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TEXTILE DYE WEIGHING MONITORING STUDY

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Exposure Evaluation Division
Economics and Technology Division
Office of Toxic Substances
U.S. Environmental Protection Agency
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CONTENTS

CONTENTS
(Continued)

TABLES

TABLES
(Continued)

FIGURES

LIST OF ACRONYMS

ATMI	American Textile Manufacturers Institute, Inc.
CEB	Chemical Engineering Branch (within ETD)
CIH	Certified Industrial Hygienist
DDB	Design and Development Branch (within EED)
EED	Exposure Evaluation Division (within OTS)
EPA	U.S. Environmental Protection Agency
ETD	Economics and Technology Division (within OTS)
ETAD	Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry
FSB	Field Studies Branch (within EED)
HHI	Health and Hygiene, Inc.
ICB	Industrial Chemistry Branch (within ETD)
MRI	Midwest Research Institute
OTS	Office of Toxic Substances (within EPA)
PEI	PEI Associates (formerly PEDCO Environmental, Inc.)
QAM	Quality Assurance Manager
QAPP	Quality Assurance Project Plan
SAS	Statistical Analysis System
WCG	The Washington Consulting Group

AUTHORS AND CONTRIBUTORS

This survey of particulate dye levels in air of dye weighing rooms (drug rooms) of textile wet processing plants is distinctive in that it represents the voluntary joint cooperative efforts of industry and EPA. Industry was represented by the American Textile Manufacturers Institute, Inc. (ATMI) and the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry (ETAD). These industry trade associations were supported by their contractor, Health and Hygiene, Inc. of Greensboro, N.C.

EPA participation was from two divisions of the Office of Toxic Substances (OTS). This included the Economics and Technology Division (ETD), with support from the Chemical Engineering Branch (CEB) and the Industrial Chemistry Branch (ICB); and the Exposure Evaluation Division (EED) with support from the Field Studies Branch (FSB) and the Design and Development Branch (DDB). Contract support to OTS included PEI Associates for ETD and Midwest Research Institute, the Washington Consulting Group, Inc. and Westat, Inc. for EED.

American Textile Manufacturers Institute, Inc. (ATMI)

ATMI, in conjunction with ETAD, proposed the initial study plan to OTS; cooperated with OTS in development of the final study plan; contacted industry sites that were selected for each phase of the study, explained the objectives and mechanism and encouraged participation; provided information on the composition of the industry; provided technical assistance from design to analysis; served as a clearinghouse for all industry contacts; edited the final reports; forwarded reports to each participant.

Key personnel included:

Maggie Dean, ATMI	Eugene Roberts, West Point Pepperell
Carlos Moore, ATMI	John Tritsch, ATMI
O'Jay Niles, ATMI	Nancy Weinberg, ATMI

Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry (ETAD)

ETAD, in conjunction with ATMI, proposed the initial study plan to OTS; cooperated with OTS in development of the final study plan; supplemented the OTS site identification list; provided technical assistance from design to analysis; assisted in the development of an analytical methodology for the measurement of dye dust concentrations; contacted industry sites that were selected for dye dust monitoring and encouraged participation; edited the final reports. Key personnel included:

Barry Bochner, Atlantic Industries, Inc.
Edward Boland, CIBA-GEIGY Corporation
Eric Clarke, ETAD
Jay Dayan, BASF Corporation
David Hackathorn, Mobay Corporation
Tucker Helmes, ETAD
Joseph LoMenzo, CIBA-GEIGY Corporation
Per Stensby, CIBA-GEIGY Corporation
Heinz Trebeitz, Hoechst Celanese
Harshad Vyas, Mobay Corporation
Wolfe Wagner, ICI Americas, Inc.

Health & Hygiene, Inc. (HHI)

HHI, in support of industry groups, scheduled dates for monitoring with sites that had agreed to participate; with PEI representatives, interviewed site executives and walked through sites prior to monitoring; conducted dye dust air monitoring with personal and area sampling pumps; collected samples of all powder dyes encountered and of appropriate chemicals; sketched a floor plan and dye flow sheet for each site; assisted PEI in on-site activities; conducted a gravimetric analysis of dye dust on monitor filters; assisted in preparation and review of 24 individual site reports. Key staff included:

William Dyson
Ronald Hill
Melvin Witcher, Jr.

Economics and Technology Division (ETD)

Based on its responsibilities in the assessment of worker exposure, ETD introduced the need for a study to ETAD and ATMI; jointly with EED provided overall management of planning, design and implementation of the project. ETD coordinated work within OTS with the industry groups; identified industry dye user sites; supervised field data collection efforts, which included identifying and cataloguing all dyes encountered at each site; identified chemical structures of dyes; developed a data base characterizing sites, workers, workplace activities and industrial hygiene; managed the preparation of the 24 individual site reports; and participated in the development and review of the final report. Key staff included:

William Burch
Russell Farris
George Heath

Exposure Evaluation Division (EED)

EED participated in development of a final study plan; jointly with ETD managed overall project, supervised all aspects of this study that were related to statistical design, site selection, questionnaire development, data collection, quality assurance (QA), chemical analysis of dye dust samples, and statistical analysis of results; performed field QA audits; supervised preparation of the final report; edited and finalized the overall report. Key staff included:

Joseph Breen
Margaret Conomos
Mary Frankenberry
Joseph Glatz
Martin Halper
Richard Kent
Thomas Murray
Eileen Reilly-Wiedow
Bradley Schultz
Sarah Shapley
Cindy Stroup

PEI Associates (PEI)

In support of ETD, PEI with HHI interviewed the site executives and walked through sites prior to monitoring; gathered on-site data characterizing dyes encountered, sites, workers, workplace activities and industrial hygiene; assisted HHI in on-site activities; prepared 24 individual site reports; prepared drafts of field sampling and results sections of the final report; prepared characterization tables for the final report. Key staff included:

Tom Corwin
Paula Morelli-Schroth
Kenneth Troutman
Leslie Ungers
Donald Unruh
Robert Willson

The Washington Consulting Group, Inc. (WCG)

In support of EED, WCG assisted in development of data quality objectives; designed the survey; prepared the quality assurance project plans; selected sites for the study; conducted the data analysis and interpreted the results; prepared drafts of the final report. Key staff included:

Harry Chmelynski
David Cox
Arnold Greenland
Ayah Johnson
Annie Lo
Bryan Porter
Charles Smith
Vicki Stoltz

Midwest Research Institute (MRI)

In support of EED, MRI developed an innovative spectrophotometric method of measuring total levels of several widely used classes of textile dyes on air monitoring filters; assisted in the development of the chemical analytical quality assurance project plan; performed laboratory analyses of plant samples; prepared individual reports of the analytical results for each monitored plant; prepared the draft of the chemical analysis methodology. Key staff included:

Jack Balsinger	Cynthia Palmer
Paul Constant	Robin Paris
Jairus Flora, Jr.	Roger Rembecki
John Going	Julie Ryan
Don Harbin	

Westat, Inc.

In support of EED, Westat, Inc. conducted the mailing of questionnaires to plants in the first phase of the survey. Key staff included:

Stephen Dietz	Sharon Gregory
Susan Engelhardt	Diane Ward

ACKNOWLEDGMENT

The authors and contributors of this report express their sincere appreciation to the management and staff at each of the textile plants who participated in this survey. Without their cooperation this study would not have been possible. The authors and contributors convey their gratitude to reviewers from the Universities of Georgia and Alabama, the Georgia Institute of Technology, the National Institute for Occupational Safety and Health, and the Amalgamated Clothing and Textile Workers Union for their helpful comments and suggestions.

EXECUTIVE SUMMARY

I. INTRODUCTION

This report presents the results of a survey conducted jointly by the U.S. Environmental Protection Agency (EPA), the American Textile Manufacturers Institute, Inc. (ATMI), and the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry (ETAD) to estimate airborne concentrations of dye dust in the dye weighing rooms (drug rooms) of plants that use powder dyes in the dyeing and printing of textiles. The purpose of the project was to conduct a well-designed study of representative textile dye weighing rooms, in order to improve the assessment of workplace exposure associated with the use of powder dyes in the American textile industry.

More than 1,000 domestic textile processing sites have been identified where dyeing or printing operations may occur. However, the available data on potential exposure levels of workers associated with the weighing or mixing of powder dyes are limited, and they are not always representative of textile dyeing operations. Textile workers may be exposed to powder dyes via inhalation during dye weighing or mixing operations, and the EPA is concerned about a number of potential health hazards from exposure to dye dust. For example, some dyes or some of their metabolites are thought to be carcinogens or mutagens.

The distribution of dye dust concentrations obtained in this survey provides the EPA with improved estimates of occupational exposures for use in developing risk assessments for powder dyes. Information about the mass, frequency, and number of powder dye compounds weighed during a typical shift was collected, along with a physical characterization of the drug room, to assist in understanding the factors related to airborne dye dust concentrations. The survey was based on a probability sample of 24 sites chosen at random from textile plants where powder dyes are weighed. Estimates produced from probability samples in carefully executed studies, such as this one, are strongly preferred to case study evidence of a limited nature, which has been the only information previously available to the EPA on textile dye exposure. The estimates obtained in this study substantially improve the credibility of estimates of exposure of textile weighers to dye dust over those based on previously available data.

II. OBJECTIVES OF THE STUDY

To address the issue of improving the assessment of human exposure via inhalation from the use of powder dyes, industry and EPA agreed that the study should have the following objectives:

1. Estimate the distribution of dye concentrations in dye weigher breathing zones (8-hr time-weighted average (TWA) concentration).

2. Determine factors upon which dye concentrations in the breathing zone are dependent, including the amount of dye weighed and number of weighings per shift. Determine whether there is a functional relationship between these factors and airborne dye concentrations.

3. Estimate the distribution of dye classes and individual dye compounds weighed during a shift.

4. Summarize selected drug room observations and general plant information.

5. Obtain an extensive first-hand qualitative view of drug room operations and characterize industrial hygiene practices at each site.

III. APPROACH

The survey was conducted in two phases. The first phase consisted of a survey of 240 plants selected at random from a list of 1,390 textile facilities thought to use powder dyes. The plants selected were screened by telephone to determine eligibility, and 171 eligible plants received questionnaires in the mail to gather information on plant characteristics and determine which plants were qualified as candidates for on-site monitoring. The response rate to the questionnaire mailed in the first phase was 47%.

In the second phase, both respondents and nonrespondents to the questionnaire were selected for monitoring. Of 52 plants selected, 24 were monitored, resulting in a response rate of 46% for phase two. While the group of establishments not monitored in phase two represents an appreciable portion of the total selected, examination of the information gathered on the plants in the two groups did not reveal any concern for bias.

Monitoring of airborne dye levels in the plants and observation of drug room activities were included in phase two of the survey. A two-member team of certified industrial hygienists recorded measurements and observations in each plant to satisfy the study objectives. In addition, a more extensive examination of practices and potential exposure was conducted for one randomly selected dye weigher at each plant during one randomly selected shift.

Monitoring of airborne dye levels took place over the course of an 8-hr work shift. Personal monitors were used to collect solids from the air in the breathing zone of the workers wearing the monitors. Area sampling was also conducted. Area samples provide data on ambient dye levels, while samples from personal monitors measure potential exposure levels for individual workers, without consideration of personal protective equipment.

All the samples collected were analyzed in a laboratory to determine total dust mass and total dye mass. The total dust mass is a simple gravimetric measurement, but it was necessary to develop a new analytical method to estimate dye levels. This innovative method involved a complex process, since the samples contained mixtures of several to many dyes in unknown proportions. The methodology was developed by testing a set of 23 "typical" textile dyes selected by ETAD and ATMI. The relative percent error of the analytical method was estimated to range from -8 to +32 percent for mixtures of 10 of these dyes, and from -41 to +16 percent for mixtures of 20 dyes.

For each weigher selected at random for more extensive monitoring, the team of industrial hygienists recorded the amount of each powder dye and chemical weighed, the number of powder dyes weighed, the total number of weighings, the amount of time the weigher spent in the weighing area, and other qualitative and quantitative information. Information was also recorded on the size of the dyeing operation, cleanliness, ventilation, possible routes of exposure, and other qualitative characteristics.

An individual site report was prepared for each plant, and copies were forwarded to the plant. In order to provide a context for the participants to interpret their results, a summary of unweighted average and range values for all the sites was also provided. A copy of the summation can be found in Table A-1 of Appendix A, and a summary of the individual site characterizations is provided in Table A-2.

IV. RESULTS

The mean airborne concentration of commercial dye dust[1] for the target population of plants monitored was estimated to be 0.18 milligrams per cubic meter (mg/m^3). This estimate falls within a 95% confidence interval that ranges from 0.11 to 0.31 mg/m^3. The geometric mean of the distribution of commercial dye dust was 0.11 mg/m^3, with a geometric standard deviation of 2.80. The 95th percentile of this distribution (representing an estimate of the concentration level that would be exceeded by only 5% of all textile dyeing plants) is 0.57 mg/m^3. The mean airborne concentration of active colorant for the population was estimated to be 0.085 mg/m^3, with a 95% confidence interval from 0.049 to 0.15 mg/m^3 and a 95th percentile value of 0.27 mg/m^3. The geometric mean of the distribution of active colorant was 0.049 mg/m^3, with a geometric standard deviation of 2.85. The estimated values for concentrations of both commercial dye and active colorant closely followed a lognormal distribution, as is typical of occupational exposure data.

Significant correlations were observed between dye concentration and 5 of 21 variables sampled during the study, for both commercial dye and active colorant concentrations. The five variables with significant correlation coefficients were number of dyes weighed, mass of dye weighed, number of weighings of dyes, number of suppliers, and number of dye classes. Although the first three of these variables (number of dyes weighed, mass of dye weighed, and number of weighings) were expected to be influential, the significance of the other two (number of suppliers and number of dye classes) was surprising.

On the basis of these findings, several statistical models were examined for their ability to predict dye dust concentrations from the estimated values of other variables. The best of these models explained up to half of the variability in dye dust concentrations. The remaining variability may be due to many factors, such as variables not measured in the survey and random characteristics of the samples, including uncertainty in the estimates of dye concentrations for each plant.

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[1]Because the response of textile dyes to the analytical method used was proportional to the purity of the dyes measured, correction for dye purity, or active colorant content, was required. Therefore, results are presented for both total commercial dye dust and active colorant. The results presented in this report are based on data for samples from personal exposure monitors, unless otherwise noted.

V. CONCLUSIONS

The major accomplishment of the study is the acquisition of representative data on concentrations of commercial dye dust and active colorant in the air of textile wet processing plants. In addition, the new analytical method developed to estimate dye levels from air samples will be useful for future studies of exposure to textile dyes. The observations of industry weighing activities and industrial hygiene practices recorded in this study provide insight into the factors that contribute to and control exposure of dye weighers. The data gathered here will be useful both in EPA's existing chemicals program and in its premanufacture notification (PMN) process for new chemicals. The data also provide an information base for future studies and for the development of explanatory and predictive models of airborne dye concentrations and other exposure-related factors in the textile dyeing process.

Chapter 1

INTRODUCTION

I. BACKGROUND

Data which document potential exposure levels of workers associated with the weighing or mixing of powder dyes are limited, and not always representative of textile dyeing operations. The purpose of this project was to conduct a well-designed study of representative textile dye weighing rooms (drug rooms) in order to improve the assessment of workplace exposure associated with the use of powder dyes in the American textile industry. Prior assessments were based on industrial hygiene survey reports of benzidine-azo dyes prepared by the National Institute for Occupational Safety and Health, 1977-1978. More than 1,000 domestic textile processing sites where dyeing or printing operations may occur have been identified. Textile workers may be exposed to powder dyes via inhalation during dye weighing or mixing operations, and the EPA is concerned about a number of potential health hazards from exposure to dye dust. For example, some dyes or some of their metabolites are thought to be carcinogens or mutagens.

In the current study, dyes are divided into two categories, as follows:

(1) Active Colorant--Undiluted chemical substance(s) that can be affixed to a substrate in order to provide coloring effects.

(2) Commercial Dye--Formulated mixture of active colorant(s) and one or more other substances offered to the trade, usually under a name specific to the supplier and often identified by a Color Index Name. Other components may include diluent, dispersing agent, solubility promoter, dedusting oil or other chemicals to enhance usage on a commercial scale. A given supplier may formulate a commercial dye at several concentration levels of active colorant, usually reflected in its price.

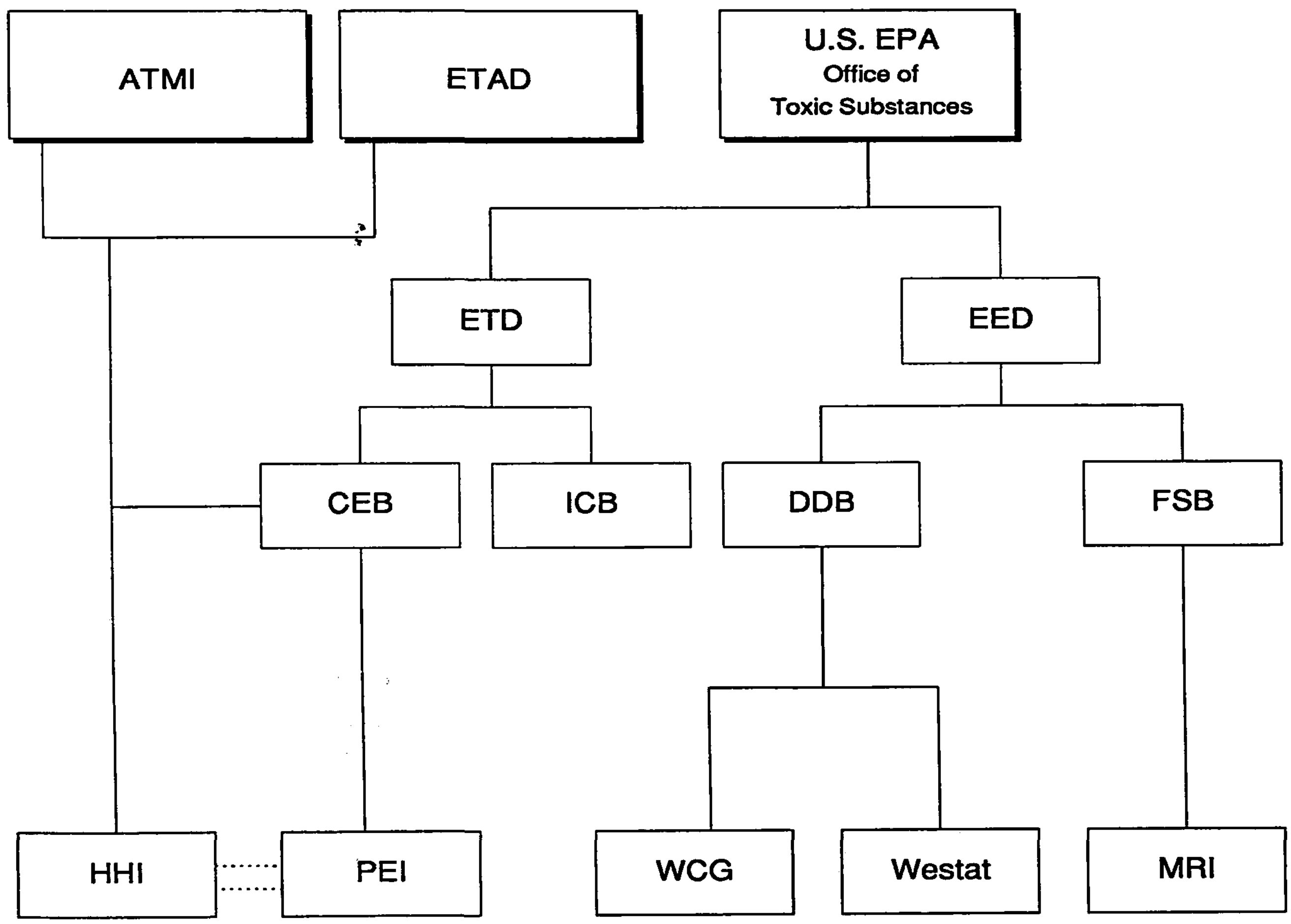
The study was initially proposed to the Environmental Protection Agency (EPA) by representatives from the American Textile Manufacturers Institute, Inc. (ATMI) and the Ecological and Toxicological Association of the Dyestuffs Manufacturing Industry (ETAD). The implementation of the study plan was from the beginning a collaborative effort between the industry representatives and EPA;

representatives of the three organizations met regularly throughout the study to review the progress and provide direction.

The organization of the study team is illustrated in Figure 1-1. As shown in the figure, within EPA the study was managed by the Office of Toxic Substances (OTS). Responsibilities were shared by the Economics and Technology Division (ETD) and the Exposure Evaluation Division (EED). Four branches in those divisions were involved in the study. They were the Chemical Engineering Branch (CEB) and Industrial Chemistry Branch (ICB) from ETD and the Design and Development Branch (DDB) and the Field Studies Branch (FSB) from EED. Figure 1-1 also shows the contractors who provided support to ATMI, ETAD, and EPA. The

Figure 1-1

TEXTILE DYES SURVEY: PROJECT ORGANIZATION



specific contractors involved as well as all of the contributions of organizational participants are given in the Authors and Contributors section of this report.

The major tasks in the study were survey design, quality assurance, drawing a national sample of textile dye plants, developing data collection procedures and materials, site visits (including recording of worker activities and industrial hygiene practices and monitoring and collecting bulk dye samples), chemical analysis of collection media (filters), data preparation, statistical analysis, interpretation of results, and report writing. Quality assurance plans were written for each aspect of the project.

II. STUDY OBJECTIVES

To address the issue of how to improve the assessment of human exposure via inhalation from the use of powder dyes, industry and EPA agreed that the study should have the following objectives:

1. Estimate the distribution of dye weigher breathing zone dye concentration (8-hr TWA concentration).

2. Determine factors upon which dye concentrations in the breathing zone are dependent. Factors to be explored will include at least the amount of dye weighed and the number of weighings per shift. Determine whether a functional relationship exists between concentration and these factors.

3. Estimate the distribution of dye classes and individual dye compounds weighed during a shift.

4. Summarize selected drug room observations and general plant information.

5. Obtain an extensive first-hand qualitative view of drug room operations and characterize industrial hygiene practices at each site.

III. OVERVIEW OF THE REPORT

This report describes how the study was conducted and presents the study results. Chapter 2 describes the study's conclusions. Chapter 3 provides an overview of the quality assurance program. Chapter 4 describes the survey design and how the textile plants were selected. Chapter 5 describes field sampling procedures which were followed for collecting in-plant data. Chapter 6 explains the methodology used for the chemical analysis of the filters. Chapter 7 presents the analytical results and statistical analysis of the survey data. Chapter 8 discusses the facility operations, worker activities, powder dyes encountered, and control characteristics of the textile plants visited. Detailed tables presenting site-specific data and summary tables of survey-based estimates for the national population of textile dyeing plants are included in the Appendixes to this report. Copies of study materials such as the quality control project plans, questionnaires, and other information can be found in a separate supplemental volume accompanying this report.

Chapter 2

RESULTS AND CONCLUSIONS

The overall accomplishment of this study has been the acquisition of data on airborne concentrations of dye dust in the dye-weighing areas of textile processing plants which are more representative of the industry than data previously available to EPA. The random site selection process coupled with records of dyes encountered, masses weighed, weighing frequency and other quantities collected at each site have allowed a study of factors which affect dye concentrations in air. Recorded observations of industry weighing activities and industrial hygiene practices provided insight that was previously unavailable into factors contributing to and controlling exposure of dye weighers. These values will be useful in both EPA's existing chemicals program and its premanufacture notification process for new chemical substances. The study has also provided an information base for future studies and development of explanatory and predictive models of airborne dye concentration and other exposure-related characteristics of textile dyeing processes.

While this survey at both stages had less than optimum response rate, no evidence of response bias was found. This is mentioned here to provide a context within which to interpret the results presented below. When there is a small response rate, it is important to consider the possibility of bias in the estimates. In phase one, of the 171 plants to which questionnaires were mailed, 81 plants, or 47%, responded with completed questionnaires. Due to this large nonresponse rate in phase one, the sites for monitoring in phase two were selected at random from both respondents and nonrespondents to the phase one questionnaire. Phase two had a response rate of 46% with 24 plants monitored. An examination of the respondents and nonrespondents did not reveal any reason for concern. No specific evidence, other than the existence of the nonresponse, was uncovered to indicate that there was a problem. There was no perceptible difference between airborne dye concentration estimates for the plants which responded to the mailed-out questionnaire and those that did not. This was taken to mean that the incidence of plant response may not be related to the level of airborne dye concentration encountered.

I. PRIMARY FINDINGS

Specific results and conclusions are presented below for each of the survey's objectives.

1. Estimate the distribution of dye weigher breathing zone dye concentrations (8-hour time-weighted average concentration).

Concentrations of total dust, commercial dyes, and active colorants in the breathing zone of 24 textile dye weighers over a period of one shift have been measured analytically. The summary statistics for the distributions of concentration for dye dust, commercial dye and active colorant measured at monitored sites are given in Table 2-1, and the analytical measurements are provided in Tables 7-1, 7-2, and 7-3. These results demonstrate that average airborne dye dust exposures are substantially lower than prior assessments.

Table 2-1

STATISTICAL SUMMARY OF ANALYTICAL RESULTS

Concentration in mg/m^3
(Weighted by Plant)

Parameter	Total Dust	Total Commercial Dyes	Total Active Colorant
Lowest Value	0.023	0.013	0.007
Median	0.39	0.11	0.049
Geometric Standard Deviation	2.09	2.80	2.849
Mean	0.51	0.18	0.085
85th Percentile	0.84	0.31	0.15
90th Percentile	1.0	0.39	0.19
95th Percentile	1.3	0.57	0.27
Highest Value	1.37	1.20	0.56

Note: The "Lowest" and "Highest" values are simply the minimum and maximum sample measurements. These values are not appropriate for describing the target population of plants. All other parameters are population estimates. All three of these distributions were found to follow the lognormal distribution, a probability distribution which is often associated with occupational exposure measurements. The percentile estimates were computed using this assumption. For this distribution, the median is also an estimate of the geometric mean.

2. **Determine factors upon which dye concentrations in the breathing zone are dependent. Factors to be explored will include at least the amount of dye weighed and the number of weighings per shift. Determine whether a functional relationship exists between concentration and these factors.**

A statistical analysis was done to identify relationships between the approximately 21 variables on which data were collected in the study and the measured airborne dye concentrations. The following five variables were found to have a statistically significant (at the 5% level) correlation:

- Number of Dye Suppliers;
- Number of Dyes Weighed;
- Mass of Dye Weighed;
- Number of Weighings; and
- Number of Dye Classes.

Two of the variables, Number of Suppliers and Number of Dye Classes, displayed significant correlations to airborne concentrations of commercial dye. These results are counter to intuition, but the variables may be surrogates for other variables not measured in this study.

Further analysis was carried out using correlation and stepwise regression techniques to investigate interrelationships among various study variables and airborne commercial dye concentrations. The "best" regression equation selected by a stepwise regression procedure was that which included only Number of Suppliers, with an R^2 value of 0.56. (This value of R^2, the coefficient of determination, implies that Number of Suppliers explains 56% of the observed variation across plants in airborne dye concentration.) This finding does not have a plausible explanation. The next "best" regression equation included only Mass Weighed, with an R^2 value of 0.39.

While the stepwise regression procedure selected only 1-variable models, 2-variable regression models were also considered. When Number of Dye Weighings was included in addition to Mass Weighed, this second variable was found to have marginal significance, with an increase in the R^2 for the regression to 0.47.

3. **Estimate the distribution of dye classes and individual dye compounds weighed during a shift.**

Besides active colorant and commercial dye airborne concentration, many other variables were collected from the study. These ranged from the total number, mass and frequency of dye compounds weighed to the availability and use of personal protective equipment by workers in the drug room. Results for variables of particular interest are provided below. Descriptive statistics for each dye encountered and all the other variables are presented in Appendix A.

POWDER COMMERCIAL DYES

VARIABLE	WEIGHTED MEAN VALUE	RANGE OF VALUES	
		Low	High
Mass Weighed	58.2 kg/shift/site	2.1	283.9
Number of Dyes Used	17.1 dyes/shift/site	2	46
Number of Weighings	60.3 weighings/shift/site	7	259

4. Summarize selected drug room observations and general plant information.

At each site, drug room and general facility characteristics were recorded for use in the evaluation of drug room operational factors which may affect the potential for worker exposure.

Although some sites were quite similar to others, textile wet processing operations in general were found to vary considerably in size, scope, and processing equipment, and some were atypical among those monitored. Examples of similarities among 24 sites included vertical management (20), location in EPA Region 4 (19), 24-hr operation per day (18), and batch processing equipment (18). Examples of variables exhibiting wide variability included production volumes (0.3 to 25 million pounds per year), number of dyeing machines in operation (1 to 75), number of dye weighings made per shift (7 to 259), mass of powder commercial dye weighed per shift (2 to 284 kg), number of dyes weighed per shift (2 to 46), and a variety of end products. Each site is described fully in individual site reports and summations, which are contained in Appendix A.

5. Obtain an extensive first-hand qualitative view of drug room operations and characterize industrial hygiene practices at each site.

Dye house operations were found to vary considerably. However, among the many operational procedures described by the industrial hygienists, the mechanism for weighing and mixing powder dyes was notably consistent at the 24 sites. Other than a universal absence of engineering controls to control dye dust exposure, industrial hygiene practices also displayed wide variation.

II. ADDITIONAL FINDINGS

Finally, although not directly related to the survey's objectives, there were important results related to the chemical analytical methodology that was used. Many different analytical approaches were evaluated to find one that could reliably measure dye mixture concentrations in drug room samples. Air sample filters collected during the study could contain as many as 46 different textile dyes from up to 5 dye classes. Conventional methods of dye quantification were found to be limited in this regard, necessitating the development of a novel analytical technique.

An innovative method developed for the study was a spectrophotometric procedure by which the weighted average of the individual dye's "spectral" absorptivity constants were used to derive a constant of the mixture of dyes trapped on a filter. This average absorptivity was then used to estimate the amount of dye material on the filter. Overall, this analytical procedure successfully met the study objectives, although analytical difficulties were encountered with a small group of dyes that are infrequently used. Prior to beginning the full-scale study, the procedure was evaluated using known quantities of 20 commercial dyes representing the five most frequently used dye classes. The relative error for total dye measured was found to be within ± 40%; this level of accuracy was determined to be acceptable for the purpose of this study. It should be emphasized, however, that this figure is not necessarily representative for all 24 plant sites in the study. The levels of accuracy for the analytical method can be so variable that a general value for the accuracy cannot be stated prior to obtaining information about the absorption characteristics of the specific dyes being analyzed. In addition, a few infrequently used classes of dyes cannot be measured by this procedure.

Chapter 3

QUALITY ASSURANCE PROGRAM

I. INTRODUCTION

Every aspect of the project was subject to quality assurance (QA) considerations. Such measures as thoroughly reviewing all work and assuring that all project personnel have adequate experience and training for their responsibilities were followed throughout. Some aspects of the project work, however, had specific QA procedures, which are summarized in this chapter.

The approach to QA planning defined for the study by the study work group was the preparation of Quality Assurance Project Plans (QAPPs) setting forth strategies for producing error-free and highly reliable data. A QAPP was prepared for each of the three major components of the survey:

- Statistical Design, Data Objectives, and Data Analysis;
- Field Sample and Data Collection at the Plants; and
- Analytical Methodology Development and Analysis of Field Samples.

These plans (Section A of Supplement) complement each other and together constitute a complete quality assurance plan for this study. Methods for in-plant monitoring, recording observations, and making the chemical analyses were pretested at a pilot textile dyeing site.

The following sections discuss the QA procedures associated with the survey design, data collection, and creation of the study data base, and the quality control activities used before and during site visits, laboratory analysis, and data analysis.

II. STATISTICAL/QUALITY CONTROL PLANNING

The data presented in this report are based on a sample survey. In common with all survey data, they are subject to sampling and nonsampling errors. These two types of error are discussed below. Before presenting that discussion, the advantages of data collected in a survey over anecdotal evidence, expert opinion, and attempted complete enumerations which include a very low percent of the universe are reviewed.

The advantages of survey-based data are that it is known what the final estimates represent. Specifically, the universe of plants to which the estimates apply can be stated; the type of monitoring conducted is specified and uniform; the same data items are collected for all selected plants using common definitions; the laboratory analyses are conducted in a known fashion with specified quality control procedures; the tabulations are made using established definitions and the level of precision of the estimates can be measured by estimating the sampling error from the data.

Errors encountered in sample surveys are commonly classified into two groups: sampling and nonsampling errors. Sampling errors are discrepancies between the sample estimates and the actual population values being estimated. If the statistical procedures for selecting the elements of the survey are carefully controlled, the sampling errors for a probability sample can be estimated.

In contrast, nonsampling errors are those which result from sources other than those attributable to sampling. There were various potential sources of nonsampling error in this survey. Although the impact of such errors on the estimates is not generally quantifiable, it is important to acknowledge these sources so that users of the survey data may be aware of their possible effects.

Potential sources of nonsampling errors include: nonresponse bias (discussed below in III.A); failing to sample a representative group of textile dyeing plants; errors in laboratory analysis of bulk samples; and errors in data collection, transcription, keypunching, or computer manipulations. The QAPP given in Section A of the Supplement addresses each of these potential sources of error. Although such errors may still have occurred, there is no evidence to suggest that they introduced bias into the survey results.

A. Frame Construction

Frame errors are those caused by incorrectly including or excluding units on the list of plants from which the sample was selected. To minimize such errors, a list of textile plants, both known and suspected users of powder dyes, was constructed using Davison's Textile Blue Book of Manufacturers.[1] The list underwent an extensive verification process which included:

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[1]Nealy BN. 1983. Davison Textile Blue Book, 117th Edition. Ridgewood, NJ: Davison Publishing Company.

- Cross-checking the list with the Standard Industrial Classification listing;

- Cross-checking the list with a list of plants known to discharge dye-containing effluent;

- Additions to the list by EPA personnel familiar with the textile dyeing industry;

- Revising the list using intimate knowledge of the industry (this was done by ETAD and ATMI); and

- Conducting a pilot study (Phase I of the survey) to ensure that there were no systematic omissions.

These activities resulted in a frame with 1,390 members. A telephone screening survey was then conducted on a random sample of 240 plants selected from the list of 1,390. Of these plants, a total of 171 (71% of 240) was found to be eligible for the study. Eligibility was determined primarily on the basis of sites being still in business and by their use of manual weighing of powder dyes for textile dyeing or printing operations.

B. <u>Pilot Study of the Industry--Mailed-Out Survey</u>

A survey of the 171 eligible plants was then conducted by mail to accomplish a number of quality control tasks. In particular, the survey planning team wished to collect and verify information so that frame and measurement biases would be reduced. In addition, data were requested which would contribute to the design of on-site monitoring protocols, thus reducing measurement errors. The mail survey had the following results:

- The construction of the sample list was verified. The 171 randomly selected plants did not deviate in any systematic manner from the known make-up of the textile wet processing industry. The random sample of 171 plants provided a manageable list for careful examination.

- Knowledge of the textile dyeing/printing industry for preparation of in-plant monitoring was enhanced.

- Stratification of the sample for in-plant monitoring was shown to be possible (the entire list of 1,390 was too large to be accurately classified with reasonable cost).

III. QA PLANNING FOR THE SITE VISITS

Prior to the in-plant personal and area monitoring, various activities were conducted to ensure the quality of the data. The questionnaire for the in-plant monitoring study was designed and tested in a pilot site. The various quality control activities for the site visits and the chemical analysis were completed.

A. Optimizing the Monitoring Participation Rate

One of the most critical components of a sound study is a high participation rate, since each refusal can add an uncontrolled bias to the results. In conformance with government standards and good scientific practice, a target of 75-80% participation was set. However, due to the inherent complexity of this particular study, characterized in large part by the fact that it was a voluntary program, obtaining participation rates lower than the target was considered quite likely.

A total of 62 plants was selected at random to be contacted for in-plant monitoring. To encourage a high participation rate, all selected companies were contacted prior to initiation of the site visits. A carefully crafted letter was sent by ATMI describing the study, guaranteeing confidentiality for the participants, asking for permission to monitor, and describing the potential benefits of their participation (in an industry-wide sense, and with respect to free plant monitoring and written reports on the site visit).

Where initial resistance to participation was encountered, the following actions were options to improve the response rate:

- Other appropriate trade groups, e.g., the Carpet and Rug Institute (CRI), the National Association of Hosiery Manufacturers (NAHM), or the Carpet Manufacturers Association of the West (CMAW) were asked to contact plants and encourage them to participate.

- Personal contact was made with the Chief Executive Officer (CEO) or other high official of the selected company, by a CEO or other high official of an ETAD firm participating in the study.

These letters are included in this report in Section C of the Supplement.

The actual response rates achieved for this stage of the study are shown in Table 3-1.

Table 3-1

PHASE II PARTICIPATION RATES

Stratum	Number Eligible*	Number Monitored	Percent
A. Respondents to Mailed-Out Survey	23	15	65
B. Nonrespondents to Mailed-Out Survey	29	9	31
Total	52	24	46

*This number excludes two sites contacted which agreed to be monitored but then were not (see discussion in Chapter 4) and eight sites which were found to be ineligible because they had gone out of business or did not weigh powder dyes manually.

Table 3-1 reveals that the actual participation rate was 46%, lower than the target of 75-80%. A participation rate this low leaves open the possibility of bias in estimates produced by the survey, although precision of estimates is preserved. There was no appreciable difference in estimates of airborne dye concentration for the respondents and nonrespondents to the first phase questionnaire (discussed in Chapter 7), which was taken as an indication that nonparticipation in phase two of the study might not introduce a bias. Unfortunately, the nature of nonparticipation is such that conclusions as to the impact on estimates produced cannot be drawn.

B. <u>Quality Assurance for On-Site Visits</u>

The major steps for assuring quality for on-site visits were:

- Detailed planning of the site visit protocol; and
- QA visits by EPA team members during on-site visits.

1. <u>Protocol</u>

The details of the protocol for site visits are described in Chapter 5 of this report and will not be presented here. The reader is referred to Section E of the Supplement for the form used by industrial hygienists during the on-site visits.

2. Quality Assurance Visits

To assure that all procedures defined in the QAPPs were followed, three QA visits were made by the EPA team. This allowed a further characterization of the data collected, especially in terms of site variability. One site visit each was conducted by FSB, DDB, and CEB.

The results of the QA site visits were summarized as trip reports with the following observations:

- The selection of the shift and/or the weighers was done according to protocol.
- All air sampling instruments were calibrated prior to field use.
- The personal samplers operated at a flow rate between 2.0 and 2.5 L/min.
- The area sampling pumps operated at a flow rate between 10.1 and 12.6 L/min.
- The area samplers were located according to the study protocol.
- Correct labeling of each container of bulk dye used during the sampling period was verified and identified on the field sampling form.
- Bulk dyes were collected in an unobtrusive way, with care taken to limit dust generation.
- All entries into and exits out of the drug room by weighers were recorded.
- The name of the dye was recorded for all weighings and cross-checked with the bulk dye sampled.
- Management representatives and the weighers were informed of the objectives of the study prior to sampling.
- To the maximum extent practicable, the work activities of the weighers were not altered or interrupted by the visiting industrial hygienists.

IV. QUALITY ASSURANCE FOR THE ANALYTICAL METHODOLOGY

The quality control program relating to the analytical methodology used in measuring airborne dye concentrations included the following four main components:

1. Preparation of a QAPP;

2. System audits conducted by the quality control coordinator at MRI;

3. Periodic analysis of performance audit samples (PAS); and

4. Audit by the QA Coordinator.

For a detailed description of these components, please refer to Appendix C.

V. CONSTRUCTION OF THE COMPUTER DATA BASE

The data collected in the field and in the laboratory were forwarded to WCG and to CEB. WCG entered some of the information provided by MRI on the dye concentrations observed in the laboratory for each of the participants. CEB entered the data from the on-site monitoring field visits on a PC-based spreadsheet and forwarded this file to WCG. The data were verified again by WCG personnel to ensure that no errors in data entry were made. A SAS data base was created by uploading the data from the PC-based spreadsheet to the EPA mainframe.

Chapter 4

SURVEY DESIGN AND SAMPLE SELECTION

I. DEFINITION OF TARGET POPULATIONS

Two target populations were defined for the study. The first consisted of textile dyeing plants where powder dyes are weighed, and the second consisted of workers who weigh powder dyes. These workers have the potential for inhalation and dermal exposure to powder dyes; however, this study concentrated on inhalation exposure only. Population estimates, required for both target populations, were derived from the sample data by the use of appropriate sample weights, derived from the properties of the sample design described in Section II, following. A discussion of sample weights for the plant and worker populations is contained in Section III.

II. SAMPLE DESIGN

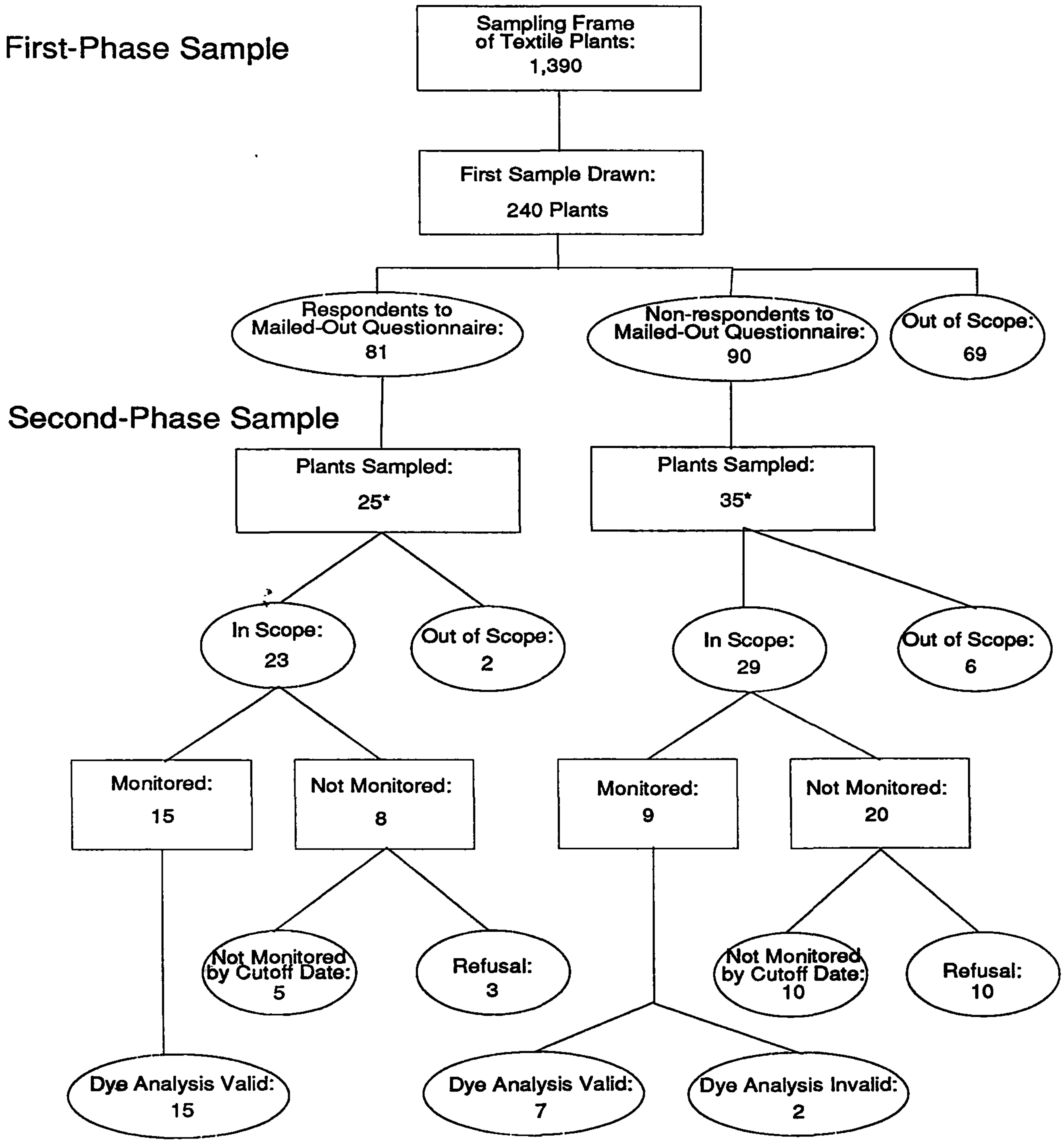
A two-phase survey design was used for the study. For the first phase the goals were to (a) ensure the accuracy of the frame; (b) provide valuable general information on textile wet processing operations including data useful to industrial hygienists in preparing for in-plant monitoring; and (c) obtain information for use during the second phase of the study. The primary goals of the second phase included breathing zone monitoring of the worker conducted in-plant, recording of typical worker activities, and characterization of industrial hygiene practices. Figure 4-1 displays the two-phase plant selection process; the following subsections describe the design in detail.

A. First-Phase Sample

Of the 1,390 plants in the United States with the potential for weighing textile dyes, 240 were chosen by simple random sampling. Telephone calls were made to all 240 units to determine eligibility for inclusion in the survey. Eligibility depended on the plant still being in the business of dyeing or printing textiles using manually weighed powder dyes. The current address was confirmed. Of the 240 contacted, 171 sites were found eligible. Questionnaires were mailed to each; a copy can be found in Section D of the Supplement. The questionnaire requested information on the location of the facility; its ownership (public or private); type of operation (vertical or commission); product lines; the fibers processed on site; classes of powder (solid) dyes weighed; number and type of dyeing or printing equipment used; frequency and volume

Figure 4-1

TEXTILE DYEING ROOM MONITORING STUDY SAMPLING EXPERIENCE



*Does not include one plant in each category which had agreed to be monitored but was not (see Table 4-1).

of powder dye handled; and presence or absence of drug room exposure controls when powder dyes are weighed.

Of 171 plants queried, 81 responded, and 90 failed to respond by the predetermined cutoff date, producing a response rate of 47%.

B. Second-Phase Sample

The sample for the second phase of this study was drawn as a subsample of those included in phase one. Of several options considered for the design of the subsample, response to the mailed questionnaire or lack thereof were selected as the only strata. This stratification plan was selected because it:

- Allowed measurement of differences in the nature of exposure levels between first-phase respondents and nonrespondents;
- Ensured that the final representation from the two groups reflected the actual population of dyeing plants; and
- Reduced the impact of refusal for in-plant monitoring bias (the act of responding to the questionnaire is seen to separate the two groups based on the likelihood of in-plant monitoring being allowed and thus reducing the refusal bias in the second phase).

The stratification plan resulted in demonstration of the two strata shown in Figure 4-1. Stratum A contained the 81 plants that responded and Stratum B contained the 90 nonrespondents to the mailed-out survey.

The sample size for in-plant monitoring was initially set at 30 but later reduced to 24, based on a combination of concern for statistical accuracy and the limits of the EPA budget for in-plant monitoring. Fourteen plants out of a total of 81 were to be drawn from Stratum A, and 16 plants out of a total of 90 were to be selected from Stratum B.

While 30 plants were targeted for monitoring, the problem of scheduling on-site visits and the likelihood that some plants would refuse to participate, dictated a strategy of over-sampling, so that 62 plants were contacted. The results of sampling at this stage are summarized in Table 4-1. Within Stratum A, 26 plants were contacted. Of these, two were judged ineligible based on new information that was not obtained through the initial telephone contact, and one which agreed to participate was not visited. Within that group of remaining plants which were contacted, 15 sites were monitored.

Table 4-1

BREAKDOWN OF SAMPLING FOR SITE VISITS: RESPONSE TO SURVEY

	Respondent	Nonrespondent	Total
A. Monitored sites	15	9*	24
B. Refused to allow monitoring	3	10	13
C. Willing to be monitored, not called upon**	1	1	2
D. No response--early selection but not pinned down	2	2	4
E. Not resolved--late selection--little or no communication	3	8	11
F. Ineligible	2	6	8
Total	26	36	62

*Exposure level data for two sites were unusable because of analytical complications. See Appendix C.

**These two plants were not visited because of time and monetary constraints.

In Stratum B, 36 plants were contacted. Six were judged to be ineligible, and one which had agreed to participate was not visited. Within the group judged to be eligible in Stratum B, 9 plants were monitored.

Response rates can easily be derived from Table 4-1. Response rate is defined as the number of plants monitored divided by the total of number of plants which are in scope. "In scope" indicates that the plants were engaged in textile dyeing operations which required manual weighing of powder dyes. In each stratum, there was one plant that agreed to be monitored, but which was not monitored because of time and cost constraints. These two plants were also excluded from the "in scope" category because their data were not included in the numerator of the response rate fraction. For stratum A, 15 plants were monitored from a total of 23 eligible plants resulting in a response rate in that stratum of 65%. In stratum B, 9 were monitored out of 29 eligible resulting in a stratum response rate of 31%. The overall response rate was 46%.

1. In-Plant Monitoring

A two-member team conducted an on-site survey of dye weighing operations at each plant and recorded measurements and observations on a questionnaire (see Section E of the Supplement). One worker from each plant was monitored. The shift and the particular worker within the shift to be monitored were selected at random following the procedure specified in the QAPPs. Field sampling procedures are described in Chapter 5, and the QAPP is described in Section A of the Supplement.

III. DYES STUDY WEIGHTING SCHEME

Estimates of the parameters of the target populations of plants and workers were developed using sample weights appropriate for each population. Because there are two separate target populations, textile plants and dye workers, estimates for total numbers of plants and estimates for total numbers of workers in a particular category must be developed separately. Consider first estimates for numbers of plants. The original intention was to have 14 plants monitored in Stratum A and 16 in Stratum B. Since these numbers are roughly in the proportion of the populations of interest (81 in A and 90 in B), the resulting sample would have been a self-weighting sample. As discussed earlier in this chapter and illustrated in Table 4-1, the actual numbers in the sample turned out to be different from the targeted numbers due to differential levels of nonparticipation in the two strata. In such situations it is required to develop a "nonresponse adjustment" factor to account for the fact that the numbers of sample units in Stratum A and Stratum B are not in proportion to the numbers for those two groups in the population as a whole. If estimates were produced without using a weighting adjustment, the resulting estimators could be biased. Bias is introduced as follows. Stratum A represents 81 out of 171 or 47.4% of the population as a whole. However, 15 out of 24 (or 62.5%) in the sample are in Stratum A. When estimates within these two strata differ in a substantial way, a biased estimate for the overall population could be produced unless a weighting adjustment is used. Therefore, all estimates included in this report of quantities for the universe of textile dyeing plants are calculated using the nonresponse adjustment to produce a weighting scheme.

For estimates produced for the population of dye weighers it is even more crucial to apply a carefully designed weighting scheme, because only one dye weigher was monitored at each site. In such a situation, the single worker represented all weighers at a site. Total numbers of weighers per plant varied in this data base from one to eight. Without accounting for the differences between plants due to the number of weighers, a biased estimate could be produced.

The last point can be illustrated by an example. The assumptions used are that there were only two plants in the entire population--one large and one small; that the large plant had four weighers and the small plant only one weigher; and that the exposure of the worker sampled at the large plant was small, say 0.01 mg/m^3, while the exposure at the small plant for the worker monitored was large, 0.31 mg/m^3. Using the arithmetic average of the two values (0.16 mg/m^3) as the estimator for the mean exposure of weighers is obviously biased. Too much "weight" is given in this case to the worker at the small plant. If, however, the measurements in each plant are weighted by the number of workers as follows:

$$[4 \times (0.01\ mg/m^3) + 1 \times (0.31\ mg/m^3)] / (4 + 1) = 0.07\ mg/m^3,$$

the weighted mean value produced is more representative of the average of the population of five weighers, which is the target population. The above calculation is the essence of the weight adjustment for "workers" which we define below. Consequently, all estimates for the universe of weighers will be weighted using the "worker" adjusted weights.

Each set of weights was obtained using a careful accounting of the number of textile plants in the original sampling frame and the number sampled. In addition, the set of weights derived for the dye workers was based on the total number of weighers working normally at each plant on any given day, a figure provided by management during the site visit.

A. <u>Calculation of Plant-Level Weights</u>

Plant-level and worker-level weights are listed in Table 4-2. The plant-level weights were computed as the reciprocal of the probability of being selected for inclusion in the study. The probability calculation can be easily tracked by reference to

Table 4-2

SAMPLE WEIGHTS FOR CALCULATING POPULATION ESTIMATES

	Weights for Estimates Based on 22 Plants*		Weights for Estimates Based on 24 Plants**	
Site	Plant Weights	Worker Weights	Plant Weights	Worker Weights
10	28.77	172.64	28.77	172.64
16	28.77	86.32	28.77	86.32
21	61.70	185.10	47.99	143.96
24	61.70	61.70	47.99	47.99
27	61.70	246.80	47.99	191.95
30	28.77	172.64	28.77	172.64
33	28.77	172.64	28.77	172.64
38	28.77	86.32	28.77	86.32
41	61.70	123.40	47.99	95.98
43	28.77	172.64	28.77	172.64
46	28.77	57.55	28.77	57.55
49	28.77	86.32	28.77	86.32
52	28.77	57.55	28.77	57.55
54	28.77	115.09	28.77	115.09
59	28.77	86.32	28.77	86.32
62	61.70	185.10	47.99	143.96
65	61.70	123.40	47.99	95.98
66			47.99	287.93
77			47.99	143.96
79	28.77	28.77	28.77	28.77
80	28.77	230.18	28.77	230.18
86	61.70	123.40	47.99	95.98
88	28.77	86.32	28.77	86.32
91	28.77	28.77	28.77	28.77

*Commercial and active dye concentrations were obtained from 22 plants. Population estimates for plants and workers are based on these weights for 22 plants.

**Total dust concentrations were measured in 24 plants. Population estimates for plants and workers are based on these weights for 24 plants.

Figure 4-1. Consider first the probability (P) of selection of the final 15 from Stratum A:

$$P(\text{selection}) = (240/1390)(25/81)(15/23) = 0.0348.$$

Therefore, the weight for these cases is 1/0.0348 = 28.77.

For Stratum B, the calculation is:

$$P(\text{selection}) = (240/1390)(35/90)(9/29)(7/9) = 0.0162.$$

The resulting weight is 1/0.0162 = 61.70. These weights are constant for each element in the stratum, as always for stratified samples.

B. Calculation of Worker-Level Weights

The worker-level weights (WGT_{worker}) are defined as the product of the weight for the plant (WGT_{plant}) times the total number of weighers at the plant during a typical day (NW). Thus, the general formula for worker weights is:

$$WGT_{worker} = (WGT_{plant})(NW).$$

Unlike plant-level weights, it is possible for worker-level weights to differ for each element in a stratum of the sample, if the number of workers differs across plants in each stratum.

Chapter 5

FIELD SAMPLING PROCEDURES

I. IN-PLANT OBSERVATION PROCEDURES

The purpose of each site survey was threefold: (1) to conduct personal and area industrial hygiene air monitoring to determine the potential for textile worker exposure to airborne dye particulates associated with the weighing and mixing of powder dyes; (2) to determine the dye weighers' assigned duties and to observe their activities in the performance of those duties; and (3) to record drug room and general facility characteristics for use in the evaluation of drug room operational factors which may affect the potential for worker exposure.

The on-site activities were performed by a field survey team consisting of two board-certified[1] industrial hygienists, one from Health and Hygiene, Inc. (HHI), representing ATMI and ETAD, and one from PEI Associates, Inc., representing EPA. Prior to each monitoring survey, the survey team conducted a presurvey meeting with company representatives at each site, during which they described the objectives of the study and the procedures that would be followed during the site survey. A synopsis of the plant operations was provided by the plant supervisor at that time.

During each monitoring survey, the survey team followed a prescribed procedure for taking measurements and making related observations of the dye weighing activities and the general facility operation. Personal and area air monitoring was conducted over approximately an 8-hr period during a single work shift at each facility. All facility information and observations were recorded on standard site survey forms developed for this study (see Section E of the Supplement). The facility characteristics, sampling area characteristics (including a sketch of the drug room area and materials flow patterns), the number of dyeing/printing units (available and in operation), the overall appearance of the monitored area, and the engineering controls in place were recorded. Also recorded were the number of dye weighers employed at the facility and the survey team's observations of employee work practices and use of personal protective equipment. A record was made of the number of weighings and mass weighed of each powder dye and chemical that was weighed by the person monitored. A work history was taken of each monitored dye weigher.

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[1]American Board of Industrial Hygiene.

II. DYE COLLECTION PROCEDURES

A. Industrial Hygiene Air Monitoring

The air monitoring was conducted using standard industrial hygiene sampling equipment. The personal sampling train used in the surveys consisted of an open-faced filter[2] connected to a Gilian personal sampling pump with a length of Tygon tubing. The pumps were calibrated to a prescribed flow rate of approximately 2 L/min. The flow rates and start and stop times of the sampling pumps were recorded on air sampling data sheets. The individual (dye weigher) to be monitored was selected in accordance with the method described in the QAPPs (see Section A of the Supplement). One dye weigher was monitored for one work shift per site, except at Site 5/4.[3] The monitored dye weigher at each site wore two sampling trains, with inlets located in the worker's breathing zone on each lapel. Two area samples were collected at each site on a similar sampling train with stationary high-volume pumps calibrated to a flow rate of 5 to 12 L/min, which exceeded slightly the recommended flow rate in the QA report of 5 to 8 L/min. One area sampling apparatus was located near the drug room weighing station and the other in the dye drum storage area within the drug room, in an area remote from where the monitored dye weigher was most active.

All samples (personal and area) were collected for approximately an 8-hr period. Sampling time intervals were recorded on the appropriate air sampling data sheets. Temperature, relative humidity, and barometric pressure measurements of the drug room were monitored and recorded hourly during most of the monitoring surveys. When barometric pressure was not recorded during the monitoring period, it was later obtained by contacting the weather station at the local airport for that facility.[4] Field blanks, which were

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[2]The filter used was a Metricil VML polyvinyl chloride 37-mm-diameter filter with a 5-μm pore size, manufactured by Gelman Filtration Products.

[3]At Site 5/4, two dye weighers were monitored consecutively over the latter part of the first work shift (3 p.m. to 7 p.m.) and the start of the second work shift (7 p.m. to 11 p.m.) of two 12-hr shifts. Both monitored workers wore the same sampling apparatus so that the samples would be obtained over a consecutive 8-hr time period.

[4]The failure to record data was usually the result of communication breakdown or equipment malfunction.

handled in the same manner as the sampling filters except that no air was drawn through them, were also submitted for analysis.

Although the sampling protocol described above was followed in general at each of the monitored sites, slight deviations did occur, most notably at Sites 5/4 and 7/7. At Site 5/4, previously mentioned practical problems associated with scheduling required sampling over two shifts. At Site 7/7, the personal samples were obtained with closed-faced filter cassettes. Work practices at this site resulted in excessive spraying of water. The survey team felt that this precaution was necessary in order to avoid aspiration of water and complete invalidation (or destruction) of the sample. In addition, one of the filter cassettes used at Site 7/7 fell off the sampling train and was inadvertently inserted in a backward position by the dye weigher where it remained for 30 minutes of the monitoring period before the survey team discovered the error and returned the cassette to its correct position.

B. Dye Bulk Sampling

Bulk samples of the dyes weighed during each monitoring period were obtained during each of the site surveys. Samples of each dye were placed in special containers[5] and labeled with the following information: bulk sample identification number, dye name, dye manufacturer, name of the drug room operations and operator, name of the person responsible for obtaining the sample, and the date the sample was collected. The survey team recorded the bulk sample identification number, batch ticket name, full trade name, batch or lot number, and supplier name for each bulk sample on the appropriate site survey form. After the survey, bulk samples were forwarded to the laboratory for analysis.

[5]The bulk samples were collected in 2- to 4-ounce glass or nonreactive plastic containers, amber in color (to screen degradative light), which were purchased by Health and Hygiene, Inc.

Chapter 6

ANALYTICAL METHODOLOGY

I. INTRODUCTION

An analytical method was needed for very complex samples containing trace levels of textile dyes. Conventional methods of dye quantitation would probably have required much longer analysis times and might not have permitted a complete analysis of the very complex samples. The requirements of the analyses encountered in the drug room survey necessitated the development of a novel analytical technique to ensure that the requirements of the study could be achieved. This new technique arose from the conclusion that sample complexity would preclude the determination of individual dye concentrations. The method therefore focused on making an estimate of the *total* amount of dye present on air filters.

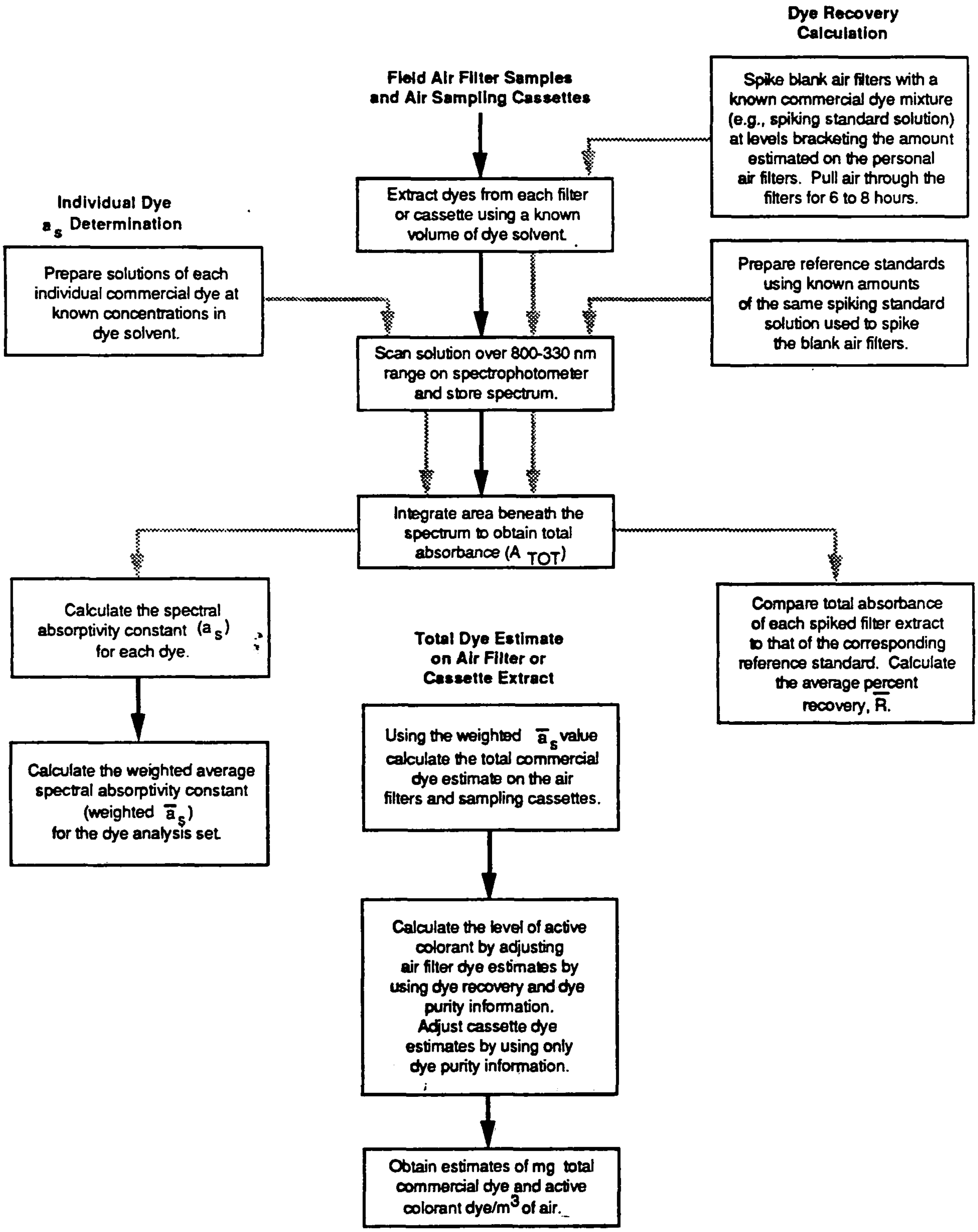
II. SCOPE OF THE METHOD

The method which was developed is basically a spectrophotometric procedure. The spectral absorptivity (a_s) constant of each individual dye handled by the monitored worker is determined. The analytical method uses a weighted average of the individual dye a_s constants to represent the a_s constant of the mixture of dyes trapped on the air filter. This average absorptivity is divided into the total absorbance measured for the filter extract to estimate the amount of dye material on the filter. The average extraction efficiency (adjustment for recovery) of the dyes from the air filters is determined by spiking a known dye mixture onto a blank air filter and exposing the filter to constant temperature, humidity, and fluorescent lighting for 8 hr. After exposure, the spiked air filter is extracted and the total absorbance is compared to that of a reference standard solution which contains an identical quantity of the dye mixture and has undergone the same exposure conditions. This dye recovery determination is then employed in the dye estimate calculation to correct for dye losses in the filter extraction process. The steps involved in the analytical procedure for air filters, bulk dyes, and spiked air filters are outlined in Figure 6-1.

A solution of dimethyl sulfoxide (DMSO) and pH 7.0 buffer (9:1, v/v) was used to extract all air filters and dissolve all bulk dye samples. With the exception of the trial plant and the first three plant sites in the study, all absorbance measurements were taken from 45 to 60 minutes after initial contact with the dye solvent.

Figure 6-1

FLOW CHART FOR THE ESTIMATION OF TOTAL DYES ON AIR FILTER



The instrumentation which was employed in the analyses consisted of a dual-beam spectrophotometer and a microcomputer-based chromatography data system.

Confidence intervals for the total dye estimates and estimated average airborne total dye concentrations were obtained through a microcomputer-based simulation program. This program simulated probable dye mixtures which could occur at a particular plant site. By performing a statistical analysis on the simulated probable dye mixtures which were generated, the uncertainty of the total dye estimate could be evaluated for each plant site, and confidence intervals could be assigned around the point estimate.

The procedure was evaluated prior to commencing the full-scale study using known quantities of 20 commercial dyes representing the five most frequently used classes. The relative error for total dye measured was found to be within ± 40%. This level of accuracy was determined to be acceptable for the purpose of this study, although it should be emphasized that this figure is not necessarily representative for all 24 plant sites in the study. The levels of accuracy for the analytical method can be so variable that a general value for the accuracy cannot be stated prior to obtaining information about the absorption characteristics of the specific dyes being analyzed.

Analytical difficulties were encountered for samples from three of the plant sites, but most of those problems occurred in the case of dye classes that had never been analyzed using the established procedure. When it was observed that triphenyl methane (TPM) basic dyes reacted with a component of the solvent, the procedure was modified. In addition, a few infrequently used classes of dyes cannot be measured by this procedure. The insolubility of vat and sulfur dyes and the reactivity of naphthol dye components in the solvent mixture precluded analytical detection. However, the analytical method was successful overall in meeting the study objectives.

III. DYE PURITY ADJUSTMENT

In addition to adjustments made based on extraction efficiency discussed earlier (Section II), adjustments were also required to account for dye purities. These are discussed briefly below. Table C-5 in Appendix C contains estimated dye purities for all dyes weighed at the 24 sites included in the survey.

The response of textile dyes to the analytical method is directly proportional to the purity of the measured dyes. Correcting for the dye purity, or active colorant content of each textile dye was therefore required to compensate for the significant variability in purity values which occurs from class to class, as well as within any particular dye class. The active colorant content of the textile dyes handled by the monitored workers was obtained from dye manufacturers by ETAD. In circumstances where dye purity information was not readily available, ETAD provided an estimate of the active colorant content.

IV. DETAILED DISCUSSION OF THE ANALYTICAL METHODOLOGY

Appendix C of this report contains a detailed discussion of the development of the analytical methodology including the theoretical basis, the description of the statistical methods used to produce confidence bounds about dye concentration values for individual sites, the quality control procedures in place for the analytical work, and further discussion of the methodology used.

Chapter 7

DATA ANALYSIS AND RESULTS

I. INTRODUCTION

Tables 7-1, 7-2, and 7-3 contain the air monitoring results for the 24 sites included in the survey. The tables list gravimetric mass of total dust, airborne concentrations of commercial dyes, and airborne concentrations of active colorants.[1] Total dust measurements were available at all 24 sites, while commercial dye and active colorant concentrations were available at 22 sites. In the three tables, results are shown for the four separate monitors used at each site and described in Section 5.I.A. Two personal monitors (denoted A and B) were worn by the selected dye weigher. The other two monitors were located in stationary positions: one at the weigh station and one at a remote storage area. The statistical analysis in this chapter is confined to the personal monitoring data, specifically, the average of monitors A and B.

Section II of this chapter presents a statistical analysis of the concentration data in Tables 7-1, 7-2, and 7-3. Survey-based estimates are provided for the population mean, median, standard deviation and selected percentiles of concentration, for both commercial dye and active colorant. Selected confidence intervals are also presented. Section III concerns tabulation of dye concentrations broken down by various categorized variables collected during the on-site monitoring. Section IV contains an analysis of the correlation of concentration data with factors (such as Mass of Dye Weighed and Number of Weighings) suspected a priori to influence concentration. Finally, Section V presents a discussion of the regression procedures.

II. ANALYSIS OF CONCENTRATION DATA

A. Statistical Methodology

Since only 22 values for airborne dye concentration were available, and it was desired to estimate upper percentiles of concentration, a model-based analysis of the data was considered the most appropriate approach. In a model-based approach, the lognormal

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[1]Dye concentrations represent the total amount found on the air filter and its associated plastic cassette. Dust concentrations represent the amount found on the air filter alone.

Table 7-1

GRAVIMETRIC WEIGHT OF TOTAL DUST PER VOLUME OF AIR SAMPLED

(mg/m^3)

	Personal Filters*			Area Filters	
Site	(A)	(B)	Average	Weigh Station	Remote Area
1/0	0.75	0.70	0.73	0.31	0.19
1/6	0.27	0.23	0.25	0.15	0.04
2/1	1.07	0.82	0.94	0.17	0.14
2/4	0.30	0.33	0.31	0.15	0.10
2/7	0.48	0.44	0.46	0.23	0.25
3/0	0.47	0.35	0.41	0.30	0.09
3/3	0.18	0.09	0.13	0.05	0.05
3/8	0.26	0.33	0.29	0.16	0.21
4/1	0.74	0.73	0.73	0.59	0.19
4/3	0.62	0.24	0.43	0.09	0.05
4/6	0.37	0.57	0.48	0.47	0.11
4/9	1.71	1.04	1.37	0.47	0.12
5/2	0.33	0.40	0.36	0.30	0.15
5/4	0.02		0.02	0.04	0.04
5/9	0.44	0.22	0.33	0.12	0.05
6/2	0.30	0.25	0.27	0.15	0.04
6/5	0.52	0.53	0.53	0.14	0.14
6/6**	1.08	0.49	0.77	0.07	
				0.36	
7/7	0.29	0.26	0.27	0.08	0.06
7/9	0.20	0.18	0.19	0.11	0.10
8/0	0.22	0.20	0.21	0.13	0.16
8/6	0.49	0.62	0.55	0.11	0.23
8/8	0.52	0.55	0.53	0.16	0.16
9/1	0.45	0.45	0.45	0.28	0.18

*(A), Personal Canister A; (B), Personal Canister B.

**The area monitors were placed at two separate weigh stations in the two adjacent drug rooms. The dye weigher weighed dyes at both weigh stations during the shift.

Table 7-2

SPECTROPHOTOMETRIC ESTIMATES OF THE AVERAGE AIRBORNE CONCENTRATION OF COMMERCIAL DYE

(mg/m^3)

	Personal Filters*			Area Filters	
Site	(A)	(B)	Average	Weigh Station	Remote Area
1/0	0.46	0.46	0.46	0.20	0.10
1/6	0.16	0.16	0.16	0.12	0.00
2/1	0.02	0.02	0.02	0.11	0.00
2/4	0.08	0.15	0.12	0.01	0.01
2/7	0.08	0.09	0.08	0.07	0.06
3/0	0.27	0.35	0.31	0.30	0.05
3/3	0.02	0.02	0.02	0.01	0.00
3/8	0.18	0.14	0.16	0.07	0.07
4/1	0.12	0.14	0.13	0.37	0.09
4/3	0.08	0.04	0.06	0.04	0.01
4/6	0.09	0.08	0.09	0.15	0.02
4/9	1.43	0.97	1.20	0.30	0.05
5/2	0.07	0.07	0.07	0.25	0.09
5/4	0.03	0.03	0.03	0.02	0.01
5/9	0.08	0.05	0.07	0.07	0.01
6/2	0.22	0.14	0.18	0.08	0.01
6/5	0.09	0.11	0.10	0.04	0.01
6/6					
7/7					
7/9	0.01	0.01	0.01	0.01	0.00
8/0	0.05	0.03	0.04	0.03	0.04
8/6	0.47	0.56	0.51	0.09	0.16
8/8	0.10	0.10	0.10	0.11	0.03
9/1	0.20	0.24	0.22	0.16	0.01

*(A), Personal Canister A; (B), Personal Canister B.

Table 7-3

SPECTROPHOTOMETRIC ESTIMATES OF THE AVERAGE AIRBORNE CONCENTRATION OF ACTIVE COLORANT

(mg/m^3)

	Personal Filters*			Area Filters	
Site	(A)	(B)	Average	Weigh Station	Remote Area
1/0	0.22	0.22	0.22	0.09	0.05
1/6	0.09	0.09	0.09	0.07	0.00
2/1	0.01	0.01	0.01	0.06	0.00
2/4	0.05	0.10	0.08	0.01	0.01
2/7	0.04	0.05	0.04	0.03	0.03
3/0	0.09	0.11	0.10	0.09	0.01
3/3	0.01	0.01	0.01	0.00	0.00
3/8	0.09	0.07	0.08	0.03	0.03
4/1	0.06	0.07	0.06	0.18	0.04
4/3	0.04	0.02	0.03	0.02	0.01
4/6	0.06	0.06	0.06	0.10	0.01
4/9	0.66	0.45	0.56	0.14	0.03
5/2	0.06	0.05	0.06	0.19	0.07
5/4	0.01	0.01	0.01	0.01	0.00
5/9	0.02	0.02	0.02	0.02	0.01
6/2	0.07	0.04	0.06	0.03	0.00
6/5	0.07	0.09	0.08	0.03	0.01
6/6					
7/7					
7/9	0.01	0.01	0.01	0.00	0.00
8/0	0.01	0.01	0.01	0.01	0.01
8/6	0.17	0.21	0.19	0.03	0.06
8/8	0.02	0.02	0.02	0.03	0.01
9/1	0.09	0.10	0.09	0.07	0.01

Note: Spectrophotometric analysis calculated on the basis of the best estimate of dye purities.
*(A), Personal Canister A; (B), Personal Canister B.

distribution is considered a good approximation to the data, as in many environmental studies. Using the mean and standard deviation of the data collected at the 22 plants, the upper percentiles were calculated on the basis of the fitted distribution. For simplicity, model determination was done using the raw, unweighted data, as discussed in Section V of this chapter. This approach greatly simplifies the statistical calculations and is considered to be an excellent approximation (since, as discussed in Chapter 4, the maximum disparity between plant-level sampling weights was at most roughly a factor of 2: 28.8 for the "respondent" stratum and 61.7 for the "nonrespondent" stratum; worker-level weights were only slightly more variable).

Figure D-1 in Appendix D shows a normal probability plot of the airborne commercial dye concentration data from Table 7-2. A Kruskal-Wallis test[2] rejected the hypothesis that the data came from a normal distribution, with a p-value less than 0.01. Indeed, the plot shows the characteristic concave shape that one would expect if the underlying distribution were lognormal rather than normal. This is confirmed by Figure D-2 in Appendix D, which shows a normal probability plot of the (natural) logarithm of the data. The plot closely approximates a straight line, indicating that the logarithm of the data is normally distributed, i.e., the data itself is lognormally distributed. This is confirmed by a Kruskal-Wallis test of the log data, which does not indicate any significant departure from normality, with $p = 0.98$. Similar results were obtained for the active colorant data.

It was concluded, based on the above considerations, that the data for both active colorant and commercial dye follow a lognormal distribution. This distribution is characterized by the two parameters m and s. If Y follows a lognormal distribution, then m is the mean value of log(Y) and s is the standard deviation of log(Y). The mean value of Y itself is:

$$v = \exp\ (m + s^2/2) \quad ,$$

while its standard deviation is:

$$u = v(\exp(s^2) - 1)^{0.5} \quad .$$

The median of Y is exp(m), while the *q*th percentile of Y is exp(m + zs), where z is the *q*th percentile of the standard normal distribution. These formulas were applied as follows. First, a

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[2]Daniel WW. 1978. <u>Applied Nonparametric Statistics</u>. Boston: Houghton Mifflin, p. 200.

standard statistical software package, the Statistical Analysis System (SAS),[3] was used to compute weighted means and standard deviations on the log scale for active colorant and commercial dye concentration at both the plant and worker level. The weights used were those described in Chapter 4. In other words, the assumed lognormal distribution was fitted using the appropriate weights for the data. The above formulas were then applied to estimate mean, median, standard deviation, and 85th, 90th, and 95th percentiles on the scale of the original measurements.

Next, it was of interest to compute approximate confidence intervals for the mean concentration and for the upper percentiles of concentration. The details of the computation of these confidence intervals are provided in Appendix D.

B. Results

Tables 7-4, 7-5, 7-6, and 7-7 summarize the results of applying statistical analysis to the airborne dye concentration data. Recalling that airborne dye concentration estimates represent a composite of all dyes used at plants monitored and not any individual dye, the following observations can be made. First, there is little difference between estimated concentration at the plant and worker level for either active colorant or commercial dye. Estimates weighted by plant are very slightly higher, perhaps indicating that plants with more weighers tend to exhibit slightly lower concentrations; however, this effect could also easily be explained by sampling variability alone. Secondly, airborne dye concentrations for commercial dye are consistently roughly twice the corresponding values of active colorant. The specific factor difference between concentration for active colorant and commercial dye can be interpreted as saying that the average strength of commercial dye preparations is approximately 50%. Thirdly, the estimated confidence intervals for the high percentiles do not appear to be so wide as to preclude the use of these percentiles for regulatory purposes.

The estimates contained in Tables 7-4 through 7-7 can also be calculated using simple unweighted estimates, as shown in Tables 7-8 and 7-9. A comparison was made between the weighted and unweighted estimates to provide a check of the possible nonresponse bias that was noted as a cause of concern in Chapter 4. Comparison demonstrated that the unweighted values were close to the weighted estimates for all variables in the tables; they were generally

[3]SAS Institute, Inc. 1985. SAS User's Guide, Version 5. Cary, NC: SAS Institute, Inc.

Table 7-4

AIRBORNE CONCENTRATION OF TOTAL COMMERCIAL DYE BY PLANT

	Concentration (mg/m^3)	95% Confidence Interval
Median	0.11	
Geometric Standard Deviation	2.80	
Mean	0.18	(0.11, 0.31)
Standard Deviation	0.26	
Percentiles		
85th	0.31	(0.18, 0.53)
90th	0.39	(0.22, 0.70)
95th	0.57	(0.29, 1.11)

Table 7-5

AIRBORNE CONCENTRATION OF TOTAL COMMMERCIAL DYE BY WEIGHER

	Concentration (mg/m^3)	95% Confidence Interval
Median	0.10	
Geometric Standard Deviation	2.90	
Mean	0.17	(0.10, 0.30)
Standard Deviation	0.25	
Percentiles		
85th	0.30	(0.17, 0.52)
90th	0.38	(0.21, 0.70)
95th	0.57	(0.29, 1.14)

Table 7-6

AIRBORNE CONCENTRATION OF TOTAL ACTIVE COLORANT BY PLANT

	Concentration (mg/m^3)	95% Confidence Interval
Median	0.049	
Geometric Standard Deviation	2.849	
Mean	0.085	(0.049, 0.147)
Standard Deviation	0.12	
Percentiles		
85th	0.15	(0.086, 0.26)
90th	0.19	(0.10, 0.34)
95th	0.27	(0.14, 0.53)

Table 7-7

AIRBORNE CONCENTRATION OF TOTAL ACTIVE COLORANT BY WEIGHER

	Concentration (mg/m^3)	95% Confidence Interval
Median	0.042	
Geometric Standard Deviation	3.075	
Mean	0.079	(0.043, 0.145)
Standard Deviation	0.12	
Percentiles		
85th	0.13	(0.072, 0.23)
90th	0.18	(0.095, 0.34)
95th	0.27	(0.13, 0.56)

Table 7-8

AIRBORNE CONCENTRATION OF TOTAL COMMERCIAL DYE (UNWEIGHTED ESTIMATES)

	Concentration (mg/m^3)	95% Confidence Interval
Median	0.10	
Geometric Standard Deviation	3.03	
Mean	0.19	(0.11, 0.34)
Standard Deviation	0.29	
Percentiles		
85th	0.32	(0.18, 0.57)
90th	0.42	(0.22, 0.79)
95th	0.63	(0.31, 1.29)

Table 7-9

AIRBORNE CONCENTRATION OF TOTAL ACTIVE COLORANT (UNWEIGHTED ESTIMATES)

	Concentration (mg/m^3)	95% Confidence Interval
Median	0.046	
Geometric Standard Deviation	3.167	
Mean	0.089	(0.048, 0.17)
Standard Deviation	0.15	
Percentiles		
85th	0.15	(0.082, 0.27)
90th	0.20	(0.10, 0.27)
95th	0.31	(0.15, 0.65)

higher than the weighted estimates, indicating that the nonrespondent stratum exhibited slightly lower average concentration levels than the respondent stratum. This mitigates a potential source of nonresponse bias, i.e., the concern that plants with higher concentration levels might have been less likely to cooperate with the study.

The fitted lognormal distributions of airborne commercial and active colorant concentrations are given in Figures 7-1 and 7-2, and parameters of the distributions such as the median, mean, and selected percentiles are also indicated. The same information is displayed in tabular form in Tables 7-10 and 7-11, which present estimates of the total number of weighers exposed to various levels of active colorant and commercial dye concentrations, respectively. From Table 7-10 there are 134 weighers (5% of the estimated weigher population) exposed to active colorant concentrations which exceed 0.27 mg/m^3; and the same number of weighers are exposed to active colorant concentrations between 0.18 and 0.27 mg/m^3. Half of the weighers (an estimated 1,345 persons) are exposed to active colorant concentrations which exceed 0.042 mg/m^3. Corresponding estimates on the commercial dye basis in Table 7-11 are: 134 weighers (5%) are exposed to commercial dye concentrations greater than 0.57 mg/m^3; another 134 weighers are exposed to concentrations between 0.38 and 0.57 mg/m^3; half of the population (estimated to be 1,345 persons) are exposed to concentrations greater than 0.10 mg/m^3.

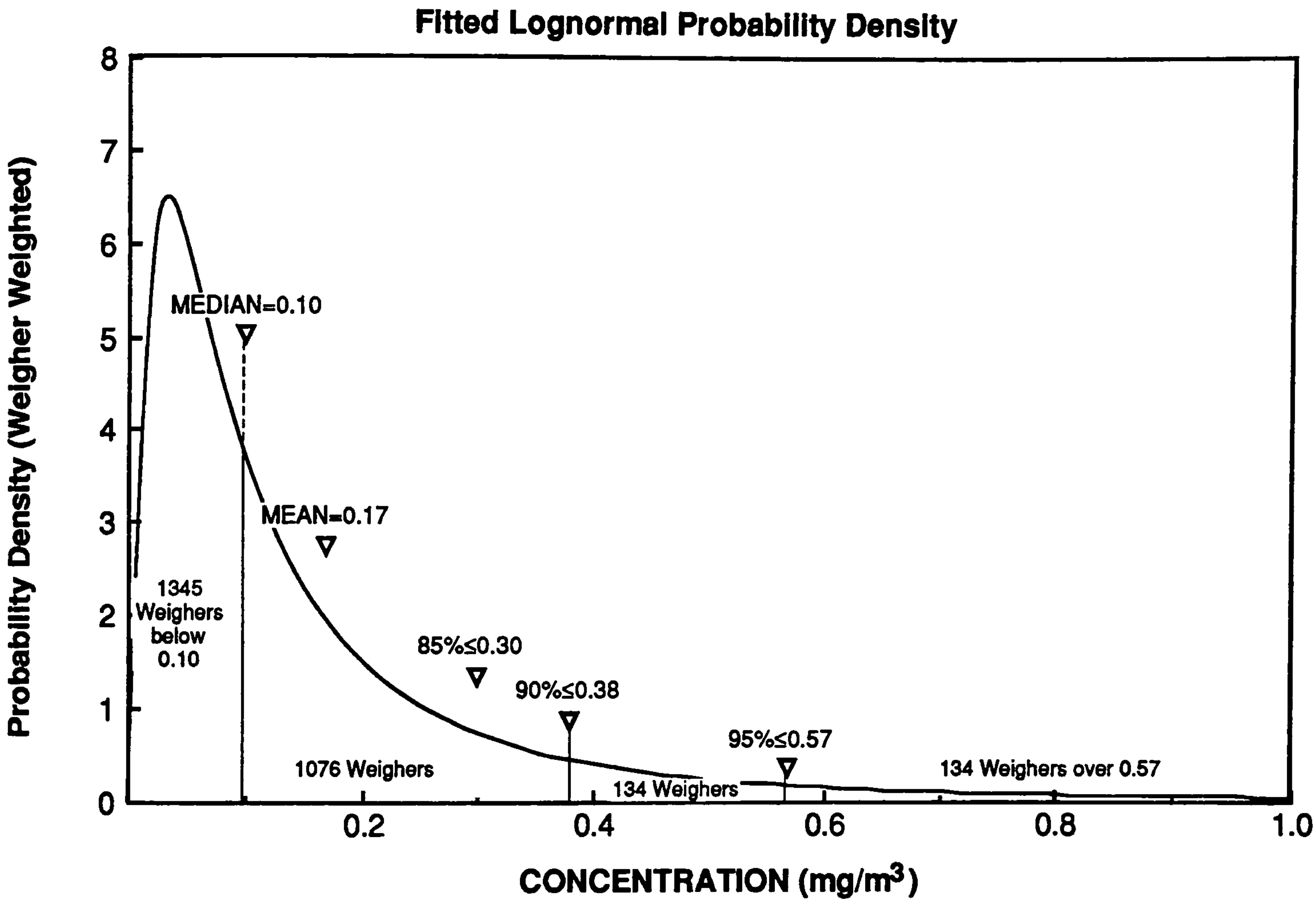
III. SUMMARY OF CROSS-TABULATIONS

In addition to tabulating the airborne dye concentration for the plants as a whole, the population was broken down into groups defined by variables collected during monitoring. These variables are among those collected on the in-plant questionnaire form (see sample in Section E of the Supplement). Data on variables such as the type of management of the plant, number of dyeing machines, type of shifts used, etc., were collected; it is interesting to see the airborne dye concentrations tabulated according to the groups so defined. A complete listing of these tabulations is shown in Appendix B.

It is important to note, at the outset of this discussion, that the sample size (though quite adequate for total industry estimates) will substantially limit the precision of estimates of subgroups of the population. For that reason, no attempt will be made to perform statistical tests of significance for the differences between the values found. Rather, they will be considered for the general information which can be obtained.

Figure 7-1

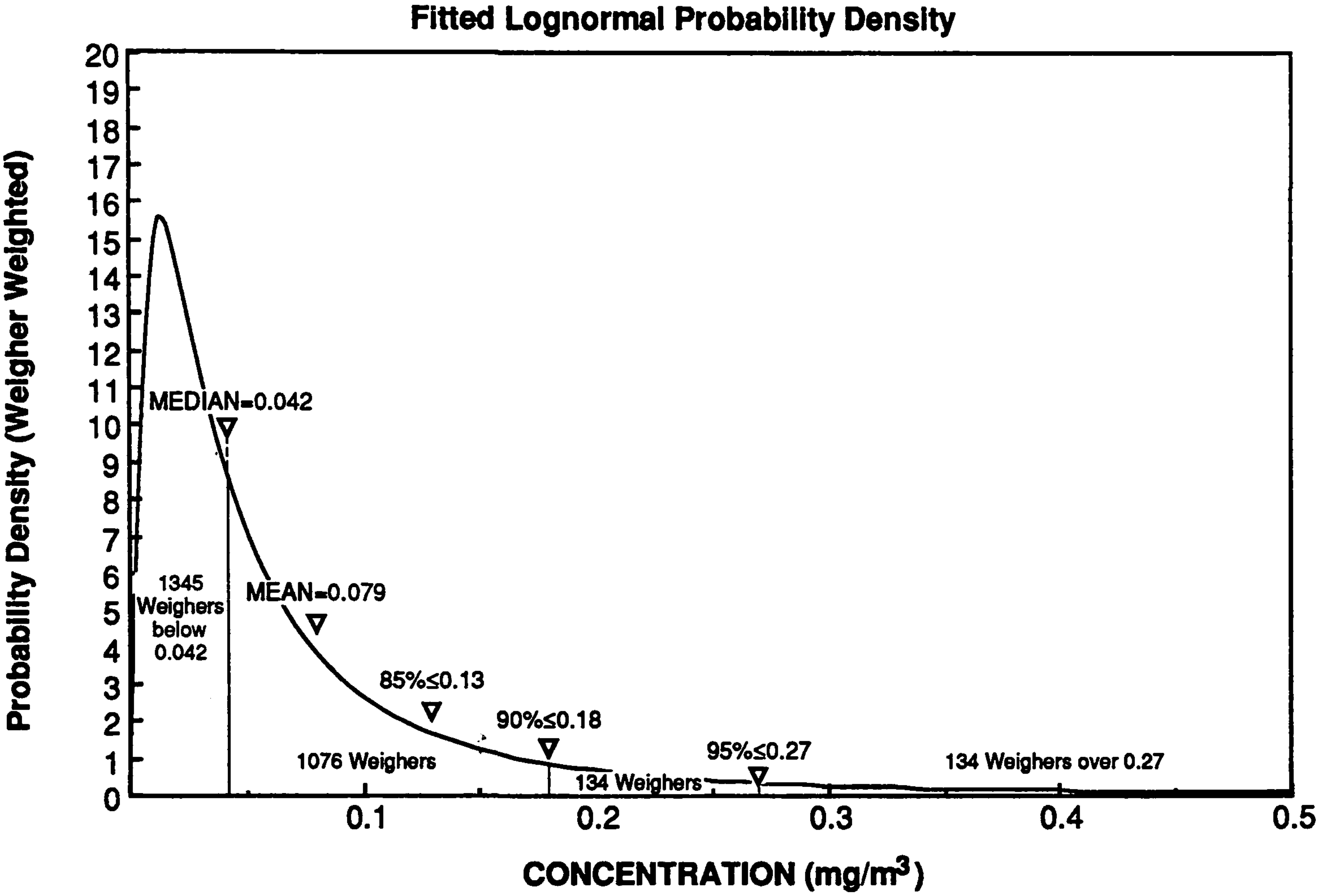
AIRBORNE COMMERCIAL DYE CONCENTRATION



The relative frequencies of total commercial dyestuff concentrations are shown. Note that of an estimated 2688 dye weighers, 134 weighers experience average concentrations above 0.57 mg/m^3, 268 weighers experience concentrations above 0.38 mg/m^3, and 1345 weighers experience concentrations above 0.10 mg/m^3. There may be more weighers than shown here if the sampling list missed some plants.

Figure 7-2

AIRBORNE ACTIVE DYE CONCENTRATION



The relative frequencies of total active colorant concentrations are shown. Note that of an estimated 2688 dye weighers, 134 weighers experience average concentrations above 0.27 mg/m^3, 268 weighers experience concentrations above 0.18 mg/m^3, and 1345 weighers experience concentrations above 0.042 mg/m^3. There may be more weighers than shown here if the sampling list missed some plants.

Table 7-10

NUMBER OF WEIGHERS WHO EXPERIENCE VARIOUS WORKPLACE CONCENTRATIONS--ACTIVE COLORANT BASIS

Concentration Range (mg/m^3)	Percentile Range	Number of Weighers in Given Range
Less than 0.042	0th - 50th	1,345
0.042 - 0.087	50th - 75th	672
0.087 - 0.13	75th - 85th	270
0.13 - 0.18	85th - 90th	134
0.18 - 0.27	90th - 95th	134
Greater than 0.27	95th and above	134

Table 7-11

NUMBER OF WEIGHERS WHO EXPERIENCE VARIOUS WORKPLACE CONCENTRATIONS--COMMERCIAL DYE BASIS

Concentration Range (mg/m^3)	Percentile Range	Number of Weighers in Given Range
Less than 0.10	0th - 50th	1,345
0.10 - 0.20	50th - 75th	672
0.20 - 0.30	75th - 85th	270
0.30 - 0.38	85th - 90th	134
0.38 - 0.57	90th - 95th	134
Greater than 0.57	95th and above	134

The tabulations are shown in Table B-1 of Appendix B. Several important types of estimates can be found in the table. First there are estimates of the numbers of plants and weighers in the population of interest. From Table B-1 and based upon the survey, it is estimated that there are a total of 863 textile dyeing plants regularly weighing powder dyes. In addition, the results of the survey indicate that an estimated total of 2,688 weighers are engaged in weighing powder dyes at those establishments. These two totals are shown broken down by a number of auxiliary variables in Table B-1.

In addition to estimates for numbers of weighers and plants, Table B-1 also contains estimates for the commercial dye concentrations (weighted by both plant and worker weights) and the associated standard errors of the estimate. The standard error of the estimate is a measure of the precision of the estimate and is a function of both the variability found in the concentrations and the size of the subgroups. Since the number of plants represented in each group is small, relatively large standard errors are to be expected.

To illustrate the use of the tables, two variables from the tables are reproduced in this section as Table 7-12. Included in that table are results for the variables Type of Ownership (private versus public) and Number of Dyes Weighed (in four categories). Consider first the case of the type of ownership. Note that estimates for the airborne dye concentrations are almost identical in the two subgroups of the population. For the plant weighted data, the group of privately owned establishments had an airborne dye concentration of 0.19 mg/m^3 compared to a value of 0.17 mg/m^3 for the publicly held establishments, indicating that the variable Type of Ownership is not a factor that explains differences in airborne dye concentration.

In contrast, consideration of the variable Number of Dyes Weighed gives a different picture. As can be seen from Table 7-12, for a group of plants weighing larger numbers of dyes there is a steady increase in that group's mean airborne dye concentration (it increases from 0.046 mg/m^3 for the plants weighing 0 to 10 dyes to 0.52 mg/m^3 in the group weighing 31 to 46 dyes). The small sample sizes in subgroups suggests that making statistically based comparisons is unwise; however, it is still interesting that the dye concentration increases as the number of dyes weighed increases.

There are no major findings of a statistical nature in these tables, and therefore, they are not included in total in the body of the report. However, Appendix B contains tabulations similar to those shown in Table 7-12 for 11 cross-tabulation variables.

Table 7-12

COMMERCIAL DYE CONCENTRATION ESTIMATES BROKEN DOWN BY OTHER VARIABLES MEASURED DURING MONITORING

	Variable					
	Ownership		Number of Dyes Weighed			
	Private	Public	0-10	11-20	21-30	31-46
Number of Sampling Cases*	12	10	5	9	5	3
Estimated Universe						
No. of Plants	444	419	144	391	243	86
No. of Workers	1,529	1,159	547	1,225	715	201
Plant-Weighted						
Total Commercial Dye Concentration in Dye Weighing Room Air (mg/m^3)	0.19	0.17	0.046	0.083	0.30	0.52
Standard Error	0.053	0.096	0.013	0.014	0.077	0.28
Worker-Weighted						
Total Commercial Dye Concentration in Dye Weighing Room Air (mg/m^3)	0.18	0.17	0.040	0.077	0.33	0.61
Standard Error	0.056	0.10	0.012	0.014	0.066	0.32

*Includes only the 22 plants with a valid concentration measurement.

Note: This table is an abridged version of Table B-1 in Appendix B.

IV. CORRELATION OF CONCENTRATION WITH VARIOUS FACTORS

As a first step in analyzing the data, correlation coefficients between airborne dye concentrations and various factors potentially influencing concentration were calculated. To mitigate the potential effect of outliers on the analysis and to detect nonlinear associations, the Spearman rank correlation coefficient[4] was used as a convenient quantitative measure of the relationship between airborne dye concentration and other factors. Table 7-13 shows Spearmán correlations between active and commercial dye basis and 14 factors of interest. An asterisk (*) indicates that an estimated correlation was statistically significantly different from zero under a two-sided test of significance at the 5% level. Under the assumption of no correlation, the magnitude of the correlation for the survey data would represent an event which would happen only 5% of the time or less. This is a commonly used level at which to accept the proposition that the correlation is not likely to have occurred by chance alone. Note that, although a number of factors other than those listed were measured in the study, none of the Spearman correlations with airborne dye concentration were close to being statistically significant.

The same five factors exhibit statistically significant correlations with dye concentration for both commercial dye and active colorant. All other factors have much smaller estimated correlations, none of which approach statistical significance. The factor Number of Suppliers, with the highest correlation with dye concentration, measures the number of suppliers the monitored plant has for those dyes weighed during the monitoring period. The high correlation exhibited was rather unexpected and has no apparent plausible basis.

The other four factors with significant correlations with the airborne dye concentration were expected. In particular, Mass of Dye Weighed and Number of Weighings had been expected a priori to be the most highly correlated with airborne dye concentrations. Two other factors--Number of Dye Classes and Number of Dyes Weighed--exhibit high correlations in Table 7-13. Their correlation with airborne dye concentration might be a surrogate for some other variables, such as Number of Weighings.

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[4]Johnston J. 1972. Econometric Methods, 2nd Edition. New York: McGraw-Hill, p. 219.

Table 7-13

SPEARMAN CORRELATIONS BETWEEN AIRBORNE DYE CONCENTRATION AND SELECTED EXPLANATORY FACTORS

Factor	Correlation with: Commercial Dye	Active Colorant
Number of Suppliers	0.76*	0.68*
Number of Dyes Weighed	0.71*	0.64*
Mass of Dye Weighed	0.64*	0.60*
Number of Weighings of Dyes	0.62*	0.58*
Number of Dye Classes	0.51*	0.51*
Number of Fibers in Final Product	0.30	0.30
Number of Minutes Weigher Was in Drug Room	0.29	0.08
Production Volume of Product	0.29	0.19
Age of Person Monitored	0.26	0.24
Average Humidity in Drug Room	0.22	0.28
Average Temperature in Drug Room	0.17	0.24
Number of Shifts Site Operates	0.16	0.10
Number of Entries into Drug Room by Weigher	-0.11	0.05
Number of Minutes Weigher Was Monitored	0.05	-0.02

*Statistically significant at 0.05 level.

V. RELATION BETWEEN AIRBORNE DYE CONCENTRATION AND OTHER VARIABLES

The first step in this analysis was the development of "best" regression equations[5] of airborne dye concentration based on the study data. A forward stepwise regression procedure was used, under which variables are introduced to the model based on their incremental contribution to its explanatory power. The final equation arrived at by this procedure is "best" in the sense of maximum explanatory power with a minimum number of variables. Explanatory power per se can be misleading if too many independent variables are used. With 22 data points a perfect fit but useless

[5]See Draper N, Smith H. 1981. Applied Regression Analysis, Second Edition, Section 6. New York: Wiley.

equation could be obtained by using any 21 independent variables plus a constant term. The natural logarithm of airborne dye concentration was examined closely for use as the scale of the dependent variable because it provides a better model fit and reduces the potential over-influence of outliers. For the sake of simplicity, the data were unweighted. This was considered reasonable because the results of weighted and unweighted analyses reported in Section B are so close. Finally, all equations were developed using commercial dye basis, because this was the measure of greater potential usefulness for the complex dye formulations assessed, and was what was directly measured by the analytical methodology used in the study.

The stepwise regression procedure was first applied with the set of explanatory variables in Table 7-13, using both measurement and log scales for these variables. Then the analysis was repeated, omitting Number of Suppliers, because this was not a logical parameter in an exposure assessment. Finally, both analyses were repeated, omitting data from the plant corresponding to the observation from Plant 4/9 in Tables 7-1, 7-2, and 7-3. The airborne dye concentration for this plant was by far the highest observed and there was concern it might be an unusually influential observation in the regressions. The results indicated no substantial differences whether plant 4/9 was included or not. The results with site 4/9 included are shown in Table 7-14.

When Number of Suppliers is omitted from the explanatory variable set, the stepwise regression always picks a single-variable equation, but the variable chosen depends on the scale of the explanatory variables. The equation with the highest R^2 value is:

$$\log(\text{estimated airborne dye concentration}) = a + b\,(\text{log of dye mass weighed out})\ .$$

That is, the airborne dye concentration is best predicted by a linear relationship using the log of the dye mass weighed out as the sole predictor. The estimates for the coefficients are given below, along with their standard errors in parentheses:

$$a = -4.13\ (0.55)$$
$$b = 0.54\ (0.15).$$

This means that if 10 kg of dye were weighed out during a shift, the average airborne dye concentration during the 8-hr shift was found to be 0.056 mg/m^3. The R^2 value is 0.39, indicating that 39% of the original variation in the data was explained by this equation. (Note that some of the variation, such as that due to sampling and laboratory variability, cannot be explained by the explanatory

Table 7-14

RESULTS OF STEPWISE REGRESSION OF log(Airborne Dye Concentration) AGAINST EXPLANATORY FACTORS (ALL DATA)

Include Number of Suppliers	Scale of the Explanatory Variables	Selected Equation	R^2
Yes	Natural Log	log(Number of Suppliers)	0.52
Yes	Measurement	Number of Suppliers	0.56
No	Natural Log	log(Mass Weighed)	0.39
No	Measurement	Number of Dyes Weighed	0.38

variables.) Plots of residuals from this regression versus predicted values and other possible variables revealed no unusual features. This can be taken as an indication that the one-variable equation is adequate.

When Number of Suppliers is included in the stepwise regression, the procedure selects a single-variable equation with that variable as the best (or its natural log when looking at logarithms of the predictors as inputs). The equation with the highest R^2 is that with Number of Suppliers (untransformed) as a predictor:

$$\log(\text{estimated airborne dye concentration}) = a + b\,(\text{Number of Suppliers}) \quad .$$

The estimates for the coefficients are given below, along with their standard errors in parentheses:

$$a = -4.03\ (0.38)$$
$$b = 0.33\ (0.065) \quad .$$

For this case the value of R^2 is 0.56, meaning that the explanatory variables explain 56% of the variability of airborne dye concentration. Although inclusion of this variable in the stepwise equation improves the R^2, this variable's relationship to airborne dye concentration is difficult to explain.

In addition to the single-variable models selected by the stepwise regression procedure, regression models with two explanatory variables were also examined. Of the five variables with significant correlations in Table 7-13, Mass of Dye Weighed and Number of Weighings of Dyes are two variables which have a direct causal relationship with airborne concentrations. Hence, 2-variable regression models were estimated for these variables, first using the original data and again using logarithms of the data. The results of these regressions are shown in Table 7-15.

The linear model was specified as follows:

$$\text{Commercial Dye Concentration} = a + b\ (\text{mass weighed}) + c\ (\text{number of weighings})\ .$$

Estimates of the coefficients a, b, and c are shown in Table 7-15, with the standard errors of the estimates included in parentheses. The specification of the log-log regression model in Table 7-15 was similar to that for the linear model, except that logarithms of all variables were used.

Table 7-15

RESULTS OF TWO-VARIABLE REGRESSION ANALYSIS FOR COMMERCIAL DYE CONCENTRATIONS (DATA FROM PERSONAL MONITORS)

		Coefficient Estimates (and Standard Errors)		
Type of Model	R^2	Intercept (a)	Mass Weighed (b)	Number of Weighings (c)
Linear	0.39	-0.0010	0.0020 (0.0007)	0.0011 (0.0008)
Log-Log	0.47	-5.361	0.400 (0.165)	0.447 (0.256)

In both the linear and log-log regressions, the estimated coefficients for the Mass Weighed variable are highly significant, since these estimates are larger than twice the standard error. The estimated coefficient for the Number of Weighings variable is not significant in the linear model. With a t-statistic of 1.74, this coefficient is not significantly different from zero at the 0.05 probability level in the log-log model. However, at the 0.10 probability level, there is evidence that the coefficient is significantly different from zero. Hence, there is only marginal evidence for including Number of Weighings in the model.

The R^2 of the linear regression model with only Mass Weighed as a single variable is 0.34, and inclusion of the Number of Weighings variable increased the R^2 to 0.39. In the log-log regression model, the R^2 increases from 0.39 for the single-variable model with Mass Weighed (discussed previously) to 0.47 when Number of Weighings is included. The increase of R^2 due to the Number of Weighings variable is insignificant at the 0.05 level in the linear model. Based on the regression F test, the increase in R^2 has only marginal significance when the second variable is added in the log-log form of the model.

As previously noted, residual analysis of the log-log model with Mass of Dye Weighed as the only explanatory variable indicated that the model is "adequate"; that is, no other variable provides significant additional information for predicting airborne dye concentration. Furthermore, using a jackknife procedure which examined the ability of each model to predict individual site values when these sites are omitted from the data set, the 2-variable model with Mass of Dyes Weighed and Number of Weighings provided only slightly higher predictive power versus the Mass of Dyes Weighed model alone. (The predictive performances were compared using the mean absolute predictive error and the mean square predictive error as criteria.)

To summarize, the set of explanatory factors for concentration on which data was collected in the study appears to have moderate explanatory power. A (forward) stepwise regression procedure always picks single-variable equations under a variety of scenarios, with the best of these simple equations explaining 56% of the variability in the airborne dye concentration data. However, the equation with the highest R^2 is for Number of Suppliers, a variable which cannot logically be expected to have a causal relationship with airborne dye concentration. When Number of Suppliers is omitted from the stepwise regression procedure, a log-log equation with Mass Weighed as the explanatory variable is selected by the stepwise procedure.

For this regression the functional relationship between the variables is

$$\log(\text{airborne dye concentration}) = -4.13 + (0.54)(\text{log of dye mass weighed, in kg}),$$

or, equivalently,

$$\text{airborne dye concentration} = \exp[-4.13 + (0.54)(\text{log of dye mass weighed, in kg})].$$

Residual analysis indicated that this 1-variable explanatory was adequate. This equation has an R^2 of 0.39, and the chosen variable has a clear causal relationship with airborne dye concentration.

Chapter 8

INDIVIDUAL SITE CHARACTERIZATIONS

I. INTRODUCTION

Information was collected during the 24 site visits to obtain a better understanding of the operations associated with the use of powder dyes in the textile industry. At each site, the information collected included the facility's physical and operational characteristics, the dye weighers' activities, and the engineering controls and personal protective equipment used to limit worker exposure to chemicals and dyestuffs.

II. FACILITY CHARACTERISTICS

A. General Characteristics

Dyehouses may be owned by the textile manufacturer (vertical basis), or operate independently (commission basis). Vertical dyehouses may also operate on a commission basis. Most of the facilities surveyed (16 of 24) operated solely on a vertical basis. Fourteen of the facilities were privately-owned and 10 were publicly owned. The annual production volume of the facilities ranged from 300,000 pounds to 25 million pounds of various textile products. While processes included batch dyeing, continuous dyeing, and printing operations, most of the facilities monitored (18 of 24) were engaged in batch dyeing. Dyeing equipment included machines in which the dye liquor was transported through the stationary textile substrate (package, beam, skein, and stock machines); machines in which the textile material was transported through essentially dormant dye liquor (jig, beck, and pad machines); and machines in which both the dye liquor and the material were in motion (jet, paddle, rotary, and some skein machines). The number of dyeing machines available for operation at each site varied from 1 to 75, and all but one of the sites were operating at 50% or greater capacity during the monitoring period.

Fibers dyed during the monitoring period were not recorded. Site end products were composed of acrylic/modacrylic, acetate, rayon, wool, nylon, polyester, cotton, silk, and flax fibers, either neat or as blends. Variations in fiber suppliers and types were not noted. Almost all of the sites dyed more than one fiber; one site reported up to nine fibers in the various end products. Product lines of the facilities surveyed included raw stock (staple); apparel, space dyed and carpet yarns; hosiery and intimate wear; woven and knitted apparel fabrics for indoor and/or outerwear uses;

automotive and upholstery fabrics; garments, woven industrial fabrics; and carpets. Table A-2 in Appendix A presents a summary of the specific facility characteristics recorded during the monitoring period, and Table A-3 summarizes these characteristics. Table A-4 summarizes the number of fibers processed annually at a facility and the number of dye classes encountered during the monitoring period.

B. Process Characteristics

1. Drug Room Operations

For purposes of this study, the area in which powder dyes were weighed was considered the "drug room" of concern at each facility. The drug room was usually well-defined within a walled area, but at some sites the lack of physical barriers necessitated a definition of the drug room boundaries by the survey team. At most facilities, dyes were stored in the area where they were weighed. Generally, the drug rooms where dyestuffs and chemicals were stored and weighed were rooms or areas separated from areas where mixing equipment and dye machines were located. Mixing facilities were located within the drug room at six sites. The physical characteristics of two sites were significantly different than those of the other 22 sites.[1] Dyes were stored in closed drums varying in size from 50- to 100-pound containers, to 200- to 275-pound barrels. At some sites, liquid dyes and dry chemicals were also stored and weighed in the drug room. At three sites, drum storage areas were separate from the drug room. Open dye drums were usually located on the floor and along the walls of the room with the lids loosely in place; however, at many sites, frequently used drums of dyes were placed in an area close to the weighing station. The weighing station included at least one and often several scales for weighing the dyes or chemicals.

Some of the drug rooms were temperature- and humidity-controlled by ventilation systems independent of the general facility ventilation system. Most of those observed during the surveys, however, had either no controlled ventilation or only the passive ventilation provided by the general building or area ventilation system. At one of the sites visited, the drug room was

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[1]At Site 8/0, the dye weighing station was contained within the production area where mixing and dyeing occurred. The entire production area was considered the drug room at that facility for purposes of recording the dye weigher's time in the drug room. At Site 6/6, two drug rooms were in operation and both were used by the dye weigher monitored at that site.

previously used as a vault; thus the only ventilation available in that drug room was through the door, which was kept open.

About half of the drug rooms were relatively clean of visible accumulated dye materials; at 11 of the sites visited, a significant accumulation of dye was observed on the drug room floor, dye drums, and equipment, indicative of dye spillage. The amount of accumulated dye particulates within the drug room did not appear to be related to the number of dye weighings performed or the amount of dye weighed on the day of the survey. The accumulation of dye in these drug rooms may contribute to the amount of dyestuff collected on the filter.

2. Dye Weigher Activities

Most of the facilities visited (13) operated under a three 8-hr work shift schedule. Five facilities operated on two 12-hr shifts, three operated two 8-hr shifts, and only three operated a single work shift of 8-10 hr. Monitoring was conducted on the first work shift (day) at 12 facilities, on the second work shift (evening) at 8 facilities, and on the third work shift (night) at 3 facilities. Parts of the first and second shifts were monitored at one of the sites (see Chapter 1, Section 8). At facilities where the dye weighers' responsibilities were limited to weighing dyes (and sometimes chemicals), one or two dye weighers were typically employed per shift. At other facilities, dye weighers also mixed the weighed dyes. At some sites, dye machine operators also had the responsibility for weighing and mixing dyes. Table A-5 in Appendix A presents individual shift characteristics, and Table A-6 summarizes these characteristics.

Duties of the dye weigher typically included transporting full and empty drums both into and out of the storage area; relocating drums within the storage area and drug room and recording the amount weighed on batch tickets; transferring the weighed dye from the scale pan to a transfer container, usually a metal bucket, and then transferring the container of weighed material to the mixing area; and cleaning the dye storage and weighing areas.

The amount of time that the dye weigher spent in the drug room varied according to his assigned duties. The time the dye weigher spent in the drug room was reduced if some of the worker's assigned job responsibilities took place in other areas of the plant. The monitored dye weighers spent less than 25% of the monitoring period in the drug room at six sites, and more than 25% but less than 50% of the monitoring period at seven sites. The dye weighers at the remaining sites spent more than 50% of the monitoring period in the drug room. At one site the dye weigher spent 99% of the time in the drug room. At the four sites where the personal air monitoring results indicated the highest concentrations of both formulated dye and active colorant in worker's breathing zones, the dye weighers spent more than 60% of the respective monitoring periods inside the drug room (84%, 95%, 84%, and 62%, respectively). However, no correlation between exposure and time in the drug room was found. Table A-7 presents individual worker activities during the monitoring period and Table A-8 summarizes these activities.

Regardless of assigned duties and frequency of weighing, the actual dye weighing operation was similar at all monitored sites. The typical dye weigher's activities in filling each batch order were as follows:

(1) The weigher obtained the dyes by walking to a drum or container of the appropriate dye and, with a hand scoop, removing an approximate quantity of dye.

(2) The weigher then transferred the scoop of dye to the weighing station, where the required amount of dye was poured into the scale pan.

(3) Any unused portion of the dye left in the hand scoop was poured back into the dye container from which it came.

(4) The weighed portion of the dye was poured into a transfer container, most often a metal bucket. (For purposes of this study, each dye transfer as described in steps 1 through 4 was recorded by the survey team as a separate weighing.)

(5) Steps 1 through 4 were repeated until all the weighings specified on the batch ticket had been completed. At times, the dye weigher accumulated several dyes on the scale pan prior to transferring them into the transfer bucket.

At most facilities, the dye weigher then transported the bucket of weighed materials directly to the mixing area, where he either left it near the tank and stirring equipment (usually a rotary blade mixer or homogenizer) for dissolution in hot water by another operator, or added it to the tank and dissolved/ dispersed the weighed dyes himself. The dye solution was then transferred manually or by pipeline from the mixing tank to the dyeing machine. At nine sites, the dye weigher actually added liquid (hot water in most cases) directly to the transfer bucket containing the weighed dye. At one site (Site 6/5), in a unique departure from the behavior observed at other sites, the dye weigher manually added the dry dye to the addition spout of the "washing machine-like" rotary dyeing machines. This method of operation--the direct addition of dry dye into dyeing machines--differed significantly from operations at other monitored sites where the dry dyes were first dissolved or dispersed in water (often with the aid of a hand mixer or homogenizer) before addition to the dyeing machines. Five of the monitored weighers were actually dyeing machine operators who operated dyeing equipment, and in two of those cases also loaded and unloaded fabrics. Dye weighing was but one of several diverse responsibilities for these operators.

At some facilities, when a barrel or drum of dye was almost empty, the dye weighers inverted the spent barrel over a new open barrel of dye to transfer the dregs from the old container into the new one. Each such transfer created an additional potential for exposure to the dyestuffs through possible airborne contamination and dermal contact. This activity was observed at five sites.

At several sites, variations in work practices and operating procedures were observed which could affect the dye weigher's level of exposure. Specific observations were noted as follows:

- Site 6/6--Ninety-five percent of all dyes stored and handled at this site were liquid dyes. Most of the dyes used on the day of monitoring were liquid Vat dyes. Eight weighings of only two powder substances (a Naphthol and a Naphthol Salt) were performed on the day of monitoring. In addition, a process malfunction during the monitoring period at this facility resulted in a steam loss and forced postponement of several scheduled dyelots.

- Site 1/0--The monitored dye weigher performed several activities that could increase the amount of airborne dye particulates, such as banging the scale pan on the table to loosen the dye material.

- Site 3/3--At this, the only monitored screen printing site, the weighing activities were different from those at comparable size dyehouses in three ways. First, all weighings were at the beginning of the shift, and the dye weigher was in the drug room for only 125 minutes of the 447 minutes that he was monitored. Second, the dye weigher performed 42 dye weighings and only 3 chemical weighings, yet the mass of chemicals weighed amounted to more than 75% of the total mass weighed. Third, following the weighing activity, the dye weigher was still being monitored but he was engaged in other pursuits.

- Site 7/9--After the appropriate dyes for a particular batch were weighed, the container into which the weighed material was transferred was sealed with a plastic lid, reducing the potential for the dyestuffs to become airborne during transfer to the mixing tanks or dye machines.

- Site 6/2--Some dyes remaining in almost depleted supply barrels were transferred to unused replacement barrels of the same dye by inverting or dumping. The dregs in other depleted barrels were permitted to remain in place and the containers were used as trash receptacles in the drug room.

C. Dye Characteristics

There was a wide variety at the monitored sites in the fiber composition of textiles that were processed, production volume, and product lines. These parameters evidently governed the classes of dyes and individual dyes within classes that were used, quantities weighed, number of weighings, and shades produced. Table A-9 in Appendix A catalogues the number of powder dyes from each dye class that were used. Tables A-10 and A-11 provide the number of weighings and the mass weighed, respectively, from each dye class, and Table A-12 summarizes these statistics by dye class. Table A-13 is a summary of commercial dye weighed by dye class, broken down into the three categories: All Dyes, All But Black Dyes, and Black Dyes Only.

Table A-14 lists by Color Index Name[2] all individual dyes that were encountered and the number of weighings and quantities that were weighed.

D. Controls and Safety

The presence of engineering controls and the use of personal protective equipment were recorded during each monitoring survey. One of the drug rooms at Site 6/6 was equipped with an overhead exhaust hood for the removal of airborne dye particles. At Site 5/2, a small 10-inch exhaust fan was located in the wall of the drug room near the weighing station to exhaust airborne particles. None of the other drug rooms was equipped with local exhaust ventilation for control of worker exposure to the dye material.

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[2]Dye identification postscripts commencing with U or M refer to unidentified or mixture dyes, respectively, for which no color index number had been assigned.

As previously described, more than 50% of the drug rooms were observed to have a relatively low amount of visible accumulated dye on the drug room walls, floors, equipment, and storage containers. Almost all of the drug rooms reported using wet mopping techniques to clean up spilled dye material. At several locations, mopping was replaced or augmented with direct water washing using hoses and spray nozzles. Direct water washing was conducted at one site during the monitoring period (necessitating the previously described alteration in sampling procedure at that site); other facilities reportedly use direct water washing procedures either as part of the drug room cleaning between shifts or during weekly cleaning operations. Wet mopping on a regular basis controls the accumulation of dye material in the drug room, reduces the potential for the dye material to become airborne and inhaled by workers, and the possible damage to the textile materials through contamination.

The monitored dye weighers' work practices use of personal protective equipment and general safety and personal hygiene practices were recorded at each site. Table A-15(a) and (b) in Appendix A presents individual facility characterization, and Table A-16 summarizes them. (At one site, during an approximately 8-hr apparatus monitoring period, the pump was worn by two individuals). At 12 of the 24 monitored sites, dye weighers wore disposable dust-mask respirators while performing dye weighing operations, at 6 they wore negative pressure air-purifying cartridge respirators, and at 1 the weigher wore a powered, positive pressure air-purifying respirator. Several of the workers that were using air-purifying respiratory protective equipment during the surveys were observed as not using the respirators properly to attain optimum protection. For example, the monitored dye weigher at one site who wore a dust-mask respirator had a full beard; facial hair greatly increases the air leakage around the respirator and renders it less effective. At two sites, the monitored dye weigher wore his dust-mask respirator in such a way that, at times, both elastic straps were not positioned for proper fit and mask-to-face seal. Dye weighers at the site which had the greatest concentration of dye dust in the air used powered, positive pressure air-purifying respirators. Only four of the monitored dye weighers who were using respirators indicated they had received training in the proper use and maintenance of respiratory protective equipment (Sites 1/0, 1/6, 2/4, and 7/7).

The monitored dye weighers used various forms of protective equipment to control dermal exposure to the powder dyes. They wore gloves while weighing dye batches at 15 of the 24 facilities monitored. Leather work gloves were worn at one of the facilities; eight facilities provided the dye weighers with latex or butyl rubber gloves. The nature of the glove material was not recorded for six of the facilities where glove use was noted. Because the dye weighers must often reach deep into a dye barrel to retrieve the dyestuffs, the use of protective gloves did not always prevent dermal contact with the dye materials, especially on the lower and upper arms. Significant dermal contact with the dye material was observed on the hands and arms of the dye weighers who were not using protective gloves. Eight of the monitored dye weighers wore protective clothing (in the form of a protective apron or smock), 9 wore protective boots or steel-toed safety shoes, and 6 of the 24 monitored dye weighers wore safety glasses or goggles to prevent eye exposure to the dyestuffs.

The dye weighers' eating, drinking, and smoking habits while in the drug room were noted during the monitoring surveys to assess the additional potential for exposure to the dye material through ingestion. Monitored dye weighers were observed eating and/or drinking in five of the facilities monitored, although almost all of the facilities stated that company policy prohibited such activities in the drug room. Eight of the 24 monitored dye weighers smoked while in the drug room. This practice can result in the ingestion of dye material through transfer from hands that have not been thoroughly washed prior to cigarette handling or exposure through inhalation as a combustion product in the air moving through the cigarette. Potential for ingestion of the dye material was also noted at one site, where the monitored dye weigher used chewing tobacco while in the drug room.

Appendix A

SUMMARY OF MEASUREMENTS FOR THE 24 SITES MONITORED

Table A-1

SUMMARY DATA FOR THE 24 SITES

	Average	Range	Units
Dye Usage			
Number of Individual Powder Dyes Handled	17.4	2-46	No. of Dyes
Number of Powder Dye Weighings	59.5	7-259	No. of Weighings
Total Weight of Commercial Powder Dyes Weighed	56.7	2.1-283.9	kg per shift
Air Monitoring Results			
Concentration of Total Particulates in Drug Room Air, Gravimetric Analysis			
Average of 2 Personal Monitors	0.46	0.02-1.37	mg/m^3
Weighing Station Area	0.21	0.04-0.59	mg/m^3
Drum Storage Area	0.12	0.04-0.25	mg/m^3
Concentration of Total Commercial Powder Dyes in Drug Room Air, Spectrophotometric Analysis			
Average of 2 Personal Monitors	0.19	0.01-1.20	mg/m^3
Weighing Station Area	0.12	0.01-0.37	mg/m^3
Drum Storage Area	0.04	<0.01-0.16	mg/m^3

Note: This table summarizes site data sent with individual site reports to each study site to provide a context for the interpretation of individual results. These are not survey estimates and do not represent the population of dye houses as a whole.

Table A-2

INDIVIDUAL SITE CHARACTERISTICS RECORDED DURING EACH MONITORING PERIOD

Site ID	Product Line	Production volume, mm lbs	Type of Business*	Type of Management**	Type of Equipment	Dyeing Process***	Units Available	Units in Operation	Percent of Capacity in Operation
1/0	piece goods/outerwear	18.0	V	priv.	jet/beck	B	75	75	100.0
1/6	piece goods/outerwear	5.0	C	publ.	jig/beam/pad	B/C	17	14	82.4
2/1	apparel/knit goods	3.5	V	publ.	beck	B	11	11	100.0
2/4	stock	2.5	V	publ.	stock	B	33	20	60.6
2/7	apparel/knit goods	6.0	C	priv.	jet	B	11	11	100.0
3/0	upholstery yarn	25.0	V	priv.	package	B	12	12	100.0
3/3	upholstery	2.2	V	priv.	rotary screen	P	2	1	50.0
3/8	yarn	24.0	V/C	priv.	package/skein	B	35	31	88.6
4/1	stock	6.0	V	publ.	stock/atmosph	B	7	7	100.0
4/3	yarn	14.0	V/C	publ.	package	B	15	15	100.0
4/6	carpet yarn	2.0	V	priv.	KDK space dye	C	2	1	50.0
4/9	yarn	12.0	V	publ.	package	B	15	15	100.0
5/2	carpet yarn/roll goods	4.8	V	publ.	skein/beck	B	8	7	87.5
5/4	sheets-woven piece goods	13.0	V	publ.	beck	B	11	11	100.0
5/9	woven piece goods	5.5	V/C	publ.	jet/beck/pad	B/C	18	9	50.0
6/2	knit goods-tricot/auto	23.0	V	publ.	jet/beam	B	33	33	100.0
6/5	garments-socks	0.4	V	priv.	rotary	B	5	5	100.0
6/6	apparel/piece goods	1.2	C	priv.	pad	C	3	2	66.7
7/7	yarn/apparel-sweaters	1.5	V	priv.	package/paddle	B	10	10	100.0
7/9	garments	0.9	C	priv.	paddle	B	7	7	100.0
8/0	woven seat belts	6.0	V	priv.	pad	C	4	1	25.0
8/6	novelty yarn	3.0	V/C	priv.	space dye	B	9	7	77.8
8/8	warp yarns	2.2	V	priv.	beam	B	4	4	100.0
9/1	garments-socks	0.3	V	priv.	rotary	B	11	8	72.7
Plant Weighted Mean		7.1					14.6	12.9	84.9
Unweighted mean		7.6					14.9	13.2	83.8
Minimum Value		0.3					2.0	1.0	25.0
Maximum Value		25.0					75.0	75.0	100.0

*Type of Business: V, vertical; C, commission; V/C, both vertical and commission.
**Type of Management: priv., private; publ., public.
***Dyeing Process: B, batch; C, continuous; P, print; B/C, both batch and continuous.

Table A-3

SUMMARY OF SITE CHARACTERISTICS RECORDED DURING EACH MONITORING PERIOD

Variable	Number
Production Volume (million pounds)	
0.0 to 5.0	13 sites
5.1 to 10.0	4 sites
10.1 to 20.0	4 sites
20.1 to 25.0	3 sites
Management Type	
Vertical	16 sites
Commision	4 sites
Both	4 sites
Ownership	
Private	14 sites
Public	10 sites
Dyeing Processes Performed	
Batching Dyeing	18 sites
Continuous Dyeing	3 sites
Both	2 sites
Printing	1 site
Number of Dyeing Machines	
1 to 5	6 sites
6 to 10	5 sites
11 to 15	7 sites
16 to 35	5 sites
75	1 site
Location (EPA Region)	
Region 1 (New England)	1 site
Region 3 (Middle-Atlantic)	2 sites
Region 4 (Southeast)	19 sites
Region 5 (Great Lakes)	1 site
Region 7 (Central)	1 site

Table A-4

SUMMARY OF FIBERS PROCESSED OR DYE CLASSES USED PER SITE

Variable	Number
Number of Fibers Processed	
1	2 sites
2	3 sites
3	6 sites
4	3 sites
5	4 sites
6	4 sites
7-9	2 sites
Fibers Processed	
Acetate	3 sites
Acrylic/modacrylic	13 sites
Cotton	17 sites
Nylon	17 sites
Polyester	18 sites
Rayon	11 sites
Wool	12 sites
Other	5 sites
Number of Dye Classes (powder dyes only)	
1	9 sites
2	6 sites
3	4 sites
4	4 sites
5	1 site
Dye Classes Encountered (powder dyes only)	
Acid	14 sites
Chrome	2 sites
Disperse	15 sites
Basic	9 sites
Reactive	6 sites
Direct	6 sites
Vat	1 site
Naphthol	1 site

Table A-5

INDIVIDUAL SHIFT CHARACTERISTICS MONITORED DURING EACH MONITORING PERIOD

Site ID	Typical Daily Dye Weighing Activities: No. Hrs.	Typical Daily Dye Weighing Activities: No. Shifts	Shift Monitored	No. of Dye Weighers Working During Monitoring Period	No. of Fibers Processed (per year)	No. of Powder Dye Classes Used	No. of Powder Dyes Weighed	No. of Solid State Chemicals Weighed
1/0	24	3	3	2	5	3	30	1
1/6	24	3	2	1	4	2	11	1
2/1	24	3	2	1	3	3	15	0
2/4	8	1	1	1	2	1	21	0
2/7	24	2	2	1	3	3	16	0
3/0	24	3	1	2	2	2	21	0
3/3	24	3	3	1	5	1	8	1
3/8	24	3	1	1	6	4	46	1
4/1	16	2	1	1	3	1	17	0
4/3	24	3	2	1	6	2	18	4
4/6	24	2	1	1	1	1	6	1
4/9	24	3	2	1	6	4	31	2
5/2	24	2	1	1	1	1	3	0
5/4	24	2	1-2	4	4	2	16	0
5/9	24	3	2	1	7	4	18	1
6/2	24	3	1	1	4	2	30	0
6/5	16	2	1	1	5	3	12	8
6/6	24	3	2	2	6	1	2	2
7/7	24	3	3	1	3	1	7	0
7/9	8	1	1	1	2	1	9	0
8/0	24	2	1	3	3	1	3	0
8/6	16	2	1	1	9	4	25	0
8/8	24	3	2	1	3	2	11	3
9/1	8	1	1	1	5	5	41	1
Plant Weighted Mean				1.3	4.1	2.2	17.1	1.1
Unweighted Mean				1.3	4.1	2.3	17.4	1.1
Minimum Value				1.0	1.0	1.0	2.0	0.0
Maximum Value				4.0	9.0	5.0	46.0	8.0

Table A-6

SUMMARY OF SHIFT CHARACTERISTICS RECORDED DURING EACH MONITORING PERIOD

Variable	Number
Shifts Regularly in Operation	
3 shifts, 8 hours each	13 sites
2 shifts, 12 hours each	5 sites
2 shifts, 8 hours each	3 sites
1 shift, 8 - 10 hours each	3 sites
Shift Monitored	
First Shift (7am - 3 pm)	12.5 sites
Second Shift (3 pm - 11 pm)	8.5 sites
Third Shift (11 pm - 7 am)	3 sites
Average Number of Dye Weighers Working on a Shift	1.3 dye weighers per shift per site

Table A-7

WORKER ACTIVITY

Site ID	Time Monitored (minutes)	Minutes in Weighing Room	Number of Entries into Weighing Room	Number of Weighings of Powder Dyes	Number of Weighings of All Solid Substances	Weight of All Powder Dyes Weighed (kg)	Weight of All Solid Substances Weighed (kg)
1/0	449	376	11	97	98	121.8	123.0
1/6	464	407	10	54	56	56.4	56.7
2/1	367	84	12	20	20	64.0	64.0
2/4	440	213	18	108	108	44.7	44.7
2/7	475	124	16	27	27	25.6	25.6
3/0	428	263	18	72	72	97.9	97.9
3/3	447	125	18	42	45	4.5	22.9
3/8	469	342	12	149	150	74.6	74.6
4/1	445	94	14	38	38	30.9	30.9
4/3	457	96	9	29	51	60.0	556.8
4/6	447	46	16	15	23	54.2	83.9
4/9	426	359	4	62	65	197.8	206.7
5/2	454	137	19	84	84	5.2	5.2
5/4	400	287	7	46	46	10.7	10.7
5/9	452	403	7	44	54	51.1	143.6
6/2	459	456	4	88	88	283.9	283.9
6/5	463	36	9	15	35	6.4	107.1
6/6	446	217	18	8	14	39.6	223.3
7/7	369	16	3	7	7	6.0	6.0
7/9	435	320	6	33	33	15.5	15.5
8/0	474	437	8	11	11	2.1	2.1
8/6	434	413	4	259	259	73.5	73.5
8/8	458	146	8	17	26	10.1	58.8
9/1	465	127	12	103	104	24.1	24.1
Plant-Weighted Mean	440.7	220.9	10.9	60.3	63.7	58.1	97.1
Unweighted Mean	442.6	230.2	11.0	59.5	63.1	56.7	97.6
Minimum Value	367.0	16.0	3.0	7.0	7.0	2.1	2.1
Maximum Value	475.0	456.0	19.0	259.0	259.0	283.9	556.8

Table A-8

SUMMARY OF WORKER ACTIVITY

Variable	Number of Sites
Number of Total Weighers Normally Working on Any Day	
1	3
2	5
3	7
4	2
5	1
6	5
8	1
Kilograms of Dye Weighed	
0 to 10	5
10.01 to 30	5
30.01 to 60	6
60.01 to 80	4
80.01 to 284.3	4
Number of Dyes Weighed	
0 - 10	7
11 - 20	9
21 - 30	5
31 - 46	3
Number of Dye Weighings	
0 - 20	7
21 - 40	4
41 - 60	4
61 - 80	2
81 - 100	3
100 - 259	4
Hours in the Drug Room	
0.00 - 2 (< 25% of monitoring period)	6
2.01 - 4 (25-50% of monitoring period)	7
4.01 - 6 (50-75% of monitoring period)	5
6.01 - 8 (> 75% of monitoring period)	6

Table A-9

DYE FREQUENCY DURING MONITORING PERIOD, SITE BASIS

(Number of Powder Dyes Encountered by Class of Dyes)

Site ID	Dye Class								Total No. of Dyes at Each Site
	Acid	Chrome	Disperse	Basic	Reactive	Direct	Vat	Naphthol	
1/0	0	0	8	11	0	11	0	0	30
1/6	10	0	1	0	0	0	0	0	11
2/1	0	0	5	2	8	0	0	0	15
2/4	21	0	0	0	0	0	0	0	21
2/7	0	0	4	6	0	6	0	0	16
3/0	7	0	14	0	0	0	0	0	21
3/3	8	0	0	0	0	0	0	0	8
3/8	16	1	11	18	0	0	0	0	46
4/1	17	0	0	0	0	0	0	0	17
4/3	0	0	6	0	12	0	0	0	18
4/6	6	0	0	0	0	0	0	0	6
4/9	13	3	8	0	7	0	0	0	31
5/2	3	0	0	0	0	0	0	0	3
5/4	0	0	6	0	0	10	0	0	16
5/9	3	0	7	4	0	4	0	0	18
6/2	8	0	22	0	0	0	0	0	30
6/5	8	0	0	1	3	0	0	0	12
6/6	0	0	0	0	0	0	0	2	2
7/7	0	0	0	7	0	0	0	0	7
7/9	0	0	0	0	0	9	0	0	9
8/0	0	0	3	0	0	0	0	0	3
8/6	4	0	5	4	12	0	0	0	25
8/8	0	0	5	0	0	0	6	0	11
9/1	17	0	5	4	6	9	0	0	41
	----	----	----	----	----	----	----	----	----
Total Number of Unique Dyes	101	3	62	34	42	38	6	2	288
Total Number of Dye Encounters	141	4	110	57	48	49	6	2	417
Number of Sites Where Dye Class Was Weighed	14	2	15	9	6	6	1	1	24
Average Number of Dyes in Class Per Site*	10	2	7	6	8	8	6	2	17

*Includes only sites where the class of dyes was weighed during the monitoring period.

Table A-10

DYE WEIGHING ACTIVITY DURING MONITORING PERIOD: NUMBER OF WEIGHINGS OF EACH DYE CLASS

Site ID	Dye Class: Acid	Chrome	Disperse	Basic	Reactive	Direct	Vat	Naphthol	Total Number of Weighings at Each Site
1/0			20	21		56			97
1/6	53		1						54
2/1			5	2	13				20
2/4	108								108
2/7			4	17		6			27
3/0	13		59						72
3/3	42								42
3/8	24	2	11	112					149
4/1	38								38
4/3			7		22				29
4/6	15								15
4/9	26	5	22		9				62
5/2	84								84
5/4			23			23			46
5/9	6		24	5		9			44
6/2	8		80						88
6/5	11			1	3				15
6/6*								8	8
7/7				7					7
7/9						33			33
8/0			11						11
8/6	18		33	58	150				259
8/8			9				8		17
9/1	61		5	4	7	26			103
Total	507	7	314	227	204	153	8	8	1,428
Average	36	4	21	25	34	26	8	8	60

*Site was operating under atypical conditions during the monitoring period.

Table A-11

DYE WEIGHING ACTIVITY DURING MONITORING PERIOD: WEIGHT OF WEIGHINGS OF EACH DYE CLASS

Site ID	Dye Class: Acid	Chrome	Disperse	Basic	Reactive	Direct	Vat	Naphthol	Total Weight of Weighings at Each Site*
1/0			38.10	11.40		72.30			121.768
1/6	56.30		0.10						56.410
2/1			22.30	5.10	36.60				63.961
2/4	44.70								44.674
2/7			1.90	2.10		21.60			25.592
3/0	10.80		87.10						97.926
3/3	4.50								4.489
3/8	13.80	19.00	18.70	23.20					74.577
4/1	30.80								30.846
4/3			8.90		51.20				60.029
4/6	54.20								54.245
4/9	60.60	51.30	85.00		0.80				197.837
5/2	5.20								5.239
5/4			5.80			4.90			10.708
5/9	8.30		40.90	1.60		0.30			51.082
6/2	0.50		283.40						283.912
6/5	3.30			0.30	2.80				6.404
6/6**								39.6	39.585
7/7				6.00					6.034
7/9						15.50			15.510
8/0			2.10						2.114
8/6	2.40		4.20	15.80	51.00				73.496
8/8			1.20				8.80		10.077
9/1	7.40		8.10	0.70	2.90	5.00			24.082
Total	303.0	70.2	608.5	66.2	145.3	119.6	8.8	39.6	1,360.597*
Number of sites	14	2	15	9	6	6	1	1	
Average	21.6	35.1	40.6	7.4	24.2	9.5	8.8	39.6	56.691*

*Totals for each site may not be consistent with the sum of each dye class for a particular site due to rounding errors.
**Site was operating under atypical conditions during the monitoring period.

Table A-12

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: COMMERCIAL POWDER DYES WEIGHED, CLASS BASIS

					Powder Dyes Average Weighed (kg)		
Number of Dyes	Class of Dye	Number of Sites	Number of Weighings	Total Weighed (kg)	Per Site Used	Per Weighing	Per Dye Encountered
101	Acid	14	507	303.0	21.6	0.60	3.0
3	Chrome	2	7	70.2	35.1	10.03	23.4
62	Disperse	15	314	608.5	40.6	1.94	4.5
34	Basic	9	227	66.2	7.4	0.29	1.9
38	Direct	6	153	119.6	19.9	0.78	3.1
42	Reactive	6	204	145.3	24.2	0.71	3.5
6	Vat	1	8	8.8	8.8	1.11	1.5
1	Naphthol Salt	1	2	24.9	24.9	12.47	24.9
1	Naphthol	1	6	14.7	14.7	2.45	14.7
288	TOTAL	24	1428	1361.3	56.7	0.95	4.7

Table A-13

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: COMMERCIAL POWDER DYES WEIGHED, COLOR BASIS

Dye Category: Class	Dye Category: Color	Total Mass of Category Weighed (kg)	Number of Dyes Encountered in Category	Average Mass Weighed of Each Dye in Category (kg/dye)	Number of Sites Where Dye Class Used	Average Mass of Category Weighed per Site Where Class Used (kg/site)
Acid	Yellow	63.995	21	3.05	14	4.57
Acid	Orange	29.177	10	2.92	14	2.08
Acid	Red	40.152	24	1.67	14	2.87
Acid	Violet	13.617	4	3.40	14	0.97
Acid	Blue	40.127	22	1.82	14	2.87
Acid	Green	20.354	4	5.09	14	1.45
Acid	Brown	29.047	7	4.15	14	2.07
Acid	Black	66.575	9	7.40	14	4.76
Acid	Total	303.044	101	3.00	14	21.65
Chrome	Yellow	0.000	0	0.00	2	0.00
Chrome	Orange	1.770	1	1.77	2	0.89
Chrome	Red	0.000	0	0.00	2	0.00
Chrome	Violet	0.000	0	0.00	2	0.00
Chrome	Blue	0.000	0	0.00	2	0.00
Chrome	Green	0.000	0	0.00	2	0.00
Chrome	Brown	0.000	0	0.00	2	0.00
Chrome	Black	68.441	2	34.22	2	34.22
Chrome	Total	70.211	3	23.40	2	35.11
Disperse	Yellow	35.013	13	2.69	15	2.33
Disperse	Orange	136.067	4	34.02	15	9.07
Disperse	Red	131.817	23	5.73	15	8.79
Disperse	Violet	13.636	3	4.55	15	0.91
Disperse	Blue	181.632	14	12.97	15	12.11
Disperse	Green	0.272	1	0.27	15	0.02
Disperse	Brown	0.000	0	0.00	15	0.00
Disperse	Black	110.027	4	27.51	15	7.34
Disperse	Total	608.464	62	9.81	15	40.56

Table A-13

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: COMMERCIAL POWDER DYES WEIGHED, COLOR BASIS (Continued)

Dye Category: Class	Dye Category: Color	Total Mass of Category Weighed (kg)	Number of Dyes Encountered in Category	Average Mass Weighed of Each Dye in Category (kg/dye)	Number of Sites Where Dye Class Used	Average Mass of Category Weighed per Site Where Class Used (kg/site)
Basic	Yellow	23.441	11	2.13	9	2.60
Basic	Orange	1.767	2	0.88	9	0.20
Basic	Red	24.292	7	3.47	9	2.70
Basic	Violet	1.302	3	0.43	9	0.14
Basic	Blue	10.217	9	1.14	9	1.14
Basic	Green	2.843	1	2.84	9	0.32
Basic	Brown	0.000	0	0.00	9	0.00
Basic	Black	2.329	1	2.33	9	0.26
Basic	Total	66.191	34	1.95	9	7.35
Direct	Yellow	6.418	4	1.60	6	1.07
Direct	Orange	8.778	5	1.76	6	1.46
Direct	Red	22.318	10	2.23	6	3.72
Direct	Violet	0.002	1	0.00	6	0.00
Direct	Blue	32.471	11	2.95	6	5.41
Direct	Green	0.000	0	0.00	6	0.00
Direct	Brown	8.103	3	2.70	6	1.35
Direct	Black	41.554	4	10.39	6	6.93
Direct	Total	119.644	38	3.15	6	19.94
Reactive	Yellow	17.413	10	1.74	6	2.90
Reactive	Orange	5.012	3	1.67	6	0.84
Reactive	Red	56.865	11	5.17	6	9.48
Reactive	Violet	0.897	2	0.45	6	0.15
Reactive	Blue	55.978	14	4.00	6	9.33
Reactive	Green	0.000	0	0.00	6	0.00
Reactive	Brown	0.000	0	0.00	6	0.00
Reactive	Black	9.113	2	4.56	6	1.52
Reactive	Total	145.278	42	3.46	6	24.21

Table A-13

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: COMMERCIAL POWDER DYES WEIGHED, COLOR BASIS (Continued)

Dye Category: Class	Dye Category: Color	Total Mass of Category Weighed (kg)	Number of Dyes Encountered in Category	Average Mass Weighed of Each Dye in Category (kg/dye)	Number of Sites Where Dye Class Used	Average Mass of Category Weighed per Site Where Class Used (kg/site)
Vat	Yellow	0.785	1	0.79	1	0.79
Vat	Orange	2.352	1	2.35	1	2.35
Vat	Red	0.000	0	0.00	1	0.00
Vat	Violet	2.887	2	1.44	1	2.89
Vat	Blue	0.861	1	0.86	1	0.86
Vat	Green	0.000	0	0.00	1	0.00
Vat	Brown	1.962	1	1.96	1	1.96
Vat	Black	0.000	0	0.00	1	0.00
Vat	Total	8.847	6	1.47	1	8.85
Naphthol	Salt	24.932	1	24.93	1	24.93
Naphthol	Base	0.000	0	0.00	1	0.00
Naphthol	Dye	14.700	1	14.70	1	14.70
Naphthol	Total	39.632	2	19.82	1	39.63
GRAND TOTAL		1361.31	288	4.73	24	56.72

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weigh-ing	Number Encountered
ACID DYES (used at 14 of 24 sites)						Sites: 4/9,3/8, 5/2,8/6,4/1, 3/0,1/6,2/4, 5/9,3/3,6/2, 4/6,6/5,9/1.
Acid Yellow 17	1	3	0.437	0.437	0.146	
Acid Yellow 19	1	12	3.774	3.774	0.315	
Acid Yellow 40	1	2	0.001	0.001	0.001	
Acid Yellow 49	5	14	7.814	1.563	0.558	
Acid Yellow 65	1	1	0.175	0.175	0.175	
Acid Yellow 79	2	3	2.746	1.373	0.915	
Acid Yellow 99	2	9	16.352	8.176	1.817	
Acid Yellow 116	1	1	0.002	0.002	0.002	
Acid Yellow 121	2	3	0.765	0.383	0.255	
Acid Yellow 127	1	1	0.002	0.002	0.002	
Acid Yellow 129	2	3	5.840	2.920	1.947	
Acid Yellow 135	1	10	2.258	2.258	0.226	
Acid Yellow 151	2	2	0.048	0.024	0.024	
Acid Yellow 159	3	15	1.176	0.392	0.078	
Acid Yellow 198	1	4	0.145	0.145	0.036	
Acid Yellow 216	1	3	0.868	0.868	0.289	
Acid Yellow 218	1	1	0.025	0.025	0.025	
Acid Yellow 219	2	22	1.663	0.832	0.076	
Acid Yellow 235	1	5	18.500	18.500	3.700	
Acid Yellow 241	1	2	1.334	1.334	0.667	
Acid Yellow U-1	1	2	0.070	0.070	0.035	
Acid Yellow Subtotal	33	118	63.995	1.939	0.542	21 Yellow Acid Dyes
Acid Orange 3	1	7	1.911	1.911	0.273	
Acid Orange 10	1	1	0.067	0.067	0.067	
Acid Orange 51	1	1	0.320	0.320	0.320	
Acid Orange 60	1	1	0.003	0.003	0.003	
Acid Orange 74	1	1	0.432	0.432	0.432	
Acid Orange 116	2	5	0.086	0.043	0.017	
Acid Orange 142	1	1	0.247	0.247	0.247	
Acid Orange 149	1	1	4.192	4.192	4.192	
Acid Orange 156	2	20	21.850	10.925	1.093	
Acid Orange U-1	1	1	0.069	0.069	0.069	
Acid Orange Subtotal	12	39	29.177	2.431	0.748	10 Orange Acid Dyes

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weigh-ing	Number Encountered
Acid Red 1	1	2	0.081	0.081	0.041	
Acid Red 52	1	1	0.100	0.100	0.100	
Acid Red 57	1	6	9.051	9.051	1.509	
Acid Red 111	1	1	0.368	0.368	0.368	
Acid Red 143	1	6	1.075	1.075	0.179	
Acid Red 158	1	1	1.840	1.840	1.840	
Acid Red 182	2	3	1.221	0.611	0.407	
Acid Red 186	1	1	0.481	0.481	0.481	
Acid Red 194	1	1	2.086	2.086	2.086	
Acid Red 259	1	2	0.046	0.046	0.023	
Acid Red 260	2	5	0.382	0.191	0.076	
Acid Red 266	3	16	7.928	2.643	0.496	
Acid Red 299	3	7	3.099	1.033	0.443	
Acid Red 337	1	2	0.173	0.173	0.087	
Acid Red 357	1	6	0.702	0.702	0.117	
Acid Red 359	1	1	3.457	3.457	3.457	
Acid Red 360	1	1	0.364	0.364	0.364	
Acid Red 361	2	8	3.134	1.567	0.392	
Acid Red 396	1	1	0.001	0.001	0.001	
Acid Red 399	1	6	0.201	0.201	0.034	
Acid Red M-2	1	35	2.476	2.476	0.071	
Acid Red U-3	1	2	0.014	0.014	0.007	
Acid Red U-5	1	2	1.614	1.614	0.807	
Acid Red U-6	1	12	0.258	0.258	0.022	
Acid Red Subtotal	31	128	40.152	1.295	0.314	24 Red Acid Dyes
Acid Violet 7	1	2	0.008	0.008	0.004	
Acid Violet 48	2	6	0.715	0.358	0.119	
Acid Violet 90	1	1	0.760	0.760	0.760	
Acid Violet 121	1	1	12.134	12.134	12.134	
Acid Violet Subtotal	5	10	13.617	2.723	1.362	4 Violet Acid Dyes

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

				Average Weighed (kg)		
Name of Commercial Dye	No. of Sites	No. of Weighings	Total Weighed (kg)	Per Site	Per Weighing	Number Encountered
Acid Blue 7	1	1	0.001	0.001	0.001	
Acid Blue 25	4	31	15.050	3.763	0.485	
Acid Blue 40	2	9	0.501	0.251	0.056	
Acid Blue 45	1	4	0.270	0.270	0.068	
Acid Blue 62	2	3	0.004	0.002	0.001	
Acid Blue 80	3	11	5.747	1.916	0.522	
Acid Blue 90	1	1	0.007	0.007	0.007	
Acid Blue 102	1	1	0.368	0.368	0.368	
Acid Blue 113	4	9	9.972	2.493	1.108	
Acid Blue 158	2	6	3.519	1.760	0.587	
Acid Blue 177	1	1	0.015	0.015	0.015	
Acid Blue 205	1	1	0.454	0.454	0.454	
Acid Blue 239	1	3	0.092	0.092	0.031	
Acid Blue 258	1	6	0.607	0.607	0.101	
Acid Blue 264	1	1	0.182	0.182	0.182	
Acid Blue 277	1	1	0.110	0.110	0.110	
Acid Blue 281	1	6	0.174	0.174	0.029	
Acid Blue 284	1	1	0.995	0.995	0.995	
Acid Blue 290	1	4	0.129	0.129	0.032	
Acid Blue 324	2	34	1.477	0.739	0.043	
Acid Blue 335	1	1	0.034	0.034	0.034	
Acid Blue 345	1	1	0.419	0.419	0.419	
Acid Blue Subtotal	34	136	40.127	1.180	0.295	22 Blue Acid Dyes
Acid Green 25	3	7	8.161	2.720	1.166	
Acid Green 28	1	3	0.466	0.466	0.155	
Acid Green 104	1	1	3.718	3.718	3.718	
Acid Green 108	1	1	8.009	8.009	8.009	
Acid Green Subtotal	6	12	20.354	3.392	1.696	4 Green Acid Dyes

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weigh-ing	Number Encountered
Acid Brown 45	1	2	0.035	0.035	0.018	
Acid Brown 227	2	2	3.496	1.748	1.748	
Acid Brown 298	2	10	21.937	10.969	2.194	
Acid Brown 330	1	3	2.183	2.183	0.728	
Acid Brown 384	1	6	1.059	1.059	0.177	
Acid Brown M-1	1	3	0.045	0.045	0.015	
Acid Brown U-2	1	4	0.292	0.292	0.073	
Acid Brown Subtotal	9	30	29.047	3.227	0.968	7 Brown Acid Dyes
Acid Black 52	1	3	6.499	6.499	2.166	
Acid Black 58	2	2	7.933	3.967	3.967	
Acid Black 60	1	3	4.020	4.020	1.340	
Acid Black 107	2	13	12.112	6.056	0.932	
Acid Black 172	1	4	21.429	21.429	5.357	
Acid Black 187	1	1	2.121	2.121	2.121	
Acid Black M-1	1	2	7.520	7.520	3.760	
Acid Black M-2	1	2	0.481	0.481	0.241	
Acid Black M-3	1	4	4.460	4.460	1.115	
Acid Black Subtotal	11	34	66.575	6.052	1.958	9 Black Acid Dyes
TOTAL--ACID DYES	**141**	**507**	**303.044**	**2.149**	**0.598**	**101 Acid Dyes, all colors**
CHROME DYES (used at 2 of 24 sites)						Sites: 4/9,3/8.
Mordant Orange 3	1	1	1.770	1.770	1.770	1 Orange Chrome Dye
Mordant Black 9	1	1	15.400	15.400	15.400	
Mordant Black 11	2	5	53.041	26.521	10.608	
Mordant Black Subtotal	3	6	68.441	22.814	11.407	2 Black Chrome Dyes
TOTAL--CHROME DYES	**4**	**7**	**70.211**	**17.553**	**10.030**	**3 Chrome Dyes, all colors**

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weighings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weighing	Number Encountered
DISPERSE DYES (used at 15 of 24 sites)						Sites: 4/9,3/8, 2/1,8/6,2/7, 3/0,5/4,1/0, 1/6,5/9,8/0, 8/8,4/3, 6/2,9/1.
Disperse Yellow 3	2	2	0.080	0.040	0.040	
Disperse Yellow 23	1	1	13.276	13.276	13.276	
Disperse Yellow 42	3	14	12.194	4.065	0.871	
Disperse Yellow 54	2	3	0.761	0.381	0.254	
Disperse Yellow 64	1	1	0.054	0.054	0.054	
Disperse Yellow 67	1	1	0.109	0.109	0.109	
Disperse Yellow 86	1	1	4.646	4.646	4.646	
Disperse Yellow 93	1	3	0.620	0.620	0.207	
Disperse Yellow 108	1	3	0.171	0.171	0.057	
Disperse Yellow 114	1	1	0.114	0.114	0.114	
Disperse Yellow 184:1	1	1	0.100	0.100	0.100	
Disperse Yellow 198	1	3	1.360	1.360	0.453	
Disperse Yellow 218	2	8	1.528	0.764	0.191	
Disperse Yellow Subtotal	18	42	35.013	1.945	0.834	13 Yellow Disperse Dyes
Disperse Orange 29	1	3	0.081	0.081	0.027	
Disperse Orange 30	4	35	90.587	22.647	2.588	
Disperse Orange 37	1	4	4.126	4.126	1.032	
Disperse Orange 41	2	5	41.273	20.637	8.255	
Disperse Orange Subtotal	8	47	136.067	17.008	2.895	4 Orange Disperse Dyes
Disperse Red 4	1	1	0.021	0.021	0.021	
Disperse Red 43	1	5	1.370	1.370	0.274	
Disperse Red 55	1	4	1.198	1.198	0.300	
Disperse Red 60	7	17	5.717	0.817	0.336	
Disperse Red 65	1	1	1.552	1.552	1.552	
Disperse Red 72	1	6	0.808	0.808	0.135	
Disperse Red 73	3	7	4.185	1.395	0.598	
Disperse Red 82	2	3	0.268	0.134	0.089	
Disperse Red 86	1	3	0.440	0.440	0.147	
Disperse Red 88	1	2	2.734	2.734	1.367	
Disperse Red 91	2	5	7.451	3.726	1.490	

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Per Weigh-ing	Number Encountered
Disperse Red 135	2	2	11.604	5.802	5.802	
Disperse Red 151	1	1	5.045	5.045	5.045	
Disperse Red 159	1	6	15.039	15.039	2.507	
Disperse Red 167	1	5	32.350	32.350	6.470	
Disperse Red 167:1	1	4	5.657	5.657	1.414	
Disperse Red 177	1	4	5.126	5.126	1.282	
Disperse Red 211	1	9	0.914	0.914	0.102	
Disperse Red 263	2	4	12.224	6.112	3.056	
Disperse Red 305	1	2	2.036	2.036	1.018	
Disperse Red 333	1	2	13.937	13.937	6.969	
Disperse Red 338	1	1	0.793	0.793	0.793	
Disperse Red U-2	1	1	1.348	1.348	1.348	
Disperse Red Subtotal	35	95	131.817	3.766	1.388	23 Red Disperse Dyes
Disperse Violet 26	1	1	0.159	0.159	0.159	
Disperse Violet 48	1	2	0.680	0.680	0.340	
Disperse Violet 57	1	5	12.797	12.797	2.559	
Disperse Violet Subtotal	3	8	13.636	4.545	1.705	3 Violet Disperse Dyes
Disperse Blue 3	2	2	0.017	0.009	0.009	
Disperse Blue 27	3	12	19.893	6.631	1.658	
Disperse Blue 56	8	20	35.494	4.437	1.775	
Disperse Blue 60	7	19	18.818	2.688	0.990	
Disperse Blue 73	5	13	13.849	2.770	1.065	
Disperse Blue 77	2	5	26.009	13.005	5.202	
Disperse Blue 79	3	13	10.870	3.623	0.836	
Disperse Blue 87	1	3	8.374	8.374	2.791	
Disperse Blue 109	2	2	4.770	2.385	2.385	
Disperse Blue 139	1	1	0.078	0.078	0.078	
Disperse Blue 281	2	6	16.991	8.496	2.832	
Disperse Blue 337	1	6	7.479	7.479	1.247	
Disperse Blue M-3	1	1	13.349	13.349	13.349	
Disperse Blue U-4	2	5	5.641	2.821	1.128	
Disperse Blue Subtotal	40	108	181.632	4.541	1.682	14 Blue Disperse Dyes

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weighings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weighing	Number Encountered
Disperse Green 9	1	1	0.272	0.272	0.272	1 Green Disperse Dye
Disperse Black M-1	1	4	41.645	41.645	10.411	
Disperse Black M-2	1	2	11.900	11.900	5.950	
Disperse Black M-3	1	6	53.693	53.693	8.949	
Disperse Black M-4	1	1	2.789	2.789	2.789	
Disperse Black Subtotal	4	13	110.027	27.507	8.464	4 Black Disperse Dyes
TOTAL--DISPERSE DYES	**109**	**314**	**608.464**	**5.582**	**1.938**	**62 Disperse Dyes, all colors**
BASIC DYES (used at 9 of 24 sites)						Sites: 3/8,7/7, 2/1,8/6,2/7, 1/0,5/9, 6/5,9/1.
Basic Yellow 11	2	29	8.045	4.023	0.277	
Basic Yellow 13	1	1	0.018	0.018	0.018	
Basic Yellow 21	1	1	0.068	0.068	0.068	
Basic Yellow 24	1	2	1.072	1.072	0.536	
Basic Yellow 25	1	3	2.662	2.662	0.887	
Basic Yellow 28	4	16	5.009	1.252	0.313	
Basic Yellow 29	1	2	1.635	1.635	0.818	
Basic Yellow 40	1	1	3.747	3.747	3.747	
Basic Yellow 51	1	1	0.420	0.420	0.420	
Basic Yellow 87	1	8	0.432	0.432	0.054	
Basic Yellow 91	1	1	0.333	0.333	0.333	
Basic Yellow Subtotal	15	65	23.441	1.563	0.361	11 Yellow Basic Dyes
Basic Orange 21	2	2	1.707	0.854	0.854	
Basic Orange 30	1	1	0.060	0.060	0.060	
Basic Orange Subtotal	3	3	1.767	0.589	0.589	2 Orange Basic Dyes

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

				Average Weighed (kg)		
Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Per Site	Per Weigh-ing	Number Encountered
Basic Red 14	3	5	1.543	0.514	0.309	
Basic Red 15	2	8	6.050	3.025	0.756	
Basic Red 29	2	25	11.821	5.911	0.473	
Basic Red 46	4	16	1.081	0.270	0.068	
Basic Red 49	1	1	0.866	0.866	0.866	
Basic Red 51	1	16	2.835	2.835	0.177	
Basic Red U-2	1	5	0.096	0.096	0.019	
Basic Red Subtotal	14	76	24.292	1.735	0.320	7 Red Basic Dyes
Basic Violet 14	1	1	0.074	0.074	0.074	
Basic Violet 16	2	6	1.183	0.592	0.197	
Basic Violet 37	1	1	0.045	0.045	0.045	
Basic Violet Subtotal	4	8	1.302	0.326	0.163	3 Violet Basic Dyes
Basic Blue 3	4	9	0.975	0.244	0.108	
Basic Blue 21	1	1	0.015	0.015	0.015	
Basic Blue 41	3	19	4.390	1.463	0.231	
Basic Blue 45	1	2	0.030	0.030	0.015	
Basic Blue 54	3	6	2.312	0.771	0.385	
Basic Blue 69	1	16	2.071	2.071	0.129	
Basic Blue 124	1	13	0.286	0.286	0.022	
Basic Blue 141	1	1	0.068	0.068	0.068	
Basic Blue U-1	1	2	0.070	0.070	0.035	
Basic Blue Subtotal	16	69	10.217	0.639	0.148	9 Blue Basic Dyes
Basic Green 4	4	5	2.843	0.711	0.569	1 Green Basic Dye
Basic Black M-1	1	1	2.329	2.329	2.329	1 Black Basic Dye
TOTAL--BASIC DYES	**57**	**227**	**66.191**	**1.161**	**0.292**	**34 Basic Dyes, all colors**

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weighings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weighing	Number Encountered
DIRECT DYES (used at 6 of 24 sites)						Sites: 2/7,5/4, 1/0,5/9, 7/9,9/1.
Direct Yellow 44	1	1	1.362	1.362	1.362	
Direct Yellow 58	1	1	0.078	0.078	0.078	
Direct Yellow 106	5	23	4.318	0.864	0.188	
Direct Yellow 142	1	6	0.660	0.660	0.110	
Direct Yellow Subtotal	8	31	6.418	0.802	0.207	4 Yellow Direct Dyes
Direct Orange 34	1	1	0.147	0.147	0.147	
Direct Orange 72	1	3	0.013	0.013	0.004	
Direct Orange 80	1	1	1.345	1.345	1.345	
Direct Orange M-2	1	5	7.243	7.243	1.449	
Direct Orange M-3	1	1	0.030	0.030	0.030	
Direct Orange Subtotal	5	11	8.778	1.756	0.798	5 Orange Direct Dyes
Direct Red 9	2	2	2.274	1.137	1.137	
Direct Red 72	1	6	8.151	8.151	1.359	
Direct Red 75	1	9	2.278	2.278	0.253	
Direct Red 80	2	5	0.150	0.075	0.030	
Direct Red 89	1	7	3.023	3.023	0.432	
Direct Red 149	1	1	0.117	0.117	0.117	
Direct Red 224	1	1	2.316	2.316	2.316	
Direct Red 227	1	8	2.565	2.565	0.321	
Direct Red 243	2	6	0.371	0.186	0.062	
Direct Red U-1	1	1	1.073	1.073	1.073	
Direct Red Subtotal	13	46	22.318	1.717	0.485	10 Red Direct Dyes
Direct Violet 9	1	1	0.002	0.002	0.002	1 Violet Direct Dye

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weighings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weighing	Number Encountered
Direct Blue 25	1	1	0.019	0.019	0.019	
Direct Blue 78	1	4	0.051	0.051	0.013	
Direct Blue 80	2	7	1.085	0.543	0.155	
Direct Blue 106	1	1	0.381	0.381	0.381	
Direct Blue 160	1	2	3.895	3.895	1.948	
Direct Blue 189	1	1	0.026	0.026	0.026	
Direct Blue 191	2	5	9.744	4.872	1.949	
Direct Blue 218	1	4	0.463	0.463	0.116	
Direct Blue 251	1	2	5.926	5.926	2.963	
Direct Blue U-1	1	1	7.045	7.045	7.045	
Direct Blue M-2	1	8	3.836	3.836	0.480	
Direct Blue Subtotal	13	36	32.471	2.498	0.902	11 Blue Direct Dyes
Direct Brown 113	1	3	0.049	0.049	0.016	
Direct Brown 115	2	12	8.042	4.021	0.670	
Direct Brown 116	1	1	0.012	0.012	0.012	
Direct Brown Subtotal	4	16	8.103	2.026	0.506	3 Brown Direct Dyes
Direct Black 2	1	1	0.644	0.644	0.644	
Direct Black 62	1	1	0.038	0.038	0.038	
Direct Black 80	2	9	32.196	16.098	3.577	
Direct Black M-1	1	1	8.676	8.676	8.676	
Direct Black Subtotal	5	12	41.554	8.311	3.463	4 Black Direct Dyes
TOTAL--DIRECT DYES	**49**	**153**	**119.644**	**2.442**	**0.782**	**38 Direct Dyes, all colors**

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weigh-ing	Number Encountered
REACTIVE DYES (used at 6 of 24 sites)						Sites: 4/9,2/1, 8/6,4/3, 6/5,9/1.
Reactive Yellow 3	1	1	0.692	0.692	0.692	
Reactive Yellow 15	1	3	0.870	0.870	0.290	
Reactive Yellow 25	1	2	0.230	0.230	0.115	
Reactive Yellow 27	2	8	1.447	0.724	0.181	
Reactive Yellow 37:1	1	1	0.043	0.043	0.043	
Reactive Yellow 58	1	2	0.642	0.642	0.321	
Reactive Yellow 64	1	1	0.117	0.117	0.117	
Reactive Yellow 125	1	39	13.267	13.267	0.340	
Reactive Yellow 160	1	1	0.101	0.101	0.101	
Reactive Yellow U-2	1	1	0.004	0.004	0.004	
Reactive Yellow Subtotal	11	59	17.413	1.583	0.295	10 Yellow Reactive Dyes
Reactive Orange 16	1	3	3.832	3.832	1.277	
Reactive Orange 70	1	1	1.112	1.112	1.112	
Reactive Orange 82	1	1	0.068	0.068	0.068	
Reactive Orange Subtotal	3	5	5.012	1.671	1.002	3 Orange Reactive Dyes
Reactive Red 40	2	11	1.196	0.598	0.109	
Reactive Red 43	2	2	2.949	1.475	1.475	
Reactive Red 94	1	2	16.991	16.991	8.496	
Reactive Red 120	2	2	3.270	1.635	1.635	
Reactive Red 152	1	1	1.602	1.602	1.602	
Reactive Red 168	1	2	0.247	0.247	0.124	
Reactive Red 180	1	3	5.820	5.820	1.940	
Reactive Red 198	1	2	9.060	9.060	4.530	
Reactive Red U-2	1	1	0.030	0.030	0.030	
Reactive Red U-3	1	1	0.036	0.036	0.036	
Reactive Red U-4	1	41	15.664	15.664	0.382	
Reactive Red Subtotal	14	68	56.865	4.062	0.836	11 Red Reactive Dyes

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

				Average Weighed (kg)		
Name of Commercial Dye	No. of Sites	No. of Weighings	Total Weighed (kg)	Per Site	Per Weighing	Number Encountered
Reactive Violet 5	1	1	0.045	0.045	0.045	
Reactive Violet 33	1	2	0.852	0.852	0.426	
Reactive Violet Subtotal	2	3	0.897	0.449	0.299	2 Violet Reactive Dyes
Reactive Blue 7	1	2	10.352	10.352	5.176	
Reactive Blue 10	1	5	5.990	5.990	1.198	
Reactive Blue 18	1	1	1.007	1.007	1.007	
Reactive Blue 21	2	4	5.930	2.965	1.483	
Reactive Blue 27	2	2	0.394	0.197	0.197	
Reactive Blue 29	1	5	0.810	0.810	0.162	
Reactive Blue 52	1	1	0.166	0.166	0.166	
Reactive Blue 114	1	1	0.960	0.960	0.960	
Reactive Blue 116	1	2	13.161	13.161	6.581	
Reactive Blue 137	1	1	11.570	11.570	11.570	
Reactive Blue U-1	1	2	0.202	0.202	0.101	
Reactive Blue U-3	1	32	4.130	4.130	0.129	
Reactive Blue U-4	1	3	0.034	0.034	0.011	
Reactive Blue U-5	1	1	1.272	1.272	1.272	
Reactive Blue Subtotal	16	62	55.978	3.499	0.903	14 Blue Reactive Dyes
Reactive Black 5	1	1	8.787	8.787	8.787	
Reactive Black U-1	1	6	0.326	0.326	0.054	
Reactive Black Subtotal	2	7	9.113	4.557	1.302	2 Black Reactive Dyes
TOTAL--REACTIVE DYES	**48**	**204**	**145.278**	3.027	0.712	**42 Reactive Dyes, all colors**

Table A-14

TEXTILE DYE WEIGHING ROOM MONITORING STUDY: INDIVIDUAL DYES ENCOUNTERED (Continued)

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Per Weigh-ing	Number Encountered
VAT DYES (used at 1 of 24 sites)						Site: 8/8.
Vat Yellow 2	1	1	0.785	0.785	0.785	1 Yellow Vat Dye
Vat Orange 2	1	1	2.352	2.352	2.352	1 Orange Vat Dye
Vat Violet 1	1	1	1.562	1.562	1.562	
Vat Violet 13	1	2	1.325	1.325	0.663	
Vat Violet Subtotal	2	3	2.887	1.444	0.962	2 Violet Vat Dyes
Vat Blue 6	1	2	0.861	0.861	0.431	1 Blue Vat Dye
Vat Brown M-1	1	1	1.962	1.962	1.962	1 Brown Vat Dye
TOTAL--VAT DYES	**6**	**8**	**8.847**	**1.475**	**1.106**	**6 Vat Dyes, all colors**
NAPHTHOL DYES (used at 1 of 24 sites)						Site: 6/6.
Azoic Diazo Compound 13	1	2	24.932	24.932	12.466	1 Naphthol Salt
Azoic Coupling Compound 17	1	6	14.700	14.700	2.450	1 Naphthol Dye
FLUORESCENT WHITENING AGENT (used at 1 of 24 sites)						Site: 3/8.
FWA (non-dye) 61	1	1	0.045	0.045	0.045	1 Fluorescent Whitening Agent

Table A-14

**TEXTILE DYE WEIGHING ROOM MONITORING STUDY:
INDIVIDUAL DYES ENCOUNTERED
(Continued)**

Name of Commercial Dye	No. of Sites	No. of Weigh-ings	Total Weighed (kg)	Average Weighed (kg) Per Site	Average Weighed (kg) Per Weigh-ing	Number Encountered
All Black Dyes	**26**	**73**	**298.04**	**11.46**	**4.08**	**22 Black Dyes**
				13.55 kg Weighed per Average Black Dye		
All Non-black Dyes	**390**	**1355**	**1063.27**	**2.73**	**0.78**	**266 Non-black Dyes**
				4.00 kg Weighed per Average Non-black Dye		
TOTAL--ALL DYES	**416**	**1428**	**1361.31**	**3.27**	**0.95**	**288 Total Dyes**
					4.73 kg Weighed, Average per Dye	
	24 sites			56.72 kg Weighed, Average per Site		

Table A-15

CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT AND ENGINEERING CONTROLS

	Respiratory Protective Equipment Used During Dye Handling*				Dermal Protection Used During Dye Handling		
Site ID	Disposable Dust Mask	Neg. Press. AP-Resp.	Pos. Press AP-Resp.	Gloves	Apron/ Smock	Boots/ Safety Shoes	Safety Glasses/ Goggles
1/0	yes			yes	no	no	no
1/6		yes		no	no	no	no
2/1		yes		yes	yes	no	yes
2/4	no respiratory protection used			no	no	no	no
2/7		yes		no	no	yes	no
3/0	yes			yes	no	yes	yes
3/3	yes			no	no	yes	no
3/8	yes			yes	yes	yes	no
4/1	yes			yes	no	no	no
4/3	no respiratory protection used			**	no	yes	**
4/6	no respiratory protection used			no	no	no	no
4/9			yes	yes	yes	yes	yes
5/2	yes			yes	no	no	no
5/4	yes			yes	no	no	no
5/9	yes			no	no	yes	no
6/2	yes			yes	yes	yes	yes
6/5		yes		yes	yes	no	yes
6/6	yes			yes	no	no	no
7/7		yes		yes	yes	no	no
7/9	no respiratory protection used			yes	yes	no	no
8/0		yes		no	no	yes	no
8/6	yes			yes	yes	no	yes
8/8	yes			no	no	no	no
9/1	no respiratory protection used			yes	no	no	no

*Neg. Press. AP-Resp.--negative pressure air-purifying respirator; Pos. Press. AP-Resp.--positive pressure air-purifying respirator.
**These protective items were worn only when weighing caustics, not when handling dyestuffs.

Table A-15

CONTROLS AND PERSONAL PROTECTIVE EQUIPMENT AND ENGINEERING CONTROLS (Continued)

	Dye Weigher Activities		Engineering Controls	
Site ID	Eat/Drink in Weighing Room	Smoke in Weighing Room	Local exhaust ventilation	Wet mop floors
1/0	no	yes	no	yes, reportedly between shifts
1/6	yes	***	no	information not recorded
2/1	no	no	no	information not recorded
2/4	no	no	no	information not recorded
2/7	no	yes	no	information not recorded
3/0	no	no	no	yes, reportedly between shifts
3/3	no	yes	no	yes, reportedly weekly
3/8	no	yes	no	information not recorded
4/1	no	no	no	information not recorded
4/3	no	yes	no	yes, reportedly between shifts
4/6	no	yes	no	yes, frequency not reported
4/9	no	no	no	yes, reportedly between shifts
5/2	no	no	yes	information not recorded
5/4	no	no	no	yes, observed during monitoring period
5/9	no	no	no	yes, reportedly between shifts
6/2	yes	no	no	yes, reportedly weekly, dry swept between shifts
6/5	no	no	no	information not recorded
6/6	yes	yes	yes	information not recorded
7/7	no	no	no	information not recorded
7/9	no	no	no	information not recorded
8/0	yes	yes	no	yes, reportedly weekly
8/6	yes	no	no	information not recorded
8/8	no	no	no	no, reportedly dry swept only
9/1	no	no	no	no, reportedly dry swept weekly

***Employee used chewing tobacco while in the drug room.

Table A-16

USE OF PROTECTIVE EQUIPMENT AND PERSONAL HYGIENE PRACTICES AT EACH SITE

Variable	Number of Sites
Use of Respirators	
Disposable Dust Mask	11
Negative Pressure Air, Purifying Type	6
Positive Pressure Air, Purifying Type	1
None	6
Dermal Protection	
No Protection	4
Gloves Only	6
Shoes Only	4
Gloves and Apron	2
Gloves, Apron, Eyewear	2
Gloves, Apron, Shoes	1
Gloves, Shoes, Eyewear	3
All Four Types	2
Weigher Activities in Drug Room	
Eat/Drink Only	2
Smoke Only	6
Both	3
None	13
Engineering Controls in Place	
Local Exhaust	2
Wet Mop Observed	13
Wet Mop Indicated/Not Observed	5
None	4

Appendix B

TEXTILE DYEING PLANTS:
POPULATION AND SUBPOPULATION ESTIMATES

This appendix contains two types of estimates. First there are estimates for the numbers of plants and weighers included in certain categories. These estimates are produced by summing the plant and weigher level weights (described in Chapter 7) to produce estimates for the categories. The categories break the population into groups based upon information obtained from the in-plant monitoring. For example, in Table B-1, the first variable in the table is Management Type (Vertical, Commission or Both). The table shows the number of sample cases represented (for example 15 for the Vertical only Management Type), the estimated number of plants in the population having vertical management -- 596, and an estimate of the total number of weighers at such plants -- 1,858. The remainder of the line for each of the entries contains estimates of commercial dye concentration for the specific subgroup of the population defined in the far left column.

It is important to remember that the survey was not designed to produce accurate estimates in subgroups of the population so finely configured. In many of the subgroups shown there are only 2 or 3 cases; in some there are only 1 case. Having such small numbers in the individual cells makes the prospect of making inferences from the data very remote. However, the data are useful to present from a general informational point of view.

The second type of estimate included in Table B-1 is for concentration of commercial dye. These estimates are broken down by subgroups of the population. Continuing the example started above, in the first row of the table (vertically managed plants), the commercial dye concentration for the population of plants is 0.18 mg/m^3. This means that for the universe of plants, the survey produced an estimate for the typical vertically managed plant as having an airborne dye concentration for commercial dye of 0.18 mg/m^3. The estimate for the population of weighers in vertically managed plants is 0.19 mg/m^3. Again, this can be interpreted as saying that the typical weigher in one of these plants would be exposed to that much commercial dye per air volume breathed.

The final comment to make relates to the inclusion of standard errors of estimates. These are included for estimates of commercial dye concentration for both the plant and weigher populations. They are used as follows. Construct an interval about the estimates which is equal to approximately twice the standard error. This interval is a 95% confidence interval. Roughly speaking, if two intervals for two different classes of the same variable do not overlap, the estimates for these classes are significantly different. Again, the idea is illustrated with an example. For the variable, Management Type, and for the groups vertical versus commission, we have the following situation:

	Estimate	Standard Error	Interval
Vertical	0.18	0.070	(0.04 - 0.32)
Commission	0.084	0.031	(0.022 - 0.15)

It is clear from this example that the intervals overlap. Therefore, there is not a significant difference uncovered.

As mentioned above, the sample sizes per cell are so small that it is not appropriate to highlight such analyses; and this analysis was, therefore, not included in Chapter 7. It is provided, here, for the readers' use to facilitate their understanding of the table. It can be considered as producing qualitative information about the data which can help the reader better understand the population of interest.

Table B-1

COMMERCIAL DYE CONCENTRATION ESTIMATES BROKEN DOWN BY OTHER VARIABLES MEASURED DURING MONITORING

		Estimated Universe		Plant-Weighted		Worker-Weighted	
Variable	No. of Sampling Cases	No. of Plants	No. of Workers	Commercial Dye Concentration (mg/m^3)	Standard Error	Commercial Dye Concentration (mg/m^3)	Standard Error
Management Type							
Vertical	15	596	1,858	0.18	0.07	0.19	0.074
Commission	3	119	362	0.084	0.031	0.095	0.029
Both	4	148	469	0.27	0.11	0.2	0.1
Ownership							
Private	12	444	1,529	0.19	0.053	0.18	0.056
Public	10	419	1,159	0.17	0.096	0.17	0.10
Number of Dyeing Machines							
1 to 5	5	177	670	0.074	0.015	0.056	0.016
6 to 10	4	181	333	0.23	0.11	0.25	0.11
11 to 15	7	267	1,007	0.22	0.14	0.2	0.13
16 to 75	6	238	678	0.18	0.048	0.23	0.063
Production Volume (million pounds)							
0.0 to 5.0	11	448	1,011	0.15	0.050	0.13	0.052
5.1 to 10.0	4	181	687	0.089	0.017	0.074	0.017
10.1 to 20.0	4	115	547	0.44	0.24	0.36	0.21
20.1 to 25.0	3	119	444	0.21	0.037	0.23	0.041
Dyeing Processes Performed							
Batch Dyeing	17	720	2,056	0.20	0.065	0.21	0.069
Continuous Dyeing	2	58	288	0.063	0.017	0.048	0.016
Both	2	58	173	0.11	0.032	0.11	0.032
Printing	1	29	173	0.019	NA	0.019	NA

Table B-1

COMMERCIAL DYE CONCENTRATION ESTIMATES BROKEN DOWN BY OTHER VARIABLES MEASURED DURING MONITORING (Continued)

Variable	No. of Sampling Cases	Estimated Universe: No. of Plants	Estimated Universe: No. of Workers	Plant-Weighted: Commercial Dye Concentration (mg/m³)	Plant-Weighted: Standard Error	Worker-Weighted: Commercial Dye Concentration (mg/m³)	Worker-Weighted: Standard Error
Shifts							
3 - 8 hour shifts	11	382	1,492	0.22	0.097	0.22	0.089
2 - 12 hour shifts	4	148	650	0.065	0.013	0.059	0.013
2 8 hour shifts	4	214	428	0.22	0.096	0.22	0.096
1 - 10 hour shifts		29	29	0.013	NA	0.013	NA
1 - 8 hour shifts	2	90	90	0.15	0.037	0.15	0.037
Time Weigher in Drug Room							
Less than 25%	5	243	662	0.08	0.019	0.071	0.018
Between 25% and 49.99%	6	238	654	0.10	0.023	0.076	0.022
Between 50% and 74.99%	4	115	403	0.13	0.060	0.18	0.071
At least 75%	7	267	970	0.37	0.14	0.32	0.13
Number of Weighers							
1	3	119	119	0.12	0.044	0.12	0.044
2	5	243	485	0.21	0.085	0.21	0.085
3	7	267	802	0.23	0.14	0.23	0.14
4	2	90	362	0.07	0.018	0.07	0.018
6	4	115	691	0.21	0.091	0.21	0.091
8	1	29	230	0.039	NA	0.039	NA
Mass weighed (kg)							
0 to 10 kg	4	148	584	0.066	0.017	0.049	0.016
10.01 to 30 kg	5	177	506	0.088	0.031	0.078	0.025
30.01 to 60 kg	5	210	415	0.11	0.013	0.11	0.014
60.01 to 80 kg	4	181	567	0.22	0.12	0.16	0.099
80.01 to 284.3 kg	4	148	617	0.46	0.20	0.44	0.17
Number of dyes weighed							
0 to 10	5	144	547	0.046	0.013	0.040	0.012
11 to 20	9	391	1,225	0.083	0.014	0.077	0.014
21 to 30	5	243	715	0.30	0.077	0.33	0.066
31 to 46	3	86	201	0.52	0.280	0.61	0.32
Number of dye weighings							
0 to 20	5	210	683	0.066	0.016	0.057	0.016
21 to 40	4	181	572	0.084	0.021	0.081	0.017
41 to 60	4	115	460	0.069	0.027	0.057	0.027
61 to 80	2	58	259	0.76	0.31	0.61	0.31
81 to 100	3	119	415	0.22	0.088	0.28	0.097
101 to 249	4	181	300	0.27	0.093	0.31	0.098

*Includes only the 22 plants with a valid concentration measurement.

Appendix C

ANALYTICAL METHODS

This appendix contains the details of the development of the analytical methodology. This includes the evolution of the method, statistical techniques developed to evaluate the accuracy of estimates, quality control procedures followed and some analysis of the methodology. For additional information, the interested reader may refer to the article "A Spectral Photometric Method of Total Levels of Textile Dyes in Air Monitoring Filters" in the Journal of the American Industrial Hygiene Association.[1]

I. INITIAL EVALUATION OF ANALYTICAL METHODS

Many different analytical approaches were evaluated with regard to their applicability to the anticipated complexity and low levels of dye mixtures in the drug room samples. The air filters could contain as many as 50 different textile dyes from up to six different dye classes. There were several general requirements of the analytical method to be used in the study. One of the most important requirements was the ability to detect total dye amounts of less than 20 micrograms (μg), since low levels were anticipated on many of the air filters. Because of these possible low levels, another crucial requirement of the method was to have dye recoveries of at least 60% from the air filters (but no greater than 140% of the theoretical values). An additional prerequisite of the analytical method was to minimize the amount of interference caused by the presence of any non-dye compounds on the air filters. Finally, the size of the study made it essential that the analysis time and cost of the procedure not be too great for each plant site.

The most conventional, straightforward analytical approach would be to utilize high performance liquid chromatography (HPLC) to separate the component dyes in the sample and employ a programmable variable wavelength ultraviolet/visible absorbance detector to quantitate each dye at its most sensitive wavelength. Using HPLC, however, was very problematic for the drug room study. The foremost problem was the anticipated need to develop multiple chromatography systems to analyze dyes from different dye classes. Coupled with that requirement was the probable need to "fine tune" these chromatography systems to optimize the recovery and separations required for each unique plant site. The total number of plant sites to be sampled and the sheer number of dyes which could be encountered led to the conclusion that HPLC, and chromatography in general, would not be a viable analytical technique for the drug room study.

Due to the sample complexity problems, a nonspecific, general dye screening procedure appeared to present the best solution to the

[1]Harbin DN, Going JE, Breen JJ. 1990. A spectrophotometric method of estimating total levels of textile dyes on air monitoring filters. J Am Ind Hyg Assoc 51(4):185-193.

analytical challenge. This approach satisfied the needs of the study, since individual dye quantitations were not essential in the overall results. A method based on integrated absorbance measurements over the visible wavelength range was judged to be subject to few interferences and sufficiently sensitive to detect levels of dyes in the range of 10 to 20 µg.

II. DEVELOPING THE ANALYTICAL METHOD

A. Theoretical Concepts

Conventional dye quantitation methods which employ spectrophotometry are based on the Beer-Lambert law. This law is often expressed by the following formula:

$$A = a \times b \times c$$

where A is the absorbance of the absorbing species at a specified wavelength, a is the absorptivity constant of the absorbing species at the specified wavelength, b is the absorption pathlength, and c is the concentration of the absorbing species in the sample. For the case of spectrophotometric measurements on solutions of the same absorbing species, the a and b terms will be constant and the Beer-Lambert law can be simplified to the statement that absorbance at the specified wavelength is directly proportional to the concentration of the absorbing species. Since dye mixtures having absorbance across the entire visible region could be encountered in the drug room study, it is necessary to measure absorbances accordingly to ensure that all dyes present are detected. Therefore, a total integrated absorbance from 380 to 750 nm was used.

The approach used in this study basically extended the Beer-Lambert law over a designated wavelength interval:

$$A_{TOT} = a_s \times b \times c$$

where A_{TOT} is the total measured absorbance of the sample solution over a specified wavelength interval and a_s is the "spectral" absorptivity constant for the absorbing species over the specified wavelength interval. The total absorbance of a sample solution can be obtained by integrating the area beneath the absorbance spectrum over the specified wavelength interval and converting the area to absorbance units. In a mixture of n absorbing components, the following relationship will exist if Beer's law is obeyed:

$$A_{TOT} = b \sum_{i=1}^{n} a_{si} \times c_i$$

where A_{TOT} is the total measured absorbance of the mixture, b is the absorption pathlength, a_{si} is the spectral absorptivity constant for the ith component, and c_i is the concentration of the ith component.

Taken as a whole, the absorbance characteristics of a dye mixture can be considered to be a composite of the individual dye absorptivity constants. As a result, the average value of the individual dye absorptivity constants (a_s) is a reasonable approximation of the overall absorptivity of the dye mixture, provided that no single component dye has a grossly disproportionate presence in the mixture. Similarly, the individual dye concentrations in the mixture can be summed together to result in a total dye concentration (C_{TOT}). In applying this quantitation method, the individual a_s constant for each of the possible component dyes is experimentally determined. An average a_s value ($\bar{a}_s$) for the entire group of possible component dyes is then calculated. By measuring the observed A_{TOT} for the sample solution and knowing the a_s value for the dye group and the pathlength, the concentration of the total amount of dyes present in solution (C_{TOT}) can be calculated using the equation:

$$C_{TOT} = \frac{A_{TOT}}{b \times \bar{a}_s}$$

The total weight of the dyes in solution therefore can be determined from the concentration and the volume of the sample solution.

Because the method is based on an average spectral absorptivity constant from many different dyes, the result of the calculations will be considered to be a total dye estimate rather than a conventional quantitation. The advantages that this method has over more conventional analytical approaches are substantial in terms of analysis time and cost.

B. Method Development

Method development work was initiated to determine the magnitude of the uncertainties of the total dye estimate method. In addition, a great many practical aspects to the development of a general estimation method for textile dyes were investigated in the initial phase of the developmental work. ETAD provided samples of 23 "typical" textile dyes from the following dye classes: acid, basic, direct, disperse, and reactive. Initial work was spent devising a solvent mixture which could dissolve all 23 dyes. A mixture of dimethylsulfoxide (DMSO) and water, 9:1 (v/v), was discovered to be an excellent solvent for all of the dyes. Subsequent laboratory work was directed towards interfacing a spectrophotometer and computer-based integration hardware.

Laboratory work then focused on the spectra from individual dyes. Analysis of individual dyes confirmed that A_{TOT} values are linear over a wide range of dye concentrations. The observed range for the experimentally determined a_s constants in the visible wavelength region (380-750 nm) for each of the 23 test dyes was approximately an order of magnitude. There was no apparent relationship between the a_s value and either dye color or class. If these dyes are truly typical, then use of an average a_s value to estimate a group of dyes is judged to be sufficiently accurate in most circumstances.

Validation of the analytical method consisted of three phases. The goal of the first phase was to determine the magnitude of the relative errors when various dye mixtures were prepared and analyzed. The criteria for acceptable performance of the method was that the relative errors not exceed 50% of the true value. The second phase of the validation process consisted of developing a satisfactory filter extraction procedure which would be used to analyze the plant site air filters. The validation criterion was that dye recoveries be in the range of 60 to 140% of theoretical values. The final phase of method validation was to successfully analyze spiked filters and performance audit samples associated with a pilot study site.

One of the characteristics of using an average a_s constant ($\bar{a}_s$) derived from all possible component dyes, is the fact that errors can arise whenever predominant components on the air filter consist of "outlier" dyes (i.e., dyes with a_s constants that are significantly different from the overall $\bar{a}_s$ value). In these instances the errors incurred from basing the total dyes' estimation on the $\bar{a}_s$ constant can be substantial. Many times such a "worst case" scenario can be identified by comparing the absorbance spectrum of the sample with that of the individual component dyes. If the predominance of outlier a_s dyes on the air filters can be confirmed by such a comparison, then the numerical value of $\bar{a}_s$ could be adjusted appropriately. The "worst case" scenario is more problematic if it cannot readily be identified from the sample absorbance spectrum. For this reason a significant proportion of the experimental work in developing the method was performed on known dye mixtures prepared to simulate some "worst case" scenarios. The resulting data were used to gauge the magnitude of the errors arising when the $\bar{a}_s$ constant was employed to make the total dye calculation.

Experimental work on known dye mixtures began with relatively simple solutions and eventually grew in complexity to better simulate the expected composition of actual samples. Work with mixtures containing six dyes is summarized in Table C-1. Six-dye mixtures exhibited relative errors ranging from -11 to +17% in the total dye estimate based on mean $\bar{a}_s$ value when the total dye amount was approximately 160 to 200 μg. A 10-fold dilution of one of these

Table C-1

RESULTS OF TOTAL DYE ESTIMATIONS FOR 6-DYE MIXTURES[a]

Dye Mixture No.	Estimated Total Dye Concentration (μg/ml)[b,c]	Actual Total Dye Concentration (μg/ml)[c]	Percent Relative Error
1	53.2	50.0	+ 6
2	46.3	49.6	- 7
3	36.7	41.1	- 11
4	39.5	41.1	- 4
5	38.7	41.4	- 6
6	49.2	41.9	+ 17
7	43.1	41.2	+ 5
8	4.69	4.10	+ 14
9	2.44	1.63	+ 50

[a]Dye mixture composition: Acid Blue 40, Basic Blue 3, Direct Red 80, Disperse Orange 29, Disperse Yellow 23, Reactive Violet 5.
[b]Estimate based on mean $\bar{a}_s$ constant.
[c]Solution volume is approximately 4 ml.

mixtures produced a 3-fold increase in the relative error of the quantitation, while a 25-fold dilution resulted in an increase in the relative error by an order of magnitude. These increases in the relative error of the total dye estimate with decreasing concentration are ascribed to the very low absorbances being measured and the difficulty in integration of the resulting absorbance spectrum.

Work with 10-dye mixtures, as shown in Table C-2, concentrated on the simulation of "worst case" scenarios. Total dye amounts varied from 88 to 164 μg. The observed relative errors for the dye estimates based on mean $\bar{a}_s$ constants for these mixtures ranged from -39 to +40%.

Twenty-dye mixtures were prepared to simulate the complex samples which could be encountered in actual plant analyses. Within these mixtures the concentration ratios of the component dyes varied significantly, ranging from a factor of 6 in some mixtures to as much as a factor of 25 in others. The total dye amounts were similar to those employed for previous experiments (i.e., 144 to 220 μg). The results of these experiments are shown in Table C-3.

Table C-2

RESULTS OF TOTAL DYE ESTIMATIONS FOR 10-DYE MIXTURES[a]

Dye Mixture No.	Estimated Total Dye Concentration (μg/ml)[b,c]	Actual Total Dye Concentration (μg/ml)[c]	Percent Relative Error
1	43.0	40.6	+ 6
2	25.2	41.1	- 39
3	38.3	40.0	- 4
4	55.2	40.5	+ 36
5	31.8	22.6	+ 40
6	14.5	22.5	- 36

[a]Dye mixture composition: Acid Blue 40, Basic Yellow 11, Direct Blue 15, Direct Yellow 4, Disperse Brown 1, Disperse Orange 29, Disperse Red 17, Disperse Red 177, Reactive Black 5, Reactive Violet 5.
[b]Estimate based on mean $\bar{a}_s$ constant.
[c]Solution volume is approximately 4 ml.

The observed relative errors of the total dye estimates based on mean $\bar{a}_s$ constants varied from -20 to +26%.

Total dye estimates were also calculated on the basis of a <u>weighted</u> average a_s constant for the group of dyes rather than a mean value. The results are shown in Table C-4. This approach takes the relative proportions of the component dyes in the mixture into account and therefore should be more accurate. The weighted average-based calculations produced mixed results for the 10- and 20-dye mixtures. Not surprisingly, little improvement in the relative errors of the total dye estimates was observed when the numerical value of the weighted average a_s constant (weighted a_s) was similar to that for the mean a_s constant. Substantial improvements were generally seen when the value of the weighted a_s was significantly different from the mean a_s. In a few cases the relative errors were larger when the weighted a_s was used to make the total dye estimation compared to the result obtained from using the mean a_s. In these latter cases there was some circumstantial evidence that the measured absorbances were not obeying Beer's law. The most likely explanation for this behavior is dye reaction or interaction in solution. It should be emphasized that the magnitude of the relative errors arising from the apparent deviations from Beer's law was no larger than that observed when the mean a_s constant was used to make all of the dye estimate calculations.

Table C-3

RESULTS OF TOTAL DYE ESTIMATIONS FOR 20-DYE MIXTURES[a]

Dye Mixture No.	Estimated Total Dye Concentration (μg/ml)[b,c]	Actual Total Dye Concentration (μg/ml)[c]	Percent Relative Error
1	44.12	52.03	- 15
2	43.77	54.95	- 20
3	49.89	53.91	- 7
4	45.36	36.1	+ 26
5	45.14	43.1	+ 5
6	45.99	43.1	+ 7
7[d]	21.88	21.5	+ 2
8[e]	12.18	10.76	+ 13

[a]Dye mixture composition: Acid Blue 40, Acid Red 337, Acid Yellow 151, Basic Blue 3, Basic Red 15, Basic Yellow 11, Direct Blue 15, Direct Red 80, Direct Yellow 4, Disperse Blue 56, Disperse Blue 79, Disperse Brown 1, Disperse Orange 29, Disperse Orange 30, Disperse Red 60, Disperse Red 177, Disperse Yellow 23, Reactive Black 5, Reactive Blue 4, Reactive Violet 5.
bEstimate based on mean $\bar{a}_s$ constant.
[c]Solution volume is approximately 4 ml.
[d]1:1 dilution of Mixture 6.
[e]1:3 dilution of Mixture 6.

On the basis of the results obtained from analyzing the known dye mixtures, it was concluded that using a_s constants to estimate total dye amounts was a viable method. The relative errors of the results were in the 10 to 40% range when the mean a_s value was used. If additional information about the relative amounts of the component dyes can be obtained, then the accuracy of the method can be improved in many instances. In the case of the air filters, knowledge about the amounts of each dye which were handled during the air monitoring period allows a weighted a_s constant to be calculated and used to make the total dye estimation. The underlying assumption for this approach is that all dyes are equally dusty and that dyes will appear on the air filters in proportion to their use at the drug room site. Although this assumption is, in reality, not always true, its basic premise is nevertheless the most logical one given the lack of any other data. Therefore, weighted a_s constants were used for all dye estimate calculations in the study.

Table C-4

TOTAL DYE ESTIMATES BASED ON WEIGHTED AVERAGE SPECTRAL ABSORPTIVITY CONSTANTS

No. of Dyes in Mixtures	Mixture No.[a]	Percent Relative Error of Total Dye Estimate
10	1	+ 5
	2	+20
	3	+32
	4	+17
	5	- 8
	6	- 5
20	1	-15
	2	+16
	3	- 1
	4	-41
	5	-19
	6	-12
	7	-16
	8	- 7

[a]For concentration and composition of the mixtures, see Tables C-2 and C-3.

Extraction efficiencies of dyes from PVC air filters (personal sampling pump size, 37 mm) were determined by spiking blank filters with known dye mixtures and extracting them with dye solvent. The recovery of the dyes was measured in terms of the ratio of the A_{TOT} values obtained from the reference standard and the spiked filter extract. Recoveries ranged from 63 to 108% when the spike level was 40 to 160 μg. The average relative difference in recovery values between duplicate spiked filters was 7% at the 40- to 160-μg spike levels. Both the precision and the magnitude of the dye recoveries were observed to decrease with decreasing dye concentrations. No dye class appeared to have a characteristic recovery from PVC filters.

A final validation of the proposed analytical method took place when samples from a pilot study (Plant 0/0) were analyzed using the previously developed procedures. A total of 33 bulk dye samples from four dye classes were analyzed along with six PVC air filters and their associated cassettes. No dye solubility problems were encountered and the air filter extracts had more than adequate absorbance to calculate total dye estimates. The total dye estimates obtained from the Plant 0/0 air filters were compared to the gravimetric weights of the collected particulates and were found to be reasonable and internally consistent.

C. Modifications of the Analytical Method

It was discovered early in the study that many dyes from the basic class were subject to significant fading (i.e., decomposition) over time when dissolved in the standard dye solvent prior to analysis. Although a change in the pH of the dye solvent is sufficient to stabilize these basic dyes, the stability of the remaining dye classes at this different pH is very uncertain. As an alternative it was decided to maintain the standard dye solvent composition and instead initiate a narrow analysis time window into the analytical procedure. As a result, any dye decomposition occurring in the air filter extracts would presumably occur at the same rate as that observed for the corresponding bulk dye samples.

The basic dye reactivity also required a modification of the filter spiking procedure used to determine the overall dye recovery of the group of dyes being analyzed for each plant site. The modification ensured that the reference standard used to calculate dye recoveries was exposed to the same potential dye fading conditions as was the spiked filters. This eliminated a major source of potential bias in the dye recovery experiments for each plant site.

III. OBTAINING UNCERTAINTY RANGES FOR THE DYE ESTIMATES

Because of a variety of factors, the actual number and proportions of dyes found on an air filter will vary. As the number and proportions of the dyes on the filter vary, the overall a_s constant of the mixture will vary. Differences of the actual a_s constant from the value represented by the weighted average will lead to errors in the determination of the total concentration of the dyes. In order to estimate the magnitude of this source of error, a method to account for this variability was sought.

Each combination, C, of a number of dyes, r (less than or equal to the total number handled by the worker, n), that could be trapped on the filter could give a different overall a_s constant. In addition, even for a specified number of dyes, r, on the filter, there could be different overall a_s constants depending on which set of the dyes was found on the filter. Some idea of the possible variability of the method can be found by considering the different subsets of dyes that could be present and the resulting average a_s constant of each set of dyes.

For a moderate to large number of dyes, the number of combinations of subsets that could be on the filter becomes quite large. If a worker handled a total of n dyes during the sampling period, there are ${}_nC_r$ different subsets of r dyes. The sum of all possible subsets of n dyes is $(2^n - 1)$, which rapidly becomes too large to work with. Because of the large number of possible combinations of dyes that could be found on the filter, it is not practical to calculate all the possible combinations of dyes and the resulting overall a_s constants that could be found on the filter.

In order to address the problem, a simulation routine was programmed. This simulation randomly selects a sample of size r of the n dyes handled by the worker and calculates the mean a_s constant for that mixture. This is repeated 250 times to give a distribution of values for the average a_s constant for a mixture of r dyes. The simulation is run for each possible value of r from 1 to n for each plant. The result is a set of numbers that represent possible mean a_s constants for dye mixtures, including different numbers of the dyes handled by the worker.

This set of numbers is used to estimate the variability that one can expect to see in the average value of the overall a_s constant for the dye mixture. Upper and lower limits for the a_s value can be estimated from the distribution. These are then used to calculate corresponding limits on the concentration of dye material in the air estimated by the method.

The simulation assumes that the probability that a dye will be in the air and will be collected on the filter is proportional to the amount of dye used. Thus, in selecting a sample of dyes, the dyes that were used in larger amounts have a higher probability of being included in the sample. The simulation uses probability sampling with replacement and so generates samples that have a composition of the dyes proportional to the amount of each dye used. The distribution of the mean a_s constants that results from the simulation is used to obtain confidence intervals for the mean a_s constant for samples of each size. Typically, these intervals are not symmetric about either the mean a_s constant or the resulting total dye estimate.

The results of the simulation are empirical error bounds on the average a_s constant for each possible number of dyes on the filter. In order to summarize the error estimates, a convention was established to use the results for the sample of dyes that had the smallest number of dyes in it that accounted for at least 80% of the total quantity of dyes used during the sampling period. This provides an error estimate based on the major use dyes. Thus, the summary error estimate is based on the simulation for the dyes that account for 80% of the dye material weighed out during the sampling period.

The simulation is run separately for the a_s constants of the commercial dyes and for the a_s constants of the active colorant. The a_s constants of the active colorant of the dye are based on the reported purity of the dye. Any errors in the reported purity will add to the uncertainty in the active colorant concentration estimates.

The simulation routine is written in Basic and implemented on an IBM-PC computer. The program writes a file of the average a_s constants to a floppy disk. These numbers (250 for each number of dyes) are then sorted, and summary statistics are prepared using a commercial program to give the distribution of possible values used to estimate the errors. Use of the simulation is recommended with the method to give an approximate range for the dye estimate, since the uncertainty has been found to differ substantially depending on the individual dye a_s constants and the amounts of each dye used. An example of a statistically derived distribution of probable commercial dye-based weighted a_s values for Plant 4/1 is shown in Figure C-1.

IV. APPLYING TOTAL DYE ESTIMATION METHOD TO THE ANALYSIS OF ACTUAL AIR FILTERS

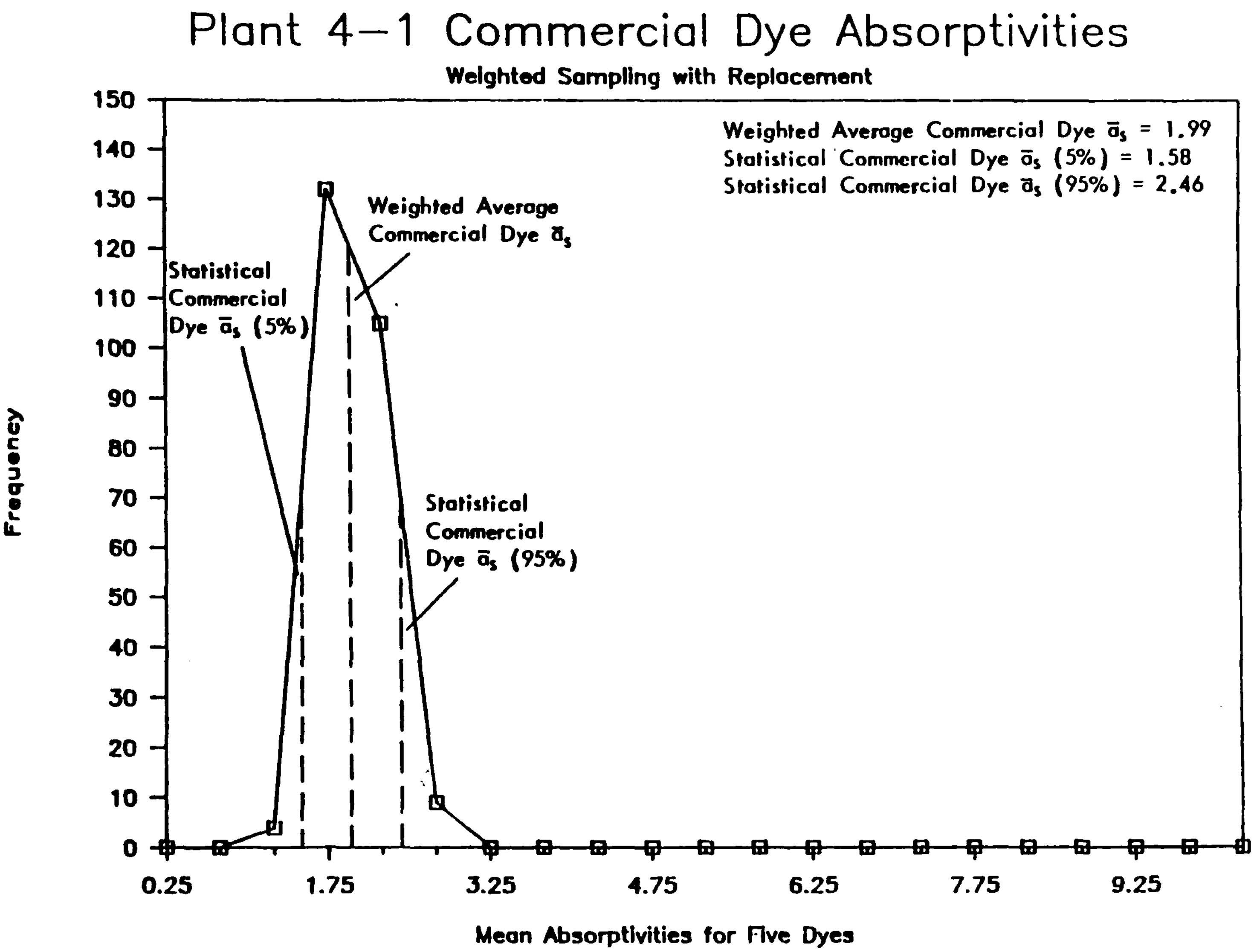
The absorbance spectrum of a known dye mixture can be used to evaluate the general accuracy of a total dye estimate made on actual air filters which contain those same dyes. Since the total dye estimate is calculated from the weighted average a_s constant of all the possible component dyes in the mixture, the validity of using a weighted average value can be assessed by a comparison of the spectra of the sample filter and that obtained from a weighted average dye mixture. Such a dye mixture is composed of all the possible component dyes in proportion to their use at the plant site. If the resulting spectrum of this mixture is similar to that of the actual air filter, then the basic assumption that dyes are present on the air filters in proportion to their usage at the plant site will be confirmed.

Obvious dissimilarities between the spectra indicate that this basic assumption may not apply, in which case the use of a weighted average a_s constant may lead to greater than expected errors in the total dye estimate.

In the case of the 25 plant sites analyzed in the drug room study, the spectrum of the dye mixture used for dye recovery experiments was employed to appraise the use of a weighted average a_s constant. The dye recovery mixture contained the dyes comprising 80% of the total quantity handled by the worker. The dyes were present at levels proportionate to their usage, and therefore the mixture was a weighted average solution. The lower use dyes were not included in the dye mixture for logistical reasons, as well as from the judgment that these components would not significantly influence the overall absorbance spectrum of the solution.

Figure C-1

SIMULATED COMMERCIAL DYE-BASED AVERAGE ABSORPTIVITIES (WEIGHTED) FOR FIVE DYES



Several plant sites in the study had dissimilarities between the dye recovery and the air filter spectra. These dissimilarities varied from moderate to substantial. In at least two instances (Plants 5/4 and 3/3) low sample absorbances contributed heavily to a significant lack of agreement between the air filter and the dye recovery spectra. In addition to low absorbances, the most common cause of spectral dissimilarities is disproportionate dye amounts on the air filters compared to dye handling information. Disparities between filter amounts and the amounts expected based on dye handling information are usually the result of differences in dye dustiness or the number of dye weighing operations for a few dyes in the group. In most cases it was possible to identify which dyes were the most likely cause of the dissimilarity and what the general consequences were for the accuracy of the total dye estimate. The more systematic approach of experimentally determining a logical dye mixture which closely matches the spectrum of the air filter was not performed due to time and cost constraints. It would be a feasible approach for a smaller study.

V. DYE PURITY INFORMATION TO CORRECT FOR ACTIVE COLORANT CONTENT IN THE DYESTUFF

The use of dye purity information for each of the possible dye mixture components is an effective means of addressing some of the uncertainties of the total dye estimate. The active colorant content of the dyestuffs can vary substantially for textile dyes, ranging from very low to very high. The commercial dye a_s constants are experimentally determined with the inert constituents present, so calculations made using a commercial dye-based weighted average a_s constant will have the inert components incorporated into the total dye estimate. The use of dye purity information is essential to compensate for this source of error in the total dye estimate. Dye purity values are used to calculate an active colorant-based weighted average a_s value for the particular group of dyes being analyzed. In this manner the total dye estimate is made in terms of the active colorant content alone.

There were several disadvantages in using dye purities, however. One of the primary disadvantages is the problem of obtaining this information from the dye manufacturers. Dye purity is often considered by the manufacturers to be proprietary information, and consequently was often difficult and time-consuming to obtain. As a result, considerable time delays occurred before enough information became available to allow active colorant-based calculations. Another disadvantage in using dye purity information was the fact that the methods used to determine active colorant content of a dye are not standardized throughout the dye industry. Since the value for active colorant content is dependent on the particular assay technique which is employed, the dye purity values are subject to varying degrees of uncertainty. The additive effect of these uncertainties can therefore produce a significant potential error for active colorant-based total dye estimates when large groups of dyes are involved.

As discussed in Chapter 6, the spectrophotometric analytic method used to calculate active colorant required estimates of dye purity values and the percent of active colorant in the commercial dyes. Table C-5 (at the end of this appendix) shows estimated dye purities for all dyes weighed at the 24 sites included in the survey.

VI. MONITORING LABORATORY PERFORMANCE BY QUALITY ASSURANCE/ QUALITY CONTROL MEASURES

There were four primary components of the quality assurance/quality control (QA/QC) program which was used throughout this study. The first component consisted of the preparation of a Quality Assurance Project Plans (QAPPs) before the study began. The QAPPs contained a detailed summary of the data quality objectives, the analytical procedures which were to be followed, responsibilities of key project personnel, and appropriate actions to be taken when any QA/QC requirements were not met. The second component of the QA/QC program involved a series of comprehensive system audits scheduled at the beginning, middle, and end of the analytical work for the study. The system audits were conducted by the quality control coordinator (QCC) and confirmed that all experimental procedures and records were consistent with the requirements outlined in the QAPPs.

The most extensive part of the QA/QC program was the periodic analysis of performance audit samples (PAS) during the course of all plant sample analyses. Three PAS samples were to be analyzed for each plant site. The QCC prepared the samples and submitted them to the laboratory technician for total absorbance (A_{TOT}) determinations. The PAS samples were composed of individual dyes from the plant site being analyzed and were unknown to the technician performing the analyses. Based on the measured A_{TOT} value and the previously established a_s constant for the dye used, the quality assurance coordinator (QAC) calculated the found concentration and compared the result to the actual value. The results for a PAS sample were judged to be acceptable if the found value was $\pm 30\%$ of the actual value. Of the 82 PAS results obtained during the study, only two samples failed to meet these data quality objectives. This success rate was fully acceptable for the study.

The final component of the QA/QC program was an audit by the QCC of the raw data generated for the analyses of samples from each plant site. The QCC documented that all of the reported data met the project's data quality objectives. In addition, each plant report was reviewed by the QCC to assure consistency with the associated data.

Due to rigorous analysis time windows specified in the QAPPs for all sample analyses, extensive documentation was kept showing that this time requirement was met for all of the samples. In addition, documentation of sample traceability was maintained. A bar code sample identification system was employed to facilitate this process.

VII. ADVANTAGES OF THE TOTAL DYE ESTIMATE METHOD

The total dye estimation method has several advantages compared to conventional quantitation techniques. Probably the foremost advantage is the capability of analyzing highly complex mixtures at very low levels. The accuracy of any quantitation method which is based on an average value for an intrinsic property of a class of compounds will tend to increase as the number of compounds being averaged increases. Conversely, any quantitation method which is based on the determination of the levels for each of the components in the mixture will tend to decrease in accuracy as the number of components in the mixture increases. This decrease in accuracy, which is due to the additivity of the uncertainties for each component being quantitated, will be magnified at trace levels, where uncertainties inevitably increase. For this reason the accuracy of the total dye estimation method can conceivably be better than that obtainable for conventional methods when analyzing complex mixtures at trace levels.

Another important advantage of the estimation method is the relative simplicity of the technique compared to conventional quantitation methods. Because all components are analyzed simultaneously, the total analysis time is considerably less than that for other methods, which would probably require multiple analytical systems to handle certain dye classes. A direct benefit of simultaneous analysis is the fact that the amount of associated data will be at least an order of magnitude less than that derived from individual component quantitation.

Finally, another asset of the total dye estimate method is the lack of sophisticated equipment or personnel training required. Practically any spectrophotometer or chromatography data system would be sufficient to perform the analysis, and a laboratory technician can easily be trained to do all of the work. The individual component quantitation methods would require sophisticated detection equipment and undoubtedly a higher level of trained personnel. Such requirements could severely limit the number of laboratories which could perform the analyses.

VIII. LIMITATIONS OF THE TOTAL DYE ESTIMATE METHOD

The total dye estimate method is affected by several factors which cannot always be controlled, and consequently the method is subject to limitations. Some of these limitations are unique to the dye estimate method, while others would affect almost any analytical method employed.

One of the most important factors, which uniquely affects the accuracy of the total dye estimate method, is the dustiness of the individual dyes. Because this information is not generally available (or easily measurable), the relative dustiness of different powder dyes cannot be taken into account in the calculations. The assumption that the composition of the unknown dye mixture on the air filter will always be proportional to the quantity of dyes handled (or the number of dye weighings) is therefore made by default. As long as the inherent dustiness of powder dyes does not differ substantially between many components of the group of dyes being analyzed, the assumption of equal dustiness will not lead to significant errors in the total dye estimate. Observations by the field sampling teams do not suggest that there were extremely large differences in dustiness between the powder dyes sampled in the plant survey.

One of the factors which would affect virtually any analytical method is the behavior of non-dye compounds which may be present on the air filters. The impact of these compounds is difficult to assess. While it is easy to measure the absorbance of a non-dye compound alone, it is not at all easy to determine the exact effect which that compound can have on the absorbance of a dye mixture. This is primarily because the magnitude of the influence, if any, will usually be proportional to the amount of the non-dye compound which is present. Since this is unknown in the case of the air filters, as are the combined effects of other non-dye compounds which may be present, it is practically impossible to determine the extent of potential interference which the non-dye compounds represent. Not many non-dye compounds encountered in the plant survey have a powerful capability to influence dye absorbance in the dye solvent. In addition, the low relative dustiness of a great many non-dye compounds encountered in the survey makes it unlikely that many of these compounds would predominate on the air filters. For these reasons, non-dye compounds have been judged to represent no substantial interference to the analytical method for the textile plant survey.

Another factor affecting most analytical methods is the behavior of dyes from untested dye classes. The total dye estimation method was validated for dyes from the acid, basic, direct, disperse, and reactive classes. The applicability of the method to analyzing dyes from other classes is unknown and would require additional method development work in many cases. Untested dye classes constitute potential interferences due to the possibility of dye interaction or instability. It is often difficult to identify dye interaction occurring in solution since these processes can be very subtle at times. Interaction is most likely to occur between dyes from different classes and can result in total absorbances that deviate from Beer's law. Evidence of dye interaction was observed at only three plant sites (Plants 2/1, 2/7, and 6/6). The spectrophotometric data from one of these sites (Plant 6/6) was dropped from the study for other reasons, and the results from the other two sites were not seriously compromised by the degree of dye reactivity which was observed. The effects from dye interaction are minimized in cases where a large number of dyes are being analyzed and the concentrations are low.

The final factor which uniquely affects the total dye estimation method is the number of dyes in the particular group being analyzed. In general, the accuracy of the dye estimation method will improve as the number of dyes increases. This is due to the fact that the adverse effects from dyes with "outlier" a_s values will tend to be moderated by a much larger group of dyes. Conversely, the potential effects of outlier dyes will be increased as the number of dyes being analyzed decreases. In such cases, the use of a mean or weighted average a_s value to make a dye estimate calculation will be subject to greater amounts of uncertainty. This trend is exactly opposite of that for conventional methods of analysis (e.g., HPLC), where the overall accuracy tends to decrease as the number of compounds in the mixture increases.

Table C-5

DYE PURITY AND ABSORPTIVITIES

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	ABSORPTIVITY (a_s) COMMERCIAL DYE
4/9	ACID	BLACK	107	44	5.76	2.53
3/3	ACID	BLACK	107	40	3.94	2.28
2/4	ACID	BLACK	172	85	4.12	3.50
4/9	ACID	BLACK	187	68	5.02	3.41
4/6	ACID	BLACK	52	85	3.60	3.06
3/8	ACID	BLACK	58	55	5.00	2.75
4/1	ACID	BLACK	58	33	4.24	1.40
4/9	ACID	BLACK	60	70	2.28	1.60
3/0	ACID	BLACK	M-1	40	7.42	2.97
9/1	ACID	BLACK	M-2	47	6.88	3.23
9/1	ACID	BLACK	M-3	50	6.33	3.16
6/5	ACID	BLUE	102	50	7.04	3.52
9/1	ACID	BLUE	113	70	18.18	5.45
3/0	ACID	BLUE	113	66	7.80	5.15
1/6	ACID	BLUE	113	66	7.34	4.84
6/5	ACID	BLUE	113	81	8.78	7.11
8/6	ACID	BLUE	158	50	7.56	3.78
3/8	ACID	BLUE	158	76	4.93	3.74
6/2	ACID	BLUE	177	24	15.31	3.67
6/2	ACID	BLUE	205	47	2.46	1.16
9/1	ACID	BLUE	239	41	2.67	1.10
2/4	ACID	BLUE	25	33	3.76	1.99
1/6	ACID	BLUE	25	65	5.72	3.72
5/9	ACID	BLUE	25	33	5.68	1.87
3/3	ACID	BLUE	25	33	3.94	1.97
4/1	ACID	BLUE	258	50	4.48	2.24
6/5	ACID	BLUE	264	50	2.96	1.48
4/1	ACID	BLUE	277	60	4.92	2.95
9/1	ACID	BLUE	281	47	2.72	1.28
4/1	ACID	BLUE	284	43	8.05	3.46
2/4	ACID	BLUE	290	26	3.94	1.02
5/2	ACID	BLUE	324	80	3.69	2.95
2/4	ACID	BLUE	324S	77	3.79	2.92
6/5	ACID	BLUE	335	58	4.81	2.79
9/1	ACID	BLUE	345	31	8.63	2.67
2/4	ACID	BLUE	40	54	3.22	2.57
9/1	ACID	BLUE	40	30	5.07	1.52
3/8	ACID	BLUE	45	60	3.23	1.94
3/8	ACID	BLUE	7	70	8.54	5.98
4/1	ACID	BLUE	80	40	2.44	0.98

Table C-5

DYE PURITY AND ABSORPTIVITIES
(Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s)	
					ACTIVE COLORANT	COMMERCIAL DYE
2/4	ACID	BLUE	80	60	2.44	1.47
4/9	ACID	BLUE	80	32	0.98	0.79
3/8	ACID	BLUE	90	67	1.98	1.32
3/0	ACID	BLUE	U-1	47	3.10	1.46
6/2	ACID	BLUE	U-1	47	3.22	1.51
4/1	ACID	BROWN	227	30	4.03	1.21
3/8	ACID	BROWN	227	61	3.67	2.24
3/3	ACID	BROWN	298	52	6.94	3.61
4/6	ACID	BROWN	298	50	7.10	3.55
4/9	ACID	BROWN	330	54	4.55	2.46
8/6	ACID	BROWN	384	60	3.22	1.93
4/1	ACID	BROWN	45	29	4.01	1.16
9/1	ACID	BROWN	M-1	46	6.06	2.79
9/1	ACID	BROWN	U-2	40	6.57	2.63
4/9	ACID	GREEN	104	80	4.03	3.22
4/9	ACID	GREEN	108	62	4.17	2.59
1/6	ACID	GREEN	25	83	3.16	2.62
2/4	ACID	GREEN	25	67	3.61	2.42
9/1	ACID	GREEN	25	60	3.05	1.83
2/4	ACID	GREEN	28	41	4.16	1.71
3/8	ACID	ORANGE	10	88	3.62	3.18
9/1	ACID	ORANGE	116	46	5.51	2.20
6/2	ACID	ORANGE	116	46	4.70	2.16
4/9	ACID	ORANGE	142	75	3.60	2.70
1/6	ACID	ORANGE	149	85	2.74	2.33
4/6	ACID	ORANGE	156	67	5.47	5.25
2/4	ACID	ORANGE	156	67	7.84	5.26
3/3	ACID	ORANGE	3	50	3.95	1.97
9/1	ACID	ORANGE	51	64	4.36	2.79
3/3	ACID	ORANGE	60	35	4.32	1.51
3/8	ACID	ORANGE	74	76	3.46	2.63
1/6	ACID	ORANGE	U-1	58	15.46	8.97
3/8	ACID	RED	1	56	4.63	2.59
6/5	ACID	RED	111	72	3.46	2.49
2/4	ACID	RED	143	65	1.17	0.76
6/5	ACID	RED	158	82	2.61	2.14
2/4	ACID	RED	182	70	4.74	3.32
3/8	ACID	RED	186	100	2.36	2.36
3/8	ACID	RED	194	38	3.24	1.23

Table C-5

DYE PURITY AND ABSORPTIVITIES
(Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	COMMERCIAL DYE
4/1	ACID	RED	259	30	2.97	0.89
6/5	ACID	RED	260	70	1.71	1.19
4/1	ACID	RED	260	70	2.09	1.46
2/4	ACID	RED	266	73	4.29	3.13
1/6	ACID	RED	266	36	5.47	1.97
4/6	ACID	RED	266	32	4.79	1.53
2/4	ACID	RED	299	46	7.93	3.65
3/0	ACID	RED	299	91	3.20	2.91
4/6	ACID	RED	299	65	4.46	2.90
2/4	ACID	RED	337	81	4.01	3.25
8/6	ACID	RED	357	91	3.31	3.01
4/1	ACID	RED	359	60	4.91	2.95
3/0	ACID	RED	360	47	7.39	3.47
4/1	ACID	RED	361	50	5.89	2.95
4/6	ACID	RED	361	43	3.33	1.43
6/2	ACID	RED	396	75	2.27	1.70
3/3	ACID	RED	399	62	4.96	3.08
1/6	ACID	RED	52	45	6.70	3.01
2/4	ACID	RED	57	40	7.21	2.88
5/2	ACID	RED	M-2	85	3.20	2.72
4/9	ACID	RED	U-1	83	3.81	3.16
3/0	ACID	RED	U-3	50	6.61	3.31
5/9	ACID	RED	U-5	40	4.14	1.66
9/1	ACID	RED	U-6	50	8.88	4.44
4/1	ACID	VIOLET	121	55	3.87	2.13
2/4	ACID	VIOLET	48	65	2.39	1.55
4/1	ACID	VIOLET	48	33	1.92	0.77
3/8	ACID	VIOLET	7	75	6.40	4.80
4/9	ACID	VIOLET	90	86	3.47	2.99
6/2	ACID	YELLOW	116	56	3.32	1.86
4/1	ACID	YELLOW	121	25	5.19	1.30
8/6	ACID	YELLOW	121	25	6.01	1.50
3/8	ACID	YELLOW	127	83	1.61	1.33
3/8	ACID	YELLOW	129	35	2.92	1.02
4/9	ACID	YELLOW	129	35	2.67	0.93
1/6	ACID	YELLOW	135	95	1.06	1.00
3/3	ACID	YELLOW	151	63	3.68	2.32
2/4	ACID	YELLOW	151	86	3.12	2.68
6/2	ACID	YELLOW	159	35	4.25	1.49

Table C-5

DYE PURITY AND ABSORPTIVITIES
(Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	COMMERCIAL DYE
9/1	ACID	YELLOW	159	35	4.58	1.60
3/0	ACID	YELLOW	159	66	5.53	3.65
3/8	ACID	YELLOW	17	78	3.08	2.40
2/4	ACID	YELLOW	19	60	2.36	1.41
2/4	ACID	YELLOW	198	56	4.62	2.56
4/1	ACID	YELLOW	216	45	2.45	1.10
2/4	ACID	YELLOW	218	58	1.60	0.93
5/9	ACID	YELLOW	219	70	5.50	3.85
5/2	ACID	YELLOW	219	71	5.50	3.91
4/9	ACID	YELLOW	235	50	2.43	1.21
4/9	ACID	YELLOW	241	87	3.16	2.75
9/1	ACID	YELLOW	40	60	2.88	1.73
1/6	ACID	YELLOW	49	62	3.91	2.42
6/2	ACID	YELLOW	49	62	4.05	2.51
3/3	ACID	YELLOW	49	78	3.18	2.48
4/1	ACID	YELLOW	49	50	4.72	2.36
2/4	ACID	YELLOW	49	78	2.98	2.33
9/1	ACID	YELLOW	65	70	5.95	4.17
4/1	ACID	YELLOW	79	75	2.11	1.58
6/5	ACID	YELLOW	79	75	2.09	1.57
1/6	ACID	YELLOW	99	50	7.72	3.86
3/8	ACID	YELLOW	99	92	2.70	2.48
9/1	ACID	YELLOW	U-1	78	1.60	1.25
7/7	BASIC	BLACK	M-1	75	3.19	2.39
3/8	BASIC	BLUE	124	52	9.22	4.79
1/0	BASIC	BLUE	141	39	5.06	1.97
5/9	BASIC	BLUE	21	30	4.29	1.29
2/7	BASIC	BLUE	3	55	1.71	0.94
7/7	BASIC	BLUE	3	71	14.10	9.99
3/8	BASIC	BLUE	3	60	17.24	10.34
1/0	BASIC	BLUE	3	27	15.53	4.19
6/5	BASIC	BLUE	41	19	35.60	6.77
5/9	BASIC	BLUE	41	35	21.50	7.52
3/8	BASIC	BLUE	41	47	15.31	7.20
8/6	BASIC	BLUE	45	51	2.73	1.39
1/0	BASIC	BLUE	54	8	19.77	1.58
3/8	BASIC	BLUE	54	40	4.89	1.96
9/1	BASIC	BLUE	54	20	12.70	2.54
8/6	BASIC	BLUE	69	58	0.36	0.21

Table C-5

DYE PURITY AND ABSORPTIVITIES
(Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	COMMERCIAL DYE
3/8	BASIC	BLUE	U-1	5	7.88	0.39
9/1	BASIC	GREEN	4	93	0.01	0.01
1/0	BASIC	GREEN	4	90	0.01	0.01
7/7	BASIC	GREEN	4	99	0.00	0.00
3/8	BASIC	GREEN	4	100	0.00	0.00
1/0	BASIC	ORANGE	21	28	7.39	2.07
9/1	BASIC	ORANGE	21	62	8.45	5.24
5/9	BASIC	ORANGE	30	30	13.78	4.14
3/8	BASIC	RED	14	64	3.08	1.97
2/7	BASIC	RED	14	23	3.37	0.78
2/1	BASIC	RED	14	46	3.08	1.42
1/0	BASIC	RED	15	21	1.29	0.27
3/8	BASIC	RED	15	44	3.28	1.44
3/8	BASIC	RED	29	24	2.83	0.68
8/6	BASIC	RED	29	24	4.22	1.01
1/0	BASIC	RED	46	15	12.84	1.93
2/7	BASIC	RED	46	75	9.93	7.45
3/8	BASIC	RED	46	90	7.24	6.52
7/7	BASIC	RED	46	72	8.69	6.25
7/7	BASIC	RED	49	35	2.78	0.97
3/8	BASIC	RED	51	66	8.62	5.69
1/0	BASIC	RED	U-2	50	7.09	3.54
9/1	BASIC	VIOLET	14	93	13.11	12.19
2/7	BASIC	VIOLET	16	77	19.57	15.07
7/7	BASIC	VIOLET	16	77	8.10	6.24
2/7	BASIC	VIOLET	37	7	60.48	4.23
3/8	BASIC	YELLOW	11	48	5.36	2.57
8/6	BASIC	YELLOW	11	50	1.35	0.68
1/0	BASIC	YELLOW	13	23	3.14	0.72
5/9	BASIC	YELLOW	21	48	4.33	2.08
3/8	BASIC	YELLOW	24	11	4.23	0.47
3/8	BASIC	YELLOW	25	50	1.81	0.91
7/7	BASIC	YELLOW	28	42	5.11	2.15
3/8	BASIC	YELLOW	28	46	4.60	2.12
1/0	BASIC	YELLOW	28	48	4.36	2.09
2/7	BASIC	YELLOW	28	42	1.68	0.70
3/8	BASIC	YELLOW	29	34	3.96	1.35
2/1	BASIC	YELLOW	40	24	3.70	0.89
1/0	BASIC	YELLOW	51	25	6.07	1.52

Table C-5

DYE PURITY AND ABSORPTIVITIES (Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	ABSORPTIVITY (a_s) COMMERCIAL DYE
3/8	BASIC	YELLOW	87	63	4.64	2.93
3/8	BASIC	YELLOW	91	62	6.36	3.94
9/1	DIRECT	BLACK	2	50	11.27	5.64
5/4	DIRECT	BLACK	62	29	5.16	1.50
9/1	DIRECT	BLACK	80	36	10.50	3.78
1/0	DIRECT	BLACK	80	76	5.69	4.32
2/7	DIRECT	BLACK	M-1	58	9.00	5.22
2/7	DIRECT	BLUE	106	34	9.08	3.09
7/9	DIRECT	BLUE	160	45	8.96	4.03
7/9	DIRECT	BLUE	189	46	6.97	3.21
1/0	DIRECT	BLUE	191	45	4.62	2.08
5/4	DIRECT	BLUE	191	45	4.47	2.01
7/9	DIRECT	BLUE	218	52	4.44	2.31
7/9	DIRECT	BLUE	25	35-40	16.44	2.30
1/0	DIRECT	BLUE	251	50	8.60	4.30
9/1	DIRECT	BLUE	78	40	4.19	1.68
5/9	DIRECT	BLUE	80	28	1.16	0.32
5/4	DIRECT	BLUE	80	28	1.14	0.32
1/0	DIRECT	BLUE	M-2	28	6.09	1.70
2/7	DIRECT	BLUE	U-1	38	1.47	0.56
9/1	DIRECT	BROWN	113	33	8.83	2.91
5/4	DIRECT	BROWN	115	17	17.71	3.01
1/0	DIRECT	BROWN	115	17	19.25	3.27
5/4	DIRECT	BROWN	116	93	4.54	4.22
5/4	DIRECT	ORANGE	34	34	6.12	2.08
9/1	DIRECT	ORANGE	72	59	3.88	2.29
9/1	DIRECT	ORANGE	80	35	2.64	2.11
1/0	DIRECT	ORANGE	M-2	40	3.01	1.21
5/9	DIRECT	ORANGE	M-3	40	5.98	2.39
9/1	DIRECT	RED	149	60	5.16	3.10
2/7	DIRECT	RED	224	39	5.17	2.02
1/0	DIRECT	RED	227	58	2.80	1.62
5/9	DIRECT	RED	243	67	3.25	2.18
5/4	DIRECT	RED	243	67	3.60	2.41
7/9	DIRECT	RED	72	57	5.79	3.30
7/9	DIRECT	RED	75	42	5.42	2.28
9/1	DIRECT	RED	80	41	8.90	3.65
1/0	DIRECT	RED	80	42	6.09	2.56
1/0	DIRECT	RED	89	34	4.46	1.52

Table C-5

DYE PURITY AND ABSORPTIVITIES
(Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	ABSORPTIVITY (a_s) COMMERCIAL DYE
7/9	DIRECT	RED	9	55	2.28	1.26
5/4	DIRECT	RED	9	80	1.46	1.17
1/0	DIRECT	RED	U-1	45	4.35	1.96
7/9	DIRECT	VIOLET	9	56	7.81	4.37
1/0	DIRECT	YELLOW	106	41	3.57	1.46
9/1	DIRECT	YELLOW	106	52	3.31	2.12
2/7	DIRECT	YELLOW	106	41	4.65	1.91
5/9	DIRECT	YELLOW	106	41	3.78	1.55
7/9	DIRECT	YELLOW	106	41	3.54	1.45
5/4	DIRECT	YELLOW	142	60	3.76	2.26
2/7	DIRECT	YELLOW	44	44	4.85	2.13
5/4	DIRECT	YELLOW	58	36	3.70	1.33
4/9	DISPERSE	BLACK	M-1	25-30	25.81	1.81
1/0	DISPERSE	BLACK	M-2	35	9.05	3.17
6/2	DISPERSE	BLACK	M-3	30	6.44	1.93
9/1	DISPERSE	BLACK	M-4	69	4.43	3.06
8/8	DISPERSE	BLUE	109	32	3.72	1.19
9/1	DISPERSE	BLUE	109	25	3.72	0.93
3/8	DISPERSE	BLUE	139	28	6.50	1.82
5/9	DISPERSE	BLUE	27	18	5.49	1.37
8/0	DISPERSE	BLUE	27	18	7.15	1.29
6/2	DISPERSE	BLUE	27	18	7.52	1.35
3/0	DISPERSE	BLUE	281	37	10.98	2.74
1/0	DISPERSE	BLUE	281	35	7.34	2.57
3/8	DISPERSE	BLUE	3	36	4.70	2.35
9/1	DISPERSE	BLUE	3	44	6.51	2.87
3/0	DISPERSE	BLUE	337	22	13.24	2.91
9/1	DISPERSE	BLUE	56	28	7.48	2.09
6/2	DISPERSE	BLUE	56	28	7.46	2.09
2/1	DISPERSE	BLUE	56	29	6.43	2.19
4/9	DISPERSE	BLUE	56	25	7.03	1.90
5/9	DISPERSE	BLUE	56	28	7.46	2.09
5/4	DISPERSE	BLUE	56	27	7.93	1.98
3/8	DISPERSE	BLUE	56	27	5.93	2.02
2/7	DISPERSE	BLUE	56	34	9.25	2.59
8/0	DISPERSE	BLUE	60	25	4.27	1.07
5/9	DISPERSE	BLUE	60	23	4.35	1.00
1/0	DISPERSE	BLUE	60	44	2.02	2.02
8/6	DISPERSE	BLUE	60	25	4.03	1.01

Table C-5

DYE PURITY AND ABSORPTIVITIES (Continued)

ID	COLOR INDEX NAME		FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	COMMERCIAL DYE
3/8	DISPERSE BLUE	60	24	3.99	0.96
3/0	DISPERSE BLUE	60	23	4.09	0.94
6/2	DISPERSE BLUE	60	44	4.59	2.02
4/3	DISPERSE BLUE	73	28	6.41	2.12
8/8	DISPERSE BLUE	73	28	7.53	2.11
3/0	DISPERSE BLUE	73	54	7.25	3.91
2/1	DISPERSE BLUE	73	26	5.50	1.93
1/0	DISPERSE BLUE	73	25	6.45	1.81
4/9	DISPERSE BLUE	77	40	4.13	1.65
6/2	DISPERSE BLUE	77	40	4.04	1.62
6/2	DISPERSE BLUE	79	60	7.54	4.53
8/6	DISPERSE BLUE	79	25	7.70	1.92
4/9	DISPERSE BLUE	79	50	7.63	3.81
6/2	DISPERSE BLUE	87	23	4.02	0.93
2/1	DISPERSE BLUE	M-3	36	6.94	2.50
1/0	DISPERSE BLUE	U-4	13	11.13	1.45
6/2	DISPERSE BLUE	U-4	28	5.02	1.41
2/7	DISPERSE GREEN	9	15	12.56	1.88
5/4	DISPERSE ORANGE	29	44	11.98	5.27
6/2	DISPERSE ORANGE	30	30	5.83	1.75
8/6	DISPERSE ORANGE	30	29	5.06	1.47
3/0	DISPERSE ORANGE	30	30	5.59	1.68
5/9	DISPERSE ORANGE	30	30	5.77	1.73
4/9	DISPERSE ORANGE	37	35	7.11	2.49
6/2	DISPERSE ORANGE	41	31	4.62	1.43
1/0	DISPERSE ORANGE	41	25	5.47	1.37
6/2	DISPERSE RED	135	41	6.14	2.52
4/3	DISPERSE RED	135	40	6.18	2.47
4/3	DISPERSE RED	151	34	8.13	2.76
3/0	DISPERSE RED	159	24	3.35	0.80
6/2	DISPERSE RED	167	45	6.71	3.02
3/0	DISPERSE RED	167:1	30	9.57	2.87
5/9	DISPERSE RED	177	25	15.40	3.85
8/6	DISPERSE RED	211	27	9.30	2.51
3/0	DISPERSE RED	263	25	2.74	0.68
6/2	DISPERSE RED	263	25	3.43	0.86
3/0	DISPERSE RED	305	38	10.87	4.13
6/2	DISPERSE RED	333	28	10.60	2.97
5/4	DISPERSE RED	338	25	12.90	3.23

Table C-5

DYE PURITY AND ABSORPTIVITIES (Continued)

ID	COLOR INDEX NAME	FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	ABSORPTIVITY (a_s) COMMERCIAL DYE
3/8	DISPERSE RED 4	17	4.47	0.76
3/0	DISPERSE RED 43	25	17.83	4.46
6/2	DISPERSE RED 55	23	4.22	0.97
4/9	DISPERSE RED 60	27	3.91	1.05
9/1	DISPERSE RED 60	25	3.99	1.00
5/9	DISPERSE RED 60	23	3.42	0.92
4/9	DISPERSE RED 60	23	3.74	0.86
5/4	DISPERSE RED 60	28	2.05	1.11
2/1	DISPERSE RED 60	20	2.98	0.80
2/7	DISPERSE RED 60	27	3.97	1.07
3/8	DISPERSE RED 60	28	2.35	1.13
3/8	DISPERSE RED 65	59	10.58	6.24
8/0	DISPERSE RED 72	20	9.61	2.40
8/0	DISPERSE RED 72	22	11.86	2.61
1/0	DISPERSE RED 73	22	6.51	2.87
6/2	DISPERSE RED 73	22	6.70	2.95
4/9	DISPERSE RED 73	44	12.86	5.66
8/6	DISPERSE RED 82	30	10.83	3.25
3/8	DISPERSE RED 82	30	12.31	3.69
8/8	DISPERSE RED 86	41	3.03	1.24
4/3	DISPERSE RED 88	24	14.03	3.37
3/0	DISPERSE RED 91	25	3.62	0.90
6/2	DISPERSE RED 91	25	3.50	0.88
2/1	DISPERSE RED U-2	41	9.47	3.88
5/4	DISPERSE VIOLET 26	34	3.06	1.04
3/0	DISPERSE VIOLET 48	25	11.81	2.95
6/2	DISPERSE VIOLET 57	33	3.93	1.30
8/8	DISPERSE YELLOW 108	30	5.23	1.57
4/3	DISPERSE YELLOW 114	45	5.13	2.31
1/6	DISPERSE YELLOW 184:1	10	18.96	1.90
3/0	DISPERSE YELLOW 198	21	6.59	1.38
3/8	DISPERSE YELLOW 218	25	7.17	1.79
5/4	DISPERSE YELLOW 218	25	7.13	1.78
3/8	DISPERSE YELLOW 23	38	13.81	5.25
6/2	DISPERSE YELLOW 3	55	4.17	2.29
3/8	DISPERSE YELLOW 3	49	4.32	2.11
4/3	DISPERSE YELLOW 42	29	2.99	0.87
5/9	DISPERSE YELLOW 42	59	1.50	0.88
2/7	DISPERSE YELLOW 54	53	5.29	2.81

Table C-5

DYE PURITY AND ABSORPTIVITIES (Continued)

ID	COLOR INDEX NAME	FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s) ACTIVE COLORANT	ABSORPTIVITY (a_s) COMMERCIAL DYE
6/2	DISPERSE YELLOW 54	29	2.99	0.87
1/0	DISPERSE YELLOW 54	40	2.22	0.89
6/2	DISPERSE YELLOW 64	19	2.84	0.54
8/8	DISPERSE YELLOW 67	24	3.53	0.85
6/2	DISPERSE YELLOW 86	46	1.72	0.79
3/0	DISPERSE YELLOW 93	45	6.46	2.91
4/9	MORDANT BLACK 11	58	12.74	7.39
3/8	MORDANT BLACK 11	58	12.82	7.43
4/9	MORDANT BLACK 9	30	14.18	4.25
4/9	MORDANT ORANGE 3	75	4.31	3.24
4/3	REACTIVE BLACK 5	60	7.06	4.24
8/6	REACTIVE BLACK U-1	35	8.35	2.92
2/1	REACTIVE BLUE 10	91	3.06	2.78
8/6	REACTIVE BLUE 114	30	6.11	1.83
8/6	REACTIVE BLUE 116	30	11.64	3.49
2/1	REACTIVE BLUE 137	91	1.38	1.26
9/1	REACTIVE BLUE 18	50	15.45	3.86
4/3	REACTIVE BLUE 21	60	4.46	2.68
8/6	REACTIVE BLUE 21	25	10.67	2.67
4/9	REACTIVE BLUE 27	50	2.81	1.40
4/3	REACTIVE BLUE 27	50	2.86	1.43
8/6	REACTIVE BLUE 29	53	2.20	1.16
9/1	REACTIVE BLUE 52	60	4.69	2.81
2/1	REACTIVE BLUE 7	99	2.85	2.83
4/9	REACTIVE BLUE U-1	45	2.77	1.25
8/6	REACTIVE BLUE U-3	60	6.90	4.14
4/3	REACTIVE BLUE U-4	50	3.79	1.90
6/5	REACTIVE BLUE U-5	84	2.60	2.18
4/3	REACTIVE ORANGE 16	62	3.55	2.20
2/1	REACTIVE ORANGE 70	71	2.46	1.75
4/3	REACTIVE ORANGE 82	40	5.72	2.29
2/1	REACTIVE RED 120	96	2.72	2.61
9/1	REACTIVE RED 120	96	2.36	2.27
2/1	REACTIVE RED 152	94	3.10	2.91
4/3	REACTIVE RED 180	50	4.18	2.09
4/3	REACTIVE RED 198	40	4.87	1.95
6/5	REACTIVE RED 40	70	3.23	2.26
8/6	REACTIVE RED 40	70	2.66	1.86
2/1	REACTIVE RED 43	72	4.04	2.91

Table C-5

DYE PURITY AND ABSORPTIVITIES
(Continued)

ID	COLOR INDEX NAME			FINAL PURITY (PERCENT)	ABSORPTIVITY (a_s)	
					ACTIVE COLORANT	COMMERCIAL DYE
9/1	REACTIVE	RED	43	72	3.90	2.81
4/3	REACTIVE	RED	94	75	3.96	2.97
4/9	REACTIVE	RED	U-1	35	3.59	1.26
4/9	REACTIVE	RED	U-2	35	5.11	1.79
4/9	REACTIVE	RED	U-3	45	4.39	1.98
8/6	REACTIVE	RED	U-4	35	4.45	1.56
8/6	REACTIVE	VIOLET	33	35	3.50	1.22
4/3	REACTIVE	VIOLET	5	55	2.51	1.38
8/6	REACTIVE	YELLOW	125	50	5.15	2.58
4/3	REACTIVE	YELLOW	15	50	3.96	1.98
4/3	REACTIVE	YELLOW	160	65	1.70	1.10
8/6	REACTIVE	YELLOW	25	70	2.74	1.92
6/5	REACTIVE	YELLOW	27	58	2.93	1.70
8/6	REACTIVE	YELLOW	27	58	2.88	1.67
2/1	REACTIVE	YELLOW	3	80	2.13	1.71
9/1	REACTIVE	YELLOW	58	55	2.24	1.23
9/1	REACTIVE	YELLOW	64	60	2.41	1.45
4/9	REACTIVE	YELLOW	U-1	45	2.59	1.16
4/9	REACTIVE	YELLOW	U-2	50	5.15	2.58
8/8	VAT	BLUE	6	14	0.39	0.05
8/8	VAT	BROWN	M-1	25	0.42	0.11
8/8	VAT	ORANGE	2	14	1.76	0.25
8/8	VAT	VIOLET	1	16	3.10	0.50
8/8	VAT	VIOLET	13	31	1.07	0.33
8/8	VAT	YELLOW	2	13	0.38	0.05

Note: 10 grams = 0.3527 ounce; 1,000 grams = 2.2046 pounds.

Appendix D

STATISTICAL METHODOLOGY

I. NORMAL PROBABILITY PLOTS

A normal probability plot of the commercial dye concentrations observed in the 22 plants is shown in Figure D-1. As discussed in Section VII, the plot indicates significant departures from normality. A normal probability plot of the (natural) logarithms of the commercial dye concentrations is shown in Figure D-2. The approximately straight-line shape of this plot indicates that a lognormal distribution will provide a good fit to the observed airborne concentrations.

II. COMPUTATION OF PERCENTILE ESTIMATES FOR THE STATISTICAL ANALYSIS OF DATA

Procedures for estimating the mean, variance, and percentiles of the lognormal distributions were presented in Chapter 7. In this appendix, we discuss derivation of confidence intervals for the estimated percentiles of the lognormal distribution.

First consider the percentiles exp(m + zs). Our approach was to compute a 95% confidence interval for m + zs on the log scale and then exponentiate back to the measurement scale. In estimating the sampling variance of the estimate m + zs we treated m and s as if they were computed from a simple random sample from a normal distribution. This leads to the approximation

$$\mathrm{Var}(m + zs) = \mathrm{Var}(m) + z^2\mathrm{Var}(s)$$

$$= s^2(n^{-1} + z^2(1 - 2G(n/2)^2/(n - 1)G((n -1)/2)^2)$$

where G is the gamma function[1] and n(= 22 here) is the sample size.

Now, an approximate 95% confidence interval for m + zs can be computed as

$$m + zs \pm 1.96\ (\mathrm{Var}(m + zs))^{0.5}$$

This interval can be exponentiated to give a confidence interval for the percentile exp(m + zs) of the measurement data. In a similar fashion, we find the formula

$$\mathrm{Var}(m = s^2/2) = s^2/n + s^4/2(n - 1),$$

treating s^2 as having a Chi-squared distribution with (n - 1) degrees of freedom.[2] A confidence interval for $m + s^2/2$ and hence

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[1]See Theorems 1.3.1 and 1.3.3 in Bickel PJ, Doksum, KA. 1977. Mathematical Statistics. San Francisco.

[2]Ibid., Theorem 1.3.3.

Figure D-1

AIRBORNE COMMERCIAL DYE CONCENTRATION: NORMAL PROBABILITY PLOT

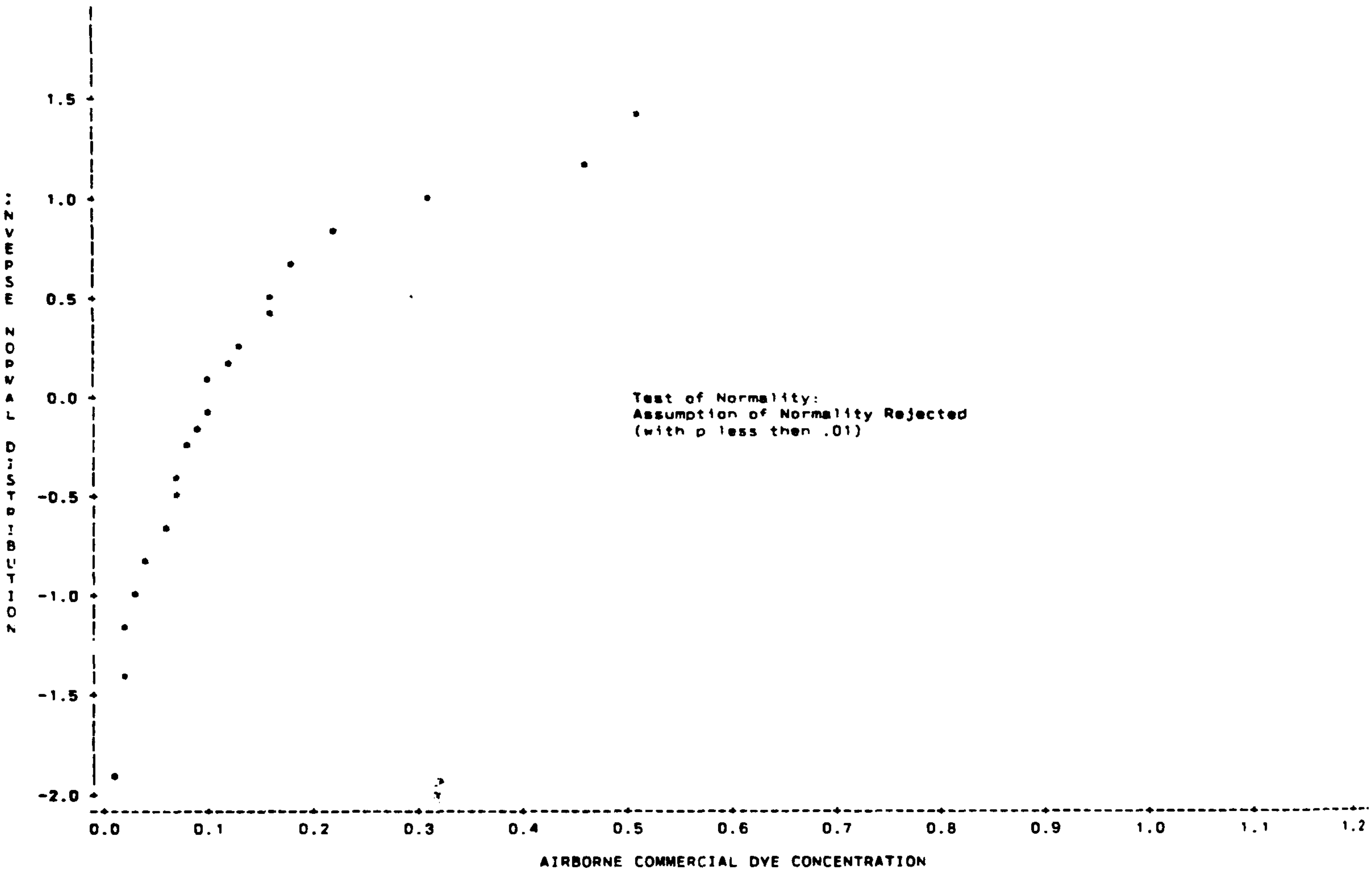
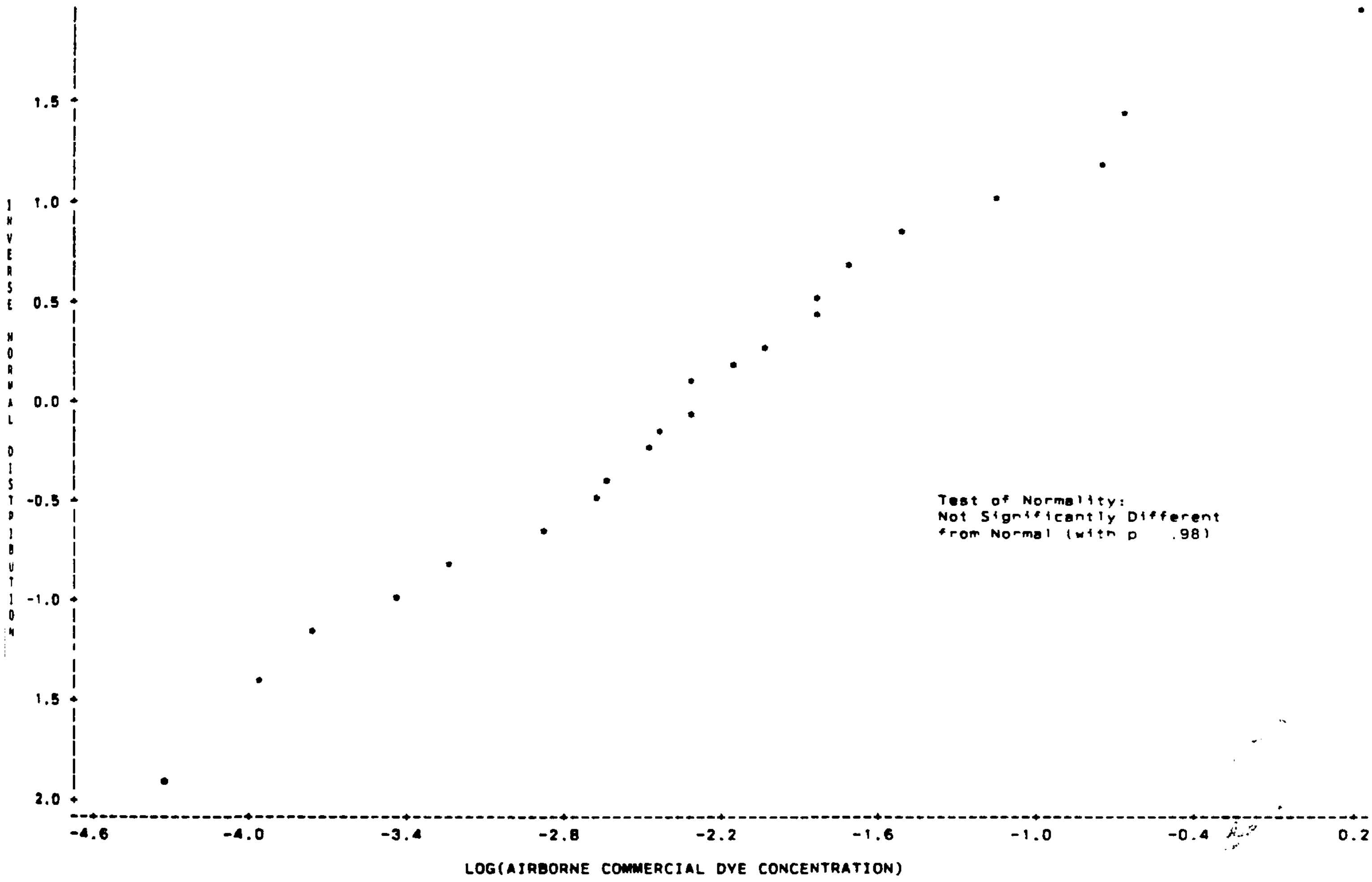


Figure D-2

LOG(AIRBORNE COMMERCIAL DYE CONCENTRATION): NORMAL PROBABILITY PLOT



for $v = \exp(m + s^2/2)$, the mean of the data on the measurement scale, can then be constructed as before.

III. SENSITIVITY ANALYSIS OF DYE CONCENTRATION ESTIMATES DUE TO MEASUREMENT ERROR

A. Introduction

This section is a sensitivity analysis of the effect of measurement error for airborne dye concentration. In this analysis ANOVA techniques were applied to estimate the component of total sample variance due to measurement errors and to the underlying population variance. The estimated population variance is then applied to generate percentiles of the population distribution which are not biased upward by the additional variance due to measurement errors.

While many ANOVA techniques have been proposed, the standard one-way, random effects model will be considered here.[3] The one-way model is applied to separate the total sample variance into two components: one for the variation of exposure levels within-plants; and another for variations across (or between) plants. In the former case, it is appropriate to consider the deviations of each observation from the mean of all observations for that plant. In the latter case, we consider the squared deviation of the plant means from the overall mean for all plants.

Measurement errors are shown to affect both the within-plant and across-plant components of variance in the survey. Within-plant variance is affected by the traditional field/laboratory airborne chemical measurement sources of variation such as variations in flow rates of collection devices, filter efficiency, efficiency of sample recovery and extraction, and errors inherent in laboratory measurements using spectrometric devices. These errors add to the spatial variation of dye concentration within the weighing area and the variation due to left- and right-handed workers. The total of such within-plant variations is collectively estimated in the within-plant component of variance.

In the survey, there is also an effect of measurement error in the estimated across-plant variance. This second type of measurement error relates to the problem of measuring the total concentration of multiple dyes with a single spectrophotometric measurement. To accomplish this, it is necessary to know the relative amounts of each dye in the collected sample. In the survey, these relative amounts are based on physical measurement of the amount of each dye weighed. Due to variations in "dustiness" of

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[3]See, for example, Snedecor and Cochran, Statistical Methods, 6th Ed., Chapter 10.

each dye weighed, the true airborne relative concentrations may differ from the weighed concentrations.

This type of measurement error affects all measurements within a plant in a similar fashion, and is not a component of the within-plant variation. This type of measurement error is contained in the estimated across-plant component of variance. Hence, the total variance across plants is larger than the true population variance across plants.

The purpose of ANOVA is to identify the within- and across-plants components of variance. Additional simulations[4] were necessary to estimate the amount of measurement error affecting the across-plants component of variance. A final estimate of the underlying population variance is obtained by subtracting the variance due to the across-plant type of measurement error from the total across-plant variance.

In the following section, the ANOVA procedures for estimating total, within, and across-plant variances are summarized. In the final section of this report, the across-plant component of variance is decomposed into one component which represents across-plant measurement error, and the remaining component is identified as the underlying population variance. Population statistics are then presented based on the estimated population mean and variance.

B. ANOVA Results

The final survey data set contains measurements of airborne concentrations tabulated both on an active dye basis and on a commercial dye basis. The analysis of variance was conducted separately for each set of measurements. While the general discussion is phrased in terms of active dye concentrations, analogous results hold for the commercial dye concentration measurements. The active dye measurements contain one set of two observations (left and right) in each of 22 plants, yielding a total of 44 data points. Sampling weights are available for estimating population parameters for all plants and separately for all workers.

Frequency plots of the unweighted observations on an active dye basis are shown in Figures D-3(a) and D-3(b). Figure D-3(a) depicts the original data, while the frequency plot of the natural logarithm of the observations is shown in Figure D-3(b). In both figures, left and right measurements are shown separately. Figures D-4(a) and D-4(b) show equivalent plots on a commercial dye basis. Examination of the figures demonstrates that the distribution of the logarithm of the observations is approximately a normal

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[4]These simulations, performed by Midwest Research Institute, are discussed in Appendix C of this report.

Figure D-3(a)
ACTIVE DYE CONCENTRATIONS MEASURED ON LEFT AND RIGHT FILTERS:
FREQUENCY DISTRIBUTION

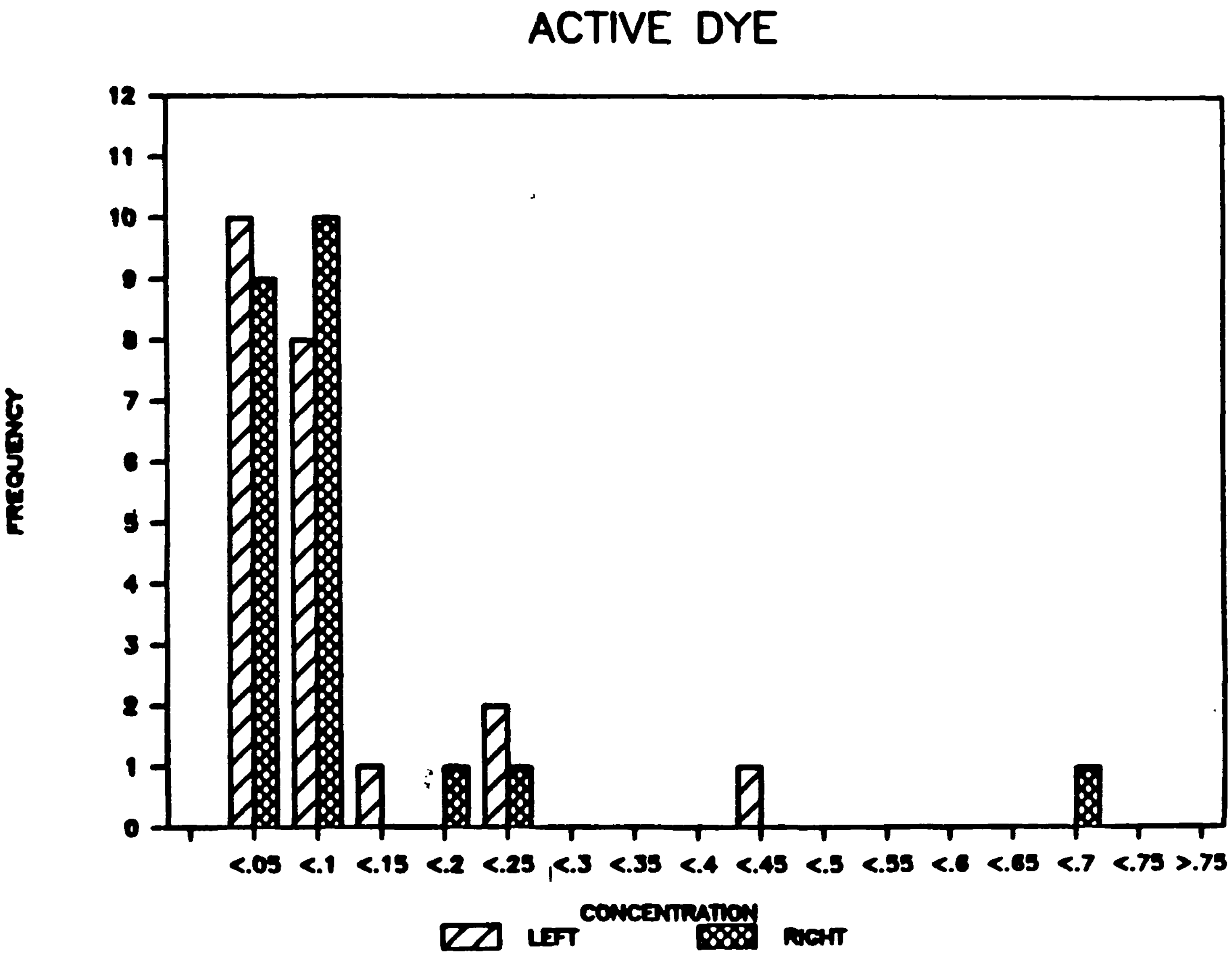


Figure D-3(b)
Log(ACTIVE DYE CONCENTRATION) MEASURED ON LEFT AND RIGHT FILTERS:
FREQUENCY DISTRIBUTION

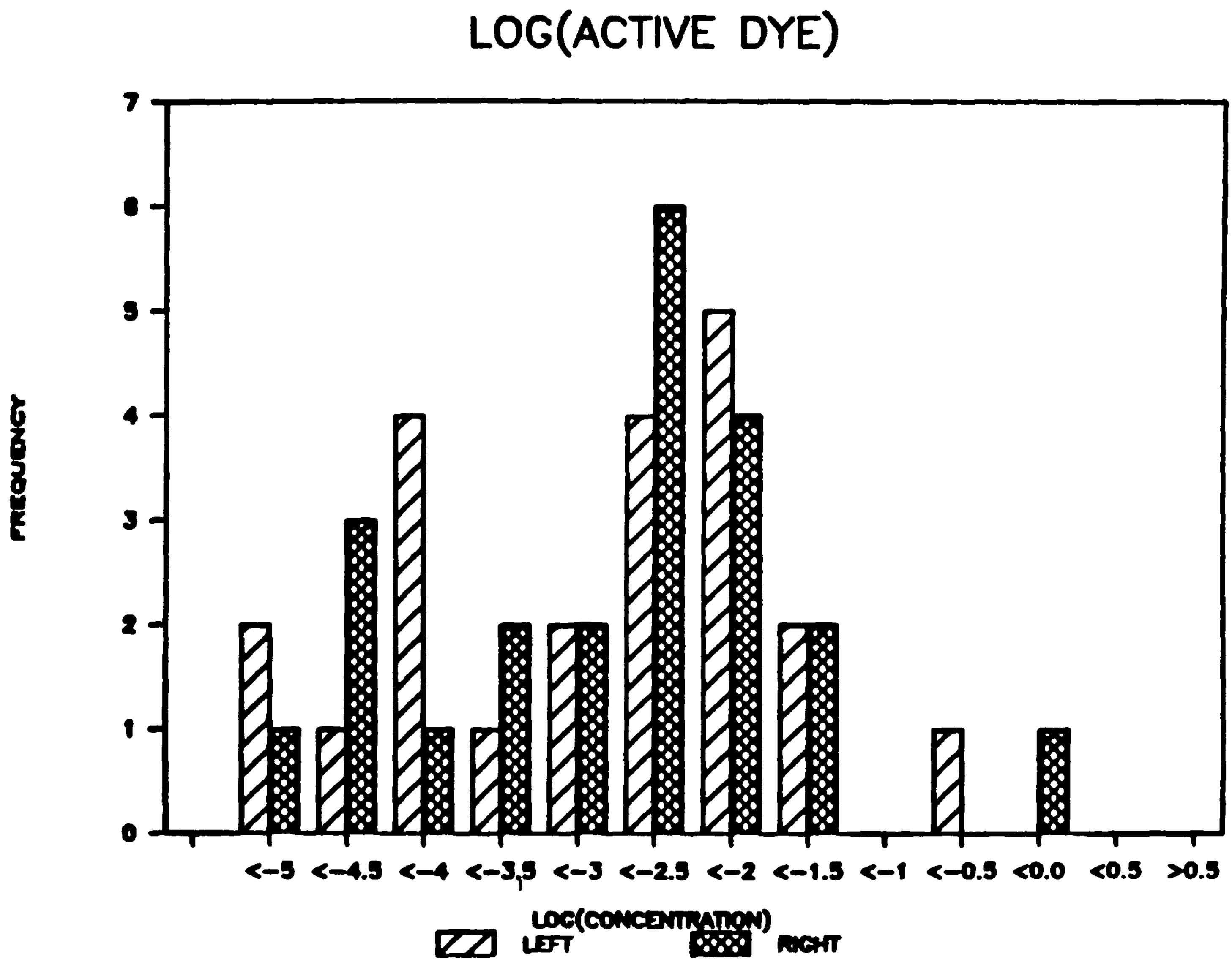


Figure D-4(a)
COMMERCIAL DYE CONCENTRATIONS MEASURED ON LEFT AND RIGHT FILTERS:
FREQUENCY DISTRIBUTION

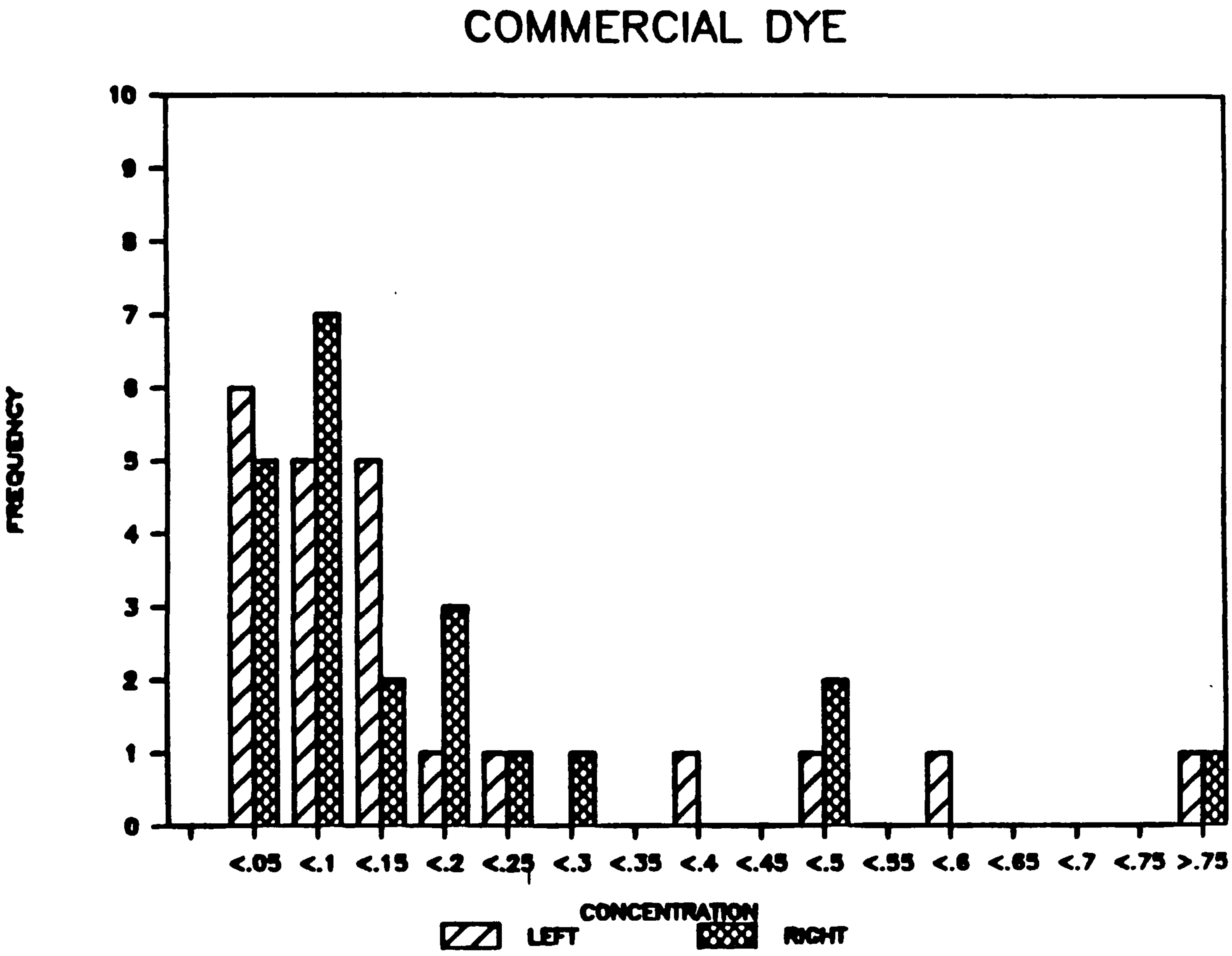
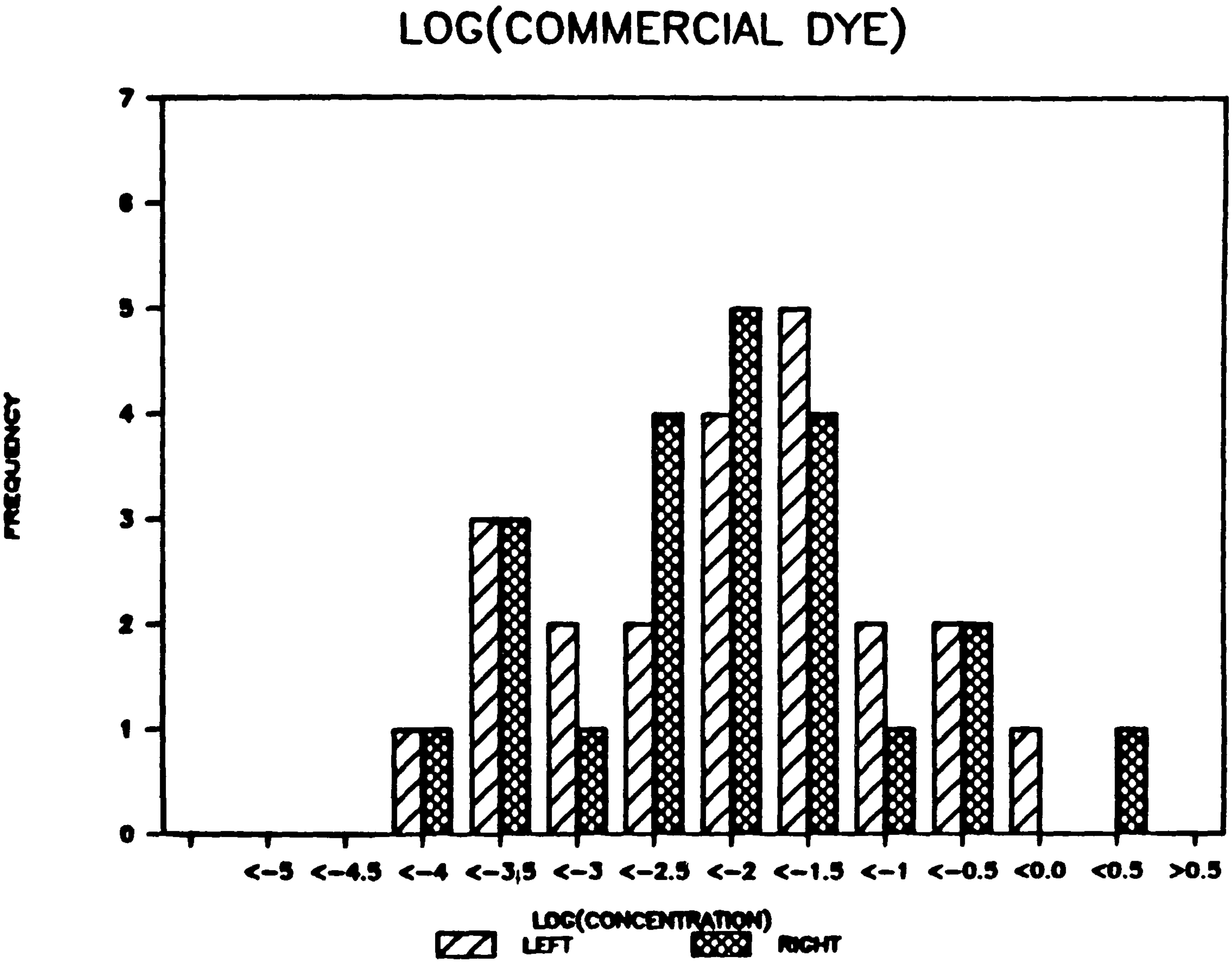


Figure D-4(b)
Log(COMMERCIAL DYE CONCENTRATION) MEASURED ON
LEFT AND RIGHT FILTERS: FREQUENCY DISTRIBUTION



distribution. The figures also demonstrate that there is no apparent difference between the left and right measurements in terms of mean or variance.

Based on the above observations, the following random effects log-linear model is adopted:

1) Natural numbers - multiplicative model:

$$Y_{i,j} = M\ A_i\ E_{i,j} \quad (i = 1, \ldots, N_i;\ j = \text{left, right})$$

where the $Y_{i,j}$ denote the original airborne concentration measurements in plant i, on side j, using the active dye basis. The fixed parameter M will be discussed below. The terms A_i denote random (lognormal) multiplicative effects for variation across plants, and the $E_{i,j}$ denote random (lognormal) variations within plants. Taking the logarithms of equation (1) yields:

2) Logarithms - additive model:

$$y_{i,j} = m + a_i + e_{i,j}$$

where

$$\begin{aligned} y_{i,j} &= \log\ (Y_{i,j}), \\ m &= \log\ (M), \\ a_i &= \log\ (A_i), \text{ and} \\ e_{i,j} &= \log\ (E_{i,j}). \end{aligned}$$

In Equation (2), the a_i are normally distributed random effects across plants with mean zero and variance s_a^2. The $e_{i,j}$ are normally distributed error terms within plants with mean zero and variance s^2. The fixed parameter m represents the overall mean of the logarithms of the data. By the theory of the lognormal distribution, the fixed parameter M ($=e^m$) in Equation (1) above represents the overall <u>median</u> of the observations expressed in original numerical form. The parameter M is also an estimate of the median of the underlying population distribution, because the a_i and $e_{i,j}$ have mean zero. The symbol s_a^2 denotes the across-plant variance component, while the symbol s^2 denotes the within-plant component of variance. As noted in the introduction above, s_a^2 includes both the variance due to the population distribution and due to the across-plant component of measurement error. The purpose of the ANOVA presented in this section is to estimate s^2 and s_a^2. In the following section, our simulation-based estimate of the across-plant measurement error is removed from s_a^2 to yield an unbiased estimate of the population variance.

Note that all estimates produced by the ANOVA procedure are statistics calculated from the logarithms of the observations. Use of logarithms implies that s_a^2 estimates the across-plant variance in the logarithms and s^2 estimates the within-plant variance in the logarithms. Use of logarithms in ANOVA is equivalent to analyzing the percent variations in the original observations. Thus, the variance of the logarithms translates to the mean square percent variation in the original numbers, and the mean of the logarithm translates to the median of the original numbers. The mean of the original numbers is a function of both the median and the variance estimates, due to the skewness of the lognormal distribution. All results presented in this section are in terms of the logarithms. Similarly, the across-plant component of measurement error estimated in the following section is presented in terms of logarithms. The final results for population characteristics will be presented in original numerical form, however.

The log-linear random effects ANOVA model in equation (2) above was estimated using both weighted and unweighted logarithms. The use of sampling weights detracts from the simplicity of the required calculations for unweighted ANOVA. First, we discuss the unweighted analysis procedure, and then present these results. This section concludes with an analysis of the weighted results.

Calculation Procedures for Unweighted ANOVA

A. Within plants:

1. Plant i Mean

$$y_{i,.} = (y_{i,right} + y_{i,left})/2$$

2. Squared Deviations

$$d_{i,j}^2 = (y_{i,j} - y_{i,.})^2 \quad .$$

3. Mean Squared Error Estimate

$$MSE_w = SSW\ d_w \quad ,$$

where SSW is the simple average of the squared deviations within-plants

$$SSW = \frac{1}{2n_i} \sum_i \sum_j d_{i,j}^2 \quad ,$$

and d_w is the correction factor for the available within-plant degrees of freedom,

$$d_w = n_i n_j / n_i (n_j - 1) = 2 \quad .$$

4. Within-plant Component of Variance

$$s^2 = MSE_w$$

B. Across plants:

1. Overall Mean

$$y_{.,.} = \frac{1}{n_i} \sum_i y_{i,.} \quad .$$

2. Squared Deviations

$$d_{i,.}^2 = (y_{i,.} - y_{.,.})^2 \quad .$$

3. Mean Squared Error Across Plants

$$MSE_a = SSA\ d_a \quad ,$$

where SSA is the simple average of the squared deviations across plants

$$SSA = \frac{1}{n_i} \sum_i d_{i,.} \quad ,$$

and d_a is the correction factor for the available across-plants degrees of freedom

$$d_a = n_i n_j / (n_i - 1) = 44/21 = 2.095 \quad .$$

4. Across-plant Component of Variance

$$s_a^2 = (MSE_a - s^2)/2 \quad .$$

Inspection of the unweighted ANOVA results in Tables D-1(a) and D-1(b) confirms the following conclusions:

a. The within-plant variation is small compared to across-plant variation (3.4 percent on an active dye basis and 3.7 percent on a commercial dye basis).

b. The variance within plants is approximately equal, in both a commercial or active dye basis.

c. The variance component across plants is 1.306 on an active dye basis and 1.202 on a commercial dye basis. This component includes both the population variance and the across-plant measurement error.

Table D-1(a)

UNWEIGHTED LOGARITHMIC ANOVA RESULTS: ACTIVE DYE BASIS

Source of Variation	Across Plants	Within Plants	Total
Degrees of Freedom	21	22	43
Sums of Squares	55.81	1.019	56.83
Mean Square Error	2.658	0.0463	--
Variance Component	1.306	0.0463	1.352
Percent of Total Variance	96.6	3.4	100.0

Overall Mean = -3.0894

Table D-1(b)

UNWEIGHTED LOGARITHMIC ANOVA RESULTS: COMMERCIAL DYE BASIS

Source of Variation	Across Plants	Within Plants	Total
Degrees of Freedom	21	22	43
Sums of Squares	51.47	1.020	52.49
Mean Square Error	2.451	0.0464	--
Variance Component	1.202	0.0464	1.249
Percent of Total Variance	96.3	3.7	100.0

Overall Mean = -2.2871

Calculation Procedures for Weighted ANOVA

The four steps described above for obtaining the across-plant and within-plant variance components proceed in an analogous fashion for weighted ANOVA, with the simple averages replaced by weighted averages, and squared deviations from the mean replaced with weighted squared deviations from the weighted mean. Because the weights w_i on both observations within a plant are identical, the weighted mean within plants equals the unweighted mean within plants.

The following steps summarize the calculations performed for the weighted analysis of variance:

A. Within plants:

1. Plant i Weighted Mean

$$y^*_{i,.} = y_{i,.} \quad .$$

2. Squared Deviations

$$(d^*_{i,j})^2 = (y_{i,j} - y^*_{i,.})^2 = d_{i,j} \quad .$$

3. Weighted Mean Square Error, Within Plants

$$MSE_a^* = SSA^* \quad d_a \quad ,$$

where SSA* is the weighted average of the squared deviations within plants,

$$SSA^* = \sum_{ij} w_i (d^*_{i,j})^2 / n_j \sum_{i} w_i \quad ,$$

and d_a is the same correction factor for the available within-plant degrees of freedom as in the unweighted analysis of variance.

4. Within-plant Component of Variance

$$s^2 = MSE^*_w \quad .$$

B. Across plants:

1. Overall Weighted Mean

$$y^*_{.,.} = \sum_{i} w_i y^*_{i,.} / \sum_{i} w_i \quad .$$

2. Squared Deviations

$$(d^*_{i,.})^2 = (y^*_{i,.} - y^*_{.,.})^2 \quad .$$

3. Weighted Mean Squared Error, Across Plants

$$MSE_a = SSA^* \quad d_a \quad ,$$

where SSA* is the weighted average of the squared deviations across plants

$$SSA^* = \sum_i w_i (d^*_{i,.})^2 / \sum_i w_i \quad ,$$

and d_a is the same correction factor for the available across-plants degrees of freedom as in the unweighted analysis of variance.

4. Across-plant Component of Variance

$$s_a^2 = (MSE^*_a - s^2)/2 \quad .$$

Results for the weighted ANOVA based on establishment weights on an active and commercial dye basis are presented in Tables D-2(a) and Table D-2(b). Similar results using weigher level weights are presented in Tables D-3(a) and D-3(b).

III. PRESENTATION OF FINAL RESULTS

The across-plant variance estimated in Section II.B above contains both the population and the across-plant measurement variances.

Simulations by MRI of the errors induced by possible variations of the airborne dye mixture from the weighed dye proportions were used to provide an estimate of the variance due to measurement error. These calculations are shown in Table D-4.

In this table, an estimate of the across-plant measurement variance is computed from the .05 and .95 percentiles of the simulation results. An estimate of the across-plant measurement variance was obtained based on the lognormal model using the formula

$$s_{m,i} = \log\ [P_i(.95)/P_i(.05)]/2(1.64)$$

for each simulation in plant i. The resulting estimates of the standard deviations were then averaged to produce an average standard deviation

$$s_m = \frac{1}{n_i} \sum s_{m,i} \quad .$$

Table D-2(a)

ESTABLISHMENT-WEIGHTED LOGARITHMIC ANOVA RESULTS: ACTIVE DYE BASIS

Source of Variation	Across Plants	Within Plants	Total
Degrees of Freedom	21	22	43
Sums of Squares	48.111	1.071	49.18
Mean Square Error	2.291	0.0487	--
Variance Component	1.121	0.0478	1.169
Percent of Total Variance	96.8	3.2	100.0

Table D-2(b)

ESTABLISHMENT-WEIGHTED LOGARITHMIC ANOVA RESULTS: COMMERCIAL DYE BASIS

Source of Variation	Across Plants	Within Plants	Total
Degrees of Freedom	21	22	43
Sums of Squares	46.45	1.054	47.50
Mean Square Error	2.212	0.0479	--
Variance Component	1.082	0.0479	1.130
Percent of Total Variance	95.8	4.2	100.0

Table D-3(a)

WORKER-WEIGHTED LOGARITHMIC ANOVA RESULTS: ACTIVE DYE BASIS

Source of Variation	Across Plants	Within Plants	Total
Degrees of Freedom	21	22	43
Sums of Squares	55.67	1.148	56.82
Mean Square Error	2.651	0.0522	--
Variance Component	1.300	0.0522	1.352
Percent of Total Variance	96.1	3.9	100.0

Table D-3(b)

WORKER-WEIGHTED LOGARITHMIC ANOVA RESULTS: COMMERCIAL DYE BASIS

Source of Variation	Across Plants	Within Plants	Total
Degrees of Freedom	21	22	43
Sums of Squares	50.02	1.157	51.18
Mean Square Error	2.382	0.0526	--
Variance Component	1.165	0.0526	1.217
Percent of Total Variance	95.7	4.3	100.0

Table D-4

ESTIMATION OF ACROSS-PLANT MEASUREMENT VARIANCE

Plant	P(.05)	P(.95)	$s_{m,i}$
A. Commercial Dye Basis			
10	2.13	3.36	0.139
16	2.51	4	0.142
21	1.67	2.63	0.138
24	2.16	3.69	0.163
27	1.39	5.31	0.409
30	1.55	2.86	0.187
33	1.98	3.43	0.168
38	3.25	5.81	0.177
41	1.58	2.46	0.135
43	2.34	3.29	0.104
46	2.66	4.68	0.172
49	2.11	4.59	0.237
52	2.72	3.59	0.085
54	1.22	2.26	0.188
59	1.71	3.71	0.236
62	1.45	2.2	0.127
65			
79	2.6	3.79	0.115
80	1.18	2.61	0.242
86	1.42	2.76	0.203
88			
91	1.99	3.52	0.174
			3.540 = Sum
			20 = n
			0.177 = s_m

Table D-4

ESTIMATION OF ACROSS-PLANT MEASUREMENT VARIANCE (Continued)

Plant	P(.05)	P(.95)	$s_{m,i}$
B. Active Dye Basis			
10	6.51	9.32	0.241
16	5.63	7.02	0.159
21	3.98	5.41	0.219
24	4.54	5.82	0.179
27	5.95	9.42	0.292
30	6.9	8.94	0.182
33	4.85	5.94	0.125
38	8.88	11.2	0.151
41	4.11	5.12	0.128
43	5.43	7.33	0.171
46	5.7	6.56	0.114
49	6.79	8.93	0.191
52	3.93	4.9	0.130
54	4.93	7.53	0.313
59	7.34	11.01	0.228
62	5.73	6.54	0.092
65			
79	6.41	7.91	0.137
80	8.47	11.86	0.223
86	5.75	8.06	0.250
88			
91	6.45	8.27	0.170
			3.694 = Sum
			20 = n
			0.185 = s_m

The measurement error variance was then obtained as s_m^2. As shown in Table D-4, these variances are quite small, roughly the same size as the within-plant variance component obtained in Section II.B above.

To generate the final population statistics, the quantity s_m^2 was subtracted from the across-plant variance component from the ANOVA:

$$s_{pop}^2 = s_a^2 - s_m^2 \quad ,$$

where all terms are variances of logarithms.

The theory of the lognormal distribution was then applied to estimate population parameters from the overall mean of the logarithms and the population variance s_{pop}^2. Results of these calculations are shown in Tables D-5(a) and D-5(b), for active and commercial dye, respectively. The difference between adjustment for across-plant measurement error and no adjustment is high-lighted by including the estimates obtained directly from the across-plant variance, s_a^2. The effects of adjustment for the across-plant measurement variance is quite small.

After reviewing the compact of measurement error estimates it was decided not to adjust estimates of airborne dye concentration because of measurement error. This was done for two reasons.

First, the impact of measurement error was quite small in this case;

In addition, the adjustment technique described above is very complicated. It was decided that the extra complexity introduced by the method was not worth the increased difficulty in explaining the results considering that the estimates in general were changed to two significant digits.

Table D-5(a)

CHARACTERISTICS OF THE DISTRIBUTION OF ACTIVE INGREDIENTS

Exposure (mg/m^3)	Corrected for Measurement Error (s_{pop}^2)	Uncorrected for Measurement Error (s_a^2)
A. Plant Level		
- Median	.0484	.0484
- Average	.0833	.0847
- Standard Deviation	.1168	.1218
- Percentiles		
.85th	.1425	.1449
.90th	.1840	.1879
.95th	.2688	.2760
B. Weigher Level		
- Median	.0413	.0413
- Average	.0777	.0790
- Standard Deviation	.1239	.1290
- Percentiles		
.85th	.1324	.1345
.90th	.1744	.1778
.95th	.2624	.2690

Table D-5(b)

CHARACTERISTICS OF THE DISTRIBUTION OF COMMERCIAL DYE

Exposure (mg/m^3)	Corrected for Measurement Error (s_{pop}^2)	Uncorrected for Measurement Error (s_a^2)
A. Plant Level		
- Median	.1045	.1045
- Average	.1767	.1795
- Standard Deviation	.2410	.2508
- Percentiles		
.85th	.3024	.3072
.90th	.3888	.3964
.95th	.5642	.5784
B. Weigher Level		
- Median	.0970	.0970
- Average	.1710	.1737
- Standard Deviation	.2481	.2579
- Percentiles		
.85th	.2924	.2969
.90th	.3796	.3868
.95th	.5589	.5725