IN-DEPTH SURVEY REPORT:

CONTROL TECHNOLOGY FOR MANUAL DYE WEIGH-OUT OPERATIONS

AT

Multi Color Industries Inc.
Brooklyn, New York

REPORT WRITTEN BY:
Marjorie Edmonds Wallace
William A. Heitbrink
Cheryl Fairfield Estill
Stephen S. Smith
Ronald J. Kovein

REPORT DATE:
May 1995
Revised: November 1995

REPORT NO.:
ECTB 197-14a

U.S. Department of Health and Human Services
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
4676 Columbia Parkway - R5
Cincinnati, Ohio 45226

DISCLAIMER

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

PLANT SURVEYED:	Multi Color Industries 791 Kent Avenue Brooklyn, New York 11205
SIC CODE:	2261
SURVEY DATES:	July 26-27, 1994 August 22-26, 1994 October 17-21, 1994
SURVEYS CONDUCTED BY:	Marjorie Edmonds Wallace William A. Heitbrink Ronald J. Kovein Cheryl Fairfield Estill Stephen S. Smith
EMPLOYER REPRESENTATIVE CONTACTED:	Liby Goldman, Owner
EMPLOYEE REPRESENTATIVE CONTACTED:	No Union
ETAD REPRESENTATIVE:	Dr. Barry Bochner, Fabricolor
ANALYTICAL SERVICES:	DataChem Laboratories Salt Lake City, Utah
MANUSCRIPT PREPARATION:	Deanna L. Elfers Debra A. Lipps

TABLE OF CONTENTS

SUMMARY v

INTRODUCTION 1

PROJECT HISTORY 1

PLANT AND PROCESS DESCRIPTIONS 2

POTENTIAL HAZARDS OF MANUAL POWDER WEIGH-OUT OPERATIONS 6

EXPOSURE EVALUATION CRITERIA 7

EVALUATION PROCEDURES 8

RESULTS AND DATA ANALYSIS 11

DISCUSSION 22

CONCLUSIONS 26

REFERENCES 27

APPENDIX A 30

APPENDIX B 32

APPENDIX C 40

APPENDIX D 44

APPENDIX E 50

APPENDIX F 59

SUMMARY

This study addresses manual dye weigh-out operations in a small dye house. In these operations, powder dye is quantitatively transferred from drums and boxes to small paper bags. The weigh-out operator can be exposed to dye dust when scooping, transferring, weighing, or bagging the dye. The objective of the study was to determine whether engineering controls can effectively reduce worker dye dust exposures during weigh-out operations. The engineering control selected for evaluation during this study was a semi-down draft, recirculating ventilation booth. Additionally, the effect of drum height was to be evaluated as previous studies of powder scooping operations had found substituting short drums for tall drums reduced worker exposures.

A pre-control study was conducted to obtain data before installation of any engineering controls. Air samples showed that worker dust exposures were below the permissible exposure limit, however, the levels were above outdoor ambient concentrations for total suspended particulate. Aerosol monitoring results indicated that the individual tasks during the weigh-out operation contributed about equally to the worker's overall dust exposure.

During the post-control study it was apparent that it would be infeasible to perform the entire weigh-out operation inside the booth. Due to site logistics, manually moving the dye drums in and out of the booth could have posed an ergonomic problem to the worker. Therefore the drums remained stationary and the worker continued to perform most scooping tasks without controls. Since the worker could be exposed to dust during the resulting uncontrolled transport tasks, the room setup was modified so that several drums containing dusty dyes or frequently used dyes were permanently placed inside the booth or were located near the booth.

Air samples taken during the post-control study showed that dust exposures to the worker were of the order of magnitude of ambient total particulate air pollution. This does not imply that dye dust exposure is negligible or zero. When adjusted for production rate, the post-control filter concentration data was about three times lower than the pre-control filter concentration data. However, this difference was not found to be significant. The aerosol monitoring data indicated that the booth controlled dust exposures to the worker when inside the booth. Compared to the pre-control study, the use of the booth in this facility during the post-control study resulted in about a five-fold reduction in worker exposure. Within the post-control study, worker dust exposures were measured to be about three times lower when working inside the booth than when working outside the booth. Additional exposure reduction could be obtained by performing all scooping in the booth.

A separate study was conducted to evaluate the effect of drum height upon worker exposure while in the booth. Two dyes were used; one appeared visibly dustier. For the dustier dye, use of a shorter drum reduced exposure by a factor of seven for particles larger than 3 µm. For the less dusty dye, an exposure reduction of about a factor of three was found for particles larger than 3 µm when using a shorter drum. This implies that the height of the drum can affect worker dye dust exposures and that the use of shorter drums can help to control these exposures.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is the primary federal organization engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions conducted by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering has been given the lead within NIOSH to study the engineering aspects of health hazards prevention and control.

Since 1976, ECTB has conducted several assessments of health hazard control technology based on industry, common industrial process, or specific control techniques. The objective of each of these studies has been to document and evaluate effective techniques for the control of potential health hazards in the industry or process of interest, and to create a more general awareness of the need for, or availability of, effective hazard control measures. As such, a study of manual dye weigh-out operations was undertaken by the Engineering Control Technology Branch to provide control technology information for the prevention of occupational disease in this industry.

A partner to ECTB on this project was the U.S. Operating Committee of the Ecological and Toxicological Association of Dyes and Organic Pigments Manufacturers (ETAD); an international organization comprised of representatives from various dye manufacturing companies. ETAD recognizes the potential risks associated with using dyes and strives "to coordinate and unify the efforts of manufacturers of synthetic organic colorants to minimize possible impacts of these products on health and the environment."

To achieve this goal, ETAD organized a steering committee which included members from ETAD, NIOSH, the U.S. Environmental Protection Agency (EPA), the American Textile Manufacturer's Institute (ATMI), and the Amalgamated Clothing and Textile Workers Union (ACTWU). This steering committee identified dye weighing operations as requiring research to develop improved techniques to reduce worker exposure to dye dust. NIOSH researchers were specifically asked to assist in projects to improve existing work practices and identify/develop local exhaust ventilation controls for the manual dye weigh-out process.

PROJECT HISTORY

The objective of the manual dye weigh-out study was to provide dye and textile shops with information about practical, effective engineering control methods that control worker exposure to air contaminants (dust). To develop this information, the weigh-out operation was observed at field sites to determine how individual tasks contributed to worker exposures. An evaluation was then made of how these tasks, combined with parameters such as drum height, could be modified to reduce worker dust exposures.

Potential survey sites selected by NIOSH, ETAD, and ATMI were based upon the following considerations: plant size (preferably a small business), high frequency of performing the manual dye weigh-out operation, ability to reproduce data collection conditions (i.e., amounts and types of dyes weighed being fairly constant), predominant use of powder dyes rather than liquid dyes, lack of engineering controls for the task, and willingness of plant management to participate and allow installation of controls at their site. ECTB researchers also observed powder weigh out operations at a paint plant to gain an initial understanding of the process. This study found that workers' dust exposures were elevated when they scooped from the bottom of drums. A summary of this study is documented elsewhere[1].

In 1993, a dyehouse was chosen as the study site and a pre-control study was conducted. Initial data confirmed a need for engineering controls at this site, particularly for the scooping task. Unfortunately, no further research was performed at this location as the dyehouse filed for bankruptcy in early 1994. Details of this study are documented in a report available through NTIS[2].

In July 1994, a walk-through survey was scheduled at a new study site. After the dyehouse was found to meet the requirements, a pre-control study was conducted in August 1994, to observe the weigh-out operation, determine its potential hazards, and collect air sampling data. This data was used to obtain the worker's baseline dust exposures and help identify whether engineering controls were needed. Although dust exposures were low during the pre-control study, it was decided to test whether a ventilated booth could further reduce the worker's dust exposure.

Through literature searches[3] and conversations with people in the industry,[4,5] NIOSH researchers located a commercially available ventilated booth used extensively in European dyehouses, and manufactured in England. NIOSH researchers witnessed a demonstration of this booth at the manufacturer's North American distribution center in New York. A similar booth installed by the manufacturer at a pharmaceutical company was also evaluated.[6] Based upon their observations, NIOSH researchers recommended that a booth be purchased for additional evaluation at the study site. ETAD funded and oversaw the implementation of the booth. In October 1994, a post-control study was conducted to test the effectiveness and ability of the booth to control worker dust exposures.

PLANT AND PROCESS DESCRIPTIONS

The survey site was a small dye house in business since 1975. A typical work day is 12 hours; from 7:00 a.m. to 7:00 p.m. About 99 percent of the work is with cotton textiles, using direct dyes. The dye house receives finished clothes, usually in white or natural colors, from garment manufacturers who want the clothes dyed specific colors. Batches are placed in dye machines, which basically operate as industrial-sized clothes washers. In-house laboratory technicians formulate a recipe listing the various dyes needed to obtain the exact color desired by the customer. These dyes are weighed out and added to the dye machine. After dying a batch of clothing, the dye operator spot dries an item and compares it to a test swatch. If the color is off, the recipe is adjusted and the batch of clothing is redyed. If the color is satisfactory, the clothes are transferred to the drying machines. The dyed clothing is then shipped back to the customer.

DESCRIPTION OF WORK AREA

The weigh-out operation was performed in an enclosed room consisting of two areas, each approximately 28 feet in length (Figure 1). The front room, where the weighing occurred and drums were stored, was about 11 feet wide. The door to this room was kept closed. A four foot wide wall opening separated the front room from the back room. The floor inclined slightly from the front room to this entrance. The back room was used exclusively for storage of drums, usually stacked one or two high along the walls. This area was about 7 feet wide and could be accessed through a freight door when new dye drums were brought in. The front room's ceiling was about 16 feet high; about 2 feet higher than the back room's ceiling.

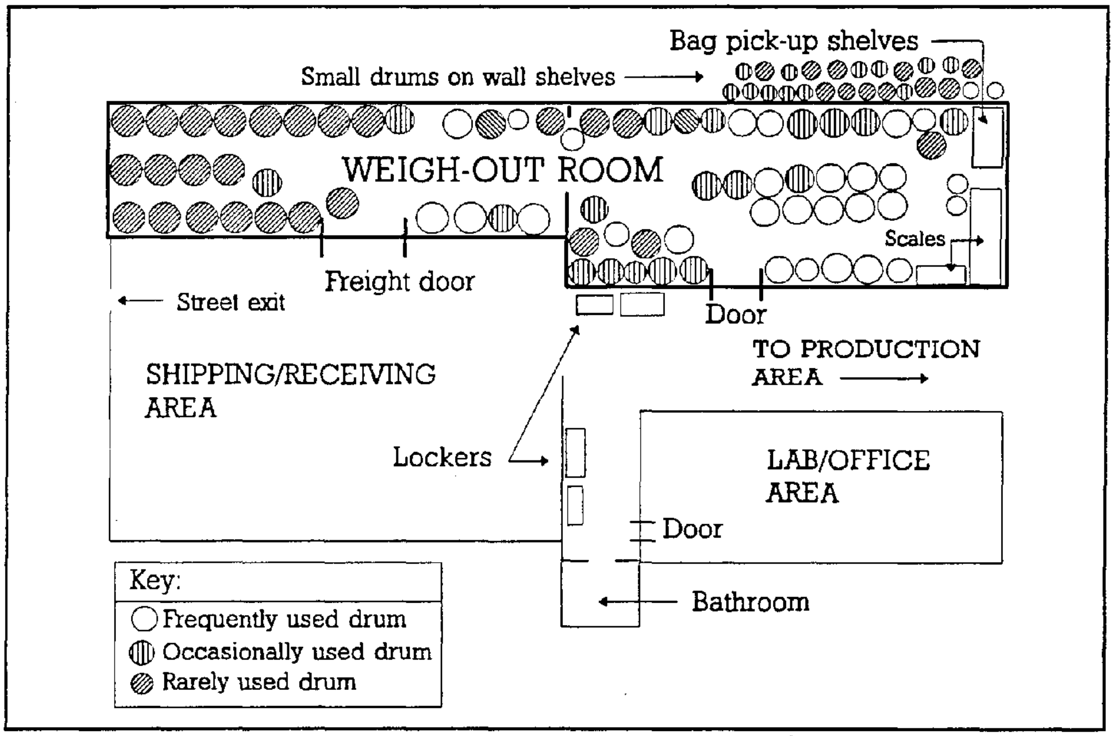


Figure 1: Dye weighout room at Multi Color Industries.

The dye drums ranged from 12 to 23 inches in diameter and 15 to 36 inches in height. Most drums were stored on wooden slats. The floor was uneven and cracked in some places and cardboard covered parts of the floor. Small drums (and some boxes of dye) were stored on angled wall shelves at about shoulder level. Three scales were used during the weigh-out procedure; a 100 pound scale (14" high, 14" wide, 14" long), a 100 gram scale (9" high, 19" long) and a 10 gram scale. During the pre-control study, the scales were placed on a 24" high stainless steel table. Paper bags with small amounts of excess dye were kept on another table, 37" high. No ventilation controls were used at the site during the pre-control study.

During the post-control study, the ventilated booth was installed in the front room where the scales had previously been located (Figure 2). Drums were arranged so that dyes used frequently were closest to the booth, while those used infrequently were stored in the back room. Several drums that were used very often, or which the worker thought contained dusty dyes, were placed directly inside the booth.

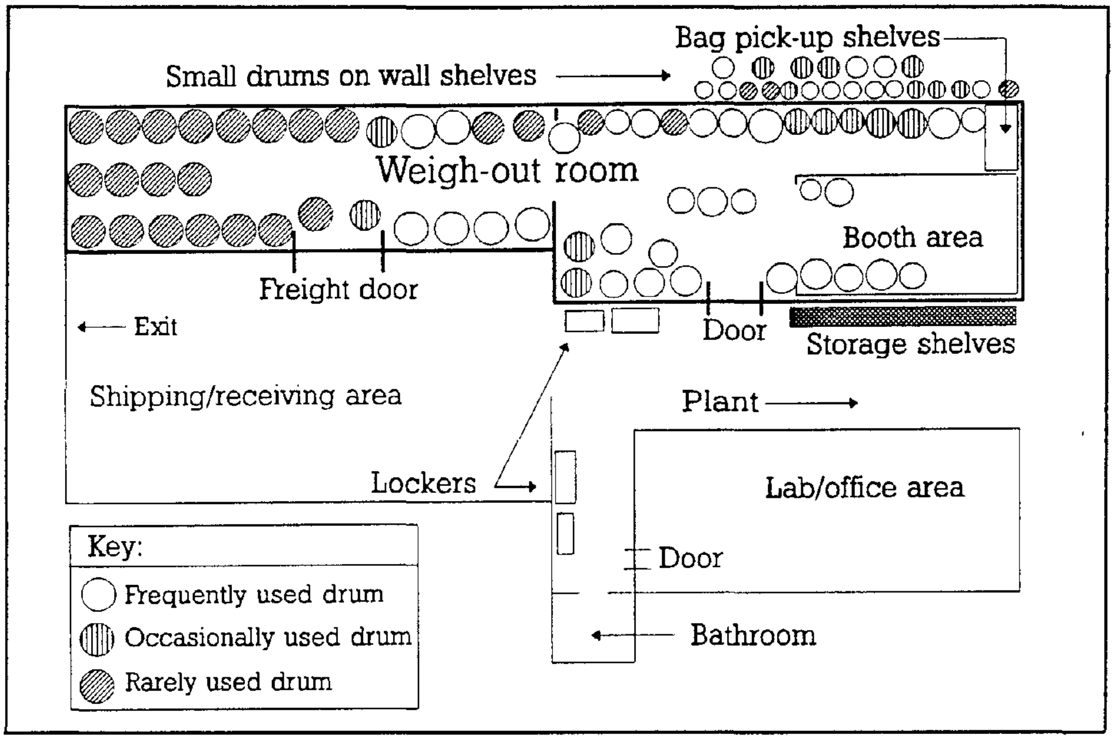


Figure 2: Dye weigh-out room at Multi Color Industries after installation of booth.

DESCRIPTION OF VENTILATED BOOTH

The 2.0 meter 'D' Range Dyestuff Dust Control Booth was manufactured and installed by Extract Technology, LTD. The booth is constructed of single skin, white epoxy coated, mild steel and is outfitted with lights and power sockets. Figure 3 presents a front view of the booth and provides the booth's dimensions. In this booth, a fan draws air through the exhaust grilles at the back of the booth. Fine dust filters are located directly behind the exhaust grilles. The fan is designed to discharge about one-tenth of this filtered air back into the plant area through bleed filters, which

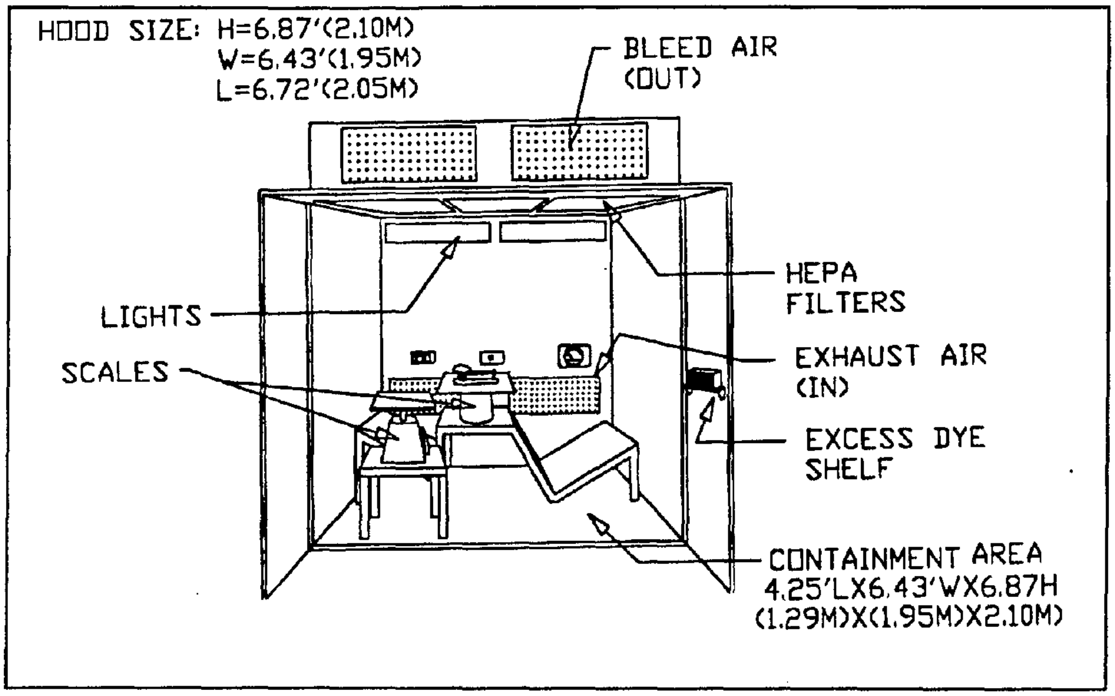


Figure 3: Ventilated Booth.

are high efficiency particulate (HEPA) filters. The remaining air is recycled through HEPA filters located in the ceiling of the booth. The ceiling HEPA filters act as an air distribution screen, resulting in a clean, vertical air shower which pushes airborne dust down, out of the worker's breathing zone, where it can be captured and pulled into the exhaust grilles. This push-pull system is only claimed to be effective within the containment area which is outlined on the booth. Turbulent air coming into the booth from the surrounding work area can be controlled by the air shower within the containment zone. As such, eddy currents are not produced and dust is not carried into the worker's breathing zone.

The total air volume of the booth was comprised of the supply air, measured from the ceiling of the booth, and the bleed air, measured from the exhaust filters at the top of the booth. The total ceiling filter area was 29.76 ft^2 and the total bleed filter area was 4.18 ft^2. The booth was designed to have a total air volume of 3370 cubic feet per minute (cfm), with a supply air volume of 3065 cfm and a bleed air volume of 305 cfm. During installation, tests by the manufacturer found the booth exceeded the design requirements, with a total air volume of 3864 cfm, a supply volume of 3364 cfm, and a bleed volume of 500 cfm.[7]

A workbench, designed and installed by the booth manufacturer, was located at the back of the booth and consisted of two slanted platforms on either side of a flat platform (Figure 3). The angled platforms were designed so that when drums are placed on them, the opening of the drum would be towards the scale. This particular set-up was designed so that, by tilting the drums, the worker would be able to reach the bottom of the drums more easily.[8]

DESCRIPTION OF WEIGH-OUT PROCESS

One worker, directly trained by the owner, was responsible for all the weigh-out tasks. When this worker was not performing his weigh duties, he provided assistance in the laboratory. On a typical day, the worker received numerous recipes from the lab technicians. After reading a formula, the weigh-out operator placed a paper bag (larger than lunch-size) on the 100 pound scale, picked up a scoop, and walked to the drum containing the first dye in the formula. He then removed the lid from the drum, scooped out an appropriate amount of dye, and carried the full scoop back to the scale. If the formula called for five or more pounds of the dye, the weigh-out operator dispensed the dye directly into the paper bag, reading the weight in pounds. However, if a formula required less than 5 pounds, the dye was dispensed directly onto the 100 gram scale's plastic weigh boat or the 10 gram scale's pan. If more dye was needed, the worker repeated these steps until the correct weight was reached. If the gram scales had been used, the dye was transferred to the paper bag before moving on to the next dye and the pan or weigh boat was cleaned off in a container of Glauber salts. The scoop was also cleaned off in the container of Glauber salts after each dye.

This process was followed until all the dyes in the formula were weighed and deposited into the paper bag. The bag was then neatly folded over and stapled shut with the formula attached. The worker carried the filled bag to the corner of the room which was designated as the bag pick-up area (Figure 2). This area consisted of five shelves placed 5 to 70 inches off the floor, and backed by a sliding door which was opened from the plant area. Each of the ten dye machines in the plant was represented by a specific space on the shelves. The worker placed the filled bag of dye at the location corresponding to the machine specified by instructions on the formula. Throughout the workday, plant operators would slide open the door to the pick-up area, grab a bag located in the space for his specific machine, and re-close the sliding door.

POTENTIAL HAZARDS OF MANUAL POWDER WEIGH-OUT OPERATIONS

Previous studies[9,10,11] have documented potential exposure levels and hazards of workers during manual powder weigh-out operations in various industries. One study at a rubber plant evaluated the dust exposure of workers who weighed and transferred powdered materials from bags and bins to smaller containers. During the sampling period, the majority of personal respirable dust concentration measurements were below 2 mg/m^3. During weigh-out activities, however, dust concentrations increased, peaking at 40 mg/m^3, suggesting an average respirable dust exposure of 15-20 mg/m^3.[10] A similar study of manual powder weigh-out operations in a plastic plant found that most breathing zone samples exceeded 10 mg/m^3.[11] A third study, performed in a textile drug room, found that the permissible exposure limits were not exceeded for total or respirable dust during the weigh-out operations.[12] However, the author of this study stressed that there could be potential inhalation hazards from these dyes since their constituents may have established permissible exposure limits which cannot be ignored.

Exposure to powders or dyes can be through three primary routes: inhalation, ingestion, and dermal contact. The main route of entry for dye dusts is through inhalation. The inhaled particles can irritate the respiratory system producing symptoms such as coughing, runny nose, or an irritated throat. The particles can also be absorbed from the lungs, or cleared from the lungs, swallowed, and absorbed from the gastrointestinal tract. This can lead to potential systemic effects arising from the metabolism of the dye into a more toxic substance than the original dye.[12] In addition, benzidine-based dyes have been recognized by NIOSH as potential occupational carcinogens which may cause bladder cancer.[13] Dyes based on benzidine congeners o-toluidine and o-dianisidine may also pose a cancer hazard.[14] As such, the Environmental Protection Agency is currently proposing a voluntary phase-out of benzidine congener dyes.[15] However, it should be noted that the ACGIH TLV committee has proposed changing o-toluidine from a suspected human carcinogen to an animal carcinogen[16]. There is also evidence that a worker in a Leicester, England dyehouse died from a severe allergic reaction to reactive dyes.[17,18]

EXPOSURE EVALUATION CRITERIA

As a guide when evaluating hazards posed by workplace exposures such as those from manual weigh-out operations, NIOSH field staff employ environmental evaluation criteria. These criteria assess several chemical and physical agents and are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects due to individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy).

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by evaluation criteria. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria in the United States that can be used for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs); (2) the American Conference of Governmental Industrial Hygienists's (ACGIH) Threshold Limit Values (TLVs); and (3) the U.S. Department of Labor (OSHA) Permissible Exposure Limits (PELs). The OSHA PELs are required to consider the feasibility of controlling exposures in various industries where the agents are used; the NIOSH RELs, by contrast, are based primarily on concerns relating to the prevention of occupational disease. ACGIH Threshold Limit Values (TLVs) refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. ACGIH states that the TLVs are guidelines. The ACGIH is a private, professional society. It should be noted that industry is legally required to meet only those levels specified by OSHA PELs.

A Time-Weighted Average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling values that are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures.

The overall objective of this study is to control worker exposure to dust generated by manual powder weigh-out activities. Therefore, the exposure evaluation criteria is based primarily on controlling total and respirable dust. The PELs established by OSHA require industry to control the 8-hour time-weighted average (TWA) of total dust to 15 mg/m^3 and respirable dust to 5 mg/m^3.[19] The PELs for respirable and total dust were not changed by the 1989 amendment of OSHA's existing Air Contaminants Standard, 29 CFR 1910.1000, which has since been vacated by the courts. Therefore, the PELs listed above continue to be enforceable by OSHA. The TLVs suggested by ACGIH are set at a 10 mg/m^3 TWA for total dust and 5 mg/m^3 TWA for respirable dust.[20] There are no RELs recommended by NIOSH for total or respirable dust; however, NIOSH does list benzidine-, o-toluidine-, and o-dianisidine-based dyes as potential occupational carcinogens, and sets the RELs at the lowest feasible concentration.[21] The goal of the study is to control both the total and respirable dust exposure from all powdered dyes to as far below the PEL and TLV as possible for the textile dye weigh-out process.

EVALUATION PROCEDURES

The objective of this study was to obtain an appreciation of the typical dye weigh-out operation and to evaluate the effectiveness of engineering controls to reduce the associated worker exposures to airborne contaminants at this site. To aid in evaluation, air sampling and video exposure monitoring techniques were performed. In addition, ventilation measurements were taken during the post-control study to evaluate the booth's integrity and to determine air flow patterns in the booth and weigh-out room. Assessments were also made on the type of scoop used during weighing; the ergonomic factors involved in the tasks; changes to the room layout between the two studies; and the dimensions of the drums used, including the depth to the dye within the drum.

DUST SAMPLING

The worker's exposure to total dust was measured using NIOSH Method 0500.[22] In this method, a known volume of air is drawn through a preweighed PVC filter. The weight gain of the filter is then used to compute the milligrams of dust per cubic meter of air.

Short-term and full-shift personal samples were collected during both surveys. The full-shift samples were collected by continuously monitoring the air in the worker's breathing zone. A filter, positioned in the worker's personal breathing zone, was attached by Tygon® tubing to a personal sampling pump (SKC Inc., Eighty Four, Pennsylvania). The pump was hooked onto the worker's belt and operated at a constant flow rate of 5 L/min. In contrast, the short-term samples were collected only when the weigh-out operation was performed. A filter was mounted on a Hand-held Aerosol Monitor (HAM) positioned in the worker's breathing zone. The HAM, an instrument which is described later in greater detail, was connected by a long length of Tygon® tubing to a floor mounted carbon vane pump. The tubing length allowed the worker to walk throughout the weighout room without restriction during sampling. The carbon vane pump was used to draw air through the filter and, subsequently, the HAM at a flow rate of 13 L/min. If the HAM was not used during a sampling session, the filter for the short-term personal sample was attached directly to the Tygon® tubing using a luer.

Area samples were also collected to obtain the background level of air contaminants. The filters were connected by Tygon® tubing to sampling pumps (SKC Inc., Eighty Four, Pennsylvania) which ran full shift at a constant flow rate of 5 L/min. Area samples was collected inside the weigh-out room and directly outside the weigh-out room. During the post-control study, an additional area sample was collected inside the ventilated booth.

INSTRUMENTAL MONITORING

Video exposure monitoring was used to study in greater detail how specific tasks affected the worker's exposure to air contaminants.[11,23] An aerosol photometer, the Hand-held Aerosol Monitor (HAM) (PPM Inc., Knoxville, Tennessee), was positioned on the worker's chest using a belt and harness. The carbon vane pump mentioned above was used to draw air through the HAM's sensing chamber. In the HAM, light from a light-emitting diode is scattered by the aerosol, and forward-scattered light is detected. The amount of scattered light is proportional to the analog output of the HAM. However, the calibration of the HAM varies with aerosol properties such as refractive index and particle size.[24] Therefore, HAM measurements are expressed as "relative exposure" or "the HAM analog output" which has units of volts. The HAM was set at a sensitivity level of 2 mg/m^3 with a one second averaging time constant. Using this sensitivity level, the analog output of one volt was equated to a dust concentration of 1 mg/m^3 for a calibration dust.

The analog output of the HAM was recorded by a data logger also attached to the worker's belt. A Rustrak Ranger data logger (Gulton, Inc., East Greenwich, Rhode Island) was used during the pre-control study. A Metrosonics data logger (Model dl-3200, Metrosonics, Inc., Rochester, New York) was used for the post-control study. When the data collection was completed, the data logger was downloaded to a personal computer (Compaq Portable III, Compaq Computer Corp., Houston, Texas) for storage and analysis. The worker's activities were simultaneously recorded on video (Video Camera Recorder Hi8 Handycam, CCD-V701, Sony Corp.) for use in a detailed task analysis of the weigh-out operation.

Optical particle counters (Model 227, Met One, Grants Pass, OR) were also used to obtain information on aerosol concentrations on the worker and in the weigh-out room. When used as a personal sampler, the instrument was clipped onto the worker's belt and the inlet was positioned in his breathing zone. A 30-cm length of 5-mm inside diameter Tygon® tubing was used to transport the aerosol from the sensor to the instrument. To monitor dust concentrations in the weigh-out room, the Met One was placed along the wall, across from the door to the room.

The Met One instruments continuously record the number of particles counted during a series of consecutive sampling periods. During this study a sampling rate of 2.83 liters per minute (lpm), a sampling period of one minute, and a time between sampling periods of one second were set. Two channels were used to store the number of particle counts in a time interval. One channel stored the total number of particles counted greater than $0.3\mu m$. The second channel was set to count the number of particles larger than $3.0\mu m$. These particles were assumed to be the dye dust. The particles were sized based upon the amount of scattered light detected by the photo detector. In reality, the magnitude of the light pulse scattered by the particles varies with particle size, optical properties, and surface roughness. The stored data was downloaded to a printer to obtain the particle counts for each sampling period. According to the instrument manufacturer, the time printed out was the end time of the sampling segment. This data was then correlated with the video tape to determine relationships between events and exposures.

VENTILATION MEASUREMENTS

The need for ventilation measurements was minimal during the pre-control study since no engineering controls were being used. However, a hot wire anemometer (Model 1040 Digital Air Velocity Meter, Kurz, Carmel Valley, California) was used to measure the air flow in the room, and smoke tubes were used to test for room pressure and any airflow patterns. During the post-control study, the hot wire anemometer again was used to measure air flow, both in the room and within the ventilated booth. In the ventilated booth, airflow volumes through the bleed filters were calculated from the measured face velocities. In addition, a Balometer™ (Alnor, Niles, Illinois) was used to measure the volumetric airflow rate through 23" by 23" sections of the ceiling filters. These measurements were used to determine the total volume of air entering the booth through the ceiling filters. Smoke tubes and a smoking wire apparatus were used to visualize the air flow patterns in and around the booth. The smoking wire apparatus consisted of a wire stretched between two rods and connected to a battery operated ignition source. Prior to each use, the wire is coated with paraffin, using a small paint brush. When the battery is switched on, the wire heats up and the paraffin burns. This results in a sheet of smoke coming off the wire which allows a larger work area to be evaluated for air flow patterns than can be evaluated with smoke tubes alone.

RESULTS AND DATA ANALYSIS

ERGONOMIC ANALYSIS

The worker's anthropometric measurements were taken; stature was 66.8 inches (169.7 cm) (34 percentile male),[25] weight was 165 lb (74.8 kg) (52 percentile male),[26] forward functional reach was 30 in (76 cm) (29 percentile male),[26] crotch height was 30 in (76 cm) (5 percentile male),[27] and elbow to fingertip distance was 18.5 in (47.0 cm) (34 percentile male).[26]

Table 1 summarizes the weigh-out operations performed during the pre-control study.

Table 1. Ergonomic Assessment Data - Pre-Control Study

Day	Total Dye Weigh-out Time (min)	Total Dye Weight Lb (kg)	Heaviest Recipe Lb (kg)	# of Recipes Completed	Number of Times Scoop Dye
1	108	114.5 (51.9)	18.5 (8.4)	29	83
2	119	222.8 (101.0)	29.5 (13.4)	29	75
3	147	270.35 (122.6)	29.9 (13.6)	36	97

The frequency of finishing a recipe was approximately 0.26 recipes/minute. The frequency of scooping a dye from a drum was approximately 1.45 scoops per minute. Using the revised NIOSH lifting equation,[28] the recommended weight limit for lifting from the scale to the upper recipe storage shelf is 35.9 lb (16.3 kg) and to the lower recipe storage shelf is 44.2 lb (20.0 kg). Therefore, the weights of the dye lifted are within the NIOSH recommended limits.

The scoop was made of plastic and weighed 0.24 lb (109 g). The handle was 2.5 in (64 mm) long with a ⅞ in (22 mm) diameter. The scooping portion was 7¾ in (19.7 cm) long and 4 in (10.2 cm) wide. Since hand widths range from 79 mm (1 percentile female) to 99 mm (99 percentile male), the recommended handle length is 100 mm.[29] Therefore, the scoop used at this site should have had a longer handle. Also, the recommended handle diameter for power lifts is 50 to 60 mm so that the hand can reach around the handle without the finger and thumb touching.[30] Again, the scoop used in the study fell short of the ideal. In addition, the handle should have no finger indentations and be located near the tool's center of gravity.

During the post-control study, although the worker and basic job tasks remained the same, the installation of the ventilated booth and other workstation modifications necessitated changes in the worker's operating procedures. For example, during the pre-control study the worker would occasionally dispense small quantities of dye into paper bags kept on a back table instead of carrying the excess dye back to its drum. During the post-control study small plastic bins attached to the inside wall of the booth were used for storage in lieu of the paper bags.

Another change to the operation was the placement of the weigh scales. At the time of this assessment the drums were not being brought into the booth, so the workbench was not being used as designed. However, the flat platform was being used as a work area on which the 100 gram scale was placed for dye weight measurements. The height of the flat platform appeared to be too low as an upside down bucket was placed on top of it to bring the scale up to a functional height for the worker. The pound scale was placed on top of a small table adjacent to the workbench (Figure 3).

VENTILATION MEASUREMENTS

During the pre-control study, the airflow in the weigh out room averaged about 10 feet per minute (fpm), although the room air overall was fairly stagnant. Smoke tubes indicated that some air was coming into the weigh out room via the area near the freight door, and some air was leaving the room through the sliding door at the bag pick-up area.

During the post-control study, use of smoke tubes and the smoking wire apparatus allowed eddy currents to be observed in the booth (Figure 4). Although the back room was stagnant, the booth was found to provide some dilution ventilation for the front room. It appeared that the operation of the booth caused the room air in front of the booth to be captured and pulled into the booth. This generated an eddy current directly at the entrance of the booth, outside the containment area, which caused nearby air to be pulled upwards.

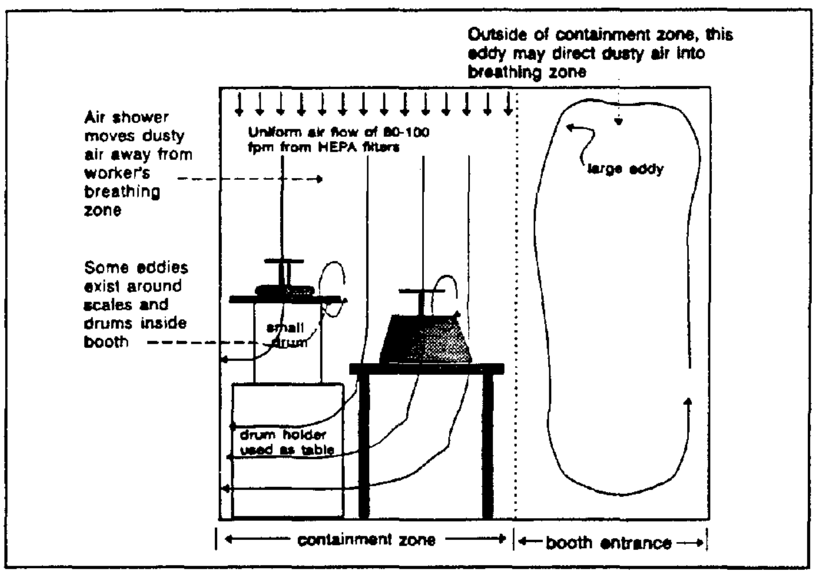


Figure 4: Observed airflow patterns in the weighout booth. In the containment area, the airflow appears to keep contaminated air out of the worker's breathing zone.

Generally, the airflow within the containment area was downwards. However, when a filled bag was closed it could cause a puff of air to be sent upwards into the worker's breathing zone. It appeared that closing the bag on top of the scales could cause exposures since the air was expelled at the same height as the breathing zone. Slight eddies were also noted to occur around the gram weigh scale boat when the worker faced the back of the booth. These eddies usually broke up and were pulled down into the exhaust grilles.

Measurements made during the post-control study, showed an average face velocity of 76 fpm from the ceiling of the booth using the Balometer™. This resulted in a supply air volume of approximately 2270 cfm, which was only 74 percent of the design volume. Using the hot wire anemometer, the velocity at the bleed filters was found to be 100 fpm. This resulted in a bleed air volume of 418 cfm which was greater than design, but below the manufacturer's test volume. The overall air volume of the booth was found to be about 80 percent of design with a total of 2688 cfm.

The ventilated booth was also evaluated using the Met One when the weigh-out operation was not being performed. Upon holding the sensor up to the ceiling filters, the air shower was found to be very clean with an average of 0 particles greater than 3.0 μm over a sample time of 12 minutes, or 0 particles/liter of air. The area sample taken near the scale also resulted in a very low particle count with an average of 9 particles greater than 3.0 μm in a one minute, 2.8 liter sample, or about 3 particles/liter of air.

DUST SAMPLING

The mass of each filter was calculated by subtracting the mean weight change of the blank filters from the analyzed total weight of the sample filter. Concentration data were then computed by dividing the mass of each filter by the sample volume. The sampling data for both the pre-control and post-control studies are presented in Appendix A. The highest short-term exposure during the pre-control study was 0.31 mg/m^3 compared to 0.26 mg/m^3 during the post-control study. The highest full shift exposure during the pre-control study was 0.18 mg/m^3 compared to 0.31 mg/m^3 during the post-control study. None of the personal or area samples exceeded the OSHA PEL of 15 mg/m^3 for total dust.

Since most industrial hygiene data can be assumed to follow a log normal distribution curve, the concentration data for the short-term personal samples were transformed by taking the logarithms before statistical analysis.[30] Details of the statistical analysis are presented in Appendix E. Table 2 presents the geometric mean and geometric standard deviation for each study.

Table 2. Total Dust Concentration Data for Personal Short-Term Samples

Study	N	Geometric Mean (mg/m^3)	Geometric Standard Deviation
Pre-control	6	0.160	1.970
Post-control	6	0.094	2.522

Air quality data for the Brooklyn/Manhattan area were obtained to compare the total particulate concentration measured in the plant to total suspended particulate concentrations measured by the local air pollution control agency.[31] The geometric mean of the 1993 annual average total suspended particles (TSP's) measured was computed to be 0.059 mg/m^3 (Appendix F). Based upon a one-sided t test, the total particulate concentrations measured during the pre-control study were larger than this geometric mean of average TSP concentration ($p = 0.007$). During the post-control study, this difference was not significant ($p = 0.13$). Apparently, ambient air pollution can explain most of the total particulate concentrations measured during the post-control study and some of the total particulate concentration measured on the worker during the pre-control study.

To account for differences in total mass of dye weighed during each sampling period the concentrations were adjusted using the following equation:

$$\textit{Adjusted Concentration} = \frac{\textit{Concentration}}{\text{(dye usage rate)}}$$

The adjusted concentrations during the post-control study were about three times lower than the pre-control study data (Table 3).

Table 3. Total Dust Concentration Data for Personal Short-Term Samples Adjusted for Production Rate.

Study	N	Geometric Mean (mg/m^3)	Geometric Standard Deviation
Pre-control	6	0.114	3.591
Post-control	6	0.039	2.664

Based upon pooled t-tests, chance could explain observed differences in concentration ($p = 0.35$) and in adjusted concentration ($p = 0.3$). Inspection of the adjusted concentrations revealed that many of the adjusted concentrations from the post-control study were smaller that those for the pre-control study. A non-parametric rank-sum test (the Mann-Whitney U-statistic[32]) found that the difference in adjusted concentration is approaching statistical significance ($p = 0.066$).

EFFECT OF WORKER ACTIVITY UPON DUST EXPOSURE AS MEASURED BY THE HAM

During the pre-control study, three sets of personal sampling data were collected with the HAM. However, half this data was obtained with a faulty NiCad battery powering the instrument which caused a shift in the baseline (Graphs B1 to B2, Appendix B). Therefore, only the HAM data collected using a 9 volt battery was usable for quantitative data analyses (Graphs B3 to B4). Two area samples were also collected, primarily to measure background levels. These samples had average relative exposures of 0.08 and 0.11 volts (Graphs B5-B6). During the post-control study, 8 sets of personal sampling data were collected using the HAM (Graphs B7 to B14). Four of these sessions were used to analyze the effect of drum height on worker exposure levels; four sessions were used to determine the effectiveness of the ventilated booth. The drum data will be discussed in a later section. In addition, an area sample collected during the post-control study in the laboratory/office area had an average relative exposure of 0.06 volts (Graph B15).

The personal sampling data of the two good pre-control weigh-out sessions were separated into six tasks:

1.) weighing or performing duties around the weigh scale (w)
2.) scooping, including opening and closing drums (s)
3.) transporting the dye with the scoop or in an open bag (t)
4.) closing the bag (b)
5.) transporting the stapled bag to the bag pick-up area and returning to the weigh scale (tb)
6.) other events not associated with weigh-out task (o).

Each session ran about 43 minutes, with the weighing task (w) accounting for 35 to 40 percent of the times and the scooping task (s) accounting for about 22 percent of the times. The results of the task analysis are shown in Figure 5. The "other" task is not included as this data is irrelevant. Average task exposures were very close in magnitude and are summarized in Table C1 of Appendix C. The overall average relative exposure for each sampling session was about 0.15 volts.

For the booth analysis during the post-control study, the weigh-out operation was coded using the same task identifiers from the pre-control study, except that the scooping task was broken down into scooping *outside* the booth (s), and scooping *inside* the booth (sb); both including opening and closing drums. These changes were made to clarify where the drum was located during scooping. The data sets were also coded to indicate whether the worker was inside or outside the booth during each task. The sampling sessions ranged from 24 to 64 minutes in length, with the weighing task (w) accounting for 35 to 45 percent of the total times. The transport task (t) was .

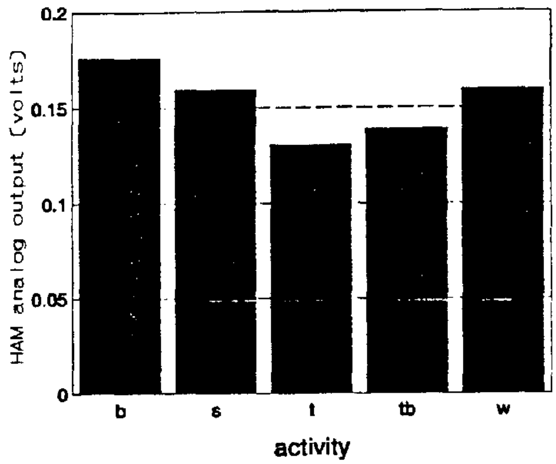


Figure 5: The response of the HAM does not appear to vary much with the activity. HAM analog outputs shown are the arithmetic averages for each activity.

the second longest task at about 21 to 23 percent of the sampling times. Scooping outside the booth (s) was third longest, accounting for 12 to 15 percent of the total sampling times

Exposures during the post-control study were significantly affected ($p = 0.0001$) by the worker's activities (Figure 6). The highest average relative exposures occurred when the worker was scooping (s) or transporting the closed bag (tb). Scooping inside the booth (sb) resulted in almost a three-fold reduction in exposures when compared to scooping outside the booth (s) ($p = 0.0001$).

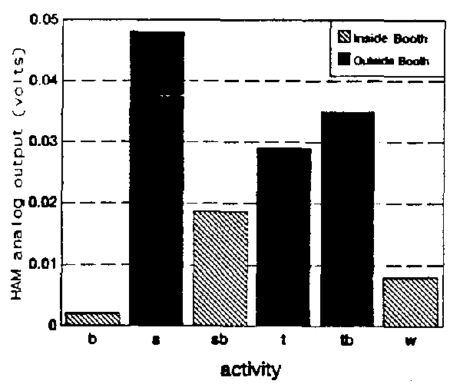


Figure 6: The response of the HAM varies with the activity. HAM analog outputs shown are the arithmetic averages for each activity.

However, the HAM response shown for scooping inside the booth does not represent the entire data set from the post-control study. A very short segment of time from one sampling session, involving the handling of an extremely dusty dye, was eliminated from the analysis as it was determined to be atypical of exposures inside the booth. Elimination of this data resulted in about a five fold reduction in the average exposure when scooping in the booth for that session; from 0.14 to 0.03 volts. If the data on this dye had been included in the analysis, no difference would have been observed between the overall average relative exposure when scooping inside and outside the booth. The considerable effect the dye had on worker exposure during that one sampling session would also have obscured the results from the remaining three sessions. Actual exposure data, including that of the dusty dye, are reported in Table C2 of Appendix C. The overall average relative exposure for the four sampling sessions was about 0.03 volts.

These same four sampling sessions were then analyzed for the average exposure to the worker when he was inside and outside the booth. Figure 7 shows that overall there is over a three-fold reduction when inside the booth versus outside the booth. In this graph, the exposure data for the dusty dye mentioned previously was included. If the data for this dye was again eliminated, the overall average exposure while inside the booth would decrease to 0.01 volts. This would result in almost a five-fold reduction in exposure when working inside the booth. The individual sampling session data are reported in Table C3 of Appendix C.

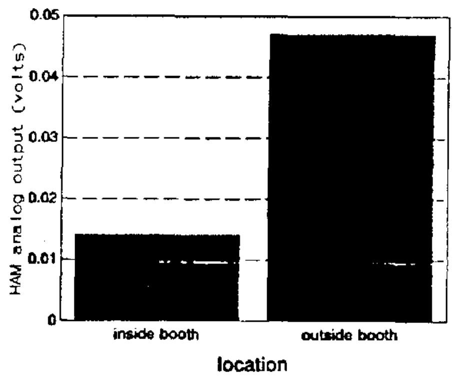


Figure 7: Effect of the booth on worker exposure. Ham analog outputs shown are the arithmetic averages for each location.

All the sampling sessions which had supporting video were then qualitatively analyzed to confirm which tasks caused exposure peaks (Graphs B1 to B4 and B7 to B10). During the pre-control study about half of the peaks were caused by the weighing task. Two peaks marked (o) occurred when the worker put on his respirator and donned latex gloves. During the post-control study, peaks resulted when the worker was at the bag pick up area (tb); retrieving a container near the scale into which he weighed a small dye sample (w); and scooping (s). During one session, elevated exposures existed over a period of time while the worker was handling the extremely dusty dye mentioned earlier. The dye was located in a tall drum placed inside the booth. The highest peak occurred when scooping from the bottom of this drum (sb). Three false peaks occurred when the HAM was readjusted during a weigh and a transport task (Graph B9) and during a miscellaneous task (Graph B8).

EFFECT OF WORKER ACTIVITY UPON DUST EXPOSURE AS MEASURED BY THE MET ONE

Only one Met One instrument was available during the pre-control study so simultaneous personal and area data could not be taken. During the post-control study, two Met One instruments were available so personal and area particle counts could be collected simultaneously.

Results of sampling with the Met One during the pre-control study are shown in Figure 8. To compare the average personal data to the average area data, the particulate counts were divided by the associated air volumes to obtain concentration data. During the weigh-out task the particle concentrations increased regardless of whether the Met One was monitoring an area or personal exposure. Individual sampling session data is reported in Table C4 of Appendix C.

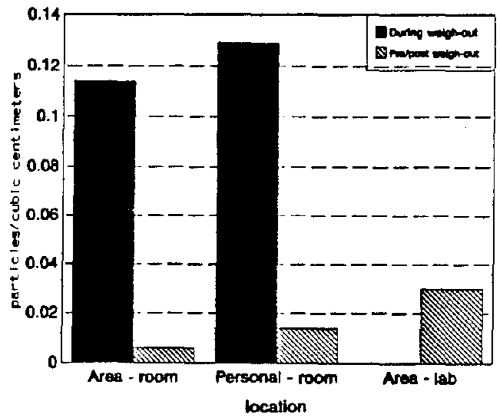


Figure 8: The concentration of particles > 3 μm on the worker and in the room during the pre-control study.

The area and personal Met One data collected simultaneously during the weigh-out task of the post-control study were also analyzed. Figure 9 shows the results of the comparison for particulate greater than 3 μm. Actual sampling data is reported in Table C5 of Appendix C. Based upon a paired-test upon the log-transformed data, there was a significant difference between area and personal Met One concentrations ($p = 0.01$).

A task analysis was performed for the Met One data sets which were video taped and simultaneously monitored with the HAM. Since several tasks could occur during each Met One sampling period, those segments which had a major exposure peak for particulate greater than 3 μm were correlated with the corresponding HAM data for that period. The results are shown in Tables D1 to D12 of Appendix D. The Met One peaks during the pre-control study appeared to be caused by the weighing, scooping, and bagging tasks. During the post-control study, the peaks were caused primarily by the scooping tasks, with some exposures arising during transport tasks.

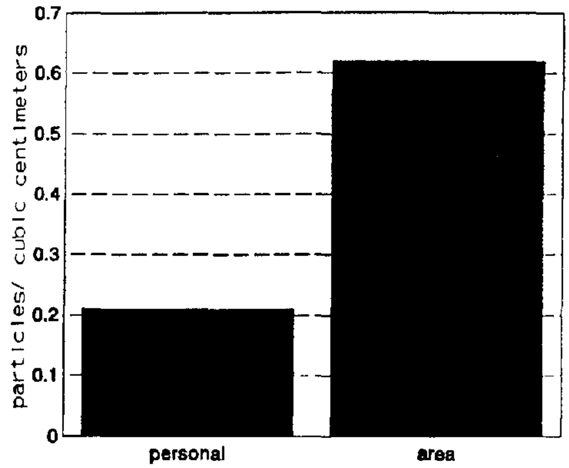


Figure 9: The concentration of particles > 3 μm on the worker and in the room.

Further analysis determined that most of the exposure to particles greater than 3.0 μm was spread out over the entire sampling session, and was not based on a few major peaks. Tables D1 to D12 show the exposure percentages calculated for the major peaks of each session. During most sessions, the largest exposure peak was only 2 to 3 times greater than what would be expected if the exposure was consistent throughout the sampling session. However, the sampling session in which the extremely dusty dye was handled had an exposure peak that was eleven times greater than what was expected (Table D5).

EFFECT OF DRUM HEIGHT ON WORKER DUST EXPOSURE

The drum analysis consisted of four sampling sessions from the post-control study. The data was coded the same as the pre-control study, except that task (tb) was eliminated since the finished bags were not moved from the booth. To better evaluate the effect of drum height on worker exposure, a number of variables were controlled during these sessions. First, only two dyes were used, one orange and one red. The worker indicated the orange dye was dustier than the red dye. Second, each dye was placed in a tall and a short drum. The worker scooped out of each drum, one at a time, until all the dye had been retrieved. The worker had to tilt the taller drums to reach the dye at the bottom. Finally, all work was conducted inside the ventilated booth. Additional data, including the overall average relative exposure for each session, are shown in Table 4.

Table 4. Drum Study Data

Dye	Drum Height (in)	Drum Diameter (in)	Depth to Dye (in)	# Bags Weighted Out	Sampling Time (min)	Relative Exposure (volts)
Orange	35	23	25	17	17	0.05
Orange	25	22	16	17	16	0.01
Red	33	22	28	9	7	0.01
Red	25	22	19	10	7	0.01

Results of the drum study broken down by task are shown in Figure 10. As discussed in Appendix E, the effect of drum varied with the dye. For the orange dye, the drum size had a significant effect upon the HAM's analog output ($p = 0.0001$). For the red dye, the effect was not significant ($p = 0.2$). Individual task data for each sampling session is reported in Table C6 of Appendix C.

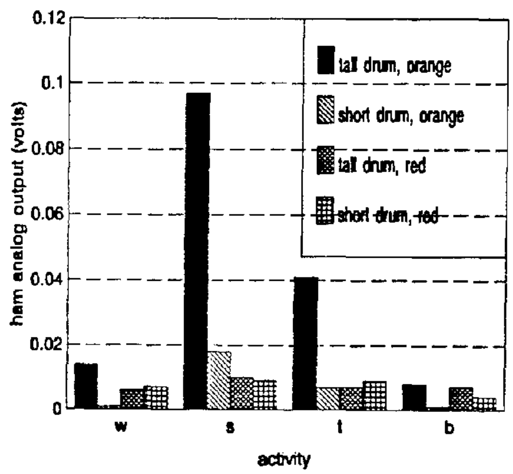


Figure 10: The effect of drum height upon the arithmetic average of each activity's HAM analog output varies with the test dye.

Qualitative analysis of the drum session peaks, shown in Graphs B11-B14, confirmed that most exposures were due to scooping. Two peaks marked "other" occurred during a HAM adjustment and when the worker momentarily stepped out of the booth to retrieve his safety glasses.

Actual particle counts obtained on the worker during the drum sessions are reported in Table C7 of Appendix C. Figures 11 and 12 present the impact of drum height upon particle concentrations as measured with the Met One.

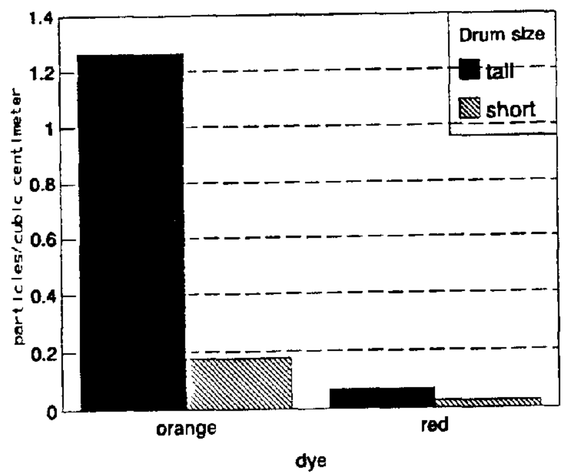


Figure 11: Effect of drum height upon concentration of particles > 3.0 μm appears to vary with the dye tested.

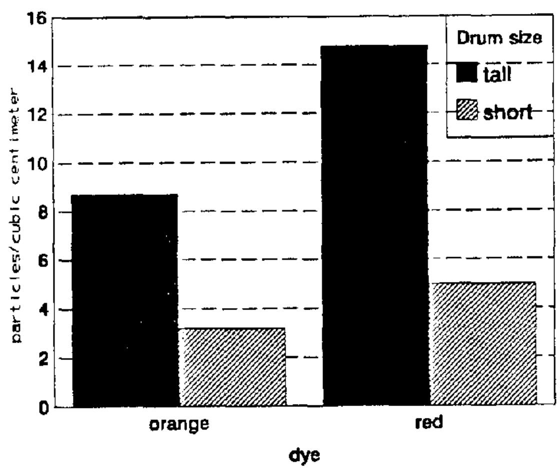


Figure 12: Effect of drum height upon the concentration of particles > 0.3 μm for two dyes.

The Met One data also was used to interpret the air samples collected during the drum study. Since one filter was used per dye it was unclear how much each drum contributed to the total concentration. To estimate the contributions from the short and tall drums of each dye, particle

$$C_{tp} = (T_t C_t + T_s C_s) / (T_t + T_s)$$

Where:

C_{tp} = Concentration for total particulate (tall and short drums)
C_t = Concentration for tall drum
C_s = Concentration for short drum
T_t = Sampling time for tall drum
T_s = Sampling time for short drum

The resulting exposures calculated for the short and tall drums of each dye are shown in Table 5. The tall drums contributed more to the total exposure from particles greater than 0.3 μm and 3.0 μm than did the short drums. The data shown for the red dye in the short drum are typical air pollution levels for total suspended particulate (TSP).

Table 5. Exposure (in mg/m^3) Attributed to Drum Height - Drum Study

Particle Size	Orange Dye in Tall Drum	Orange Dye in Short Drum	Red Dye in Tall Drum	Red Dye in Short Drum
x > 0.3 μm	0.372	0.136	0.155	0.052
x > 3.0 μm	0.440	0.062	0.151	0.057

DISCUSSION

ERGONOMICS

The manual dye weigh-out operation did not appear to be stressful to the worker's musculoskeletal system. This assessment may have changed if the worker had been required to move the drums in and out of the booth. The difficulty in transporting the drums could be attributed to: an uneven floor, the placement and orientation of drums that did not allow for easy access and handling, the design (weight, size, shape, etc) of drums which may not allow for fairly easy handling, and the lack of material handling devices. Moving drums from the narrow back storage room would have presented a special problem for the worker due to the incline at the entrance to the room. Not only would the drums have been difficult to handle, but the potential for slips or trips might have increased if the worker attempted to move these drums. Since the worker continued to use the scoop to carry the dye back and forth from the drums to the booth for weighing, the addition of the booth did not appear to significantly change any risk of musculoskeletal stress associated with the scooping and transporting tasks.

If the drums could have been safely brought into the booth and placed on the slanted bench platforms, the amount of musculoskeletal stress to the worker may have decreased by allowing the worker to more easily reach the dye in the drum. Ideally, the work bench platforms would be adjustable since a taller worker may still need to bend and reach when working with smaller drums. Additional modifications to the booth and surrounding room which should be considered include providing adjustable platforms in the booth to manipulate drum and scale height (particularly since the workbench was not being used), and rearranging drum placement and orientation in the room to allow for easier access.

Also, the scoop used at this site should be improved to include a longer handle of a larger diameter to give the worker a better grip. Attempts were made to procure such a scoop for evaluation during the post-control study, however one could not be obtained.[33] An additional benefit of having a long handled scoop is that it may help to keep the worker's head above the level of the drum when scooping from the bottom.[7]

VENTILATION

Difficulties using the Balometer™ may have caused an under reporting of the supply air volumes since the Balometer™ hood did not seal well against the ceiling filters. The resulting air loss may have lowered the supply air volume measurement. Taking this into consideration, the booth was operating close to design. The Met One measurements indicated that the booth's filtration and ventilation systems were functioning properly. Most eddy currents were controlled as long as the worker was within the containment area of the booth. Dust exposures from eddies generated during bag closing could be reduced by removing the bag from the scale and placing it on the table prior to closing it. The worker should operate within the containment area as much as possible during all tasks to eliminate dust exposures.

DUST SAMPLING

Dust levels for short-term personal samples were lower when working with a ventilated booth versus working without a booth, but they were not significantly lower. The filter data showed that the booth was able to control the worker's dust exposure to a level comparable to ambient total suspended particulate (TSP) concentrations. It is possible that if the entire weigh-out operation was performed inside the booth, the worker's overall dust exposure would be even less than ambient TSP concentrations. However, during this study, several tasks were still performed outside the ventilated booth so such results could not be achieved. Also, during the drum study, the exposures were due in large part to working with the taller drums, versus the shorter drums. Therefore, drum height has an impact on worker exposure even if the drum is located inside the ventilated booth.

Concentrations for the pre-control full-shift personal samples averaged slightly more than that of the post-control samples. Area concentrations outside the weigh-out room averaged slightly higher than those inside the room during both studies. During the post-control study, the average area concentrations inside the booth was higher than the average concentration outside the booth.

This finding was attributed to the unfortunate placement of the sampling pump and filter on top of the small plastic dye bins attached to the inside wall of the booth. Although the filters were inside the booth, they were outside the containment area and exposed to dust stirred up by eddy currents (Figure 4). Therefore, the "inside booth" filter did not give a true value for the total dust concentration in the containment area.

INSTRUMENTAL MONITORING

The real time data found the booth to be effective at reducing the worker's overall exposure to dye dust. Contrasting the HAM data of the pre-control sampling sessions with that of the post-control study showed there to be a five-fold reduction in the overall average relative exposure with the controls in place. Since this comparison was made for data taken during two separate surveys, it was possible that any differences in study conditions may have affected the results. To ensure that this was not the case, comparisons were also made between data sets taken during the post-control study. This included comparing the overall average relative exposure to the worker when he worked inside the booth versus outside the booth, and comparing the scooping task when it was performed inside and outside the booth.

The HAM data taken during the post-control study showed there to be a three-fold reduction in exposure when the worker was inside the booth versus outside the booth. However, the inside the booth data also included those times when the worker was just outside the containment area. In this area the booth ventilation does not control dust and eddy currents may have elevated the worker's exposure. Videos of the sampling sessions, overlaid with exposure data, showed that when the worker was located inside the booth, his dust exposure was higher when he was outside the containment area. If the data was adjusted to include only those times when the worker was actually within the containment area, the average relative exposure could be even lower than what was reported for inside the booth. Overall, the HAM data indicated that exposures inside the booth were very low, almost to the point of being nondetectable (see the weighing and bagging tasks in Figure 6).

The Met One data collected during the pre-control study showed that performing the weigh-out operation increased the average number of particles in the worker's breathing zone and throughout the weigh-out room (Figure 8). Also, the average number of particles greater than 3.0 μm for the personal and area samples during weigh-out was roughly the same during the pre-control study. This may indicate that the worker's exposure was dependent upon the particulate concentration inside the weigh-out room; even when his task did not generate a lot of dust, he was still exposed to residual dust suspended in the room from previous tasks. Data collected with the Met One during the post-control study showed a significant difference between the personal and area concentrations for particles greater than 3.0 μm (Figure 9). Therefore, although dust was being generated inside the weigh-out room, the worker's overall exposure was being reduced by his frequent time inside the ventilated booth.

Task analyses performed on the instrumental data provided information on how activities affected the overall exposure to the worker. Individual activities during the pre-control study did not appear to greatly affect the HAM response, although a qualitative review of the data showed that most exposure peaks were a result of the weighing and bagging tasks. In contrast, individual activities did affect the HAM response during the post-control study, particularly the scooping and occasionally the transporting tasks. Since these tasks were usually performed outside the booth, the dust was not controlled except through dilution ventilation augmented by the booth. Conducting weighing and bagging tasks inside the ventilated booth resulted in very low exposures during the post-control study. These findings were confirmed by the Met One data.

Transport of the closed bag during the post-control study resulted in exposure peaks, primarily when the worker was in the bag pick-up area. It is unclear what caused these exposure peaks. It is possible that dust or aerosols from the plant may have entered the weigh-out room through the sliding door, resulting in an increase in the HAM response. Or perhaps dirt and dust particles on the floor were stirred up by the actions of the worker in the bag pick-up area, causing the exposures to be higher. For example, the worker must occasionally climb up to the top shelves or squat down to the lowest shelves when positioning a bag, and he often must stretch or crawl forward to push the bag to the end of the shelf where it can easily be reached by the plant workers. It is also possible that dye dust may have settled on the shelving throughout the day, which may then be stirred up when the worker attempts to position the dye bags. Plant management however, is very careful to keep the bag pick-up area clean and the shelving is thoroughly washed every week to prevent dye accumulation. This is a quality control measure; if dye collected on the shelves, it might adhere to the bags, and later contaminate the final color of the dye solution when the bag was thrown into the dye machines. Thus, even though carrying dye in a closed bag would appear to be innocuous, there are several possible ways the worker's overall dust exposure may increase while in the bag pick-up area.

Scooping stood out during the post-control study as a task still needing controls to further reduce the worker's dye dust exposure. A comparison of the scooping data taken with the HAM showed that working inside the booth resulted in a three-fold reduction in worker exposure. However, even with the installation of the ventilated booth, several factors caused the worker's exposure during the scooping task. These included having to scoop from tall drums and being unable to move the drums into the ventilated booth's containment area prior to scooping. With a tall drum, the worker must reach deeply into the drum to scoop out dye from the bottom. This can place the worker's breathing zone within the confines of the drum where dust cannot be controlled by booth ventilation. A shorter drum limits the need for the worker to place his head inside the drum when scooping from the bottom. This allows a gap to exist between the worker's face and the top of the drum. Dust rising out of the drum can then be captured by the booth ventilation before it can reach the worker's breathing zone.

Results of the drum study showed that both drum height and apparent dye dustiness had an effect on the worker's exposure. The largest HAM response during the drum study was for the scooping task, using the orange dye in the tall drum. When the shorter drum was substituted for the tall drum, a five fold reduction in HAM response occurred. The Met One data showed that use of the short drum also resulted in decreased particulate exposures for the entire weigh-out operation when using the orange dye. A seven-fold reduction was found for the overall exposure to particulate > 3.0 μm, and a three-fold reduction was measured for particulate > 0.3 μm. When working with the red dye, very little difference was found between the HAM responses for the two drum sizes. However, the Met One data showed a three-fold reduction in particulate > 3.0 μm and > 0.3 μm when using the shorter drums. In terms of dye size distribution, 6 to 14 percent of the dust generated from the orange dye (by number) was from particulate > 3.0 μm as compared to 0.5 percent for the red dye. However, use of the red dye drums generated more particulate > 0.3 μm than their corresponding sized drums of orange dye.

ADDITIONAL CONTROL OPTIONS

Other control methods are available which could eliminate some of the problems encountered during this study. A mobile dust control booth, implemented in some dyehouses in the United Kingdom, is also available from the manufacturer of the booth used in this study.[34,35] This control option consists of a smaller sized, semi-down draft booth which runs on railing between fixed storage shelves. The shelving is also angled to allow the weigh-out operator to more easily reach the bottom of the drums when necessary. The sides of the booth are cut out so that the worker can directly scoop dye from the tilted drums onto the weigh scale located on a fixed bench in the weigh-out booth. Use of such a system would eliminate the need to move drums around, except during stocking. All of the tasks would also be conducted under the protection of the ventilated booth.

Another possible control option is the use of a semi-automatic storage and retrieval system for dyes. Such a system had been manufactured by a British company a few years ago, and used in conjunction with a booth similar to the one evaluated during this study.[36]. Unfortunately this company is no longer in business. The robot was a three-axis structure which enabled it to collect dye drums from a storage area and deposit them onto the back portion of a two station carousel built into the ventilated booth. The carousel was then rotated 180° so that the drums were brought into the booth where the dye could be weighed out. After weighing, the carousel was rotated again and the robot collected and returned the drums to their storage location. Like the mobile dust control booth, this system eliminated the need for manually moving the drums and ensured all tasks were performed inside the ventilated booth. A robotic system would probably be more suitable for larger dyehouses with plenty of storage room, whereas a mobile dust control booth would work well at smaller dyehouses which are tight on space, such as the study site.

CONCLUSIONS

Use of the ventilated booth during this study resulted in low dust exposures which were of the order of magnitude of ambient air pollution. Due to site constraints, ideal use of the ventilated booth was not possible. As such, the results obtained may not completely reflect how well the ventilated booth can control dust exposures to the worker. Tasks performed inside the booth's containment area were mostly controlled, however tasks in other areas of the weigh-out room were not always well controlled. Working just outside the containment area was also uncontrolled due to the eddy currents bringing dust back into the worker's breathing zone.

In spite of the very small instrument response, certain tasks appeared to elevate worker dust exposures, even when inside the booth. In particular, exposures were elevated when using drums which did not allow a space to be sustained between the worker's face and the top of the drum when scooping. Limiting the drum height seems especially important for dusty dyes. Future studies of manual powder weigh-out operations should take dye dustiness into account when evaluating worker exposures in addition to drum height.

If powder handling is performed completely inside the booth under ideal situations such as using dedusted dyes in short drums, the worker's dust exposure will be minimal. Non-ideal use of the booth can result in greater dust exposures. Improvements at this site could further reduce worker exposure to dust during the manual weigh-out operation, such as room designs which would allow drums to easily be moved into the booth, and the use of shorter drums and dedusted dyes. The use of other control methods such as a mobile dust control booth or a semi-automatic storage and retrieval system could also eliminate some of the problems encountered during this study.

REFERENCES

1. Edmonds MA, Heitbrink WA [1993]. In-Depth Survey Report: Control Technology for Manual Dye Weigh-Out Operations, Glidden Company, Huron, OH. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health, ECTB Report No. 197-11a.

2. Edmonds MA, Heitbrink WA [1993]. In-Depth Survey Report: Control Technology for Manual Dye Weigh-Out Operations, Uni-Trade Company, Inc., Newark, NJ. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, ECTB Report No: 197-12a.

3. Ryder M [1988]. Safe Dust Control for Powder Handling. Manufacturing Chemist; Powder Technology, April 1988, pp. 47-49.

4. Private phone conversations with Mr. Chris Money, Occupational Hygiene Manager, Zeneca Corporation, Manchester, England (November 29 and December 2, 1993, and March 7, 1994).

5. Private phone conversations with Mr. John Breckenridge, General Manager, Clestra Clean Room, Syracuse, New York (December 6, 1993 and January 10, 1994); and Mr. Martyn Ryder, Joint Managing Director, Extract Technology Limited, Huddersfield, England (August 1, 1994).

6. Heitbrink WA, Farwick DR [1994]. Survey Report: Control Technology for Manual Powder Weigh-Out Operations, Merck & Company, Wilson, NC. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, ECTB Report No. 197-13a.

7. Ryder M, Extract Technology Commissioning Report for 2.0m 'D' Booth Installed at Multi Color Industries, Brooklyn, New York, Contract No. 1710 [October 1994].

8. Written correspondence from Mr. Martyn Ryder, Joint Managing Director, Extract Technology Limited, to Dr. Barry Bochner, ETAD, October 1994.

9. Heitbrink WA [1985]. In-Depth Survey Report: Weighing and Batching, BF Goodrich Company, Akron, OH. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute of Occupational Safety and Health, ECTB Report No. 144-22b.

10. Gressel MG, Heitbrink WA, McGlothlin JD, Fischbach TJ [1987]. Real-Time, Integrated, and Ergonomic Analysis of Dust Exposure During Manual Materials Handling. Appl Ind Hyg *2*(3):108-113.

11. Bateman EG [1978]. Toxic Material Handling in the Textile Drug Room [Thesis]. Chapel Hill, NC: University of North Carolina, Department of Public Health.

12. ETAD [1990]. Guidelines for Safe Handling of Dyes; U.S. Operating Committee of the Ecological and Toxicological Association of the Dyestuffs Manufacturing Institute (ETAD); Washington, D.C., November 1990.

13. NIOSH [1980]. Special Occupational Hazard Review for Benzidine-based Dyes. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 80-109.

14. ACTWU [no date]. Danger and Dyeing. The Cancer Threat from Benzidine-Type Dyes. Department of Occupational Safety and Health, Amalgamated Clothing and Textile Workers Union, AFL-CIO, CLC, 15 Union Square, New York, NY.

15. BNA [1994]. Industry Proposes Exposure Controls for Benzidine Congener Dyes in Lieu of Ban. The Bureau of National Affairs, Inc., BNA Chemical Regulation Daily. April 1, 1994. Article No. 10910505.

16. ACGIH [1995]. Annual Reports of the Committees on Threshold Limit Values and Biological Exposure Indices, Notice of Intended Changes for 1995-1996, Carcinogen Designations - Proposed or Revised; ACGIH Today, Vol. 3, No. 2; Cincinnati, OH: American Conference of Governmental Industrial Hygienists, Inc.

17. Wattie JM [1987]. Study into respiratory disease in dyehouse operatives exposed to reactive dyes. Journal of Society of Dyers and Colourers, Volume 103, pp. 304-308, September 1987.

18. Shackleton S, Binks SP, and Levy LS [1989]. A Handbook on Health and Safety for Users of Dyes and Chemicals in the Textile Industry. Chemical and Dye Briefing Service, Transport and General Workers' Union Textile Group, Industrial Toxicology Unit, Institute of Occupational Health, University of Bingingham; Version 1, page 5; June 1989.

19. CFR [29 CFR 1910.1000 (1979)]. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

20. ACGIH [1992]. 1992-93 Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

21. NIOSH [1992]. NIOSH recommendations for occupational safety and health - compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute of Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

22. NIOSH [1984]. Nuisance dust total, Method 0500. In: NIOSH Manual of Analytical Methods, 3rd ed., with supplements 1, 2, 3, and 4. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, NIOSH Publication No. 84-100.

23. Gressel MG, Heitbrink WA, McGlothlin JD, Fischbach TJ [1987]. Advantages of real-time data acquisition for exposure assessment. Appl Ind Hyg *3*(11):316-320.

24. NIOSH [1992]. Analyzing Workplace Exposures Using Direct Reading Instruments and Video Exposure Monitoring Techniques. Cincinnati Ohio: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health DHHS (NIOSH) Publication No. 92-104.

25. Kroemer KHE, Kroemer HJ, Kroemer-Elbert KE [1990]. Engineering physiology, bases of human factors/ergonomics (2nd ed.). New York, NY: Van Nostrand Reinhold.

26. Eastman Kodak Company [1983]. Ergonomic design for people at work. Belmont, CA: Lifelong Learning Publications.

27. Woodson WE, Tillman B, Tillman P [1992]. Human factors design handbook (2nd ed.). New York, NY: McGraw Hill.

28. Waters TR, Putz-Anderson V, Garg A, Fine LJ [1993]. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics *36*(7): 749-776.

29. Mital A, Kilbom A [1992]. Design, selection, and use of hand tools to alleviate trauma of the upper extremities: part II - the scientific basis (knowledge base) for the guide. Int J of Ind Ergonomics *10*:7-21.

30. NIOSH [1975]. Statistical Methods for the Determination of Noncompliance with Occupational Health Standards. Cincinnati Ohio: U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 75-159.

31. EPA [1994]. New York State Air Quality Report on Ambient Air Monitoring Systems; New York State Department of Environmental Conservation, Division of Air Resources, 1993 Annual Report No. DAR-94-2.

32. Beyer W [1991]. CRC Standard Probability and Statistics Tables and Formulae. Boston, MA: CRC Press; pp. 309-310.

33. Private phone conversation and correspondence with Mr. Howard Rosenkrantz, Process Solutions (manufacturer of the ErgoScoop), Riviera Beach, Florida; September 20, 1994.

34. Extract Technology Limited. Mobile Dust Extraction Booth. Process Equipment News; Environmental, Maintenance & Safety; Enquiry No. 5058; May 1989.

35. Theta Mobile Dust Control Booth Product Literature. Extract Technology Limited, Huddersfield, England; August 1994.

36. Crocus Storage and Retrieval System Product Literature; Crocus Limited, Great Britain; 1987.

APPENDIX A - DUST SAMPLING

Table A1. Personal Short-Term Sampling Results

Date	Study	Total Time (min)	Volume (L)	Total Dye Weighed (lbs)	Number Dyes Weighed	Total Dust Concentration (mg/m³)
8/23/94	Pre-control	38	494	95.8	11	0.14
8/23/94	Pre-control	70	910	18.7	23	0.31
8/24/94	Pre-control	63	819	127.1	22	0.4
8/24/94	Pre-control	56	728	95.7	17	0.15
8/25/94	Pre-control	74	962	144.1	18	0.07
8/25/94	Pre-control	73	949	126.3	20	0.09
10/17/94	Post-control	40	520	36.2	17	0.21
10/18/94	Post-control	65	845	107.6	23	0.06
10/19/94	Post-control	43	559	84.8	15	0.09
10/19/94[1]	Post-control	33	429	238	1	0.26
10/19/94[2]	Post-control	14	182	95	1	0.11
10/20/94	Post-control	36	468	46.2	14	0.02

[1] Drum Study - Orange Dye

[2] Drum Study- Red Dye

Table A2. Personal Full-Shift Sampling Results

Date	Study	Total Time (min)	Volume (L)	Total Dust Concentration (mg/m³)
8/23/94	Pre-control	422	2,110	0.18
8/24/94	Pre-control	463	2,315	0.18
8/25/94	Pre-control	468	2,340	0.16
10/17/94	Post-control	362	1,810	0.13
10/18/94	Post-control	253	1,265	0.12
10/19/94	Post-control	420	2,100	0.31
10/20/94	Post-control	138	690	0.07

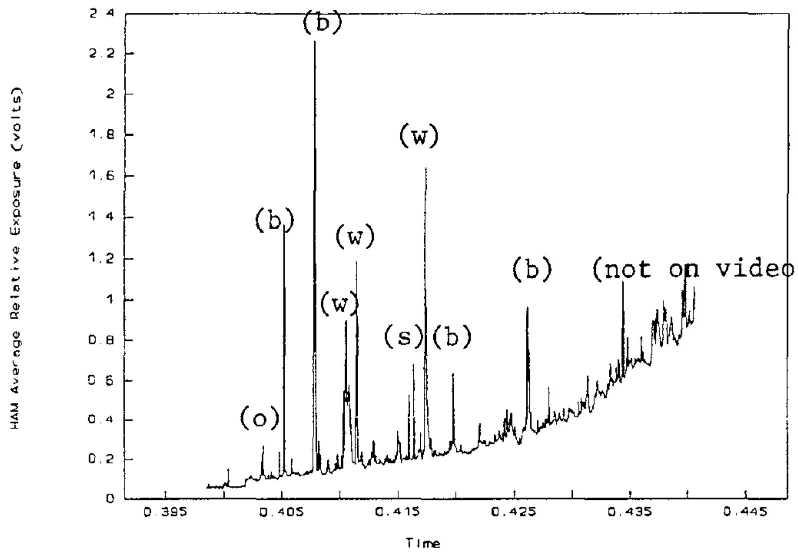
APPENDIX A (continued)
DUST SAMPLING

Table A3. Area Sampling Results

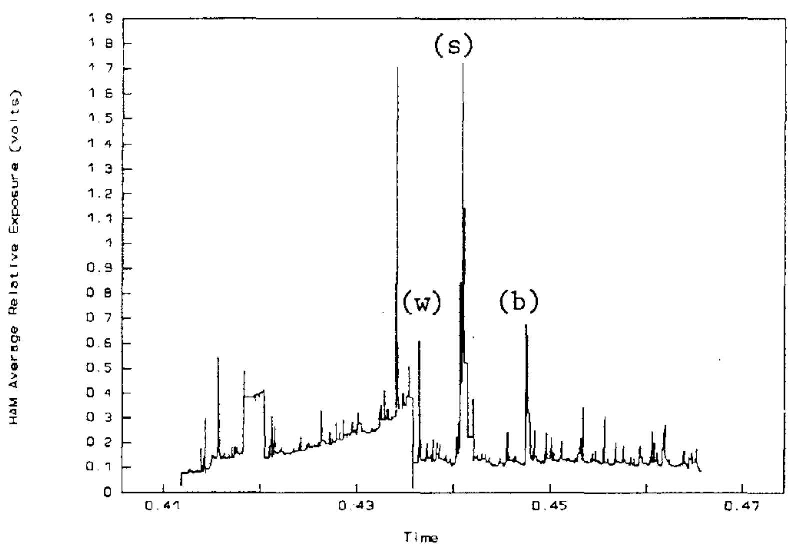
Date	Study	Location	Total Time (min)	Volume (L)	Total Dust Concentration (mg/m^3)
8/23/94	Pre-control	Outside weigh room	468	2,340	0.07
8/24/94	Pre-control	Outside weigh room	478	2,390	0.06
8/25/94	Pre-control	Outside weigh room	481	2,405	0.08
10/17/94	Post-control	Outside weigh room	368	1,840	0.09
10/18/94	Post-control	Outside weigh room	273	1,365	0.14
10/19/94	Post-control	Outside weigh room	431	2,155	0.09
10/20/94	Post-control	Outside weigh room	162	810	0.04
8/23/94	Pre-control	Inside weigh room	470	2,350	0.05
8/24/95	Pre-control	Inside weigh room	474	2,370	0.07
825/94	Pre-control	Inside weigh room	479	2,395	0.06
10/17/94	Post-control	Inside weigh room, not in booth	369	1,845	0.09
10/18/94	Post-control	Inside weigh room, not in booth	270	1,350	0.10
10/19/94	Post-control	Inside weigh room, not in booth	430	2,150	0.06
10/20/94	Post-control	Inside weigh room, not in booth	159	795	0.03
10/17/94	Post-control	Inside booth	367	1,835	0.29
10/18/94	Post-control	Inside booth	269	1,345	0.09
10/19/94	Post-control	Inside booth	430	2,150	0.13
10/20/94	Post-control	Inside booth	151	755	0.04

APPENDIX B

KEY:	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	

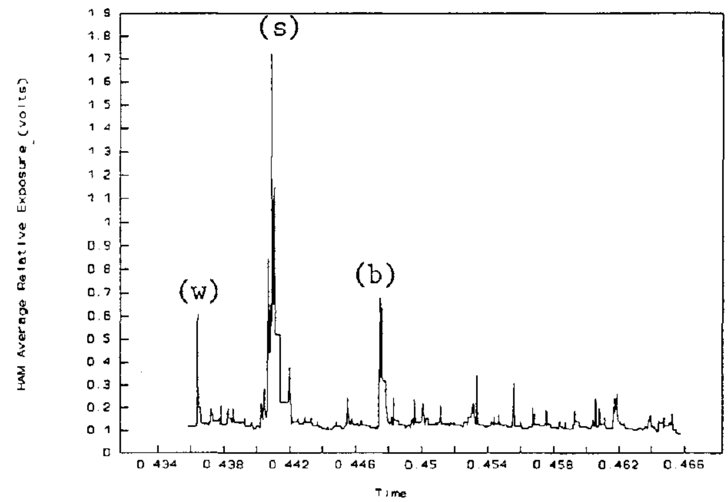


Graph B1: 8/24/94. This data was not coded as it was collected using the NiCad battery which caused the gradual rise in exposure. Total sampling time was 55 minutes.

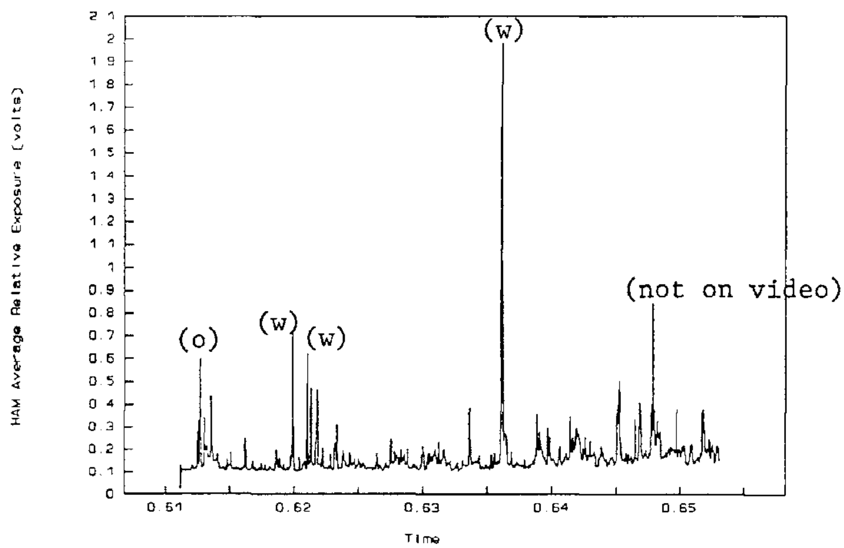


Graph B2: Morning of 8/25/94. First portion of data was collected using the NiCad battery; the remainder was collected using the 9 volt battery. Total sampling time was 74 minutes and 41 seconds.

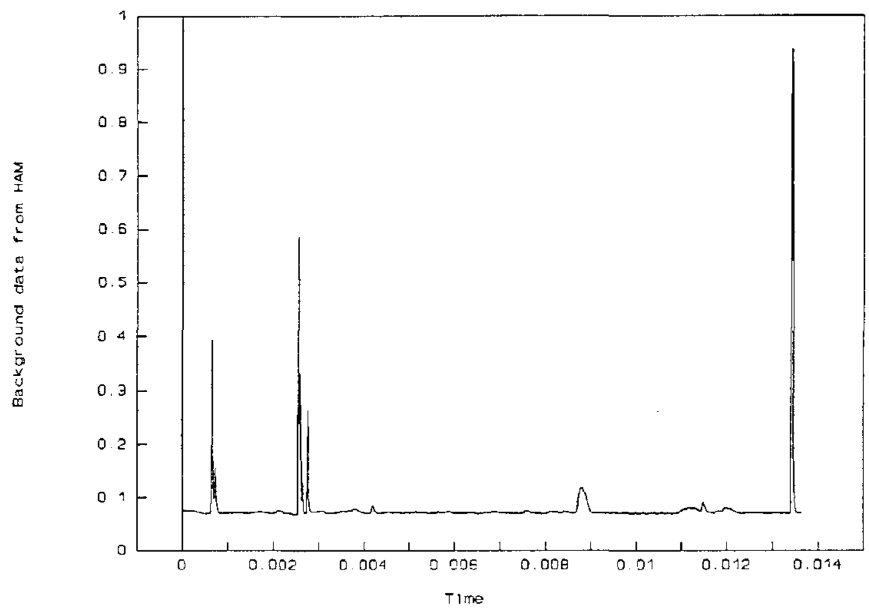
KEY:	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	



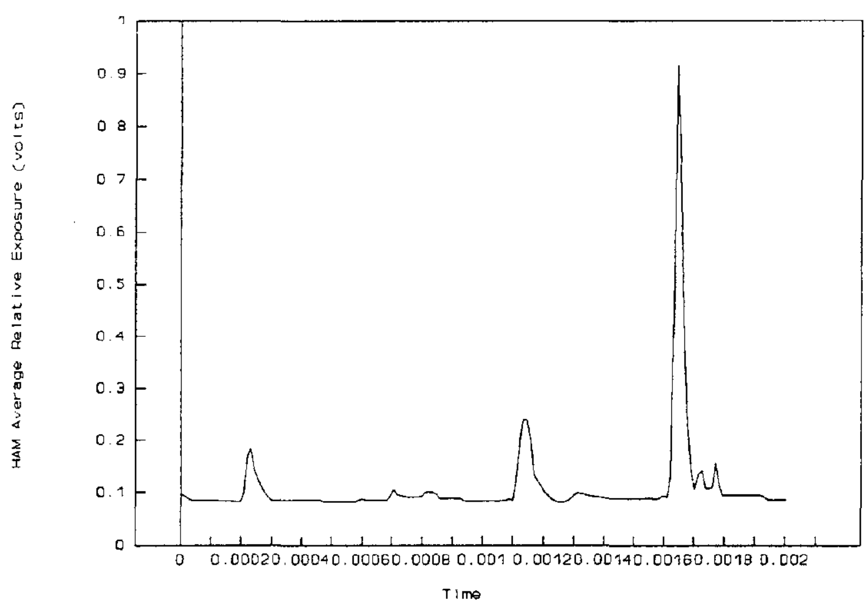
Graph B3: This is a blow-up of the portion of the data in Graph 2 that was collected with the 9 volt battery. Total sampling time was 43 minutes and 5 seconds.



Graph B4: Afternoon of 8/25/94. Data collected using a 9 volt battery over 60 minute sampling period.



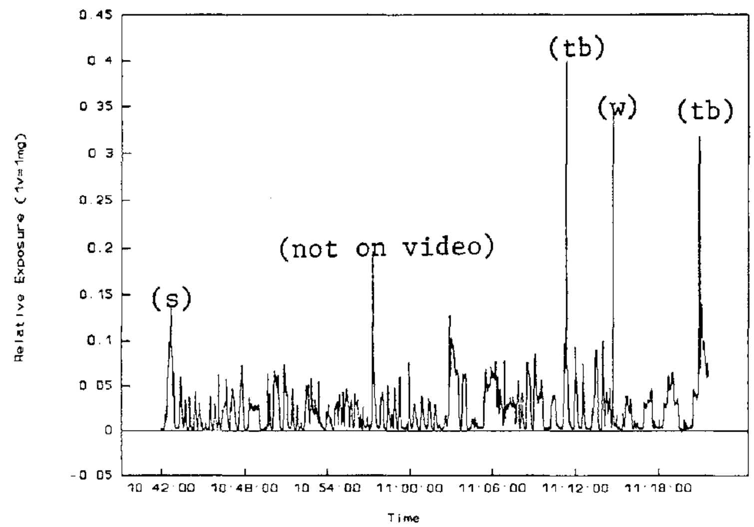
Graph B5: 8/25/94. Background data from weigh-out room when not in use. Sampling time of 19 minutes and 39 seconds.



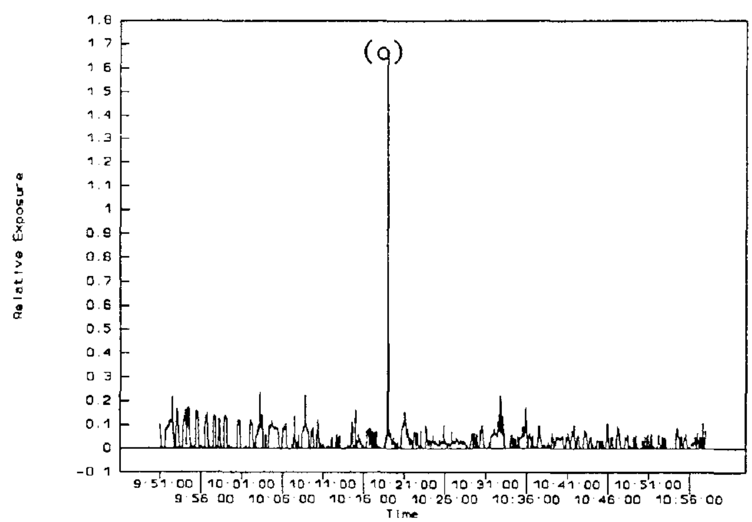
Graph B6: 8/25/94. Background data from lab/office area. Sampling time of 2 minutes and 53 seconds.

KEY:

w=weighing or near scale
s=scooping
sb=scooping in booth
t=transporting scoop or open bag
tb=transporting closed bag
b=closing bag
o=other

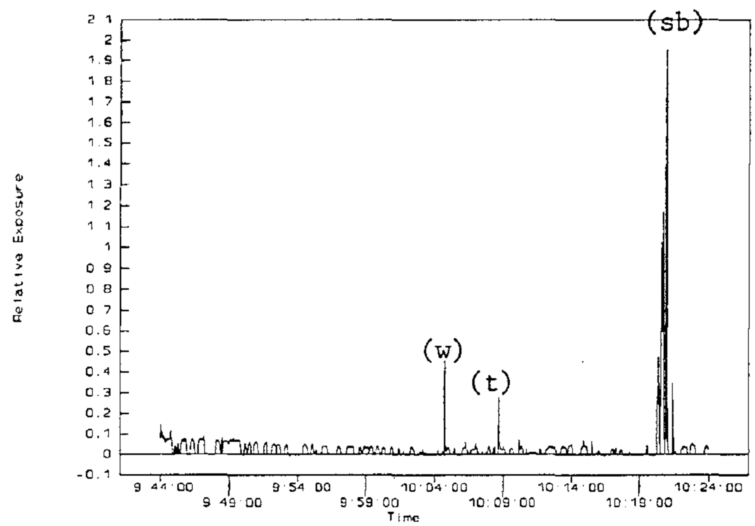


Graph B7: 10/17/94.

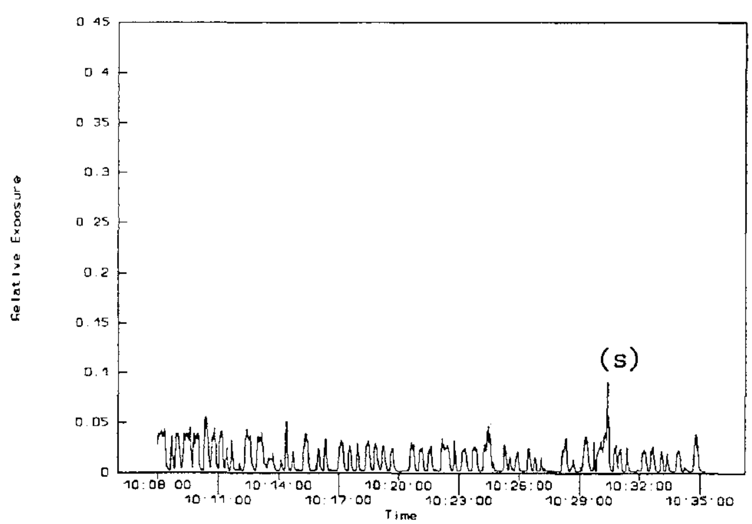


Graph B8: 10/18/94.

KEY:	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	

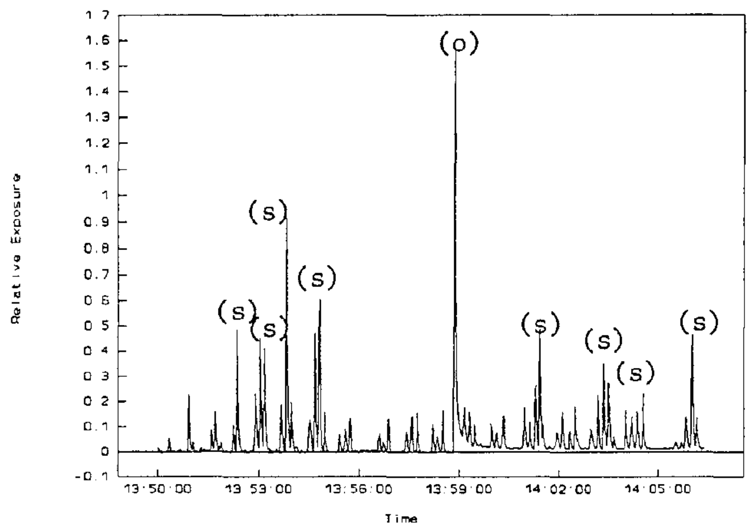


Graph B9: Morning of 10/19/94.

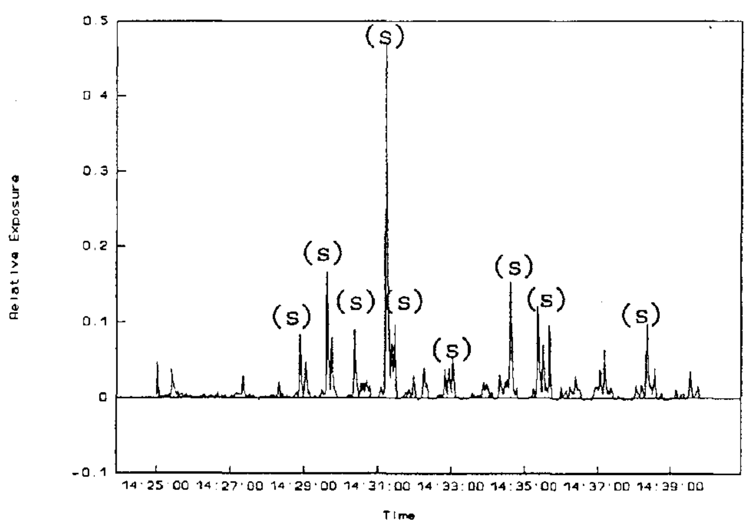


Graph B10: 10/20/94.

KEY:	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	



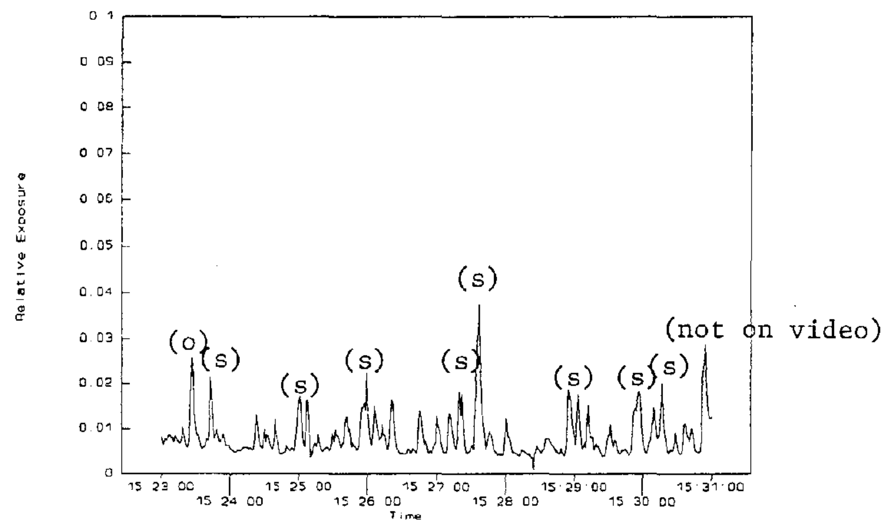
Graph B11: 10/19/94. Tall drum of orange dye.



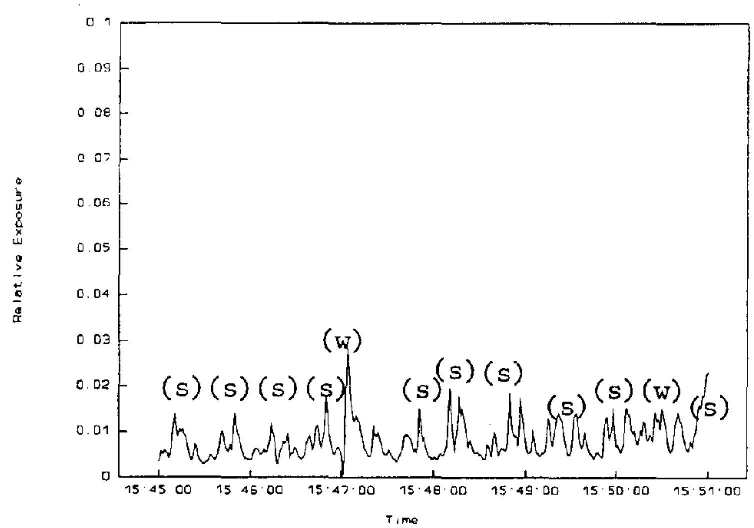
Graph B12: 10/19/94. Short drum of orange dye.

KEY:

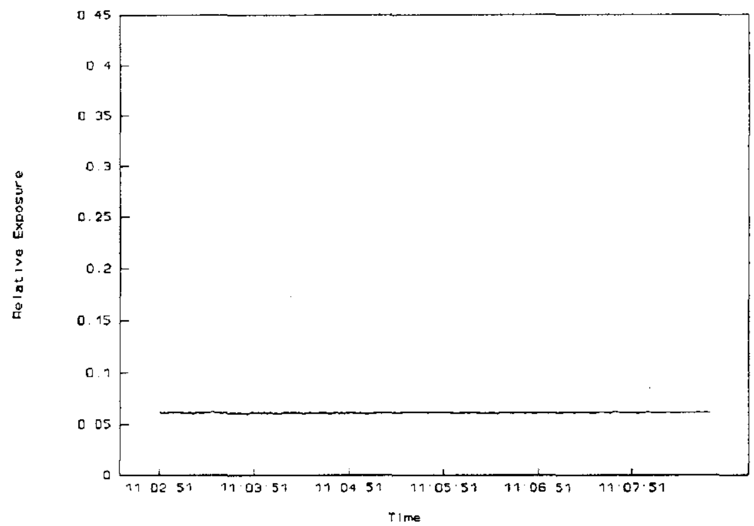
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	



Graph B13: 10/19/94. Tall drum of red dye.



Graph B14: 10/19/94. Short drum of red dye.



Graph B15: Afternoon of 10/20/94. Background voltage in lab/office area.

APPENDIX C - INSTRUMENTAL MONITORING

KEY:

w=weighing or near scale
s=scooping
sb=scooping in booth
t=transporting scoop or open bag
tb=transporting closed bag
b=closing bag
o=other

Table C1. HAM Data - Pre-Control Study

Task	Average Relative Exposure (volts)		Total Time (seconds)	
	8/25 A.M.	8/25 P.M	8/25 A.M.	8/25 P.M.
w	0.153	0.166	925	1042
s	**0.181**	0.138	567	557
t	0.131	0.130	404	397
b	0.153	**0.199**	277	184
tb	0.141	0.137	174	161
o	0.120	0.142	239	189

Highest exposure for each sampling session is highlighted.

Table C2. HAM Data - Post-Control Study.

	Average Relative Exposure (volts)				Total Time (seconds)			
Task	10/17	10/18	10/19	10/20	10/17	10/18	10/19	10/20
w	0.008	0.006	0.007	0.009	623	1347	767	744
s	**0.048**	**0.076**	**0.045**	**0.023**	171	437	280	221
t	0.031	0.050	0.036	0.016	338	816	429	353
b	0.004	0.002	-0.001	0.003	82	281	123	107
tb	**0.061**	**0.065**	0.035	0.021	152	285	140	137
sb	0.022	0.019	**0.142**	0.008	47	239	183	55
o	0.039	0.060	N/A	**0.025**	36	390	0	35

Top two highest exposure for each sampling session are highlighted.

APPENDIX C (continued)
INSTRUMENTAL MONITORING

Table C3. HAM Data - Booth Analysis

Sampling Session	Average Relative Exposure (volts) In Booth	Out of Booth	Total Time (seconds) In Booth	Out of Booth
10/17/94	0.009	**0.047**	853	596
10/18/94	0.010	**0.077**	2440	1355
10/19/94	0.028	**0.043**	1254	668
10/20/94	0.009	**0.021**	1060	592

Highest exposure for each sampling session is highlighted.

Table C4. Met One Data - Pre-Control Study.

Sampling Session	Weigh-Out Task Occurring?	Average # Particles > 0.3 μm	Average # Particles > 0.3 μm	Sampling Time (min)
8/24 Area - Weigh-out room (front)	Y	206	108,773	29
8/24 Personal	Y	490	138,301	50
8/24 Area - Lab/Office	N	85	84,767	7
8/24 Area - Weigh-out room (back)	N	17	68,109	2
8/25 Personal	N	40	123,632	17
8/25 Personal	Y	241	234,045	79
8/25 Area - Weigh-out room (front)	Y	443	221,135	99

Note: Sampling Volume is 2.83 liters.

Table C5. Met One Data - Post-Control Study -- Comparison of Particles >3.0 μm by Session and Major Peaks.

Sampling Session	Sampling Time (min)	Average # Particles >3.0 μm for Session	# of Major Exposure Peaks	Average # Particles >3.0 μm for Major Peaks
10/18 Personal	61	830	6	2060
10/18 Area	60	2590	6	4660
10/19 Personal	29	690	3	3410
10/19 Area	31	1630	8	3200
10/20 Personal	26	240	6	480
10/20 Area	26	1010	4	2080
10/19 Orange Tall	16	3580	6	6290
10/19 Orange Short	15	500	5	900
10/19 Red Tall	7	200	3	260
10/19 Red Short	5	70	2	100

Note: Sampling Volume is 2.83 liters.

Table C6. HAM Data - Drum Analysis.

Task	Average Relative Exposure (volts)				Total Time (seconds)			
	Orange Tall	Orange Short	Red Tall	Red Short	Orange Tall	Orange Short	Red Tall	Red Short
w	0.014	0.001	0.006	0.007	283	188	115	100
s	**0.097**	**0.018**	**0.010**	**0.009**	341	523	201	210
t	0.041	0.007	0.007	**0.009**	124	36	24	33
b	0.008	-0.001	0.006	0.004	168	127	70	18
o	0.087	0.0003	0.007	N/A	68	18	50	0

Highest exposure for each sampling session is highlighted.

Table C7. Met One Data - Drum Analysis -- Average Number of Particles Counted/Minute.

Particle Size	Orange Dye in Tall Drum	Orange Dye in Short Drum	Red Dye in Tall Drum	Red Dye in Short Drum
x > 0.3 μm	24,665	9041	41,805	14,100
x > 3.0 μm	3582	505	196	74

Note: Sampling Volume is 1 liter.

APPENDIX D - MET ONE DATA WITH HAM TASK ANALYSIS

KEY:	
w=weighing or near scale	s=scooping
t=transporting scoop or open bag	b=closing bag
tb=transporting closed bag	o=other

Table D1. Personal Sampling Data - 8/25/94.

End Time	% of MET exposure where x > 3.0μ	Activity - Average HAM Exposure and (Total Seconds)					
		w	s	t	b	tb	o
10:45:08	12%	0.2796 (52)	0 (0)	0 (0)	0.4428 (8)	0 (0)	0 (0)
10:34:58	6%	0 (0)	0.4097 (60)	0 (0)	0 (0)	0 (0)	0 (0)
10:35:59	6%	0.3915 (31)	0.6816 (23)	0.4215 (6)	0 (0)	0 (0)	0 (0)
10:37:00	5%	0.2225 (22)	0 (0)	0 (0)	0.2731 (17)	0.1391 (21)	0 (0)
Equivalent exposure/session = 2.4%		0.3007 (105)	0.4850 (83)	0.4215 (6)	0.3274 (25)	0.1391 (21)	0 (0)

Table D2. Area Sampling Data - 8/25/94.

End Time	% of MET exposure where x > 3.0μ	Activity - Average HAM Exposure and (Total Seconds)					
		w	s	t	b	tb	o
3:19:22	8%	0.1281 (17)	0.1290 (19)	0.1266 (24)	0 (0)	0 (0)	0 (0)
3:11:14	7%	0.1294 (25)	0.1150 (8)	0.1173 (27)	0 (0)	0 (0)	0 (0)
2:53:57	6%	0.1353 (22)	0.1125 (16)	0.1112 (22)	0 (0)	0 (0)	0 (0)
3:12:15	5%	0.1335 (35)	0.123 (10)	0.1236 (15)	0 (0)	0 (0)	0 (0)
3:10:13	4%	0.1347 (18)	0.1677 (34)	0.1450 (8)	0 (0)	0 (0)	0 (0)
Equivalent exposure/session = 2.5%		0.1324 (117)	0.1391 (87)	0.1215 (96)	0 (0)	0 (0)	0 (0)

Appendix D
MET ONE DATA WITH HAM TASK ANALYSIS (continued)

KEY:

w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	

Table D3. Personal Sampling Data - 10/18/94

End Time	% of MET Exposure where x > 3.0μ	Location Avg Ham Exp and (Total Secs)		Activity - Average HAM Exposure and (Total Seconds)						
		In Booth	Out of Booth	w	s	sb	t	tb	b	o
9:52:42	5%	0 (0)	**0.1079** (60)	0 (0)	**0.1250** (31)	0 (0)	0.0896 (29)	0 (0)	0 (0)	0 (0)
9:54:44	5%	0.0226 (15)	**0.1354** (45)	0.0122 (10)	**0.1544** (9)	0 (0)	0.1178 (17)	0 (0)	0 (0)	0.1217 (24)
10:36:25	4%	0.0154 (11)	**0.0756** (49)	0.0059 (8)	0.0665 (17)	0 (0)	**0.077** (35)	0 (0)	0 (0)	0 (0)
10:08:58	4%	0.0030 (21)	**0.0887** (39)	0.0015 (19)	**0.1057** (23)	0 (0)	0.0591 (18)	0 (0)	0 (0)	0 (0)
10:42:31	4%	0.0074 (21)	**0.0595** (39)	0.0038 (16)	**0.0597** (17)	0 (0)	0.0518 (27)	0 (0)	0 (0)	0 (0)
10:03:53	3%	0.0032 (18)	**0.1013** (42)	0.0018 (17)	**0.0903** (25)	0 (0)	0.0626 (3)	0 (0)	0 (0)	0.1223 (15)
Equivalent exposure/session = 1.6%		0.0091 (86)	0.0960 (274)	0.0041 (70)	0.0992 (122)	0 (0)	0.0771 (129)	0 (0)	0 (0)	0.1219 (39)

Table D4. Area Sampling - 10/18/94

End Time	% of MET Exposure where x > 3.0μ	Location Avg Ham Exp and (Total Secs)		Activity - Average HAM Exposure and (Total Seconds)						
		In Booth	Out of Booth	w	s	sb	t	tb	b	o
10:10:46	5%	0.0051 (35)	**0.0674** (25)	0.0057 (15)	0 (0)	0 (0)	**0.0371(** 6)	0.0597 (26)	0.0002 (13)	0 (0)
9:54:30	3%	0.0102 (25)	**0.1323** (35)	0.0049 (22)	**0.1542** (5)	0 (0)	0.1207 (9)	0 (0)	0 (0)	0.1217 (24)
9:55:31	3%	0.0072 (44)	**0.1434** (16)	0.0024 (25)	**0.1546** (4)	0.0089 (10)	0.0878 (21)	0 (0)	0 (0)	0 (0)
9:56:32	3%	0.0030 (47)	**0.1181** (13)	0.0017 (29)	**0.1302** (5)	0.0059 (2)	0.0729 (13)	0.0009 (3)	0.0012 (8)	0 (0)
9:52:38	3%	0.0012 (13)	**0.0953** (47)	0 (12)	**0.1062** (23)	0 (0)	0.0822 (25)	0 (0)	0 (0)	0 (0)
9:57:33	3%	0.0042 (38)	**0.1245** (22)	0.0034 (37)	**0.1299** (11)	0 (0)	0.1120 (12)	0 (0)	0 (0)	0 (0)
Equivalent exposure/session = 1.7%		0.0053 (202)	0.1100 (158)	0.0031 (140)	0.1231 (48)	0.0084 (12)	0.0872 (86)	0.0537 (29)	0.0006 (21)	0.1217 (24)

KEY	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	

Table D5. Personal Sampling Data - 10/19/94.

End Time	% of MET Exposure where x > 3.0μ	Location Avg Ham Exp and (Total Secs)		Activity - Average HAM Exposure and (Total Seconds)						
		In Booth	Out of Booth	w	s	sb	t	tb	b	o
10:21:25	38%	**0.3511** (60)	0 (0)	0.0456 (25)	0 (0)	**0.7175** (26)	0.1410 (9)	0 (0)	0 (0)	0 (0)
9:49:54	8%	0.0021 (2)	**0.0643** (58)	0.0014 (1)	**0.0673** (54)	0 (0)	0.0198 (5)	0 (0)	0 (0)	0 (0)
9:48:53	5%	0.0215 (27)	**0.0627** (33)	0.0274 (15)	0.0609 (3)	0 (0)	**0.0625** (15)	0.0589 (19)	0.0002 (8)	0 (0)
Equivalent exposure/session = 3.4%		0.2432 (89)	0.0637 (91)	0.0379 (41)	0.0670 (57)	0.7175 (26)	0.0795 (29)	0.0589 (19)	0.0002 (8)	0 (0)

Table D6. Area Sampling Data - 10/19/94

End Time	% of MET Exposure where x > 3.0μ	Location Avg Ham Exp and (Total Secs)		Activity - Average HAM Exposure and (Total Seconds)						
		In Booth	Out of Booth	w	s	sb	t	tb	b	o
9:47:29	9%	0.0089 (35)	**0.0719** (25)	0.0022 (22)	**0.0547** (9)	0 (0)	0.0541 (29)	0 (0)	0 (0)	0 (0)
9:53:35	8%	0.0008 (40)	**0.0411** (20)	-.0003 (37)	**0.0459** (7)	0 (0)	0.0341 (16)	0 (0)	0 (0)	0 (0)
9:48:30	8%	0.0089 (44)	**0.0627** (16)	0.0142 (20)	0.0004 (1)	0 (0)	-.0001 (3)	**0.0589** (19)	-.0006 (17)	0 (0)
9:45:27	6%	**0.0422** (60)	0 (0)	0.0058 (20)	0 (0)	**0.0680** (33)	0.0249 (7)	0 (0)	0 (0)	0 (0)
9:46:28	6%	0.0088 (22)	**0.0660** (38)	0.0023 (17)	**0.0688** (11)	0 (0)	0.0596 (32)	0 (0)	0 (0)	0 (0)
9:49:31	5%	0.0262 (5)	**0.0661** (55)	0.0200 (4)	**0.0670** (41)	0 (0)	0.0304 (14)	0 (0)	0 (0)	0 (0)
10:01:43	5%	0.0058 (49)	**0.0300** (11)	0.0003 (32)	**0.0343** (4)	0.023 (8)	0.0204 (14)	0 (0)	-.0013 (2)	0 (0)
9:50:32	5%	0.0045 (23)	**0.0545** (37)	0.0021 (19)	**0.0614** (27)	0 (0)	0.0304 (14)	0 (0)	0 (0)	0 (0)
Equivalent exposure/session = 3.2%		0.0143 (278)	0.0600 (202)	0.0035 (171)	0.0592 (100)	0.0592 (41)	0.0450 (130)	0.0589 (19)	-.0007 (19)	0 (0)

Appendix D
MET ONE DATA WITH HAM TASK ANALYSIS (continued)

KEY	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	

Table D7. Personal Sampling Data - 10/20/94.

End Time	% of MET Exposure where x > 3.0μ	Location Avg Ham Exp and (Total Secs)		Activity - Average HAM Exposure and (Total Seconds)						
		In Booth	Out of Booth	w	s	sb	t	tb	b	o
10:10:43	11%	0.0168 (25)	**0.0307** (35)	0.0143 (18)	**0.0384** (12)	0 (0)	0.0258 (30)	0 (0)	0 (0)	0 (0)
10:09:42	8%	0.0200 (25)	**0.0301** (35)	0.0217 (18)	0.0316 (14)	0 (0)	0.0257 (28)	0 (0)	0 (0)	**0.1217** (24)
10:13:46	7%	0.0139 (39)	**0.0242** (21)	0.0150 (18)	0 (0)	0.0118 (18)	0.0084 (2)	0 (0)	0 (0)	**0.0250** (22)
10:11:44	7%	0.0152 (43)	**0.0284** (17)	0.0176 (27)	**0.0333** (5)	0.0053 (8)	0.0227 (20)	0 (0)	0 (0)	0 (0)
10:12:45	6%	0.0085 (39)	**0.0269** (21)	0.0119 (18)	0 (0)	0 (0)	0 (0)	**0.0261** (23)	0.0041 (19)	0 (0)
10:24:57	6%	0.0084 (38)	**0.0251** (22)	0.0087 (25)	0 (0)	0 (0)	0 (0)	**0.0242** (26)	0.0027 (9)	0 (0)
Equivalent exposure/session = 3.8%		0.0132 (209)	0.0280 (151)	0.0147 (124)	0.0345 (31)	0.0098 (26)	0.0246 (80)	0.0251 (49)	0.0037 (28)	0.0250 (22)

Table D8. Area Sampling Data - 10/20/94.

End Time	% of MET Exposure where x > 3.0μ	Location Avg Ham Exp and (Total Secs)		Activity - Average HAM Exposure and (Total Seconds)						
		In Booth	Out of Booth	w	s	sb	t	tb	b	o
10:10:11	11%	0.0211 (21)	**0.0298** (39)	0.018 (15)	**0.0355** (17)	0 (0)	0.0261 (28)	0 (0)	0 (0)	0 (0)
10:11:12	10%	0.0205 (22)	**0.0300** (38)	0.0206 (14)	**0.0380** (12)	0 (0)	0.0249 (34)	0 (0)	0 (0)	0 (0)
10:09:10	6%	0.0149 (32)	**0.0301** (28)	0.0143 (27)	**0.0297** (11)	0 (0)	0.0276 (22)	0 (0)	0 (0)	0 (0)
10:13:14	5%	0.0196 (20)	**0.0267** (40)	0.0176 (18)	0 (0)	0 (0)	0 (0)	**0.0297** (20)	0 (0)	0.0250 (22)
Equivalent exposure/session = 3.8%		0.0186 (95)	0.0291 (145)	0.0170 (74)	0.0346 (40)	0 (0)	0.0260 (84)	0.0297 (20)	0 (0)	0.0250 (22)

Appendix D
MET ONE DATA WITH HAM TASK ANALYSIS (continued)

KEY:

w=weighing or near scale — s=scooping
t=transporting scoop or open bag — b=closing bag
o=other

Table D9. Personal Sampling Data - Tall Orange Dye Drum Study.

End Time	% of MET Exposure where x > 3.0μ	Activity - Average HAM Exposure and (Total Seconds)				
		w	s	t	b	o
1:53:02	21%	0.0143 (18)	0.1094 (23)	0.0812 (8)	0.0003 (11)	0 (0)
1:54:03	12%	0.0129 (17)	0.2358 (23)	0.0538 (9)	0.0015 (11)	0 (0)
1:52:01	9%	0.0071 (18)	0.0396 (21)	0.0146 (10)	0.0030 (11)	0 (0)
2:04:13	9%	0.0169 (20)	0.1407 (22)	0.0502 (9)	0.0145 (9)	0 (0)
1:55:04	8%	0.0146 (16)	0.1360 (24)	0.1313 (7)	0.0022 (13)	0 (0)
1:51:00	6%	0.0081 (25)	0.0511 (11)	0.0225 (4)	0 (0)	0.001 (20)
Equivalent exposure/session = 6.3%		0.0121 (114)	0.1266 (124)	0.0583 (47)	0.0039 (55)	0.001 (20)

Table D10. Personal Sampling Data - Short Orange Dye Drum Study.

End Time	% of MET Exposure where x > 3.0μ	Activity - Average HAM Exposure and (Total Seconds)				
		w	s	t	b	o
2:31:52	17%	-0.0034 (15)	0.0767 (30)	0.0326 (1)	-0.0004 (14)	0 (0)
2:34:55	16%	0.0042 (9)	0.0239 (39)	0.0046 (3)	-0.0014 (9)	0 (0)
2:36:57	11%	0.0011 (20)	0.0101 (31)	0.0013 (2)	-0.0017 (7)	0 (0)
2:29:50	8%	-0.0005 (6)	0.032 (43)	0.0028 (1)	-0.0000 (10)	0 (0)
2:32:53	7%	-0.0014 (8)	0.0107 (43)	0.007 (3)	-0.0014 (6)	0 (0)
Equivalent exposure/session = 6.7%		0.0017 (58)	0.0290 (186)	0.0073 (10)	-0.0008 (46)	0 (0)

Appendix D
MET ONE DATA WITH HAM TASK ANALYSIS (continued)

KEY	
w=weighing or near scale	tb=transporting closed bag
s=scooping	b=closing bag
sb=scooping in booth	o=other
t=transporting scoop or open bag	

Table D11. Personal Sampling Date - Tall Red Dye Drum Study.

End Time	% of MET Exposure where x > 3.0μ	Activity - Average HAM Exposure and (Total Seconds)				
		w	s	t	b	o
3:30:05	26%	0.0054 (9)	0.0098 (24)	0.0076 (5)	0.0060 (22)	0 (0)
3:23:59	17%	0.0082 (29)	0.0103 (12)	0.0085 (4)	0 (0)	0.0101 (15)
3:29:04	15%	0.0048 (7)	0.0095 (26)	0 (0)	0 (0)	0.0045 (27)
3:27:02	13%	0.0059 (16)	0.0100 (24)	0.0059 (2)	0.0065 (18)	0 (0)
3:26:01	12%	0.0067 (14)	0.0105 (31)	0.0061 (7)	0.0056 (8)	0 (0)
3:28:03	10%	0.0055 (14)	0.0114 (39)	0.0054 (2)	0 (0)	0.0094 (5)
3:25:00	8%	0.0057 (24)	0.0091 (20)	0.0076 (2)	0.0050 (13)	0.0052 (1)
Equivalent exposure/session = 14.3%		0.0064 (113)	0.0102 (176)	0.0069 (22)	0.0059 (61)	0.0068 (48)

Table D12. Personal Sampling Date - Short Red Dye Drum Study.

End Time	% of MET Exposure where x > 3.0μ	Activity - Average HAM Exposure and (Total Seconds)				
		w	s	t	b	o
3:49:40	29%	0.0068 (16)	0.0095 (41)	0.0079 (3)	0 (0)	0 (0)
3:50:41	25%	0.0089 (9)	0.0100 (45)	0.0048 (6)	0 (0)	0 (0)
3:48:39	17%	0.0057 (20)	0.0093 (35)	0.0047 (5)	0 (0)	0 (0)
3:47:38	16%	0.0089 (21)	0.0089 (35)	0.0054 (4)	0 (0)	0 (0)
3:46:37	13%	0.0053 (18)	0.0076 (31)	0.0055 (3)	0.0050 (8)	0 (0)
Equivalent exposure/session = 20%		0.0070 (84)	0.0091 (187)	0.0054 (21)	0.0050 (8)	0 (0)

APPENDIX E - STATISTICAL ANALYSIS

Generally, environmental monitoring data is log-normally distributed. As a result, all the total particulate and Met One optical particle counter concentrations were log-transformed before performing statistical analysis. The data analysis for these measurements involved straight-forward pooled or paired-t tests which are described in elementary statistical text books.[1] The analysis of the data from the Handheld Aerosol Monitor (HAM) was more complicated and the details of these analyses are discussed below.

HAM DATA FOR THE BOOTH EVALUATION DURING THE FOLLOW-UP STUDY

The HAM data was statistically analyzed to determine whether activity significantly affected the response of the HAM. For each recipe, the natural logarithm of the average value of the HAM response was computed for the t, tb, l, s, sb, b, and o activities. This variable is termed 'LC' in the following discussion. It was computed to attenuate some of the extreme, momentary concentration peaks observed in the data. Some results of the analysis are listed in Table E1.

Table E1. Data Analysis Summary for the Effect of Activity Upon Average HAM Response.

				Normality		Autocorrelation	
Task Code	n	Geometric Mean	GSD	Prob < W	Comment on stem leaf plot	Degrees of freedom	Prob > t for S[1]
b	40	0.002	2.46	0.0009		28	0.0081
o	13	0.048	2.20	0.99		3	_
s	22	0.042	1.63	0.77		7	0.2
sb	22	0.014	2.15	0.31		6	0.9
t	41	0.025	1.80	0.38		35	0.78
tb	41	0.020	3.89	0.0001	bimodal	35	0.24
w	41	0.005	2.80	0.046	skewed	35	0.04

The SAS General Linear Models Procedure was used to perform an analysis of variance (ANOVA) to evaluate whether activity or day of data collection had an effect upon LC.[2] The analysis revealed that activity affected LC (Prob > F = 0.0001) and that the day of data collection did not affect concentration (Prob > F = 0.2). As part of this analysis, the program computes the residual which, for this analysis, is the difference between the observed and mean of the dependent variable. The studentized residuals (residual/standard error of the residual) were computed and stored in a second data file along with all of the data used in the ANOVA. This file was analyzed to check assumptions for the ANOVA[3]:

1. A normal distribution of residuals,

2. independence of residuals, especially the absence of autocorrelation (e.g. a dependence of the present reading upon past residuals), and

3. equality of variances.

To test the assumption of normality, the SAS Univariate procedure was used to generate stem-leaf plots and to compute the Shapiro-Wilk (W) statistic for the studentized residuals. The probability of a smaller value of W is presented in the column labeled 'Prob < W' in Table E1. Low probabilities indicate significant deviations from a normal distribution. There are significant deviations from a normal distribution for activities b, w and tb. Inspection of the stem-leaf plot showed that the studentized residuals for the activity tb are apparently bimodal (see Figure 1).

To evaluate whether autocorrelation was present, the second data file was sorted by activity. For each activity, a regression analysis was done to evaluate whether the studentized residual is a function of the studentized residual for the prior recipe; this is termed the studentized residual at a lag of one, S_1. The value of S_1 was considered missing when:

1. The activity was not done during the prior recipe, or

2. it was collected during the first recipe of a sampling session.

To evaluate whether the variables listed above involved some autocorrelation, the data was fit to the following model:

$$S = \beta_o + \beta_1 S_1 + \epsilon \qquad (1)$$

where:

S = studentized residual,
S_1= studentized residual from preceding recipe,
β = regression coefficients; and
ϵ = the error, which is assumed to be normally distributed with a mean of 0 and a variance which is estimated as the mean square error of the regression analysis.

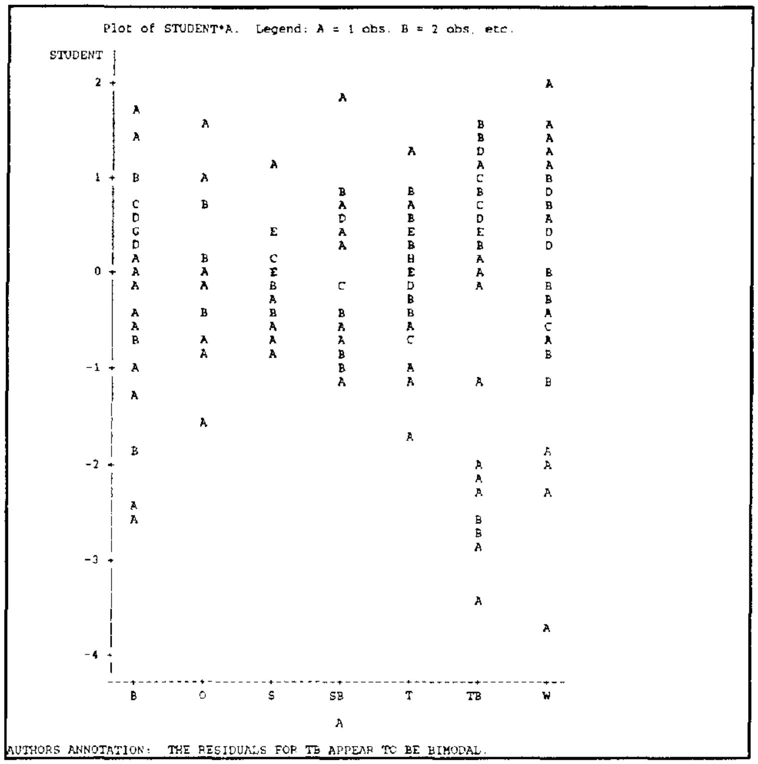


Figure 1: Studentized residuals plotted as a function of activity.

Table E1 lists the degrees of freedom for the regression coefficients and the probability of a larger T statistic for evaluating whether the regression coefficient differs from zero. Activities coded w and b involved autocorrelation.

The autocorrelation for activities b, w and s (with a regression coefficient for S_1 larger than 1, albeit non-significant) was removed by selectively excluding data from the analysis. An iterative approach was used for each variable. The approach is to remove the data for every second, third, and so on, observation. After removing the observations, the ANOVA is repeated and resulting studentized residuals are examined for autocorrelation as described in the preceding paragraph.[4] The process is repeated until the regression coefficient for S_1 does not differ significantly from 0. For activity b, every second and third observation was removed. For activity w, every other observation was removed. Because activity s did not occur for every recipe, the data was censored by removing every other record only when this activity occurred in consecutive recipes.

After purging the data of autocorrelation, the assumption of equal variances was addressed. After computing the variance of the natural logarithm of the average HAM response for each activity in the purged data, Bartlett's tests indicated that these variances were not homogeneous ($P < 0.0001$).[5] As a result, the reciprocal of these variances were used as weighting factors in the

ANOVA for the censored data and are presented in the top half of Figure 2. Because the residuals for some of the activities are not log-normally distributed, the SAS NPAR1WAY procedure was used to perform a non-parametric Kruskal-Wallis test (see bottom half of Figure 2). This test uses rank sums to evaluate whether the activity significantly affects the HAM response. As shown in Figure 2, both statistical tests found that activity affects exposure ($P = 0.0001$).

Table E2 presents the results of Tukey's HSD test which is used to examine the significance of differences in geometric means at an overall confidence level of 95%. An 'S' in Table E2 indicates that the difference is significant.

Table E2. Tukey's HSD test conducted at an overall level of confidence of 95%

	ACTIVITY CODES						
	0	S	T	TB	SB	W	B
O					S	S	S
S					S	S	S
T						S	S
TB						S	S
SB	S	S					S
W	S	S	S	S			S
B	S	S	S	S	S	S	

Note: In this table, the letter 'S' indicates a significant difference

Because there are some deviations from the assumption underlying the analysis of variance, there is some concern as to whether analysis of variance can be used to examine the differences in HAM response among the different activities. The study objective was to evaluate whether the booth reduces worker dust exposure during powder handling. Because scooping was done both inside and outside of the booth, the difference in the HAM analog output between scooping in the booth (activity sb) and scooping outside of the booth (activity s) is a measure of the exposure reduction obtained by using the booth. The significance of this difference was evaluated with a Smith-Satterthwaite pooled t-test.[6] The difference was significant ($P < 0.0001$).

```
                    General Linear Models Procedure

Dependent Variable: LC
Weight:             WGT

                                 Sum of           Mean
Source                  DF      Squares         Square   F Value     Pr > F

Model                    6  155.6761227     25.9460205     25.97     0.0001
Error                  159  158.8446825      0.9990232
Corrected Total        165  314.5208052

                  R-Square         C.V.       Root MSE              LC Mean

                  0.494963    -26.32738       0.999511           -3.7964721

Source                  DF  Type III SS    Mean Square   F Value     Pr > F

A                        6  155.6761227     25.9460205     25.97     0.0001

Author's annotation:  The variable 'WGT' is the reciprocal of the variance of LC for each
value of A

                    N P A R 1 W A Y   P R O C E D U R E

              Wilcoxon Scores (Rank Sums) for Variable C
                      Classified by Variable A

                          Sum of      Expected       Std Dev          Mean
   A             N        Scores      Under H0      Under H0         Score

   B            14     198.50000        1190.0    175.332145     14.178571
   O            13    1646.00000        1105.0    169.498420    126.615385
   S            17    2113.50000        1445.0    191.327736    124.323529
   SB           22    1518.50000        1870.0    214.043324     69.022727
   T            41    3966.50000        3485.0    272.664496     96.743902
   TB           41    3982.50000        3485.0    272.664496     97.134146
   W            21     939.50000        1785.0    209.832224     44.738095
                    Average Scores were used for Ties

          Kruskal-Wallis Test (Chi-Square Approximation)
```

Figure 2: Selected SAS output from the analysis of the censored data.

DRUM STUDY - ORANGE DYE

For each recipe, the average value of the HAM response was computed during the activities t, s, w, and b. Statistical analysis was performed on the natural logarithm's averages. These variables were termed respectively:

- lt - the natural logarithm of the average HAM response during activity t;
- ls - the natural logarithm of the average HAM response during activity s;
- lw - the natural logarithm of the average HAM response during activity w; and,
- lb - the natural logarithm of the average HAM response during activity b.

For each of these variables, a one-way analysis of variance was conducted using the SAS GLM procedure to test whether the variable was affected by the drum used. As part of this analysis the studentized residuals (residual/root mean square error) were computed and stored in a second data file. Each record of this file contained the dependent variable and the qualitative variable drum, which had a value of "s" for short or "t" for tall. This data set also contained studentized residuals at a lag of 1 and 2. The studentized residual at a lag of 1 is the studentized residual in the immediately preceding record. Where there was a break in the data collection, the lagged value was set to missing. This second data file was analyzed to evaluate the validity of underlying statistical assumptions mentioned earlier for the ANOVA.

The SAS Univariate procedure was used to evaluate whether there were significant deviations from normality. The Shapiro-Wilk (W) statistic was computed and the probability of a smaller value of W is presented in Table E3 under the column labeled 'Prob < W'. Low probabilities indicate significant deviations from a normal distribution; there does not appear to be significant deviations from a normal distribution.

Table E3. Analysis of the HAM data for the orange dye during the drum study.

Normality Tests		Regression analysis using model described by equation 2			
Variable	Prob < W	Degrees of freedom	Regression coefficient for studentized residual	Prob > t for regression coefficient	Drum effectProb > F
lt	0.19	24	0.19	0.28	0.0001
lw	0.13	31	0.17	0.23	0.0001
ls	0.93	27	0.18	0.14	0.0001
lb	0.33	26	0.62	0.0002	0.0001

Bartlett's test was used to evaluate the assumption of equal variances. For each of the dependent variables, the variance was computed for each value of drum. Bartlett's test showed that the differences in this group of variances could be due to chance (p = 0.1).

To evaluate whether the variables listed above for the orange dye involved some autocorrelation, the data was fit to the following model:

$$y = \beta_o + \beta_1 S_1 + \beta_2 D + \epsilon \qquad (2)$$

where:

$y =$ dependent variables ls, lt, lw, or lb,
$S_1 =$ studentized residual of the immediately preceding record,
$D =$ 1 if a short drum was used, otherwise D=0,
$\beta =$ regression coefficients; and
$\epsilon =$ the residual, which is assumed to be normally distributed with a mean of 0 and a variance which is estimated as the mean square error of the regression analysis.

Some results for this analysis are presented in Table E3. Inspection of the columns under the label 'Regression coefficient for studentized residual' reveals that the regression coefficient S_1 is not significantly different from zero for the variables lw, ls, and lt. Thus, these variables do not involve autocorrelation. However, the variable lb does involve autocorrelation.
Then, analysis for the variable lb was repeated by modeling lb as function of the two preceding values of the studentized residual. The regression coefficient for the studentized residual at a lag of 2 was -0.08 (Prob > t = 0.67), indicating that the model in equation 2 is adequate for addressing the effects of autocorrelation. The column labeled 'Drum effect (Prob > F)' is the probability that the observed difference in the HAM's response could be explained by chance. Apparently, the variable drum had a very significant affect upon all the variables.

In order to evaluate whether the variable drum had an overall effect upon HAM response, a multivariate analysis of variance was conducted involving the variables lt, lw, and ls. As shown by Item 1 in Figure 3, the values of lt, lw, and ls are largely independent of each other. Item 2 presents some F-tests for evaluating whether the drum had an effect upon the values of lt lw and ls. The variable lb was excluded from these analyses to avoid complications caused by autocorrelation.

```
Item 1
 Partial Correlation Coefficients from the Error SS&CP Matrix / Prob > |r|

                 DF = 30          LW         LS         LT

                 LW           1.000000  0.213581  0.285167
                                0.0       0.2405    0.1136

                 LS           0.213581  1.000000  0.671769
                                0.2405    0.0       0.0001

                 LT           0.285167  0.671769  1.000000
                                0.1136    0.0001    0.0

Item 2
             Manova Test Criteria and Exact F Statistics for
                 the Hypothesis of no Overall DRUM Effect
       H = Type III SS&CP Matrix for DRUM   E = Error SS&CP Matrix

                         S=1    M=0.5    N=13.5

 Statistic                   Value          F      Num DF    Den DF  Pr > F

 Wilks' Lambda           0.32898621    19.7165          3        29  0.0001
 Pillai's Trace          0.67101379    19.7165          3        29  0.0001
 Hotelling-Lawley Trace  2.03964113    19.7165          3        29  0.0001
```

Figure 3: SAS output from multivariate analysis of variance conducted to evaluate whether drum had an overall effect upon the HAM's analog output during tests conducted with the orange dye.

DRUM STUDY - RED DYE

For the red dye, the multivariate analysis of variance described in the preceding section was conducted and the variable drum did not have an overall effect upon the dependent variables lw, ls and lt (Prob > F = 0.2). The variable lb was not included in the analysis as the task was not performed that often using the red dye.

REFERENCES

1. Dougherty E [1989]. Probability and Statistics for the Engineering, Computing, and Physical Sciences. Englewood Cliffs, New Jersey: Prentice Hall.

2. SAS Institute [1993]. SAS Release 6.04; Cary, NC 27512-8000, U.S.A.

3. Freund R, Littell RC [1986]. SAS System for Regression. Cary, NC: SAS Institute Inc.

4. NIOSH [1992]. Analyzing Workplace Exposures using Direct Reading Instruments and Video Exposure Monitoring Techniques. Cincinnati Ohio: U.S. Department of Health and

Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health Publication; No. 92-104.

5. Walpole RE, Meyers, RH [1978]. Probability and Statistics for Engineers and Scientists. 2nd Ed. New York, NY: MacMillan Publishing Co.; p. 375.

6. Miller I, Freund J [1965]. Probability and Statistics for Engineers. Englewood Cliffs, NJ: Prentice-Hall.

APPENDIX F
TOTAL SUSPENDED PARTICULATE DATA

Average TSP Concentrations in Brooklyn and Manhattan for 1993.

Location	Average TSP for 1993 ($\mu g/m^3$)
Bowery Savings	72
Midtown Manhattan	99
Green Point	59
Susan Wagner	40
PS26	43
geometric mean	59
average	62