could result in an increase in airborne concentrations of any material in Step 2?	Yes.... No....	Chap. 2
7. If any exposure measurement indicates exposure above the action level, have you:		
a. Identified all employees so exposed?	Yes.... No....	Chap. 3
b. Sampled those employees so identified?	Yes.... No....	
c. Classified all employees according to noncompliance exposure, possible overexposure, or compliance exposure?	Yes.... No....	Chap. 4

8. Have you taken the following actions, depending on employee classification:		
a. Resampled employees with noncompliance exposures within 1 month and decided whether controls are to be instituted?	Yes.... No....	Chap. 3
b. Resampled employees with possible overexposures within 2 months and reclassified them if appropriate?	Yes.... No....	
c. Resampled employees with compliance exposures every 2 months (or if changes occurred in the operation) and reclassified them if appropriate?	Yes.... No....	Chap. 4
9. Have employees with exposures exceeding Federal standards been informed?	Yes.... No....	
10. Have all employee exposure measurements been properly recorded and filed?	Yes.... No....	Section 3.6
11. Have you instituted appropriate controls for those exposed employees needing them?	Yes.... No....	(Technical Appendix N)