IN-DEPTH SURVEY REPORT:

DESIGN OF IMPROVED WORKSTATIONS FOR HANDLING DRY CHEMICAL POWDERS

AT

B.F. GOODRICH COMPANY
INDUSTRIAL PLASTICS DIVISION
MARIETTA, OHIO

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REPORT DATE:
MARCH 1988

REPORT NO.
169-11

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
Division of Physical Sciences and Engineering
Engineering Control Technology Branch
4676 Columbia Parkway
Cincinnati, Ohio 45226

PLANT SURVEYED:	B. F. Goodrich Company Industrial Plastics Division P.O. Box 657 Marietta, Ohio 45750
SIC CODE:	3079 Miscellaneous Plastics Products
SURVEY DATES:	August 10-14, 1987 and August 17-21, 1987
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I. INTRODUCTION

The manual weigh out and transfer of powders operation is quite common in many industries such as rubber and plastics manufacturing. A previous study by NIOSH researchers of such an operation was conducted at the B.F. Goodrich Company's, Industrial Plastics Division plant in Marietta, Ohio. This plant makes a variety of products including vinyl wall covering and magnetic stripping. The manual materials weigh out operation is just one of many processes in this plant. In that initial study, several sources of worker dust exposure were identified.(1) First, scooping the powder from a nearly empty drum resulted in a significantly higher worker dust exposure than scooping from a full drum. Secondly, an eddy, induced by the booth air flow, was found in front of the worker. This eddy caused dust generated in front of the worker to be transported into his breathing zone. Finally, a second eddy, located inside the weigh out drum, tended to force any dust generated in the drum to be transported up into the work environment.

As a follow-up to this initial effort, a second study, reported herein, was conducted at the same B.F. Goodrich Company plant, in an effort to design a better system of controls for the dust exposures at the ventilated work station used in the weigh out and transfer of these powdered materials. The modification of the manual weigh out work stations that were tested and discussed herein, consisted of several approaches. First, the layout of the work table was evaluated and redesigned to improve process flow and, hopefully, reduce dust exposures. Next, a local ventilation hood was added at the bulk material drum to control the eddy in the drum, preventing the dust from escaping from the drum into the work environment. Finally, in order to control the eddy in front of the worker, an air shower was installed. All of these controls, along with varied booth flow, were tested in combination with each other to determine the most effective control scheme. In addition, a cost analysis was performed to determine the installation cost of the modified controls as well as the operating costs.

II. PROCESS DESCRIPTION

Because of the many different products manufactured at this plant, most of the powdered raw materials are received in 23 kg (50 lb) bags. If a small quantity of the raw material is used in a batch, (i.e., less than a full bag) the material is weighed out in a ventilated booth. The bags of raw material are dumped into a drum and then weighed into small paper bags. These small bags of powder are then placed into a bin or a second drum for storage until they are used in a batch. The workers in this plant are paid on an incentive system with a separate standard or weigh out time allotted for each material. This pay system motivates the workers to maintain a high output.

III. EXPERIMENTAL DESIGN

The goal of this study was to evaluate various work station configurations to determine the best control strategy. The controls evaluated were booth flows of full, two-thirds, and one-third (of full flow), the presence of an air shower above the worker, and the presence of local ventilation in the form of a slot hood behind the bulk material drum. The twelve possible combinations of these controls were tested against each other with a redesigned work table in place. Several sampling runs were made with the original work station configuration in place to obtain a baseline. There were, however, several constraints on the design of this study. Because it took place in an operating plant, the study design had to accommodate B.F. Goodrich's production schedule with as little disruption as possible. To reduce variability, a single material needed to be weighed out over the entire study sampling period. Due to inventory and production requirements, a polymethyl methacrylate powder was chosen for the experiment. Further, as the study design was developed, the number of workers which could be sampled in the two week period allotted for the study was not known. In order to reduce the effect of the worker on dust exposure, (through work practices and anthropometrics) as many workers as possible needed to be studied. Therefore, the design was developed to allow for flexibility for the number of workers participating. To increase the number of workers studied, each worker was limited to a sequence of seven 15 minute runs each; one run for the original work station layout and six randomly selected control configurations of the possible twelve. These seven runs were completed in a random order. Nine different workers were sampled with two of the workers repeating a second sequence of seven runs. To sample the nine workers, sequences were conducted on all three shifts.

IV. CONTROL DESIGN

The various controls evaluated in this study were designed to be used with the ventilated booth currently in place in the plant. The average face velocity of the booth, as measured with a hot wire anemometer, was found to be approximately 0.32 m/s (64 ft/min). With a booth face area of 2.78 m^2 (29.9 ft^2), this velocity results in an exhaust volume of 54.4 m^3/min (1920 ft^3/min). Two other face velocities were evaluated in this study: 0.22 m/s (43 ft/min), representing two-thirds flow, and 0.11 m/s (21 ft/min), representing one-third flow, resulting in volumetric flows of 36.3 m^3/min (1280 ft^3/min) and 18.1 m^3/min (640 ft^3/min) respectively. The flow of the booth was controlled by adjusting a blast gate in the ventilation duct leading from the booth.

Due to the findings of the initial study at this plant, all of the controls described here were tested with the worker scooping from half-height drums.(1) The use of the half-height drums may reduce dust exposures by up to 66% versus the full height drums (see Appendix A). The half-height drums were made by cutting the top off of fiber drums measuring 0.84 m (33 in) high and 0.60 m (23.5 in) in diameter. The half-height drums were then placed on a platform to raise the top of the drum 0.84 m (33 in) above the floor. This provided a comfortable working level for most of the workers. The half-height drums also ensured that the workers would not have to reach deep into the drum to scoop the powder.

Each worker sampled performed one run with the work station in its original configuration. Figure 1 shows a drawing of this work station. The original metal table was replaced by a similar table fabricated out of wood to allow for easy removal. The only difference between the metal table and the wooden table was the absence of a hinged platform. This platform raised to allow the bulk materials drum to be placed inside the booth. However, from the initial study of this work station, the platform adversely affected the air flow around the drum.(1) Therefore, for the purpose of this study, it was not included.

The redesigned work table, shown in Figure 2, was also fabricated out of wood. This table was setup to streamline the weigh out operation and to hopefully reduce dust exposures by moving the weighed material drum inside the booth.[2,3] The two work tables, the original and the modified or redesigned tables, were interchanged as required by the study design. The modified work table was evaluated in conjunction with the three different booth flows, local exhaust ventilation at the weigh out drum, and the air shower.

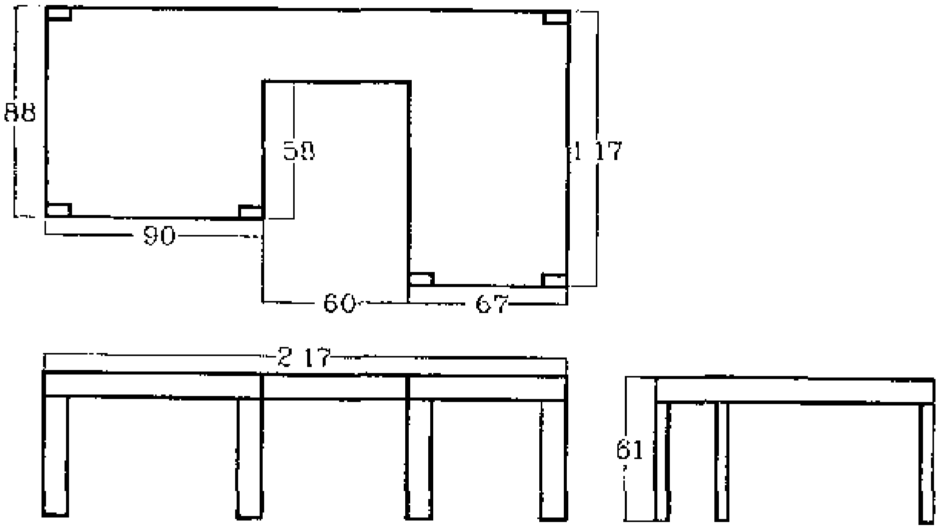

Figure 1. Original work table design.

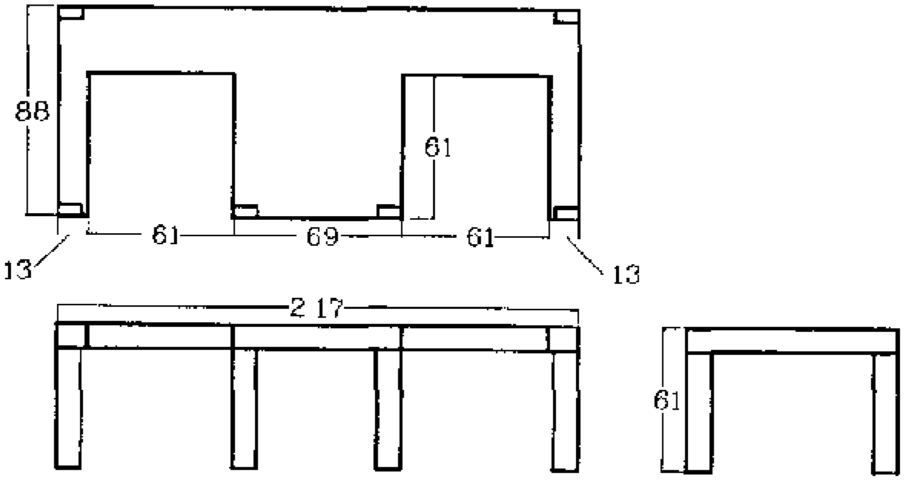

Figure 2. Modified work table design.

The local exhaust ventilation, a slot hood shown in Figure 3, was positioned behind the material weigh out drum to provide exhaust ventilation near the dust source. The slot velocity was approximately 7.6 m/s (1500 ft/min) with a resulting flow of 14.2 m^3/min (500 ft^3/min).(4) This hood was fashioned out of wood and sheet metal, and was built in such a way that it could be removed from the work station when necessary. The hood was connected to a small fan which was exhausted into a hood located elsewhere in the plant. The slot hood was designed with the idea that any dust generated inside the drum, would be captured before escaping into the work environment.

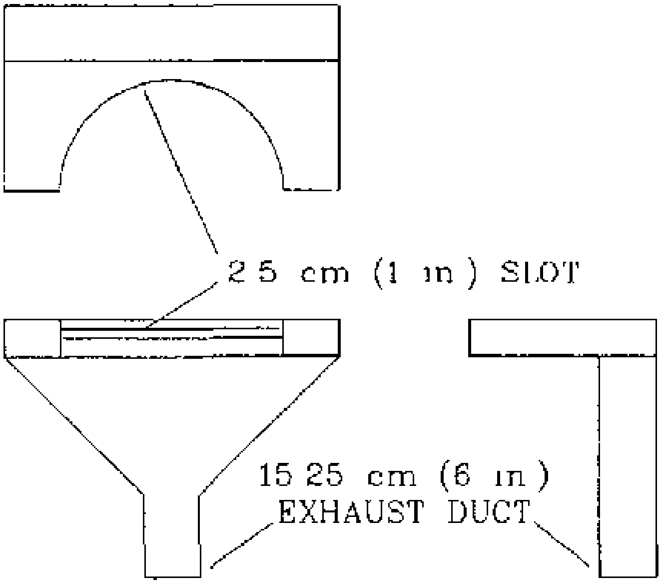

Figure 3. Local exhaust ventilation design.

The air shower, pictured in Figure 4, was a plenum consisting of a wooden box with a pegboard face acting as a distribution plate. The hole area of the distribution plate was less the one-half of the sectional area of the plenum chamber. Clean air was supplied into the box from an air filter unit, and the flow from the pegboard face provided a 0.25 m/s (50 ft/min) flow in the area in front of the worker's face. With the air shower blowing down on top of the worker, the flow of clean air would force any dusty air down, away from the worker, rather than allowing it to travel up into the worker's breathing zone. The air shower unit was positioned 2.1 m (6.9 ft) above the floor, centered less than 0.3 m (1.0 ft) behind the area normally occupied by the worker when performing the weigh out operation.

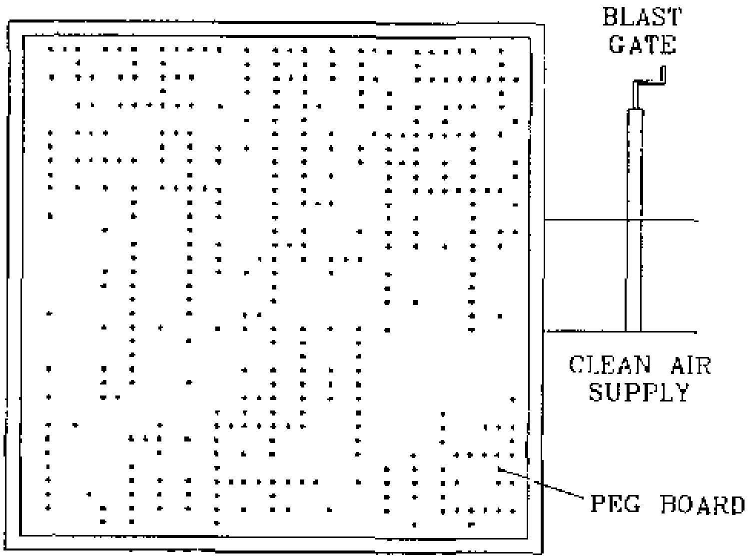

Figure 4. Air shower design.

V. COST ANALYSIS

The cost analysis for the various control configurations was broken down into three basic areas: cost of make-up air due to exhaust ventilation, fabrication costs of the individual control components, and differences in costs due to air handling capacity, mainly for new installations. This is a rough estimate due to several assumptions made during the analysis. Actual cost will depend upon site location and other installed equipment.

The cost of the make-up air will be directly dependent upon the volume of air exhausted. Depending upon the climate and operation, this air may need to be heated. Other factors affecting the cost of the make-up air are the cost of fuel, the available heat per unit of fuel, and heat required to raise the temperature of the incoming air. The "available heat per unit of fuel" term is dependent upon the type of fuel used and includes the efficiency of the heating system. The "heat required" term is dependant upon the average winter outside temperature and, depending upon how the cost is reported, may require a term describing the operating time of the system. The calculation of the cost of make-up air is given in two ways as follows:(4)

$$\text{Hourly cost} = \frac{0.001\ QN}{q} \times c \qquad \text{Yearly cost} = \frac{10325\ QD\ dg}{q} \times c$$

Where: Q = air volume, m^3/min
N = required heat, J/hr/1000 fuel units
D = operating time, hours/week
q = available heat/unit of fuel, J/fuel unit
dg = Annual Heating Degree Days, |C days
c = cost of fuel, $/fuel unit

Several assumptions were made for terms in these equations. First, for the yearly cost equation, the operating time of the weigh out work station was taken as 120 hours/week (24 hours/day, 5 days/week). Also for the yearly cost equation, the Annual Heating Degree Days for Marietta, Ohio was not readily available. Data available for Pittsburgh, Pennsylvania, which is about 165 km (103 mi) from Marietta, was used for this analysis. It was also assumed that the plant was heated to 18|C (65|F). The analysis was done for three different heating systems: oil, with an efficiency of 75%; natural gas with heat exchanger at 80% efficiency; and direct fired natural gas with 90% efficiency. The heating oil had 2.97×10^{-7} J/l (106,500 Btu/gal) of heat available at the 75% efficiency while the natural gas at efficiencies of 80% and 90% had available heats of 2.98×10^{-7} J/m^3 (800 Btu/ft^3) and 3.35×10^{-7} J/m^3 (900 Btu/ft^3) respectively. The cost of the oil was taken as $0.23/l ($0.90/gal)(4) and the cost of the gas was assumed to be $0.148/$m^3$ ($0.0042/$ft^3$).(5)

The costs of fabricating the various configurations can be broken down into three different areas: the cost of the modified work table, the cost of the local exhaust ventilation and the cost of the air shower. These costs are all dependent upon the materials of construction and the labor required for fabrication. The air shower should be constructed of 18 gauge galvanized steel. The local exhaust ventilation hood should be built of 16 gauge galvanized steel, heavier than the air shower due to the abrasive nature of the powder. The modified work table should be fabricated out of 7.6cm x 7.6cm x 0.64cm (3in x 3in x 0.25in) angle iron (framing) and 0.48cm (0.19in) gray iron plate (top). Cost estimates were formulated from price quotes from a metal fabricating contractor.(6) The estimates from the contractor did not include installation costs. The installation costs were calculated by adding 25% of the fabrication costs.(7) Costs for duct work connecting the air shower to the make-up air supply and the local exhaust ventilation to the dust collection system must also be supplied. Estimates for the duct work are available from a number of sources.(7,8) For the air shower, it was assumed that 0.20m (8in) round galvanized ductwork would be installed. For the local exhaust hood, 0.15m (6in) round galvanized ducts were assumed to be used. Since the weigh out booth is near an exhaust source, long lengths of ducts should not be needed. For the purpose of the cost analysis, this length was assumed to be 9.1m (30ft). For the air shower, however, make-up air may need to be transported long distances. Therefore, the air shower ducts will be assumed to be 30m (100ft) long.

The cost due to air handling capacity requirements deals mainly with the design of the air cleaning equipment.(9) Several assumptions were made in doing the analysis of the cost of this equipment. First, it was assumed that the weigh out operation was not the only process requiring the use of air cleaning equipment. Therefore, the general capacity of the equipment was taken to be 283 m^3/min (10,000 ft^3/min). This is not the design capacity, but rather, gives an equipment size classification. Costs for the design capacity were calculated in $/$m^3$/min. All of the configurations had the same cost per unit of air exhausted, but because of the differences in exhaust volume, they will have a different overall cost. Another assumption was that the air cleaning equipment used for the process was a shaker type baghouse. Finally, because of the wide variation in cost of filter fabric for the baghouse, this cost was assumed to be $\$61.87/m^3/min$ ($\$1.75/ft^3/min$) for all configurations. A typical installation cost of a 283 m^3/min (10,000 ft^3/min) shaker type baghouse is given in Table 1.

Table 1. Installation cost of a 283 m^3/min (10,000 CFM) shaker type baghouse ($\$/m^3/min$).

	ITEM	COST[a] DOLLARS/m^3/min
1.	FILTER FABRIC	$61.87
2.	FAN AND MOTOR	19.35
3.	DUCT WORK	50.29
4.	CONVEYING EQUIPMENT FOR DISPOSAL	7.73
5.	FOUNDATION AND INSTALLATION	21.65
6.	INSTRUMENTATION	3.89
7.	ENGINEERING AND SUPERVISION	7.73
8.	FREIGHT	3.89
9.	START-UP COSTS	7.73
	TOTAL COST	$184.13

[a] Costs adjusted from 1976 basis to forth quarter 1987 basis using M&S Equipment Cost Index.(10)

VI. STATISTICAL DESIGN

The objective of the study was to evaluate the effectiveness of the various workstation configurations at controlling worker dust exposures. The evaluation of each workstation configuration required a worker to transfer material to the bags for a designated time, using a work table configured as either original or redesigned, and, if redesigned, according to one of the possible variations of booth flow rate, air shower, and local exhaust ventilation. Because of time limitations, the study used a nested half fraction factorial design utilizing the above mentioned variables (work table, original or modified; booth flow rate; air shower; local exhaust ventilation).(11,12) This design resulted in a total of seven runs to be completed by each worker: the one original workstation run, and the six runs from the half fraction factorial experiment. If all three pairs of possible half fractions are run by different workers (6 workers in all), then the design is balanced and all interactions may be estimated. The three half fraction pairs are listed in Table 2. Workers in groups were randomly assigned to the six setups or half fractions. This randomized the order in which the six possible sets were used. The plan was to use as many workers as time permitted. Seven workers completed a single sequence, while two workers completed two sequences each. The total was treated as if eleven workers participated. Since eleven sequences were completed, all three pairs of replicates, or possible ways to split the complete factorial into two halves were used, with all but one represented twice. For each worker, the order of the 7 runs was randomized. Neither the configuration assigned to a worker nor the order of runs was known to the experimenters until the worker was ready to begin.

Table 2. Half-fractions pairs for 3x2x2 factorial design.

PAIR I	
1/3 FLOW, AIR SHOWER	1/3 FLOW
1/3 FLOW, LOCAL EXHAUST	1/3 FLOW, LOCAL EXHAUST, AIR SHOWER
2/3 FLOW	2/3 FLOW, AIR SHOWER
2/3 FLOW, LOCAL EXHAUST, AIR SHOWER	2/3 LOCAL EXHAUST
FULL FLOW	FULL FLOW, AIR SHOWER
FULL FLOW, LOCAL EXHAUST, AIR SHOWER	FULL FLOW, LOCAL EXHAUST

PAIR II	
1/3 FLOW	1/3 FLOW, AIR SHOWER
1/3 FLOW, LOCAL EXHAUST, AIR SHOWER	1/3 FLOW, LOCAL EXHAUST
2/3 FLOW, AIR SHOWER	2/3 FLOW
2/3 FLOW, LOCAL EXHAUST	2/3 FLOW, LOCAL EXHAUST, AIR SHOWER
FULL FLOW	FULL FLOW, AIR SHOWER
FULL FLOW, LOCAL EXHAUST, AIR SHOWER	FULL FLOW, LOCAL EXHAUST

PAIR III	
1/3 FLOW	1/3 FLOW, AIR SHOWER
1/3 FLOW, LOCAL EXHAUST, AIR SHOWER	1/3 FLOW, LOCAL EXHAUST
2/3 FLOW	2/3 FLOW, AIR SHOWER
2/3 FLOW, LOCAL EXHAUST, AIR SHOWER	2/3 FLOW, LOCAL EXHAUST
FULL FLOW, AIR SHOWER	FULL FLOW
FULL FLOW, LOCAL EXHAUST	FULL FLOW LOCAL EXHAUST, AIR SHOWER

Each run in this study lasted 15 minutes. Starting with a filled half-height drum, the worker would weigh 0.49 kg (1.08 lbs) of the powder into the small paper bags. The bags were then placed into the full-height receiving drum for use at a later time. Before each run, three half-height drums were filled with powder. Each worker would typically empty one or two of the half-height bulk material drums. Members of the NIOSH survey team would change the bulk material drums when they were emptied. All sampling was terminated after 15 minutes, and a different work station configuration put into place.

VII. SAMPLING METHODS

Two types of sampling were performed simultaneously in this study: gravimetric filter sampling and real time instrument sampling. While the filter samples provided average dust concentrations over the entire run, the real-time sampling could give concentrations at a specific time if necessary.

For each run, four filter samples were taken: two personal samples (right and left lapel) and two background samples. The background samples were taken approximately 9 m (30 ft) from the weigh out booth. The filters used were MSA type FWSB 37 millimeter with 5.0 micron pore size mounted in a closed faced cassette. Carbon vane pumps with critical orifices, calibrated at 13-14 liters per minute, were used to draw air through the filters. The total sample volume for each run was 195-210 liters of air.

The dust exposures were measured in real-time using a hand-held aerosol monitor (HAM, PPM Inc. Knoxville, TN.) operating in an active mode (air being drawn through the sampling chamber by a sampling pump operating at 4-5 liters per minute). The data from the HAM was collected with a Rustrak Ranger Datalogger (Gulton Inc. East Greenwich, RI), and then uploaded to a personal computer. These data were then transferred into a spreadsheet for data analysis. All of the runs were recorded on video tape. The video recorder's clock was synchronized with the clock on the data logger so that the activities causing changes in dust exposures could be identified. Besides providing information on the activities, the real-time data also gave a second means for measuring the effectiveness of the various control configurations.

Workers comments concerning their opinions about the various workstation configurations were also requested. These comments included the workers likes and dislikes of the different control devices. The workers also related their perceptions as to the effectiveness of the controls evaluated. Suggestions for improvements to the controls were also solicited at the same time.

VIII. RESULTS

The study set out to determine which of the work station configurations, if any, affected worker dust exposures as measured by the personal filter samples and the real-time measurements. The dependent variable for the analysis of the filter data was the dust exposure calculated from the weight of the personal filter samples. For the real-time data, the dependent variable was the average of the one second readings over the fifteen minute run. An analysis was performed, developing a regression equation to determine if both flow, air shower, local ventilation, the interactions of these terms, as well as work station (modified or original) and worker differences affected worker dust exposures. The worker differences were included to describe all effects that could not be attributed to the controls listed. The data were analyzed in several different ways, each giving slightly different results. These differences, however did not effect the overall conclusions. A thorough description of the analyses performed in this study is given in Appendix C.

The following summarizes the individual factors and their associated effect on worker dust exposures. Statistical effect is at the 0.05 level.

WORKER. Statistically significant effect upon dust exposures. Worker differences were responsible for most of the variation in dust exposures.

WORK STATION. No significant effect upon dust exposures

BOOTH FLOW. (within modified work station). No significant effect upon dust exposures for the three different booth flows tested in this study.

AIR SHOWER. (within modified work station). Statistically significant effect upon dust exposures. The air shower reduced dust exposures when it was turned on. Air shower was second only to worker differences in its effect upon dust exposure

LOCAL VENTILATION. (within modified work station). Statistically significant effect upon dust exposures depending upon the analysis. Some analyses indicated that local exhaust ventilation had no significant effect on dust exposures. The analyses indicated that exposures were reduced when the local exhaust ventilation was on.

BOOTH FLOW-AIR SHOWER interaction. (within modified work station). Statistically significant effect upon dust exposures depending upon the analysis. This relationship indicated that when the air shower was not operating, exposures increased as the booth flow was reduced.

All other interactions between controls did not have a statistically significant effect upon worker dust exposures.

Analyses were also performed to determine which specific configurations resulted in the lowest worker dust exposures. For these analyses, the data were restricted to the filter data from the modified work station configurations only. Two types of analyses were performed. First, a standard multiple comparison tests such as the Least Significant Difference (LSD) comparison, Scheffe's Method, and the Bonferroni or Dunn t-test comparison were performed. The listings from the multiple comparison tests are given in Table 3.

The second method for identifying the configuration resulting in the lowest dust exposure used a fitted regression equation to estimate the exposures. Like the multiple comparison tests, this analysis was done only on the modified workstation configuration data. While these estimates were used to determine the configuration resulting in the lowest exposures, no analysis was done to determine if there was a statistically significant difference between the estimated exposures. The exposure estimates from this method are given in Table 4.

Table 3. Results of multiple comparison test. Configurations are listed from lowest exposure to highest. Configurations with the same grouping letter do not have statistically significant differences in dust exposures.

CONFIGURATION	GROUPING
AIR SHOWER, LOCAL VENTILATION, FULL FLOW	A
AIR SHOWER, 1/3 FLOW	AB
AIR SHOWER, 2/3 FLOW	AB
AIR SHOWER, LOCAL VENTILATION, 1/3 FLOW	AB
AIR SHOWER, LOCAL VENTILATION, 2/3 FLOW	ABC
LOCAL VENTILATION, 1/3 FLOW	ABC
FULL FLOW	ABC
LOCAL VENTILATION, 2/3 FLOW	ABC
AIR SHOWER, FULL FLOW	ABC
LOCAL VENTILATION, FULL FLOW	BC
2/3 FLOW	BC
1/3 FLOW	C

NOTE: If not listed, control was not in place for that particular configuration.

Table 4. Predicted worker dust exposure results.

CONFIGURATION	PREDICTED EXPOSURE (mg/m^3)
AIR SHOWER, LOCAL VENTILATION, 1/3 FLOW	1.4
AIR SHOWER, LOCAL VENTILATION, FULL FLOW	1.7
AIR SHOWER, 2/3 FLOW	2.0
AIR SHOWER, 1/3 FLOW	2.0
AIR SHOWER, FULL FLOW	2.6
AIR SHOWER, LOCAL VENTILATION, 2/3 FLOW	2.7
LOCAL VENTILATION, FULL FLOW	3.1
LOCAL VENTILATION, 2/3 FLOW	4.9
LOCAL VENTILATION, 1/3 FLOW	5.3
FULL FLOW	5.5
2/3 FLOW	6.4
1/3 FLOW	8.2

NOTE: If not listed, that control was not in place for that particular configuration.

The major operating cost involved with all of the tested configurations is heating of the required make-up air. Tables 5 and 6 show the results of the cost analysis for the make-up air. Table 5 shows the cost on an annual basis while Table 6 gives the cost on an hourly basis. Both the volume of air exhausted (and hence the volume of make-up air needed) and the heating costs are given. Table 7 shows the cost of fabricating the air shower, the local exhaust ventilation and the modified work table. Table 8 lists the costs of the air cleaning equipment for each of the configurations. All costs given are only estimates as actual costs will vary with application.

After the workers had completed the seven weigh out runs, they were asked to comment on the various configurations they had used. Table 9 lists some general responses from the nine workers, along with the number of workers which made the particular comment.

Table 5. Annual contribution of make-up air cost by work station configuration.

WORK STATION CONFIGURATION	MAKE-UP AIR (m^3)	GAS DIRECT FIRED	GAS HEAT EXCHANGER	FUEL OIL
ORIG. FULL FLOW	54.4	$991	$1115	$1860
MOD. FULL FLOW, LOCAL VENTILATION	68.5	1249	1405	2345
MOD. FULL FLOW, AIR SHOWER, LOCAL EXHAUST	68.5	1249	1405	2345
MOD. FULL FLOW	54.4	991	1115	1860
MOD. FULL FLOW, AIR SHOWER	54.4	991	1115	1860
MOD. 2/3 FLOW, LOCAL VENTILATION	50.4	918	1033	1724
MOD. 2/3 FLOW, AIR SHOWER, LOCAL EXHAUST	50.4	918	1033	1724
MOD. 2/3 FLOW	36.3	660	743	1240
MOD. 2/3 FLOW, AIR SHOWER	36.3	660	743	1240
MOD. 1/3 FLOW, LOCAL VENTILATION	32.3	588	662	1104
MOD. 1/3 FLOW, AIR SHOWER, LOCAL EXHAUST	32.3	588	662	1104
MOD. 1/3 FLOW	18.1	331	372	620
MOD. 1/3 FLOW, AIR SHOWER	18.1	331	372	620

Table 6. Hourly contribution of make-up air cost by work station configuration.

WORK STATION CONFIGURATION	MAKE-UP AIR (m^3)	GAS DIRECT FIRED	GAS HEAT EXCHANGER	FUEL OIL
ORIG. FULL FLOW	54.4	$0.38	$0.43	$0.70
MOD. FULL FLOW, LOCAL VENTILATION	68.5	0.48	0.55	0.88
MOD. FULL FLOW, AIR SHOWER, LOCAL EXHAUST	68.5	0.48	0.55	0.88
MOD. FULL FLOW	54.4	0.38	0.43	0.70
MOD. FULL FLOW, AIR SHOWER	54.4	0.38	0.43	0.70
MOD. 2/3 FLOW, LOCAL VENTILATION	50.4	0.35	0.40	0.65
MOD. 2/3 FLOW, AIR SHOWER, LOCAL EXHAUST	50.4	0.35	0.40	0.65
MOD. 2/3 FLOW	36.3	0.26	0.29	0.47
MOD. 2/3 FLOW, AIR SHOWER	36.3	0.26	0.29	0.47
MOD. 1/3 FLOW, LOCAL VENTILATION	32.3	0.23	0.26	0.41
MOD. 1/3 FLOW, AIR SHOWER, LOCAL EXHAUST	32.3	0.23	0.26	0.41
MOD. 1/3 FLOW	18.1	0.13	0.14	0.23
MOD. 1/3 FLOW, AIR SHOWER	18.1	0.13	0.14	0.23

Table 7. Fabrication cost, in dollars, of modified work table, air shower and local exhaust ventilation.

CONTROL ITEM	COST, $	
MODIFIED WORKTABLE		
WORK TABLE	660	
WORK TABLE INSTALLATION	165	
TOTAL		$825
AIR SHOWER		
AIR SHOWER SUPPLY UNIT	210	
AIR SHOWER SUPPLY UNIT INSTALLATION	53	
DUCTS, INSTALLED	483	
TOTAL		$746
LOCAL EXHAUST VENTILATION		
LOCAL EXHAUST HOOD	245	
LOCAL EXHAUST HOOD INSTALLATION	61	
DUCTS	145	
TOTAL		$451

Table 8. Contribution of air cleaning cost by work station configuration.

WORK STATION CONFIGURATION	AIR TO BE CLEANED (m^3)	COST, AIR CLEANING EQUIPMENT
ORIGINAL, FULL FLOW	54.36	$10,009
MODIFIED, FULL FLOW, LOCAL VENTILATION	68.53	12,618
MODIFIED, FULL FLOW, AIR SHOWER, LOCAL VENTILATION	68.53	12,618
MODIFIED, FULL FLOW	54.36	10,009
MODIFIED, FULL FLOW, AIR SHOWER	54.36	10,009
MODIFIED, 2/3 FLOW, LOCAL VENTILATION	50.40	9,280
MODIFIED, 2/3 FLOW, AIR SHOWER, LOCAL VENTILATION	50.40	9,280
MODIFIED, 2/3 FLOW	36.25	6,675
MODIFIED, 2/3 FLOW, AIR SHOWER	36.25	6,675
MODIFIED, 1/3 FLOW, LOCAL VENTILATION	32.28	5,944
MODIFIED, 1/3 FLOW, AIR SHOWER, LOCAL VENTILATION	32.28	5,944
MODIFIED, 1/3 FLOW	18.12	3,336
MODIFIED, 1/3 FLOW, AIR SHOWER	18.12	3,336

Table 9. Worker comment responses about the workstation configurations tested.

COMMENT	NUMBER
LIKED LOCAL EXHAUST VENTILATION	7
LIKED NEW WORK TABLE	4
WORKSTATIONS NEED TO BE ADJUSTABLE FOR HEIGHT AND LEFT HANDED WORKERS	3
NEEDED MORE EXHAUST AT BOOTH	3
NEEDED MORE SPACE ON MODIFIED WORK TABLE	1
LOCAL EXHAUST HOOD NEEDED TO BE ROTATED TO GIVE BETTER ACCESS TO DRUM	1
PREFERRED FULL HEIGHT DRUM	1

IX. DISCUSSION

The data analyses of both the filter data and the real-time data tended to give similar results. While there were some differences between the two sets of analyses, the interpretation and conclusions were basically the same. Comments from the workers participating in the study were noted, and indicated the acceptance of the controls by the workers. The comments also indicated areas requiring additional work. In addition, a cost analysis calculation was made to demonstrate the possible cost or savings which may be incurred by installing a particular control configuration.

Worker differences had the most significant effect upon dust exposures for both the real time and filter data. These differences may include work practices and anthropometry. Since the emphasis of this study was to identify an effective ventilated work station configuration, the worker factor was not investigated further.

Both the real-time data results and the filter data results showed no significant difference in dust exposures between the original and the modified work stations. While the modified work station did not decrease the workers' dust exposures, it was perceived as an improvement in the work environment. From the workers' comments, most liked the modified layout. The only negative comments were that the modified table did not have as much usable area as the original and that the modified table, when used with the local ventilation, should be able to accommodate a left-handed worker.

The most significant effect on the workers' dust exposures was that from the air shower. There were two limitations upon the work station configurations utilizing the air shower. Because the air shower was located slightly behind the worker rather than directly above, it may not have been able to provide the best control of the eddy in front of the worker. The other limitation was the flow of air to the air shower unit. Since little is known about the effects of air showers at ventilated booths, the flow used in this study may not have been the optimum choice. While this study used an air shower face velocity of 0.25 m/s (50 ft/min), one study has reported air shower face velocities of 1.9 m/s (375 ft/min).(13) This later study did not use the air shower in conjunction with a ventilated booth. Both of the limitations, flow to air shower and position of air shower unit, may not have been significant in this study. Furthermore, while this NIOSH study used filtered air as the supply, fresh make-up air could be used to supply the air shower in an actual plant installation.

The filter and real-time results for the local exhaust ventilation were inconsistent. For the real time analysis, the presence of the local exhaust ventilation significantly reduced the worker dust exposures. The filter data results, though, were not as supportive. Depending upon the analysis, the local ventilation significantly reduced workers' dust exposures. Other analyses indicated this effect was not statistically significant. Besides reducing exposures during weigh out, the local ventilation also appeared to help control dust generated when the worker dumped the large bag of powder into the drum. Although no dust measurements were taken during this particular operation, visual observation showed the dust being drawn into the exhaust hood. Like the modified work station, most of the workers perceived the local exhaust ventilation as being effective and an improvement in the work environment. Several workers also used the top of the hood as a place to store the bags into which the powder is weighed. This extra bit of work space may be able to partially make up for the space lost by using the modified work table. One worker felt the hood should be rotated around the drum to give better access when scooping.

The analyses to determine which configurations resulted in the lowest exposures showed several trends. First, the configurations utilizing air shower tended to be near the top (lowest exposure). Looking further, for all analyses, the configuration with one-third flow, no air shower and no local exhaust ventilation had the highest predicted exposures. Two-thirds booth flow with no air shower and no local exhaust ventilation was also among the configurations with the highest predicted exposures. Local exhaust ventilation did not exhibit any distinguishable pattern. Although the number of groupings from the multiple comparison tests were low (two or three), these tests did help show some patterns and verifies some of the other analyses performed to determine the effects of the different controls.

X. CONCLUSIONS AND RECOMMENDATIONS

Many conclusions can be drawn from the results of this study. First, a basic ventilated booth can be configured to better manage exposures by installing additional types of controls. Further, by adding an air shower, the volume of air drawn into the booth can be cut drastically, to a face velocity of as low as 0.11 m/s (21 ft/min). Reducing the amount of air exhausted from the work station is attractive in two ways. With low exhaust volumes, less make-up air is needed. Make-up air is an expense since it must be heated in the winter. The savings due to lower make-up air requirements will vary with the climate of the plant. Secondly, because of lower exhaust volumes, less air cleaning capacity is needed for the air that is removed from the plant. In new facilities, this will result in savings on the size of the dust collector needed. In existing facilities, lower air cleaning capacity requirements for the weigh out operations results in the ability to direct the excess capacity to other areas of the plant. The particularly significant point is that by using the air shower in conjunction with the ventilated booth, worker dust exposures can be reduced, while reducing costs. From the analysis of the data, the air shower was the most significant control factor tested. Furthermore, since outside air must be supplied as make-up air, operating costs of the air shower will be relatively low.

While the analysis results for modified work station showed no significant effect on exposures and the local exhaust ventilation results showed conflicting results, these control modifications should be implemented along with the air shower. Both controls were perceived by the workers participating in the study, as an improvement in the work environment. Also, based upon observations made during the study, it appeared that the local ventilation helped control the dust exposures during filling of the material weigh out drum. While this specific operation was not the focus of the study, the local exhaust ventilation may be a worthwhile addition to the controls already in place. Because the local ventilation may have helped control dust exposures during both the weigh out operations in addition to the drum filling operations, installation of this hood would be advantageous. However, the effectiveness of the local exhaust ventilation at controlling dust exposures during drum filling should be evaluated. While most of the comments about the modified work station were positive, one worker noted the reduction in the work table area from the original work station. Before modifying the table at the work station, changes should be explored to increase the work table area.

As a single recommended configuration for the plant studied, the modified work table with the air shower, local exhaust ventilation, and one-third booth flow is the best option. In the rank ordering analyses, this configuration was consistently among the configurations with the lowest exposures. Based upon predicted exposures, the installation of this configuration may result in a 70% reduction in dust exposures versus the configuration with full flow and no air shower or local exhaust ventilation. The analyses indicated that the booth flows tested had no significant effect on worker dust exposures. Therefore, the flow at the booth can be reduced without increasing the exposures. It should be noted, however, that in the analysis to determine the configuration giving the best control, the modified work station with one-third booth and no air shower or local ventilation had the highest exposures. The analysis to determine which controls most effect dust exposures also showed that there was an interaction between the air shower and the booth flow. As the booth flow was reduced, exposures increased if the air shower was not operating. It would not be prudent, therefore, to reduce the booth flow without adding additional controls, namely the air shower.

Besides reducing exposures, the air shower, local exhaust ventilation and one-third flow configuration may reduce costs as well. This configuration had an installed fabrication cost of $2022, an annual make-up air cost of $662 per year (assuming natural gas with heat exchange operating at 80% efficiency), and an air cleaning equipment cost of $5,944. While this particular plant would see little cost saving due to reduction of air cleaning equipment costs, savings due to a reduction of make-up air will be important. With the currently installed work station having an estimated make-up air cost of $1115 per year, the recommended work station configuration will result in an annual savings of $453. Based upon the fabrication and make-up air costs only, the recommended configuration will have a payback period of about 4.5 years at current natural gas costs. Although this may not be considered a high rate of return, cost saving are not the major benefit derived from installing these controls. These controls will significantly reduce dust exposures while saving money.

While it has previously been shown that a ventilated booth alone will not adequately control dust exposures during the manual weigh out and transfer of powdered materials,(1) this study has demonstrated that these exposures can be reduced with the addition of several simple controls. Furthermore, cost savings can be incurred by installing these controls. Worker acceptance of the new controls, always important in the use of new systems, was favorable. The recommended work station with the air shower, local exhaust ventilation, and the modified work table can improve the work environment by reducing worker dust exposures by up to 70%, while, at the same time, decreasing operating costs.

XI. REFERENCES

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APPENDIX A

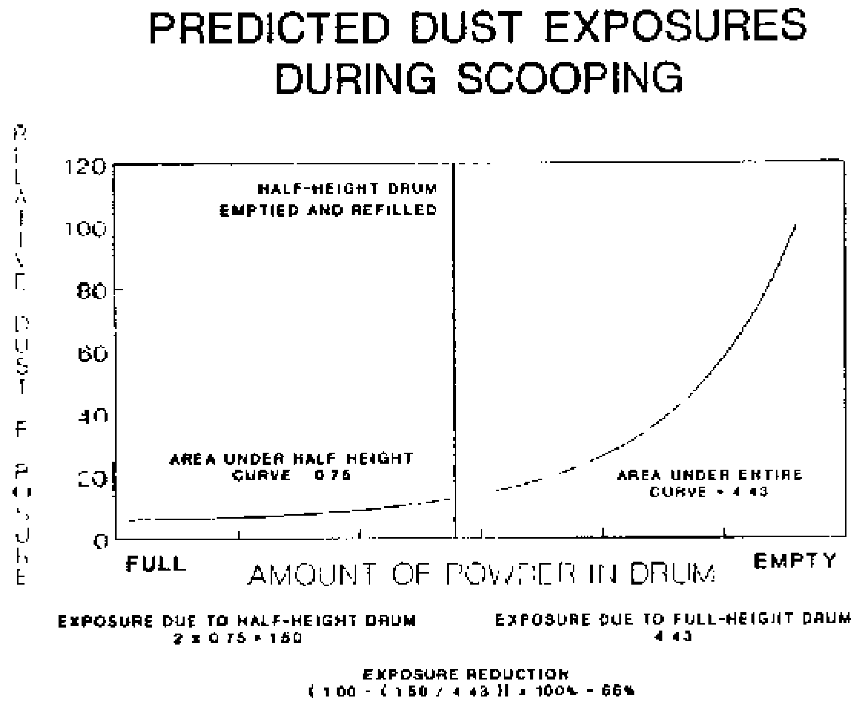

Figure A1. Predicted dust exposures during scooping and the reduction due to the use of half-height drums.(1)

The first study at the B. F. Goodrich plant in Marietta, Ohio,(1) revealed that scooping from the bottom of the drum would increase workers' dust exposures. One recommendation from that study was to use half-height drums to prevent the worker from scooping too far down. Figure A1 shows the predicted dust exposure during scooping of the powder. This figure plots exposure versus level of powder in the drum. The area under the entire curve is the total exposure when weighing from a full size drum of powder. The total exposure when weighing the same amount of powder from the half-height drums will be twice the area between the full and half full marks on the plot. Using the half-height drums will result in a 66% reduction in workers' dust exposures versus the use of the full size drum.

REFERENCES

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APPENDIX B

The objective of the study was to evaluate the effectiveness of the various workstation configurations at controlling worker dust exposures. The evaluation of each workstation configuration required a worker to transfer material to the bags for a designated time, using a work table configured as either original or redesigned, and, if redesigned, according to one of the possible 3x2x2 variations of booth flow rate, air shower, and local exhaust. Workers were a natural choice as blocks so that the treatment comparisons would be free as possible of worker variability. Within blocks, a complete replication of all treatment levels would require thirteen runs per worker: one run of the original workstation plus the 3x2x2 runs for the portion nested within the modified workstation. Due to time limitations, this appeared to be too many runs for each worker to complete. Therefore, a half fraction of the 3x2x2 design originally developed by Yates(1,2) was used for the portion of the experiment nested within the modified workstation setting. Table B1 shows the six half fractions for the 3x2x2 design. The resulting design was a nested fractional factorial: the first factor was WORK STATION: MODIFIED versus ORIGINAL. Further, a balanced half fraction of a 3x2x2 design with the factors of BOOTH FLOW, AIR SHOWER and LOCAL EXHAUST VENTILATION, was nested within the MODIFIED work station level. This design resulted in a total of seven runs to be completed by each worker: the one original workstation run, and the six runs from the half fraction factorial experiment. If all three pairs of possible half fractions are run by different workers (6 workers in all), then the design is balanced and all interactions may be estimated. Workers in groups were randomly assigned to the six setups or half fractions. This randomized the order in which the six possible sets were used. The plan was to use as many workers as time permitted. Seven workers completed a single sequence, while two workers completed two sequences each. The total was treated as if eleven workers participated. Since eleven sequences were completed, all three pairs of replicates, or possible ways to split the complete factorial into two halves were used, with all but one represented twice. For each worker, the order of the 7 runs was randomized. Neither the configuration assigned to a worker nor the order of runs was known to the experimenters until the worker was ready to begin.

Table B1. Half-fractions pairs for 3x2x2 factorial design.

PAIR I

1/3 FLOW, AIR SHOWER	1/3 FLOW
1/3 FLOW, LOCAL EXHAUST	1/3 FLOW, LOCAL EXHAUST, AIR SHOWER
2/3 FLOW	2/3 FLOW, AIR SHOWER
2/3 FLOW, LOCAL EXHAUST, AIR SHOWER	2/3 LOCAL EXHAUST
FULL FLOW	FULL FLOW, AIR SHOWER
FULL FLOW, LOCAL EXHAUST, AIR SHOWER	FULL FLOW, LOCAL EXHAUST

PAIR II

1/3 FLOW	1/3 FLOW, AIR SHOWER
1/3 FLOW, LOCAL EXHAUST, AIR SHOWER	1/3 FLOW, LOCAL EXHAUST
2/3 FLOW, AIR SHOWER	2/3 FLOW
2/3 FLOW, LOCAL EXHAUST	2/3 FLOW, LOCAL EXHAUST, AIR SHOWER
FULL FLOW	FULL FLOW, AIR SHOWER
FULL FLOW, LOCAL EXHAUST, AIR SHOWER	FULL FLOW, LOCAL EXHAUST

PAIR III

1/3 FLOW	1/3 FLOW, AIR SHOWER
1/3 FLOW, LOCAL EXHAUST, AIR SHOWER	1/3 FLOW, LOCAL EXHAUST
2/3 FLOW	2/3 FLOW, AIR SHOWER
2/3 FLOW, LOCAL EXHAUST, AIR SHOWER	2/3 FLOW, LOCAL EXHAUST
FULL FLOW, AIR SHOWER	FULL FLOW
FULL FLOW, LOCAL EXHAUST	FULL FLOW LOCAL EXHAUST, AIR SHOWER

REFERENCES

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APPENDIX C

The study set out to determine which of the work station modifications, if any, affected worker dust exposures as measured by the personal filter samples and the real-time measurements. The analyses were conducted using a personal computer and PC SAS PROC GLM software.(1) The dependent variable for the analysis of the filter data was the dust exposure calculated from the weight of the personal filter samples. For the real-time data, the dependent variable was the average of the one second readings over the fifteen minute run. Using the SAS software, an analysis was performed to develope an model to determine if both flow, air shower, local ventilation, the control interactions, as well as work table (modified or original) and worker differences affected worker dust exposures. The worker differences were included to describe all effects, such as work practices, that could not be attributed to the other terms listed.

Because there were two filter measures of dust exposure, LEFT and RIGHT lapels, the analyses to determine factors affecting worker dust exposures were performed in two ways, univariate and multivariate. The multivariate analysis reflects relationships for any linear combination of the two component variables (LEFT and RIGHT). The univariate results are more meaningful if each of the two shoulder measures is considered to characterize a separate and distinct type of exposure and there is interest in examining each one independently. Which results to use is less of a statistical question than one concerning the objectives of the analysis.

The analysis of the filter data was performed first on its original scale (no transformation). Not unexpectedly, a "funnel" shape pattern was detected in the plots of residuals against expected values for the response variables. This indicated a positive relationship between error variance and the expected or mean value. A natural logarithmic transformation of the response measurements was used to remove this relationship. Original measurements which had been zero or negative were replaced by the low value of 0.0025 for the logarithmic transformation only. A plot of the residuals of the logarithmically transformed data now displayed other patterns; generally, there was an inverse relationship between the average residual and estimated mean value although the spread among residuals appeared to remain constant, Secondly, residuals for the observations set to 0.0025 before the transformation formed a straight line parallel to the main axis of variation of the remaining residuals.

To remove these patterns, all zero or negative observations were treated as missing except those which could be replaced by estimated values. Missing RIGHT values were estimated from a fitted regression of non-missing LEFT values. Likewise, LEFT values were estimated from a fitted regression of non-missing RIGHT values. One RIGHT value was replaced by an estimate with seven others treated as missing. Seven LEFT values were also treated as missing, with two replaced with estimates. The logarithmic transformation was applied to the resulting data set. These measures drastically reduced the estimated standard errors. The residual plots from the analysis of this revised data set exhibited no exceptional pattern. However, the residual plot for the RIGHT values evidenced one negative outlier while that for the LEFT exhibited one negative and one positive outlier. Both of the negative outliers were for observation 1. The data was then analyzed again in two ways. First, the negative outliers (also the lowest values for both LEFT and RIGHT) were replaced by the next lowest observation. This still produced outliers in the resulting residual plots. Therefore, the analysis was repeated with observation 1 removed. While these modifications appeared to reduce estimated standard errors even more, none, with the exception of the logarithmic transformation, changed the statistical significance (at the 0.05 level) of the various factors. The mean square errors for the analyses are given in Tables C1-C4. The main difference between the original scale and the logarithmically transformed analyses was the effect of the local exhaust ventilation.

TABLE C1. Standard errors (mean square error) for univariate right analyses of original scale filter data.

ANALYSIS	STANDARD ERROR
UNIVARIATE RIGHT ORIGINAL SCALE	25.57
UNIVARIATE RIGHT NON-POSITIVE OBSERVATIONS ESTIMATED	27.22
UNIVARIATE RIGHT OBSERVATION 1 REPLACED BY NEXT LOWEST	27.20
UNIVARIATE RIGHT OBSERVATION 1 DELETED	27.64

TABLE C2. Standard errors (mean square error) for univariate left analyses of original scale filter data.

ANALYSIS	STANDARD ERROR
UNIVARIATE LEFT ORIGINAL SCALE	19.84
UNIVARIATE LEFT NON-POSITIVE OBSERVATIONS ESTIMATED	21.31
UNIVARIATE LEFT OBSERVATION 1 REPLACED BY NEXT LOWEST	21.30
UNIVARIATE LEFT OBSERVATION 1 DELETED	21.72

TABLE C3. Standard errors (mean square error) for univariate right analyses of log transformed filter data.

ANALYSIS	STANDARD ERROR
UNIVARIATE RIGHT LOG TRANSFORMED	3.624
UNIVARIATE RIGHT NON-POSITIVE OBSERVATIONS ESTIMATED	0.872
UNIVARIATE RIGHT OBSERVATION 1 REPLACED BY NEXT LOWEST	0.622
UNIVARIATE RIGHT OBSERVATION 1 DELETED	0.492

TABLE C4. Standard errors (mean square error) for univariate left analyses of log transformed filter data.

ANALYSIS	STANDARD ERROR
UNIVARIATE LEFT LOG TRANSFORMED	3.124
UNIVARIATE LEFT NON-POSITIVE OBSERVATIONS ESTIMATED	0.944
UNIVARIATE LEFT OBSERVATION 1 REPLACED BY NEXT LOWEST	0.841
UNIVARIATE LEFT OBSERVATION 1 DELETED	0.642

The following summarizes the individual factors and their associated effect on worker dust exposures based upon analysis of the filter data. Unless otherwise noted, statistical significance is given at the 0.05 level.

WORKER. Statistically significant effect on dust exposures for all analyses; the observed significance level was consistently at or below 0.0001.

WORK STATION. No significant effect on dust exposures between original and modified work stations.

BOOTH FLOW. (within modified work station). No significant effect on dust exposures between the three different flows for all analyses.

AIR SHOWER. (within modified work station). Statistically significant effect on dust exposures for all analyses. The observed significance level ranged from 0.006 to below 0.0001. Observed significance levels were lower (i.e., "more" significant) for right than left measures while log-transformed measures were more significant than the original scale. AIR SHOWER also became more significant as observation 1 was progressively modified. The estimated parameter for the effect, when ON, was negative, indicating that the presence of an air shower reduced exposure.

LOCAL VENTILATION. (within modified work station). The original scale multivariate results showed LOCAL VENTILATION to have significant on workers' dust exposures. The original scale univariate results for RIGHT also showed statistical significance . The RIGHT univariate analyses of the log transformed data showed LOCAL VENTILATION to approach statistical significance as observation 1 was progessively modified. The estimated effect for LOCAL VENTILATION was negative, indicating a decrease in exposure. For all other analyses, LOCAL VENTILATION did not significantly effect dust exposures.

BOOTH FLOW-AIR SHOWER interaction. (within modified work station). All of the original scale multivariate results showed a significant effect on dust exposures. The original scale univariate analysis with no modification of observation 1, showed statistical significance for RIGHT only. This effect became barely non-significant as observation 1 was progressively modified. This term was not significant for any of the logarithmically transformed analyses. This interaction indicated that as the booth flow was reduced, dust exposures increased if the air shower was not operating.

All other terms were not statistically significant for all analyses.

Tables C5-C12 lists the significance levels of the factors and interactions for all the analyses.

TABLE C5. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of original scale filter data.

FACTOR	MULTI ORIGINAL SCALE	RIGHT ORIGINAL SCALE	LEFT ORIGINAL SCALE
WORKER	0.0001	0.0001	0.0001
WORKSTATION	0.2988	0.2893	0.1186
BOOTH FLOW	0.4776	0.6354	0.7539
AIR SHOWER	0.0015	0.0006	0.0009
BOOTH FLOW-AIR SHOWER	0.0099	0.0130	0.2326
LOCAL VENTILATION	0.0118	0.0044	0.1701
BOOTH FLOW-LOCAL VENTILATION	0.4374	0.6433	0.4421
AIR SHOWER-LOCAL VENTILATION	0.6024	0.5423	0.3162
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.5411	0.8969	0.8962

TABLE C6. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of log transformed filter data.

FACTOR	MULTI LOG SCALE	RIGHT LOG SCALE	LEFT LOG SCALE
WORKER	0.0001	0.0001	0.0001
WORKSTATION	0.1156	0.1248	0.0370
BOOTH FLOW	0.3934	0.6821	0.9854
AIR SHOWER	0.0015	0.0003	0.0034
BOOTH FLOW-AIR SHOWER	0.0599	0.0600	0.1808
LOCAL VENTILATION	0.3115	0.4698	0.7142
BOOTH FLOW-LOCAL VENTILATION	0.5325	0.7024	0.5360
AIR SHOWER-LOCAL VENTILATION	0.6633	0.3950	0.3936
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.0644	0.2134	0.0875

TABLE C7. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of original scale filter data with estimates for non-positive observations.

FACTOR	MULTI ESTIMATE ORIGINAL	RIGHT ESTIMATE ORIGINAL	LEFT ESTIMATE ORIGINAL
WORKER	0.0001	0.0002	0.0001
WORKSTATION	0.3250	0.4543	0.1440
BOOTH FLOW	0.2155	0.5433	0.4507
AIR SHOWER	0.0064	0.0059	0.0019
BOOTH FLOW-AIR SHOWER	0.0434	0.0517	0.3727
LOCAL VENTILATION	0.0257	0.0089	0.1979
BOOTH FLOW-LOCAL VENTILATION	0.4536	0.6108	0.5012
AIR SHOWER-LOCAL VENTILATION	0.5004	0.6437	0.2689
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.3372	0.7918	0.8546

TABLE C8. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of log transformed filter data with estimates for non-positive observations.

FACTOR	MULTI ESTIMATE LOG	RIGHT ESTIMATE LOG	LEFT ESTIMATE LOG
WORKER	0.0001	0.0020	0.0001
WORKSTATION	0.4873	0.2728	0.2322
BOOTH FLOW	0.4412	0.7172	0.7637
AIR SHOWER	0.0011	0.0003	0.0003
BOOTH FLOW-AIR SHOWER	0.4152	0.4534	0.6611
LOCAL VENTILATION	0.2809	0.1311	0.3227
BOOTH FLOW-LOCAL VENTILATION	0.5299	0.5691	0.7597
AIR SHOWER-LOCAL VENTILATION	0.8938	0.9715	0.8217
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.8325	0.9461	0.8603

TABLE C9. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of original scale filter data with estimates for non-positive observations and observation 1 (lowest) replaced with next lowest observation.

FACTOR	MULTI REPLACE ORIGINAL	RIGHT REPLACE ORIGINAL	LEFT REPLACE ORIGINAL
WORKER	0.0001	0.0002	0.0001
WORKSTATION	0.3254	0.4606	0.1449
BOOTH FLOW	0.2156	0.5434	0.4506
AIR SHOWER	0.0064	0.0058	0.0019
BOOTH FLOW-AIR SHOWER	0.0433	0.0516	0.3725
LOCAL VENTILATION	0.0257	0.0089	0.1980
BOOTH FLOW-LOCAL VENTILATION	0.4536	0.6106	0.5012
AIR SHOWER-LOCAL VENTILATION	0.5004	0.6426	0.2686
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.3364	0.7900	0.8545

TABLE C10. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of log transformed filter data with estimates for non-positive observations and observation 1 (lowest) replaced with next lowest observation.

FACTOR	MULTI REPLACE LOG	RIGHT REPLACE LOG	LEFT REPLACE LOG
WORKER	0.0001	0.0003	0.0001
WORKSTATION	0.5381	0.6134	0.3205
BOOTH FLOW	0.4352	0.6469	0.7357
AIR SHOWER	0.0002	0.0001	0.0002
BOOTH FLOW-AIR SHOWER	0.2739	0.3192	0.6215
LOCAL VENTILATION	0.1771	0.0803	0.3001
BOOTH FLOW-LOCAL VENTILATION	0.3991	0.4520	0.7351
AIR SHOWER-LOCAL VENTILATION	0.9271	0.9533	0.7845
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.8008	0.9615	0.8772

TABLE C11. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of original scale filter data with estimates for non-positive observations and observation 1 deleted.

FACTOR	MULTI DELETE ORIGINAL	RIGHT DELETE ORIGINAL	LEFT DELETE ORIGINAL
WORKER	0.0001	0.0003	0.0002
WORKSTATION	0.4120	0.6068	0.2118
BOOTH FLOW	0.2240	0.5553	0.4569
AIR SHOWER	0.0069	0.0062	0.0021
BOOTH FLOW-AIR SHOWER	0.0449	0.0534	0.3769
LOCAL VENTILATION	0.0278	0.0097	0.2040
BOOTH FLOW-LOCAL VENTILATION	0.4615	0.6170	0.5101
AIR SHOWER-LOCAL VENTILATION	0.5042	0.6292	0.2675
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.3373	0.7641	0.8545

TABLE C12. Multivariate and univariate (RIGHT and LEFT) significance levels for analyses of log transformed filter data with estimates for non-positive observations and observation 1 deleted.

FACTOR	MULTI DELETE LOG	RIGHT DELETE LOG	LEFT DELETE LOG
WORKER	0.0001	0.0001	0.0001
WORKSTATION	0.7132	0.4669	0.7722
BOOTH FLOW	0.4465	0.6063	0.6478
AIR SHOWER	0.0001	0.0001	0.0001
BOOTH FLOW-AIR SHOWER	0.2096	0.2207	0.5000
LOCAL VENTILATION	0.1478	0.0566	0.2598
BOOTH FLOW-LOCAL VENTILATION	0.3418	0.3627	0.6700
AIR SHOWER-LOCAL VENTILATION	0.8671	0.8142	0.6209
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.7330	0.7330	0.7935

The analysis of real-time data to determine which factors affected worker dust exposure, was done in a manner similar to the filter data analysis. All analyses were performed using PC SAS PROC GLM on a personal computer.(1) A model, which included most of the same terms as the filter data analysis, was developed using the real-time data in its original scale (no transformation). Like the filter data, a plot of the residuals showed a "funnel" shaped pattern. The data was logarithmically transformed and the analysis repeated. A second plot of the residuals showed no patterns.

The results of the analysis of the real-time data were similar to the results of the filter data. Worker effects proved to have a highly significant effect (at the 0.05 level) on exposures. Local ventilation, air shower and the air shower-booth flow interaction also had a significant effect on the dust exposures. Significance levels of the terms from the real-time data analysis are given in Table C13.

TABLE C13. Significance levels for analyses of log transformed real-time data.

FACTOR	SIGNIFICANCE
WORKER	0.0001
WORKSTATION	0.4013
BOOTH FLOW	0.6860
AIR SHOWER	0.0048
BOOTH FLOW-AIR SHOWER	0.1313
LOCAL VENTILATION	0.0120
BOOTH FLOW-LOCAL VENTILATION	0.8941
AIR SHOWER-LOCAL VENTILATION	0.3002
BOOTH FLOW-AIR SHOWER-LOCAL VENTILATION	0.5846

Analyses were also performed on the filter data to determine which configuration provides the best control of dust exposures. For this ordering, the data were restricted to the modified work station configurations filter data only. The "X matrix" for the model for the factorial design was replaced by an X matrix for a single factor with 12 levels, one for each possible configuration of the factors of booth flow, air shower and local exhaust. SAS furnishes two types of analyses for the rank ordering. First, it provides several standard multiple comparison tests such as the Least Significant Difference (LSD) comparison, Scheffe's Method, and the Bonferroni or Dunn t-test comparison among a group of means. The Bonferroni method was selected although it assumes equal sample sizes, which was not exactly fulfilled (sample means were based on either 5 or 6 observations). This method does provide protection against falsely declaring one or more configurations as different when none are (probability of error is less than or equal to 0.05). This feature is somewhat nominal, as comparisons of the configurations would not be made unless the F-test for the single factor is significant at the 0.05 level. The Bonferroni method also provides greater protection than the LSD method for falsely identifying the unequal configurations given that at least one differs from the others, although the probability of this error is not known. However, neither the Bonferroni nor any of the other means comparisons methods adjust for confounding caused by lack of balance in the design, such as worker differences. The rank orderings from the Bonferroni method are given in Table C14.

Table C14. Rank ordering by Bonferroni method for data with observation 1 replaced. Configurations are listed from lowest exposure to highest.

LEFT CONFIGURATION	GROUP	RIGHT CONFIGURATION	GROUP	BOTH CONFIGURATION	GROUP
AIR, 1/3	A	AIR, LOCAL, FULL	A	AIR, 1/3	A
AIR, LOCAL, FULL	AB	AIR, 1/3	A	AIR, LOCAL, FULL	A
AIR, LOCAL, 1/3	AB	AIR, LOCAL, 1/3	A	AIR, LOCAL, 1/3	A
AIR, 2/3	AB	AIR, 2/3	A	AIR, 2/3	A
LOCAL, 1/3	AB	AIR, LOCAL, 2/3	AB	LOCAL, 1/3	AB
FULL	AB	FULL	AB	FULL	AB
LOCAL, 2/3	AB	LOCAL, 2/3	AB	LOCAL, 2/3	AB
AIR, FULL	AB	LOCAL, 1/3	AB	AIR, LOCAL, 2/3	AB
AIR, LOCAL, 2/3	AB	LOCAL, FULL	AB	LOCAL, FULL	AB
LOCAL, FULL	AB	2/3	AB	AIR, FULL	AB
2/3	AB	AIR, FULL	AB	2/3	AB
1/3	B	1/3	B	1/3	B

LOG LEFT CONFIGURATION	GROUP	LOG RIGHT CONFIGURATION	GROUP	LOG BOTH CONFIGURATION	GROUP
AIR, LOCAL, FULL	A	AIR, LOCAL, FULL	A	AIR, LOCAL, FULL	A
AIR, 1/3	AB	AIR, 1/3	AB	AIR, 1/3	AB
AIR, LOCAL, 1/3	ABC	AIR, 2/3	AB	AIR, 2/3	AB
AIR, 2/3	ABC	AIR, LOCAL, 1/3	AB	AIR, LOCAL, 1/3	AB
AIR, LOCAL, 2/3	ABC	AIR, LOCAL, 2/3	ABC	AIR, LOCAL, 2/3	ABC
LOCAL, 1/3	ABC	FULL	ABC	LOCAL, 1/3	ABC
FULL	ABC	LOCAL, 1/3	ABC	FULL	ABC
LOCAL, 2/3	ABC	LOCAL, 2/3	ABC	LOCAL, 2/3	ABC
AIR, FULL	ABC	LOCAL, FULL	ABC	AIR, FULL	ABC
LOCAL, FULL	ABC	AIR, FULL	ABC	LOCAL, FULL	BC
2/3	BC	2/3	BC	2/3	BC
1/3	C	1/3	C	1/3	C

NOTE: Configurations with the same grouping letter are not significantly different.

AIR = Air Shower 1/3 = One-third Booth Flow

LOCAL = Local Ventilation 2/3 = Two-thirds Booth Flow FULL = Full Booth Flow

If not listed, control was not in place for the particular configuration.

The second method for ranking the configurations, used a fitted model to estimate the expected exposures. This analysis was done only among the modified workstation configurations. The model had two factors: a term describing the control configurations (ONEWAY), and a term describing all other effects including the worker (WORKER). With 12 different control configurations, ONEWAY had 12 different values. Likewise, 11 different workers were sampled in the study resulting in 11 different values for WORKER. However, the SAS output for comparisons among these estimated values is not as descriptive as the Bonferroni method and comparisons among the estimated mean values are more complex as the estimates are correlated. This method is preferred, though, because of the adjustment for worker differences. These estimates were used to rank order the configurations even though an analysis to determine which differences are statistically significant was not done. The rank orderings from this method are given in Table C15.

Table C15. Rank ordering as predicted of predicted exposures (mg/m^3) from General Linear Models Procedure for data with observation 1 replaced.

CONFIGURATION	LOG LEFT	LOG RIGHT	LOG BOTH	LEFT	RIGHT	BOTH
AIR, LOCAL, 1/3	1.2	1.7	1.4	0.4	1.5	1.0
AIR, LOCAL, FULL	1.6	1.7	1.7	4.2	3.8	4.0
AIR, 2/3	1.8	2.2	2.0	4.4	5.9	5.1
AIR, 1/3	1.7	2.4	2.0	4.9	4.6	4.4
AIR, LOCAL, 2/3	2.6	2.7	2.7	5.9	3.5	4.7
LOCAL, FULL	3.1	3.2	3.1	5.0	3.3	4.2
AIR, FULL	2.0	3.3	2.6	2.3	7.0	4.7
LOCAL, 2/3	4.4	5.5	4.9	6.1	7.1	6.6
FULL	5.1	5.8	5.5	7.2	7.8	7.5
LOCAL, 1/3	4.6	6.1	5.3	6.9	7.9	7.4
2/3	6.0	6.8	6.4	9.7	8.6	9.2
1/3	6.6	10.3	8.2	10.5	15.5	13.0

NOTE: AIR = Air Shower LOCAL = Local Ventilation
1/3 = One-third Booth Flow 2/3 = One-third Booth Flow
FULL = One-third Booth Flow
If not listed, that control was not in place for the particular configuration.

In addition to the personal sampling (filter and real-time), two filter samples and one real-time measurement of background dust levels were taken in the plant during each run. The subsequent analyses of these measures confirmed that adjustment for background dust levels did not affect the results. Thus, only the unadjusted results are reported.

REFERENCES

1. SAS Institute. SAS User's Guide: Statistics. Cary NC 1982.

APPENDIX D

FILTER DATA

RUN NO	BOOTH FLOW	WORK-STATION	MODIFY	RIGHT FLOW (l/min)	RIGHT WEIGHT (mg)	RIGHT CONC. (mg/m3)	LEFT FLOW (l/min)	LEFT WEIGHT (mg)	LEFT CONC (mg/m3)	BG1 FLOW (l/min)	BG1 WEIGHT (mg)	BG1 CONC (mg/m3)	BG2 FLOW (l/min)	BG2 WEIGHT (mg)	BG2 CONC. (mg/m3)	BAG COUNT
1	FULL	ORIG	NONE	13.47	0.00667	0.0275	13.15	-0.01333	-0.0282	13.13	-0.03333	-0.0846	13.76	-0.00333	0.0000	82
2	2/3	MOD	SHOWER	13.47	0.19667	0.9899	13.15	0.42667	2.1800	13.13	-0.00333	0.0000	13.76	-0.00333	0.0000	79
3	2/3	MOD	LOCAL	13.47	1.75667	8.7107	13.15	0.59667	3.0418	13.13	-0.01333	-0.0508	13.76	-0.00333	0.0000	81
4	FULL	MOD	BOTH	13.47	0.36667	1.8312	13.15	0.53667	2.7376	13.13	-0.01333	-0.0508	13.76	-0.01333	-0.0484	85
5	1/3	MOD	LOCAL	13.47	0.78667	3.9099	13.15	1.40667	7.1483	13.13	-0.01333	-0.0508	13.76	-0.00333	0.0000	75
6	FULL	MOD	NONE	13.47	1.13667	5.6422	13.15	1.07667	5.4753	13.13	-0.01333	-0.0508	13.76	-0.02333	-0.0969	84
7	1/3	MOD	SHOWER	13.47	0.42667	2.1282	13.15	0.35667	1.8251	13.13	-0.01333	-0.0508	13.76	-0.01333	-0.0484	88
8	FULL	ORIG	NONE	13.15	1.48667	7.5539	13.47	1.02667	5.0977	13.13	-0.01333	-0.0508	13.76	-0.00333	0.0000	86
9	FULL	MOD	BOTH	13.15	0.13667	0.7098	13.47	0.05667	0.2970	13.13	0.01667	0.1015	13.76	0.00667	0.0484	79
10	1/3	MOD	BOTH	13.15	0.03667	0.2028	13.47	0.01667	0.0990	13.13	0.00667	0.0508	13.76	0.00667	0.0484	98
11	2/3	MOD	LOCAL	13.15	0.71667	3.6502	13.47	0.41667	2.0787	13.13	0.01667	0.1015	13.76	0.01667	0.0969	93
12	1/3	MOD	NONE	13.15	1.07667	5.4753	13.47	1.27667	1.5838	13.13	-0.01333	-0.0508	13.76	0.00667	0.0484	99
13	FULL	MOD	NONE	13.15	0.15667	0.8112	13.47	0.08667	0.4454	13.13	-0.00333	0.0000	13.76	-0.00333	0.0000	107
14	2/3	MOD	SHOWER	13.15	0.28667	1.4702	13.47	0.02667	0.1485	13.13	0.01667	0.1015	13.76	0.00667	0.0484	98
15	1/3	MOD	BOTH	13.47	0.76667	3.8109	13.15	0.51667	2.6362	13.13	-0.00333	0.0000	13.76	-0.02333	-0.0969	63
16	FULL	ORIG	NONE	13.47	1.97667	9.7996	13.15	1.92667	9.7845	13.13	-0.01333	-0.0508	13.76	-0.00333	0.0000	64
17	FULL	MOD	SHOWER	13.47	5.17667	25.6372	13.15	1.10667	5.6274	13.13	0.00667	0.0508	13.76	0.00667	0.0484	69
18	2/3	MOD	NONE	13.47	4.60667	22.8161	13.15	3.81667	19.3663	13.13	0.02667	0.1523	13.76	0.01667	0.0969	68
19	FULL	MOD	LOCAL	13.47	1.98667	9.8490	13.15	3.66667	18.6058	13.13	-0.01333	-0.0508	13.76	0.01667	0.0969	75
20	2/3	MOD	BOTH	13.47	1.41667	7.0280	13.15	1.90667	9.6831	13.13	0.00667	0.0508	13.76	-0.00333	0.0000	63
21	1/3	MOD	NONE	13.47	8.38667	41.5244	13.15	5.47667	27.7820	13.13	0.01667	0.1015	13.76	0.02667	0.1453	78
22	1/3	MOD	SHOWER	13.47	0.24667	1.2373	13.15	0.21667	1.1153	13.13	0.02667	0.1523	13.76	0.03667	0.1938	63
23	2/3	MOD	BOTH	13.47	0.28667	1.4353	13.15	0.30667	1.5716	13.13	0.00667	0.0508	13.76	0.01667	0.0969	65
24	1/3	MOD	LOCAL	13.47	0.50667	2.5241	13.15	0.34667	1.7744	13.13	0.00667	0.0508	13.76	0.00667	0.0484	70
25	FULL	MOD	NONE	13.47	0.75667	3.7614	13.15	1.40667	7.1483	13.13	0.00667	0.0508	13.76	-0.00333	0.0000	74
26	FULL	ORIG	NONE	13.47	1.01667	5.0483	13.15	0.68667	3.4981	13.13	0.00667	0.0508	13.76	-0.00333	0.0000	79
27	2/3	MOD	NONE	13.47	1.20667	5.9886	13.15	0.99667	5.0697	13.13	0.00667	0.0508	13.76	-0.00333	0.0000	78
28	FULL	MOD	BOTH	13.47	0.12667	0.6434	13.15	0.07667	0.4056	13.13	0.00667	0.0508	13.76	0.01667	0.0969	79
29	1/3	MOD	NONE	13.47	2.19667	10.8884	13.15	1.93667	9.8352	13.13	0.00667	0.0508	13.76	0.00667	0.0484	53
30	1/3	MOD	BOTH	13.47	0.89667	4.4543	13.15	0.93667	4.7655	13.13	-0.00333	0.0000	13.76	-0.01333	-0.0484	51
31	FULL	ORIG	NONE	13.47	0.46667	2.3262	13.15	0.34667	1.7744	13.13	-0.02333	-0.1015	13.76	-0.02333	-0.0969	55
32	FULL	MOD	SHOWER	13.47	3.75667	18.6093	13.15	3.29667	16.7300	13.13	-0.00333	0.0000	13.76	-0.02333	-0.0969	54
33	2/3	MOD	LOCAL	13.47	0.46667	2.3262	13.15	0.29667	1.5209	13.13	-0.00333	0.0000	13.76	-0.00333	0.0000	58
34	FULL	MOD	LOCAL	13.47	1.08667	5.3947	13.15	0.95667	4.8669	13.13	0.00667	0.0508	13.76	-0.01333	-0.0484	58
35	2/3	MOD	SHOWER	13.47	0.38667	1.9302	13.15	0.44667	2.2814	13.13	-0.00333	0.0000	13.76	-0.01333	-0.0484	64
36	1/3	MOD	LOCAL	13.47	0.60667	3.0191	13.15	0.42667	2.1800	13.13	0.01667	0.1015	13.76	-0.00333	0.0000	83
37	2/3	MOD	NONE	13.47	0.82667	4.1079	13.15	0.87667	4.4613	13.13	-0.00333	0.0000	13.76	-0.00333	0.0000	81

RUN NO.	BOOTH FLOW	WORK-STATION	MODIFY	RIGHT FLOW (l/min)	RIGHT WEIGHT (mg)	RIGHT CONC (mg/m3)	LEFT FLOW (l/min)	LEFT WEIGHT (mg)	LEFT CONC (mg/m3)	BG1 FLOW (l/min)	BG1 WEIGHT (mg)	BG1 CONC (mg/m3)	BG2 FLOW (l/min)	BG2 WEIGHT (mg)	BG2 CONC (mg/m3)	BAG COUNT
38	FULL	ORIG	NONE	13.47	0.40667	2.0292	13.15	0.53667	2.7376	13.13	-0.00333	0.0000	13.76	0.03667	0.1938	83
39	FULL	MOD	SHOWER	13.47	0.33667	1.6828	13.15	0.35667	1.8251	13.13	0.30667	1.5740	13.76	0.04667	0.2422	90
40	FULL	MOD	LOCAL	13.47	0.66667	3.3160	13.15	1.22667	6.2357	13.13	0.04667	0.2539	13.76	0.02667	0.1453	96
41	2/3	MOD	BOTH	13.47	0.44667	2.2272	13.15	0.34667	1.7744	13.13	0.03667	0.2031	13.76	0.01667	0.0969	93
42	1/3	MOD	SHOWER	13.47	0.31667	1.5838	13.15	0.29667	1.5209	13.13	0.01667	0.1015	13.76	0.01667	0.0969	90
43	1/3	MOD	SHOWER	13.15	0.53667	0.0000	13.47	0.85667	0.0000	13.13	0.04667	0.0000	13.76	0.03667	0.0000	83
44	FULL	ORIG	NONE	13.15	0.93667	0.0000	13.47	0.67667	0.0000	13.13	0.02667	0.0000	13.76	0.02667	0.0000	87
45	2/3	MOD	BOTH	13.15	0.46667	0.0000	13.47	0.96667	0.0000	13.13	0.01667	0.0000	13.76	0.02667	0.0000	93
46	FULL	MOD	NONE	13.15	1.91667	9.7338	13.47	0.95667	4.7513	13.13	0.02667	0.0000	13.76	0.02667	0.0000	91
47	2/3	MOD	NONE	13.15	1.10667	5.6274	13.47	0.68667	0.0000	13.13	0.06667	0.3554	13.76	0.04667	0.2422	103
48	FULL	MOD	BOTH	13.15	0.42667	2.1800	13.47	0.96667	4.8008	13.13	0.20667	1.0663	13.76	0.19667	0.9690	102
49	1/3	MOD	LOCAL	13.15	2.84667	14.4487	13.47	1.31667	6.5330	13.13	0.03667	0.0000	13.76	0.05667	0.2907	102
50	2/3	MOD	SHOWER	13.47	3.26667	16.1841	13.15	2.34667	11.9138	13.13	0.02667	0.1523	13.76	-0.00333	0.0000	35
51	2/3	MOD	LOCAL	13.15	1.16667	5.9316	13.47	1.52667	7.5724	13.13	0.01667	0.1015	13.76	-0.00333	0.0000	39
52	FULL	MOD	LOCAL	13.15	0.45667	2.3321	13.47	0.30667	1.5343	13.13	-0.01333	-0.0508	13.76	-0.00333	0.0000	46
53	1/3	MOD	NONE	13.15	2.11667	10.7478	13.47	1.59667	7.9188	13.13	-0.01333	-0.0508	13.76	0.00667	0.0484	46
54	FULL	MOD	SHOWER	13.15	0.60667	3.0925	13.47	0.60667	3.0191	13.13	-0.00333	0.0000	13.76	-0.00333	0.0000	47
55	FULL	ORIG	NONE	13.15	1.04667	5.3232	13.47	0.64667	3.2170	13.13	0.01667	0.1015	13.76	-0.00333	0.0000	46
56	1/3	MOD	BOTH	13.15	1.20667	6.1343	13.47	1.08667	5.3947	13.13	0.00667	0.0508	13.76	0.01667	0.0969	43
57	2/3	MOD	BOTH	13.15	0.11667	0.6084	13.47	0.04667	0.2475	13.13	0.00667	0.0508	13.76	0.00667	0.0484	97
58	1/3	MOD	LOCAL	13.15	0.34667	3.3270	13.47	0.20667	1.9488	13.13	-0.00333	0.0000	13.76	0.03667	0.1938	91
59	2/3	MOD	NONE	13.15	0.60667	3.0925	13.47	0.18667	0.9404	13.13	-0.00333	0.0000	13.76	-0.01333	-0.0484	105
60	FULL	MOD	LOCAL	13.15	0.08667	0.0000	13.47	0.15667	0.0000	13.13	0.00667	0.0508	13.76	0.02667	0.1453	101
61	FULL	ORIG	NONE	13.15	0.22667	0.0000	13.47	0.25667	0.0000	13.13	-0.01333	0.0000	13.76	0.00667	0.0484	97
62	1/3	MOD	SHOWER	13.15	0.20667	0.0000	13.47	0.09667	0.0000	13.13	-0.00333	0.0000	13.76	-0.00333	0.0000	105
63	FULL	MOD	SHOWER	13.15	0.23667	0.0000	13.47	0.06667	0.0000	13.13	-0.00333	0.0000	13.76	-0.01333	0.0000	99
64	1/3	MOD	NONE	13.15	2.11667	10.7478	13.47	1.11667	5.5432	13.13	0.00667	0.0508	13.76	0.01667	0.0969	77
65	FULL	MOD	BOTH	13.15	0.30667	1.5716	13.47	0.20667	1.0393	13.13	0.00667	0.0508	13.76	0.03667	0.1938	81
66	2/3	MOD	LOCAL	13.15	1.28667	6.5399	13.47	2.45667	12.1752	13.13	0.00667	0.0508	13.76	0.01667	0.0969	79
67	1/3	MOD	BOTH	13.15	0.19667	1.0139	13.47	0.10667	0.5444	13.13	0.00667	0.0508	13.76	0.96667	4.6996	73
68	FULL	MOD	NONE	13.15	1.40667	7.1483	13.47	1.28667	6.3846	13.13	0.02667	0.1523	13.76	0.01667	0.0969	77
69	2/3	MOD	SHOWER	13.15	0.13667	0.7098	13.47	0.25667	1.2868	13.13	0.00667	0.0508	13.76	0.02667	0.1453	82
70	FULL	ORIG	NONE	13.15	0.51667	2.6362	13.47	0.32667	1.6333	13.13	0.00667	0.0508	13.76	0.02667	0.1453	76
71	2/3	MOD	NONE	13.47	3.70667	18.3618	13.15	4.58667	23.2700	13.13	0.01667	0.1015	13.76	0.02667	0.1453	94
72	FULL	MOD	SHOWER	13.47	0.49667	2.4746	13.15	0.48667	2.4842	13.13	0.01667	0.1015	13.76	-0.00333	0.0000	112
73	1/3	MOD	BOTH	13.47	0.92667	0.0000	13.15	0.82667	4.2079	13.13	0.01667	0.1015	13.76	0.02667	0.1453	116
74	FULL	MOD	LOCAL	13.47	2.40667	11.9277	13.15	2.33667	11.8631	13.13	0.00667	0.0000	13.76	0.00667	0.0484	114

RUN NO.	BOOTH FLOW	WORK-STATION	MODIFY	RIGHT FLOW (l/min)	RIGHT WEIGHT (mg)	RIGHT CONC (mg/m3)	LEFT FLOW (l/min)	LEFT WEIGHT (mg)	LEFT CONC (mg/m3)	BG1 FLOW (l/min)	BG1 WEIGHT (mg)	BG1 CONC (mg/m3)	BG2 FLOW (l/min)	BG2 WEIGHT (mg)	BG2 CONC. (mg/m3)	BAG COUNT
75	2/3	MOD	BOTH	13.47	2.69667	13.3630	13.15	4.18667	21.2421	13.13	-0.01333	-0.0508	13.76	-0.01333	-0.0484	133
76	FULL	ORIG	NONE	13.47	2.62667	13.0166	13.15	1.31667	6.6920	13.13	0.04667	0.2539	13.76	0.03667	0.1938	121
77	1/3	MOD	NONE	13.47	5.19667	25.7362	13.15	5.01667	25.4499	13.13	0.09667	0.5077	13.76	0.06667	0.3391	119