IN-DEPTH SURVEY REPORT

PERCHLOROETHYLENE EXPOSURES IN COMMERCIAL DRY CLEANERS

AT

Tuchman Cleaners Shop 27
Fishers, Indiana

REPORT WRITTEN BY
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Public Health Service
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National Institute for Occupational Safety and Health
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PLANT SURVEYED	Tuchman Cleaners 11813 Allisonville Road Indianapolis, Indiana 46205
SIC CODE	7216
SURVEY DATE	May 9-12, 1994
SURVEY CONDUCTED BY	Gary S Earnest Amy Beasley Spencer Ronald Kovein Dennis O'Brien
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DISCLAIMER

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

EXECUTIVE SUMMARY

A study was conducted at the Tuchman Cleaners (Shop 27) located near Indianapolis, Indiana, to evaluate control of worker exposure to perchloroethylene (PERC) and provide recommendations to reduce exposure Dry cleaning in this shop was done using an Omega® Model CE55, 55-pound, dry-to-dry machine which was about six years old This machine had a refrigerated condenser as the primary vapor recovery device The secondary vapor recovery device consisted of a small, centrifugal fan rated at 110 cfm that was ducted to a carbon canister When the machine door was opened, a microswitch energized the fan to draw PERC laden air from the cylinder through the activated carbon In lieu of solvent distillation, clay and carbon Kleen-Rite® filters were used to remove both soluble and insoluble soils from the solvent In a normal day, approximately eight loads of clothing were processed

There were six employees at this shop Three workers were sampled the machine operator and two pressers The machine operator was exposed to between 13 and 19 ppm TWA perchloroethylene Two-thirds of this exposure resulted from loading and unloading the machine The two pressers, who did not work in close proximity to the machine, but did work closely with dry-cleaned clothing, were exposed to between 1 and 7 ppm TWA The highest area concentrations measured, 9 and 12 ppm PERC, were from samples taken on the right side of the dry-cleaning machine where a vapor leak was detected The next highest concentrations were above the machine door, probably a result of loading and unloading the machine

Surprisingly, real-time monitoring showed that average PERC exposure while loading the machine with dirty clothing was much higher than unloading garments that had been cleaned in PERC The average exposure during loading was 846 ppm, average exposure during unloading was 271 ppm The total dose (area under the curve) was also higher during loading the machine, approximately 11,850 ppm*sec versus 7,050 ppm*sec Real-time measurements taken near the carbon canister on the top of the machine showed that very high concentrations of PERC (approximately 1,500 ppm) were being blown into the work environment each time the machine door was opened The carbon canister was ineffective at capturing PERC in the exhausted air

Real-time measurements were also taken for garment off-gassing, maintenance activities, and waterproofing The garment off-gassing experiment showed that the machine was relatively effective at recovering solvent from the garments The total quantity of PERC off-gassed from the test swatch was 3,800 ppm*sec or 31 8 mg PERC/kg cloth The average PERC concentration was 6 ppm The average exposure to the operator during all of the maintenance activities was approximately 22 ppm TWA The highest maintenance exposures occurred while cleaning the lint trap and peaked over 200 ppm Another source of high exposure was during waterproofing operations where the operator was working over an open dip-tank of PERC with no exposure controls

Controls at Tuchman Cleaners Shop 27 maintained exposures below 25 ppm, which is the exposure limit that OSHA encourages dry cleaners to follow NIOSH recommends controlling PERC to the lowest feasible concentration There are

several measures which could be taken to reduce exposures further, such as modifications to the secondary vapor recovery device or local exhaust ventilation Theoretically, operator exposure could be reduced by two-thirds by eliminating exposure during loading and unloading Improvements to general ventilation could also reduce exposures Ventilation controls should be used during waterproofing operations, or waterproofing should be done completely in the machine using an external tank Personal protective equipment such as a respirator, chemical splash goggles, and proper gloves should be used during waterproofing operations and machine maintenance Chemical splash goggles and protective gloves should be used during spotting to reduce dermal exposure to hazardous chemicals A respiratory protection program should also be established

INTRODUCTION

The Engineering Control and Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE), National Institute for Occupational Safety and Health (NIOSH), has undertaken a study of the dry cleaning industry to update a 1980 NIOSH engineering control study of the industry[1] and provide dry cleaners with recommendations for practical control measures based on current technology (See Appendix A) The focus of this study is to evaluate controls for exposure to perchloroethylene (PERC), however, controls for ergonomic hazards and exposures to chemicals used in the spotting process will be evaluated on a more limited basis

During the initial phase of the study, literature was reviewed to determine areas in need of research Walk-through surveys were conducted to gain familiarity with the industry and determine sites for future in-depth studies In-depth studies lasting several days are now being performed during which quantitative data is collected Personal and area samples are obtained, and real-time monitoring is conducted Detailed reports are being written to document all findings These in-depth reports will be used to prepare technical reports and journal articles that summarize the findings concerning effective controls for occupational health hazards in the dry cleaning industry

This report describes an in-depth study conducted at Tuchman Cleaners Shop 27, located near Indianapolis, Indiana The primary purpose of this survey was to evaluate control of worker exposure to PERC from a refrigerated, dry-to-dry machine with a secondary control device consisting of local ventilation through a small, activated carbon canister, which is energized when the machine door is opened Recommendations for reducing exposure to PERC are provided

PLANT AND PROCESS DESCRIPTION

PLANT DESCRIPTION

Tuchman Cleaners, a large commercial dry cleaner located in greater Indianapolis, Indiana, has been in business since the 1940s In 1986 it was purchased by Dry Clean U S A but was allowed to keep its name Dry Clean U S A , one of the largest owners of dry cleaning shops in the United States, has between 300 and 400 shops in 14 different states

There are approximately 31 Tuchman shops located throughout Indianapolis Three of the shops are "dry stores" where no dry cleaning occurs The three dry stores receive soiled garments from the customers and transport the garments to another store for cleaning The cleaned garments are delivered to the dry store and returned to the customer Tuchman Cleaners had many more dry stores prior to 1982 However, to improve accountability and service to the customers, dry cleaning equipment was installed in many of the dry stores between 1982 and 1986 In some areas of Indianapolis, it is very important to provide same day service to the customers in order to remain competitive The focus of this in-depth survey was Tuchman Cleaner's Shop 27 located in Fishers, Indiana, a suburb of Indianapolis

Dry cleaning has been done at the Fishers shop since approximately 1988 The shop was located in a single story strip mall between a bakery and a novelty store The shop layout is shown in Figure 1 The front of the store faced the road and had one door for customers The customer counter was in the front of the shop There was one door in the rear of the shop for workers, maintenance, and deliveries This shop did all of its own dry cleaning and did not receive clothing from any other stores There was one dry cleaning machine in this shop, located near the front of the store near the side wall When standing in front, facing the machine, an Adco® waterproofing drum was located near the left rear corner of the machine, and solvent filters were located on the right side of the machine A Forenta® spotting board was located near the front corner of the machine Pressing was done along the wall adjacent to the bakery Three small electric Lattner® boilers were located along the floor in the pressing area and provided heat to the presses and dry cleaning machine One large propeller fan, which provided general ventilation for cooling, was located in the wall above the back door of the shop Pressed clothing was hung on a two-tiered, motorized clothing rack behind the sewing area, along the wall between the shop and the novelty store Laundry was done behind and under the clothing racks A restroom was located in the rear corner of the shop, and hazardous waste storage barrels were located next to the restroom An eyewash station was located in the restroom The shop cleaned between 1,100 and 1,500 pounds of clothing per week On Monday or Tuesday, the busiest days, nine or ten 45 pound loads of clothing were cleaned Later in the week, there was generally less clothing to be cleaned Hourly workers at this shop belonged to the AFL-CIO Laundry and Dry Cleaning International Union There were six employees at this shop, including the manager All employees were female The shop was open for business from 7 00 a m to 7 00 p m , Monday through Friday and Saturday 8 00 a m to 6 00 p m

PROCESS DESCRIPTION

Garments were brought to the shop by customers needing their clothing cleaned Garments arrived at the customer counter and were examined and tagged for identification Prior to being loaded into the dry cleaning machine, garments were inspected and sorted according to weight, color, and finish

Garments with visible, localized stains were treated at the spotting station The store manager operated the machine and performed any spotting that was necessary Various chemicals were used depending on the type of stain Spotting may be done before or after the clothes are cleaned in the machine Post-spotting is used more frequently today because it reduces the amount of spotting required, which is very labor intensive

Stains rarely consist of one single substance The three general categories of stains are water soluble, solvent soluble, and insoluble Each type of stain requires appropriate spotting agents Some of the chemicals and chemical families that are frequently used for stain removal, in addition to PERC are the following other chlorinated solvents, amyl acetate, petroleum naphtha, oxalic acid, acetic acid, esters, ethers, ketones, dilute hydrofluoric acid, hydrogen peroxide, and aqueous ammonia Each of these chemicals are used in small quantities

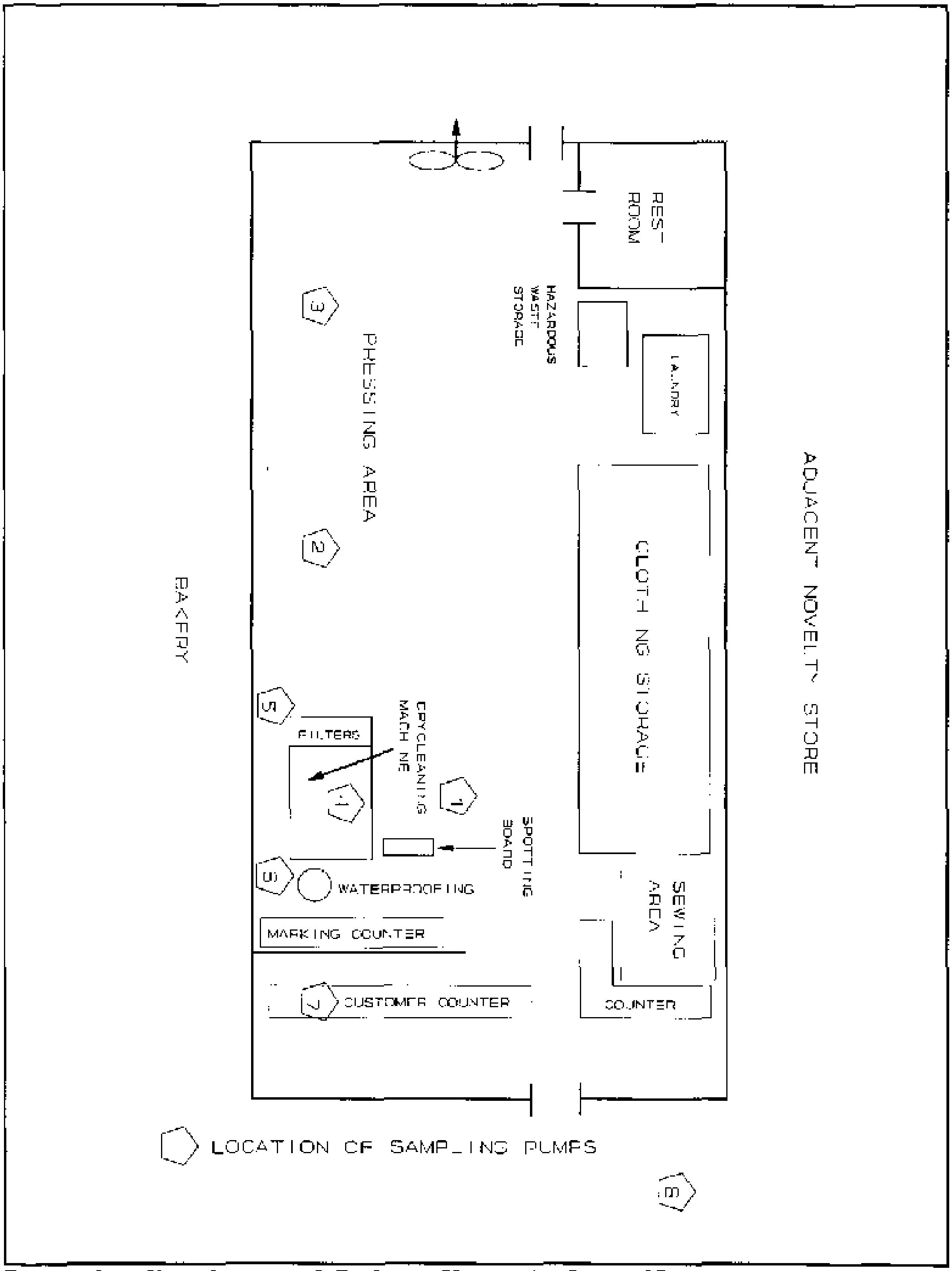

Figure 1 Shop layout of Tuchman Cleaner's Store 27

Most spotting chemicals used today are purchased from a company that supplies proprietary products to the industry At Tuchman Cleaners, the majority of spotting agents were products from the Laidlaw Corporation Some of the products used most frequently at this shop were POG®, VDS®, Protein spotter®, Wetspo®, Ban-Tan®, and PERC POG® is a mixture of diacetone alcohol, perchloroethylene, aromatic 100, orthodichlorobenzene, and pale oil VDS® is primarily trichloroethylene Protein spotter® is a mixture of ethylenediaminetetraacetic acid (EDTA) salts, nonionic surfactants, and wetting agents Wetspo® is a mixture of butyl cellosolve, aromatic 100, perchloroethylene, and potassium hydroxide Ban-Tan® is a mixture of hexylene glycol and diacetone alcohol

Spotting chemicals and chemical mixtures are either solvent-based liquids or water-based detergents They were held in small plastic squeeze bottles and applied to the stain when needed Spotting was performed on a spotting board equipped with pressurized air, steam, and water guns designed to flush the chemicals and stain from the garment Air, steam, a small brush, a spatula, and fingers were all used to help break-up the stain and wash it away A pedal actuated vacuum was used to capture the spotting chemicals, and they were held in a storage reservoir until being discarded

Dry cleaning in this shop was done using one Omega® Model CE55, 55-pound, dry-to-dry machine which was about six years old This machine had a refrigerated condenser as the primary vapor recovery device The refrigerated condenser used R-22 refrigerant to condense PERC vapors during the dry cycle The secondary vapor recovery device consisted of a small, centrifugal fan, rated at 110 cubic feet per minute (cfm) at atmospheric pressure, that was ducted to an activated carbon canister When the machine door was opened, a microswitch energized the fan to draw PERC laden air from the cylinder through the activated carbon This was designed to recover residual PERC vapors in the cylinder during loading and unloading In lieu of solvent distillation, clay and carbon Kleen-Rite® filters were used to remove both soluble and insoluble soils from the solvent In a normal day, approximately eight loads of clothing were processed The machine had a cleaning cycle of between 35 and 40 minutes Technical specifications for this machine can be seen in Table 1 The machine cost was approximately $35,000

The clothing was weighed in a basket, prior to loading into the machine The maximum capacity for the machine was 55 pounds of clothing, however, according to log sheets, the majority of loads placed into the machine were 45 pounds and a few were less than 35 pounds The weight of every load was logged onto a weekly record

Dry cleaning is a three-step process, involving the following washing, extracting, and drying A diagram of this process can be seen in Figure 2 (See Appendix B for dry cleaning technology) To begin washing, clothes were manually loaded into the cylinder of the machine through the front door After the door was closed, PERC was automatically pumped into the cylinder Water-based detergent was automatically injected into each load, based on the weight of the load

Table 1
Machine Technical Specifications

	Omega® Model CE-55
Load Capacity	55 lbs
Cage Volume	17 cubic feet
Cleaning Speed	38 rpm
Extraction Speed	400 rpm
Tank Capacities	Tank 1 85 Gallons Tank 2 45 Gallons

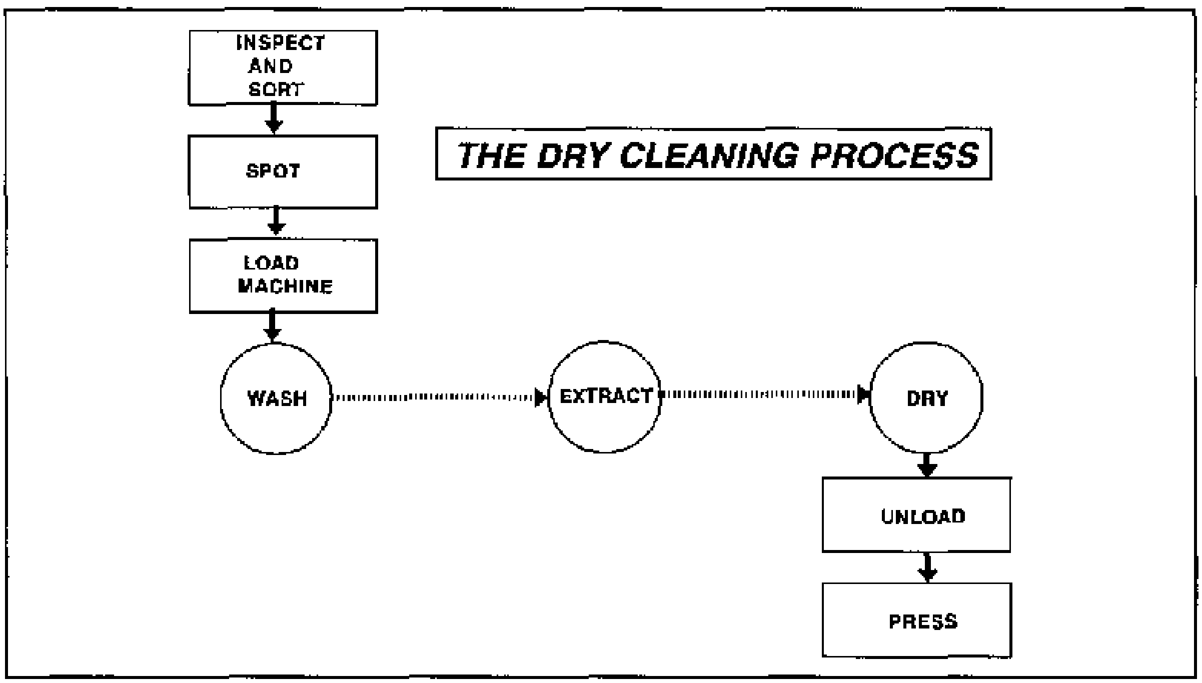

Figure 2 (Process flow diagram)

The contents of the machine cylinder were then agitated which allowed the solution to remove soils Following this step, the clothes were spun at a high speed to extract the solvent When the solvent had been removed, the fabric was tumbled dry

The drying process occurred in the same machine and consisted of two phases heat recovery and cool-down During heat recovery, warm air was recirculated to vaporize and recover the residual solvent Air was passed through the garments, a lint filter, cooling coils (with R-22 refrigerant around 60 °F), and finally through a heating coil (adjusted between 100-170 °F) and back to the drum While passing through the cooling coil, PERC vapors condensed to liquid form and were directed to the separator where the water was removed Liquid PERC flowed back into the tank while the water was piped to an external container Unheated air was passed through the system during the cool-down cycle During cool-down, the heating coil is by-passed and the temperature of the cooling coil is reduced to less than 0 °F This step relaxes the fabric fibers, helps to reduce wrinkles, and removes additional PERC

Garments removed from the machine were pressed to remove wrinkles and to restore their original shape The garments were placed on specialized pressing equipment, coming in a variety of shapes and sizes, and using steam heated to temperatures around 300 °F These utility presses and shirt presses were manufactured by Forenta® When the garments were properly situated, they were pressed between two surfaces, at least one of which was hot, to remove the wrinkles Some of the equipment used included general utility presses, puff irons, pants toppers, finishers, electric irons, bosom, body and yoke presses, collar, cuff and yoke presses, and sleevers Once the garments were completely pressed, they were wrapped in plastic and stored on the overhead rack to await customer pick-up

PERC used in the wash cycle was cleaned continuously by passing through a Kleen-rite® filtration system Kleen-rite® clay and carbon filters model KR131 were used to remove soluble and insoluble soils Normally, filtration is used to remove most of the insoluble soils, and distillation is used to remove most of the soluble soils There were four filters in two separate tubes Filters in each tube were changed after cleaning 8,000 pounds of clothing Distillation was eliminated along with the need to clean the still or dispose of hazardous waste produced during distillation

A local contractor supplied and delivered PERC when needed The solvent was delivered by a truck through the rear door of the building and pumped directly into the machine's holding tank which eliminated employee handling General dilution ventilation consisted of one large, propeller fan located in the wall above the back door The air was exhausted outside of the building Several comfort fans were located throughout the pressing area to circulate air

HAZARDS AND EVALUATION CRITERIA

POTENTIAL HAZARDS

Exposure to PERC is the primary health hazard for workers in dry cleaning facilities today Spotting involves the selective application of a wide variety of chemicals and steam to remove specific stains Individuals who perform the spotting process could be exposed to toxic chemicals through skin or eye contact or inhalation of vapors For a complete description of the potential hazards, please refer to Appendix C

EVALUATION CRITERIA

The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for PERC is 100 ppm, 8-hour time-weighted average (TWA) The acceptable ceiling concentration is 200 ppm, not to exceed a maximum peak of 300 ppm for 5 minutes in any 3-hour period [2] OSHA had lowered the PEL to 25 ppm in 1989 under the Air Contaminants Standard [3] In July 1992, the 11th Circuit Court of Appeals vacated this standard OSHA is currently enforcing the 100 ppm standard, however, some states operating their own OSHA-approved job safety and health programs will continue to enforce the lower limits of 25 ppm OSHA continues to encourage employers to follow the 25 ppm limit [4] NIOSH considers PERC to be a potential occupational carcinogen and recommends that exposure be reduced to the lowest feasible concentration [5]

METHODOLOGY

INDUSTRIAL HYGIENE SAMPLING

The objective of this site visit was to evaluate the effectiveness of the dry cleaning machine for controlling worker exposure to PERC Personal, area, and background air sampling was conducted using NIOSH Method 1003 for halogenated hydrocarbons This method calls for the use of 100 mg/50 mg coconut shell charcoal tubes and carbon disulfide desorption Analysis was done using a gas chromatograph with flame ionization detector Samples were collected over a 120 minute time period with a flow rate of 0 1 liters/minute and a volume of 12 liters The limit of detection for this process was 0 01 mg/sample [6]

Area samples were taken at various locations throughout the shop Air samples were collected in front of and behind the dry cleaning machine, in the pressing area, near the customer counter, and outside the building (Figure 1) Full-shift TWA personal sampling was gathered for the machine operator, as well as, both pressers TWA personal sampling results were compared to 25 ppm No air sampling was done for the spotting chemicals

VIDEO EXPOSURE MONITORING

Real-time monitoring was used to study in greater detail how specific manual tasks and maintenance operations affect worker exposure to PERC Some of these procedures occurred frequently throughout the day, such as loading/unloading the machine while others were less often, such as machine maintenance and waterproofing Most of these tasks took between 5 and 30 minutes Real-time monitoring of PERC exposures were performed using a MicroTIP® IS3000® (PHOTOVAC Inc, Thornhill, Ontario) with a 10 6 EV ultraviolet lamp This instrument uses a photoionization detector to provide an analog output response proportional to the concentration of ionizable pollutants present in the air The MicroTIP® was spanned using 100 ppm isobutylene span gas and calibrated using five standard concentrations of PERC gas Instrument readings and actual PERC concentrations were used to construct a calibration curve and find a predictive equation The following formula was used to convert the output of the PID (volts) to concentration of contaminant (ppm) $C(t) = IR(t) * CF * MR$

where
$C(t)$ = concentration of vapor at time t (ppm)
$IR(t)$ = instrument response at time t (volts)
CF = Conversion factor from calibration equation
MR = MicroTIP® range

Information gathered using the MicroTIP® was electronically recorded on a Rustrak® datalogger (Rustrak® Ranger, Gulton, Inc , East Greenwich, RI) and downloaded to a portable computer using Pronto® software During the gathering of real-time data, a videocamera was used to record worker activities This videotape was later used to analyze tasks, code data, and determine which work activities and movements resulted in the highest exposures

Real-time monitoring was also used to study off-gassing of garments and compare vapor recovery efficiency between machines This was accomplished using a standard test swatch approximately 5 inches by 6 inches made of 51 percent rayon and 49 percent polyester When the dry cycle had ended the test swatch was placed in a small glass test chamber As the PERC residuals vaporized, the concentrations of emitted PERC were monitored and recorded using the MicroTIP® and Rustrak® datalogger The apparatus for measuring off-gassing can be seen in Figure 3

VENTILATION

General ventilation measurements were taken with a Kurz® model 1440 velometer with a measuring range from 0 to 6,000 feet per minute Turbulent airflow near the dry cleaning machine was qualitatively evaluated using smoke tubes The capacity and dimensions of general dilution ventilation systems were also recorded

RESULTS AND DISCUSSION

INDUSTRIAL HYGIENE SAMPLING

Results of the individual air samples can be seen in Appendix E A summary of personal air samples for each day can be seen in Table 2 All of the personal samples taken at this shop were below 25 ppm The time-weighted average exposures would have been even lower if sampling had occurred for a full 8-hour shift, however, the dry cleaning machines were not operated for a complete eight hours during this survey They typically operated between four and six hours

As expected, the operator of the machine had the highest exposure to PERC which ranged from 18 64 to 13 15 ppm TWA on various days The bulk of this exposure resulted from loading and unloading the machine and performing maintenance The highest average exposure during a two hour sampling occurred

Table 2
Time-Weighted Average (TWA) PERC Exposures Over the Sampling Period

Worker	Date	Sampling Period (min)	TWA Concentration (ppm)
Operator	5/10/94	364	18 64
Presser 2	5/10/94	328	6 48
Presser 3	5/10/94	319	2 77
Operator	5/11/94	248	14 27
Presser 2	5/11/94	171	2 16
Presser 3	5/11/94	193	1 38
Operator	5/12/94	240	13 15
Presser 2	5/12/94	161	4 76
Presser 3	5/12/94	245	2 95

to the operator on the afternoon of May 10 The operator was doing dip-tank waterproofing operations during this period Although no 5-minute peak or 15-minute short-term exposures were measured, it is highly likely that both peak and short-term limits of 300 ppm and 200 ppm respectively, were exceeded during this operation The two pressers, who did not work in as close proximity to the machine as the operator (see Figure 1), but did work closely with dry cleaned clothing were exposed to between 6 48 and 1 38 ppm TWA on various days The presser whose workstation was closer to the machine was consistently exposed to a higher concentration than the other presser

Results of area air sampling can be seen in Table 3 The highest area concentrations were detected on samples located behind the right side of the machine The next highest concentrations were above the machine door A significant vapor leak from a poorly sealed panel on the vapor recovery housing of the machine was detected with the MicroTIP® This was probably the cause of the high concentrations found behind the right side of the machine Another source of exposure occurred when the residual gases in the cylinder were vented through the carbon canister when the machine door was opened and closed This canister did not appear to be functioning properly The concentrations above the machine probably came from the machine when the door was opened and closed The lowest concentrations measured were found in the reception area

In general, exposures appeared to be higher in the morning than in the afternoon, with the exception of the afternoon of May 10 when waterproofing occurred This may be due to performing machine maintenance in the morning, as well as, cleaning more clothing with slightly larger loads Bulk samples

Table 3
Area Sample Concentrations of Perchloroethylene

Location	Day	Average Sample Time (min)	Geometic Mean (ppm)	Geometric Standard Deviation (ppm)	Range (ppm)
Behind Left	5/10/94	123 00	5 8	1 4	4 2-8 8
Behind Right	5/10/94	122 67	11 5	1 5	7 6-20 7
Above Machine	5/10/94	122 33	8 3	1 2	6 5-9 4
Reception	5/10/94	121 67	2 3	1 3	1 6-3 4
Behind Left	5/11/94	123 5	4 3	2 1	2 1-9 0
Behind Right	5/11/94	124 00	8 7	2 6	3 3-23 0
Above Machine	5/11/94	123 00	5 6	1 7	3 3-9 5
Reception	5/11/94	122 50	2 0	2 0	1 0-4 0
Behind Left	5/12/94	121 00	3 8	1 9	1 9-7 3
Behind Right	5/12/94	121 00	8 5	1 9	4 5-15 7
Above Machine	5/12/94	119 00	6 0	1 7	3 6-10 1
Reception	5/12/94	119 00	2 3	1 9	1 2-4 5

were taken of the water separator run-off to see if any PERC exposure could be originating from this source Laboratory analysis found no PERC detected with a limit of detection of 001 percent (w/w)

REAL-TIME MONITORING

Video recording and real-time monitoring was performed during loading and unloading the machine, waterproofing operations, and performing maintenance on the machines such as cleaning the button traps and lint filter Real-time monitoring was also used to evaluate the effectiveness of the carbon canister (secondary control) and garment residual off-gassing The MicroTIP® was set for a measuring range between 0 to 200 ppm and 0 to 2,000 ppm depending on the operation being monitored

Clearly, the most significant source of exposure to the operator occurred during loading and unloading the machines Exposures during this procedure peaked at over 1,500 ppm More importantly, loading and unloading occurred frequently throughout the day, approximately six to ten times a day depending on business Machine maintenance normally occurred only once a day and some tasks such as waterproofing occurred even less frequently

Figures 3 and 4 show real-time data during unloading and loading the machine Figure 3 shows operator exposure, and Figure 4 shows emissions from the carbon canister on the top of the machine The process of unloading and loading the machine took 55 seconds Unloading took 26 seconds and loading took 14 seconds

Surprisingly, average PERC exposure while loading the machine with dirty clothing was much higher than unloading garments that had been cleaned in PERC Average exposure during loading was 846 ppm, average exposure during unloading was 271 ppm The total dose (area under the curve) was also higher during loading the machine, approximately 11,850 ppm*sec versus 7,050 ppm*sec This may be due to residuals being forced from the cylinder when a large quantity of uncleaned clothing is added to an empty cylinder This result alone is an indicator that the secondary control on this machine was not functioning properly

Figure 4 shows real-time measurements taken near the carbon canister on the top of the machine Each time the machine door was opened, high concentrations of PERC were being blown into the work environment This was because the carbon in the canister was not capturing the PERC in the exhausted air The carbon canister was ineffective, probably due to a variety of factors These factors could include the flow rate of the air stream, concentration of PERC in the air stream, adsorption time, capacity of the carbon bed, humidity, temperature of the air stream, and age of the carbon Generally, the flow rate and capacity of the carbon bed are the most important factors [7]

Theoretical calculations indicated that approximately one-tenth of a pound of carbon was needed per load, if the concentration in the cylinder was 2,000 ppm when the fan activated This is based upon the fact that 2,000 ppm PERC vapors evenly distributed in a 17 cubic foot cage is equivalent to 96 liters of PERC (gas phase) or 6 47 grams of PERC, or 00106 gallons of PERC Based upon an average of eight loads per day, the quantity of activated carbon currently used would need to be changed on nearly a daily basis Additionally, because the canister was positioned horizontally rather than vertically, (and air flowed from one side to the other rather than from bottom to top) the PERC laden air was able to by-pass the carbon This problem could be resolved by adding an elbow that would hold the canister in a vertical position

Even if there was sufficient carbon in the canister and the machine operated at optimal efficiency, the PERC effluent would tend to remain in the 50-150 ppm range This concentration translates to approximately 95 to 99 percent efficiency When the working capacity of the carbon is approached, the concentration of PERC in the effluent stream increases dramatically This is called breakthrough

A general rule-of-thumb in dry cleaning is that one-half pound of carbon is needed to capture the PERC residuals from one load of clothing with no other recovery device [8] Carbon will absorb approximately 40 percent of its weight, and one gallon of PERC weighs approximately 13 5 pounds Additionally, the 110 cfm, centrifugal fan was probably undersized for the intended purpose because it was unable to provide sufficient airflow at the machine door to prevent escape of PERC vapors

Operator exposure could be reduced by two-thirds by eliminating exposure during loading and unloading This can be seen by determining the operator TWA total dose in ppm*seconds during the work day from air sampling (17,040 seconds * 15 82 ppm = 270,000 ppm*sec) and comparing this to the operator total exposure during loading/unloading from real-time measurements (23,010 ppm*sec * 8 times/day = 184,100 ppm*sec/day) If exposure during loading/unloading were reduced to near 0, then the operator's total TWA exposure for the day would be reduced from approximately 15 8 ppm TWA to approximately 5 ppm TWA

Figures 5 and 6 show operator exposure during waterproofing dip-tank operations Exposures during this procedure were extremely high because the operator was working over an open tank of PERC and other chemicals to waterproof clothing The clothing was dipped in the PERC and then raised and allowed to drain It was then hand carried to the dry cleaning machine There was no ventilation during this procedure Figure 6 shows that the highest average exposures (approximately 150 ppm) occurred when the clothing was placed into the dry cleaning machine The real-time values were significantly lower than actual because the MicroTIP® was set on the 0 to 200 ppm scale The largest dose of PERC occurred when scrubbing the clothing at the barrel This was because it took longer than any other single task (approximately 140 seconds), and the average exposure was relatively high (approximately 100 ppm) It is highly likely that both 5 minute peak and 15 minute short-term exposures were exceeded during waterproofing

Figure 7 shows exposure during machine maintenance Machine maintenance was done on a daily basis and involved cleaning the lint and button traps and disposing of the hazardous waste Normally, maintenance is performed on the machine before the boilers are allowed to heat up in the morning There was no still to be cleaned on this machine The highest exposure occurred while cleaning the lint trap The average exposures during all of the maintenance on this machine was approximately 22 ppm

Finally, the garment off-gassing experiment is shown in Figure 8 During an average cycle, the machine was relatively effective at recovering solvent from the garments The total PERC off-gassing from the test swatch was 3,800 ppm*sec or 31 8 mg PERC/kg cloth The average PERC concentration was 6 ppm

VENTILATION MEASUREMENTS

Ventilation on the dry cleaning machine door at this shop was negligible Measurements taken with a Kurz® hot-wire velometer did not show an appreciable difference between face velocity at the machine door and ambient air velocity Smoke tubes indicated that there was only a very minor flow of air The machine did have a small, centrifugal, 110 cfm, fan that drew air from the cylinder when the door was opened The fan was activated by a microswitch on the door This airflow was exhausted through a small, activated, carbon canister, outside of the machine, into the work environment

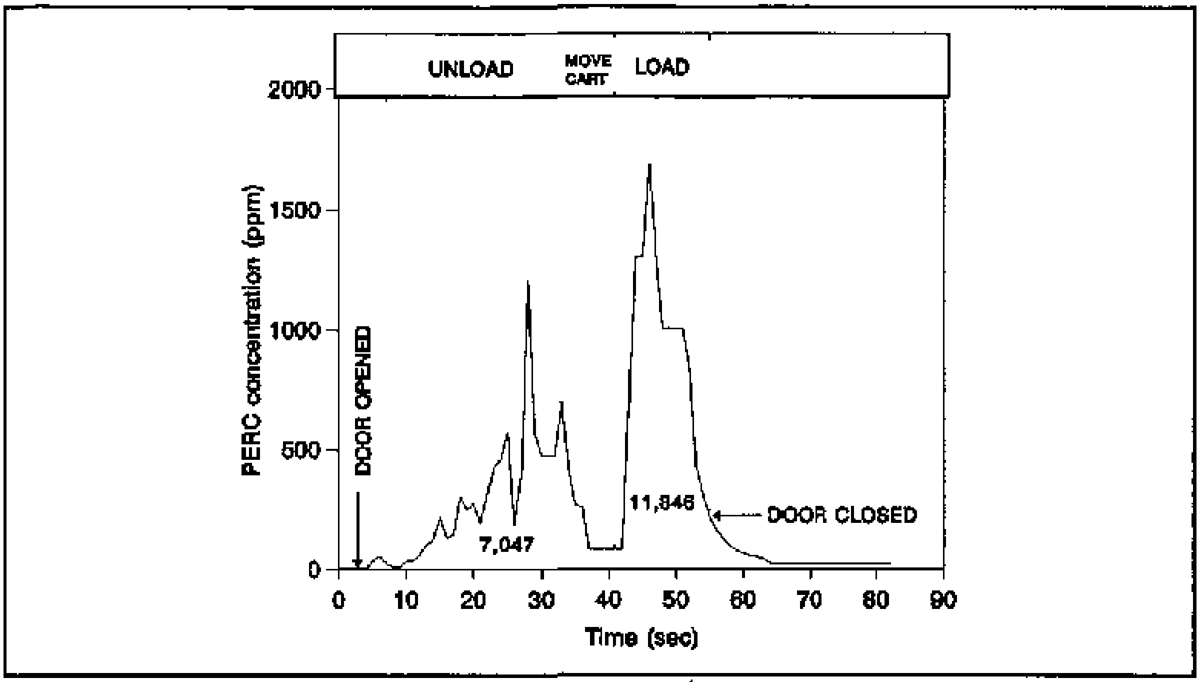

Figure 3 Operator exposure during loading/unloading Dry-cleaning Machine

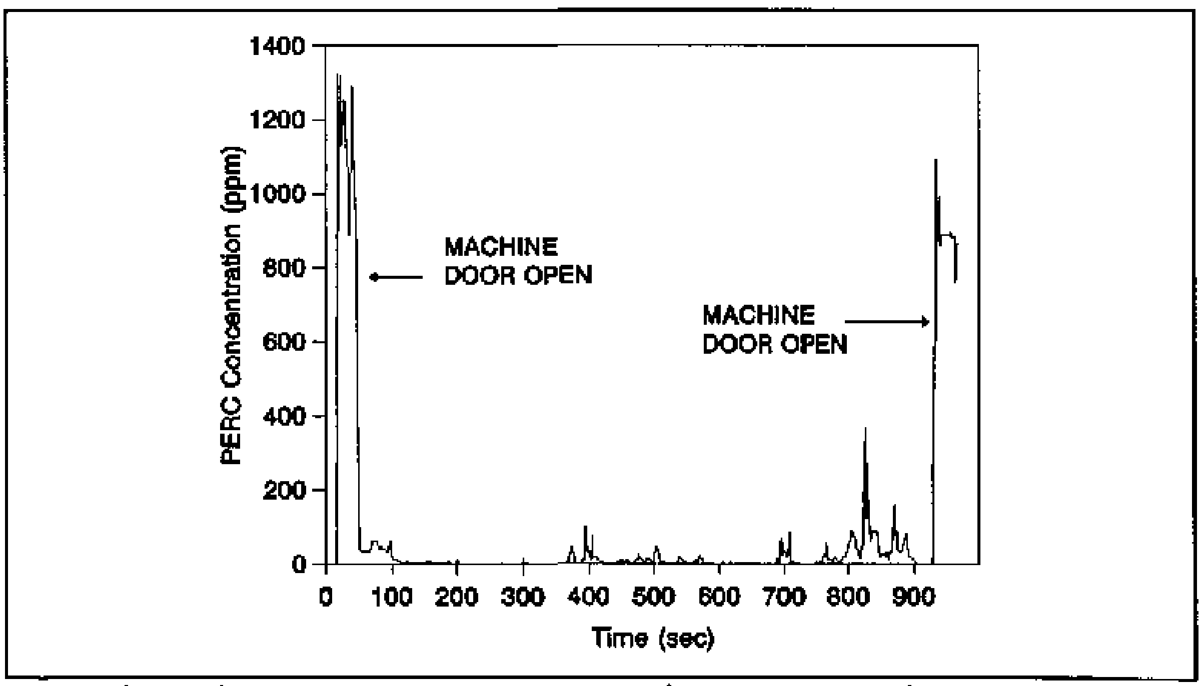

Figure 4 Real-time measurements near carbon canister exhaust

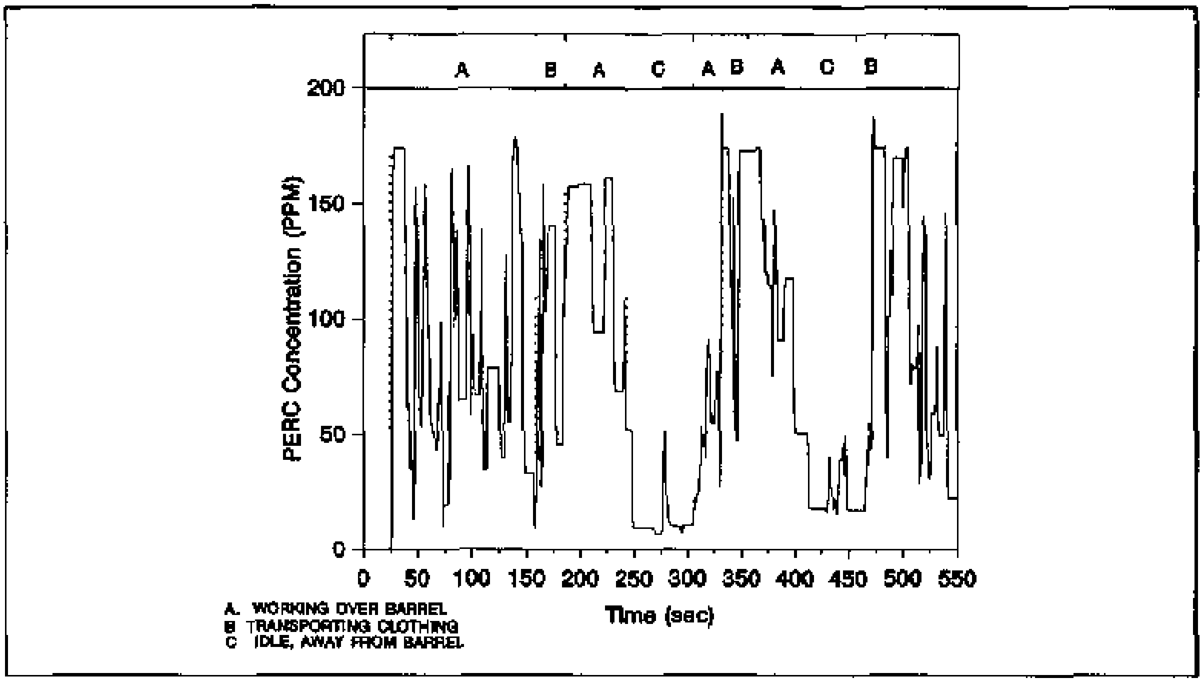

Figure 5 Operator exposure during waterproofing operations

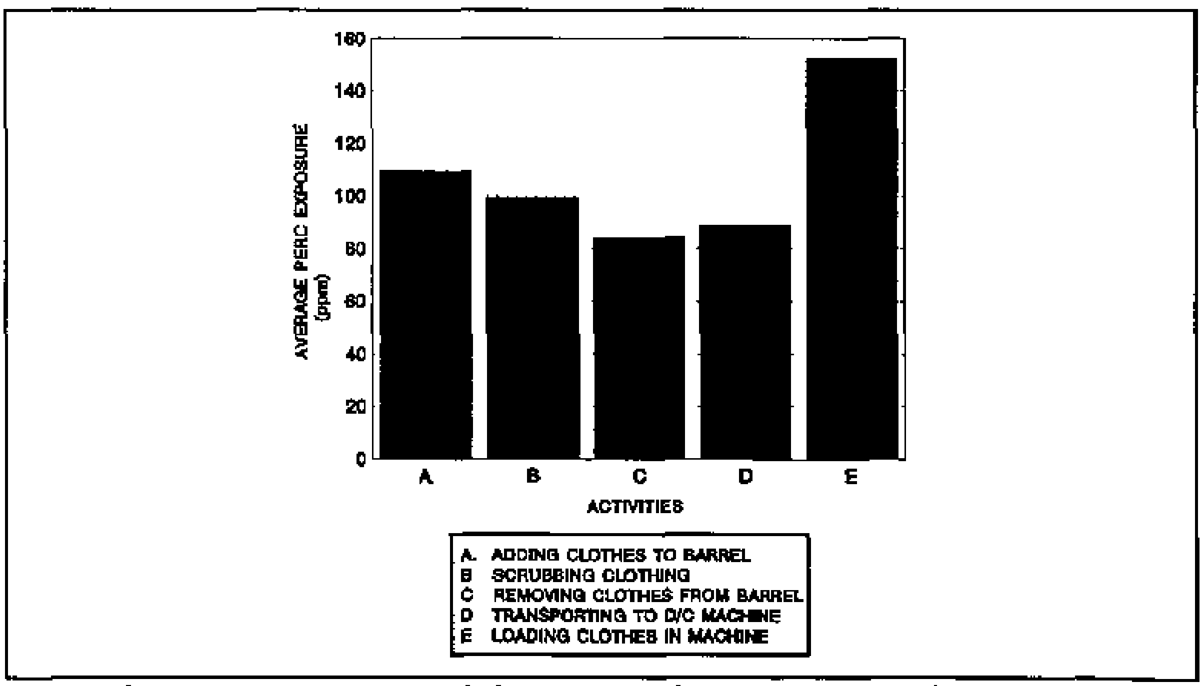

Figure 6 Average operator PERC exposure during waterproofing

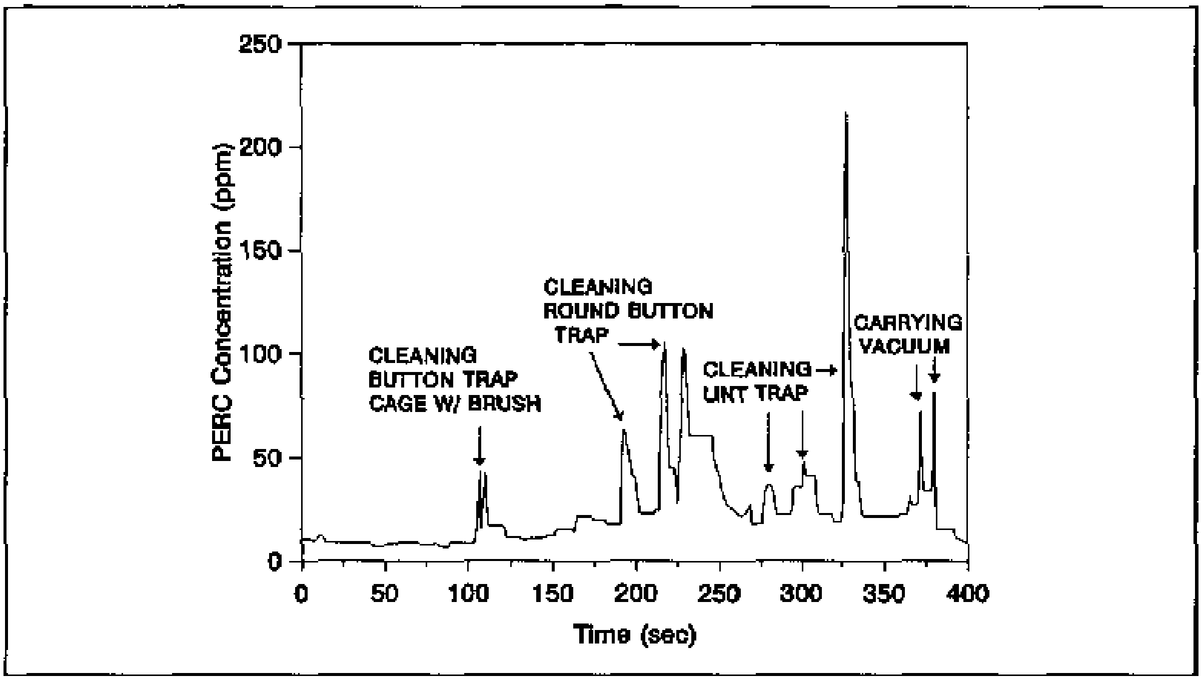

Figure 7 Operator exposure during maintenance on lint & button traps

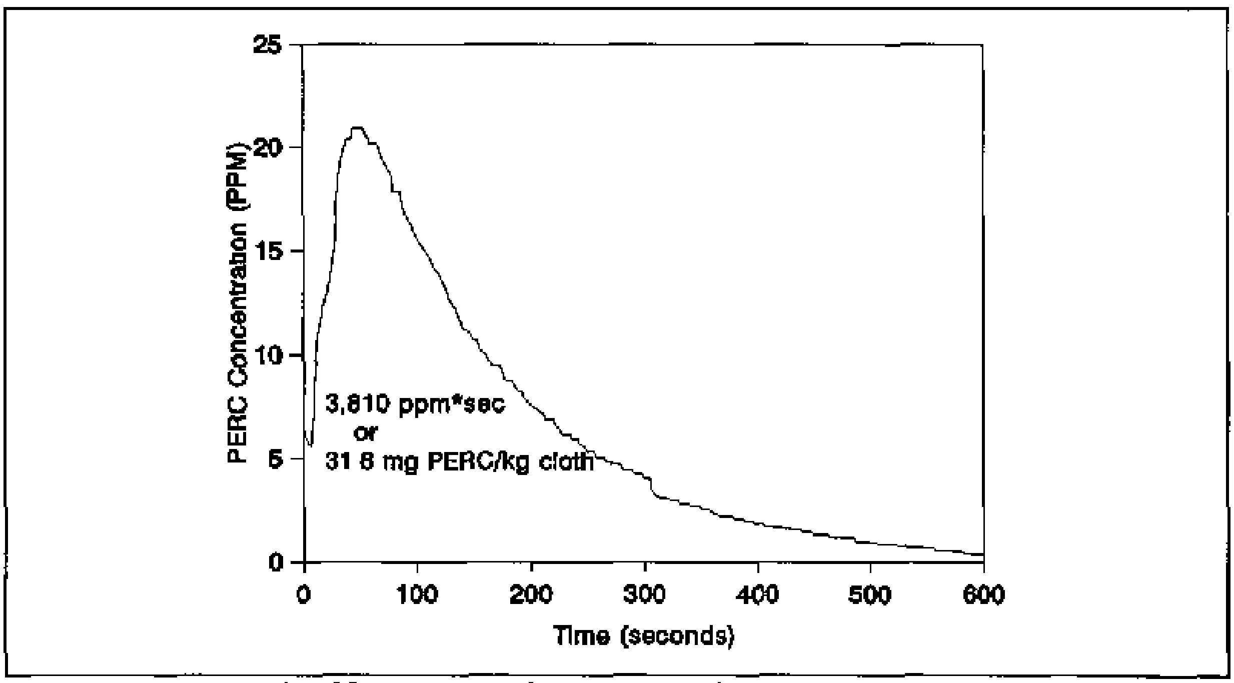

Figure 8 Typical off-gassing of test swatch

One 44-inch diameter, propeller fan was located in the rear wall of the building above the door to provide dilution ventilation Twelve air velocity measurements were taken approximately 6 inches in front of the fan in the wall The fan exhausted approximately 6,500 cfm Smoke tubes near the propeller fan indicated that the fan was ineffective at exhausting contaminated air originating from the machine Rather, any PERC that might originate from the machine was able to diffuse throughout the building This fan was able to capture air approximately 8 feet in front of it and would probably remove any emissions from the hazardous waste containers General ventilation principles require that fans should be arranged to move contaminated vapors away from the employees

OBSERVATIONS

There were approximately five maintenance personnel responsible for maintaining the 31 Tuchman shops in the Indianapolis area No liquid solvent leaks were detected in this shop during the visit This can probably be attributed to the fact that the equipment was relatively new A leak detector was not present at this shop, however, maintenance personnel from the main shop had a TIF® model 5050 halogen leak detector that was used periodically, and visual checks for leaks were performed and logged every week General maintenance and housekeeping appeared to be a problem A large vapor leak was detected on the vapor recovery housing panel that resulted from overtightening There were no open containers with solvent or solvent contaminated items observed Blue hazardous waste barrels were located inside the shop near the bathroom Passive monitoring for PERC was conducted at this shop on an annual basis

Based upon a formula provided by the International Fabricare Institute, the capacity rating for this machine was higher than recommended [9] IFI determines load capacity by multiplying cage volume in cubic feet by a load factor in pounds per cubic feet The load factor is 3 5 to 4 pounds per cubic feet for transfer equipment and 2 5 to 3 pounds per cubic feet for dry-to-dry equipment Based on this formula, the machine should have a load capacity between 42 5 and 51 pounds, instead of 55 pounds This could be a problem if consistently loaded to the full rated capacity Fortunately, the machine operator weighed and logged each of the loads of clothing Most of the loads weighed 45 pounds or slightly less

PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment at this shop consisted of a respirator and gloves Personal protective equipment was stored in a first-aid shelf between the tagging counter and dry cleaning machine The respirator was a North®, half-face, respirator with organic vapor cartridges The gloves were rubber surgical gloves The respirator was only used by the operator in case of a PERC spill Surgical gloves were sometimes used at the spotting station if a garment was contaminated with body fluids Personal protective equipment was not used by the operator when performing machine maintenance or during waterproofing operations Maintenance personnel did wear a half-face respirator with organic vapor/acid gas cartridges when changing filters There was no personal protective equipment training and no respirator fit testing Management required all new employees to sign a standard HAZCOM form, which explains the hazards present, when they begin work

CONCLUSIONS AND RECOMMENDATIONS

Tuchman Cleaners Shop 27 appeared to have adequate controls that were able to maintain exposures below 25 ppm, which is the exposure limit that OSHA encourages dry cleaners to follow NIOSH recommends controlling PERC to the lowest feasible concentration The highest TWA personal exposures were for the dry cleaning machine operator/spotter who was exposed to approximately 19 ppm TWA The pressers who were sampled were exposed to between approximately 1 and 7 ppm TWA

The primary source of exposure to the workers in this shop was the dry cleaning machine Real-time evaluation showed that loading and unloading of the machines had the greatest impact upon exposures Therefore, if management or machine manufacturers desired to reduce exposures even further, they should first seek to reduce exposures during loading and unloading By examining the total exposure during the day and total exposure due to loading and unloading, it appears that the operators exposure could be reduced nearly 66 percent by control of loading and unloading

There are a number of different measures which could be taken to reduce exposures during loading and unloading One approach is to improve vapor recovery from the refrigerated condenser There are four primary factors which effect vapor recovery at the condenser [10] machine maintenance, cooling coil efficiency, size of load, and length of dry cycle Vapor recovery from the condenser did not appear to be a significant problem at this shop

Local exhaust ventilation could also be used to significantly reduce exposures during loading and unloading This could occur by modifying the current system or by adding simple, inexpensive, external local exhaust ventilation consisting of an exhaust fan, ductwork, and hood The 110 cfm, centrifugal, Bermar® fan and carbon canister were ineffective at controlling escape of residual PERC in the cylinder after the dry cycle The fan provided insufficient airflow, and the carbon canister did not have a large enough carbon bed to capture the PERC residuals A larger fan could be added to the current system which would increase the airflow and reduce residuals escaping from the cylinder and reaching the operator's breathing zone during loading/unloading Additionally, a larger carbon bed could be added to the current system This would improve PERC capture efficiency by providing a much larger surface area to which the PERC molecules could attach Based upon theoretical calculations, the carbon canister would have to be changed almost every day

Finally, the exhaust of the current system could be ducted outside of the shop This would reduce some of the background concentrations of PERC in the shop This should not create a problem with environmental regulators because the PERC is already escaping into the shop environment The question is whether it is better to keep this inside the shop where the workers are exposed or outside of the shop where it can dissipate

A simple, inexpensive, external local ventilation system with a separate exhaust fan, ductwork, and hood is another option The captured air could then be ducted outside the building or to a vapor recovery unit Exposures during unloading have been shown to be reduced from 1,000 ppm to 28 ppm using a fan which operated at 990 cfm with a slotted hood design [11]

Controls should be implemented to reduce exposures during waterproofing operations This could occur in a number of different ways Waterproofing dip-tank operations could continue as they are currently being done if local exhaust ventilation were used along with proper respiratory protection and gloves Another option would be to consider purchasing equipment such as a dosing unit or separate tank so that waterproofing could be performed in the machine itself Although waterproofing is done on a low frequency, as needed basis, it is a very significant source of exposure when it does occur

Process isolation can be examined from two perspectives between shops and within the shop Of all 31 Tuchman Cleaners in Indianapolis, only two were "dry stores" where no dry cleaning occurred Workers at these two "dry stores" were isolated from significant exposures to PERC By converting some of the stores which do dry cleaning on the premises to "dry stores," exposures to some of the workers would be reduced

Process isolation was not used within this shop and would be difficult to do because of limited floor space If solvent emissions became a significant problem, process isolation could help to reduce the number of employees exposed Some facilities have used a wall or barrier within the shop to separate the dry cleaning machine area from other areas of the shop The Environmental Protection Agency currently requires dry cleaning facilities with a transfer machine that purchases over 1,800 gallons of PERC per year to install a room enclosure and vent the enclosure to a carbon absorber [12] The majority of PERC emissions originate from the machine Isolating employees by either time or space will reduce exposures to the employee
Because the machines were relatively new, there were no visible liquid leaks, however, a significant vapor leak was found on the poorly sealed panel on the vapor recovery housing on the machine It appeared as if the nuts which hold the panel to the housing had been overtightened and caused the panel and seal to deform

As machines age, leaks may develop and should be repaired promptly Proper maintenance can be instrumental in reducing leakage Liquid leaks are more easily seen if proper maintenance and housekeeping is performed Lint build-up is a real problem in most dry cleaning shops If lint is allowed to accumulate on the floor and in and around equipment, leaks are much harder to locate Gaskets prone to deterioration must be inspected and replaced on a regular basis Solvent usage records can be a valuable indicator of solvent leaks or machine malfunctions Several devices can aid in leak detection These include the halide torches, photoionization detectors, and pocket dosimeters The passive exposure monitoring devices used annually in this shop will not aid in leak detection but will alert management when an exposure problem exists [13]

Use of personal protective equipment (PPE) at this shop, like almost every other dry cleaning shop in this study, was not in accordance with Federal Regulation 29 CFR 1910 134 because there was no established program In addition to the measures mentioned earlier, occupational exposure could be further reduced through the proper use of PPE PPE does nothing to reduce or eliminate the source of the hazard and must be used properly to be effective

Though not recommended by NIOSH because PERC is a potential occupational carcinogen, the current respirators (half-mask facepiece with organic vapor cartridges), used for short-term exposures to low concentrations of PERC, must have the cartridges changed prior to breakthrough (approximately 130 minutes based on room concentrations) [14] Regular cartridge changes are important because the odor threshold of PERC is 27 ppm, and a worker may not smell PERC until significant breakthrough and exposure has occurred [15]

Where employees must wear respirators, an appropriate respiratory protection program in accordance with 29 CFR 1910 134 must be instituted This regulation, shown in Appendix F, contains provisions for

- a written standard operating procedure
- respirator selection based upon hazards
- instruction and training of the user concerning the proper use and limitations of respirators
- regular cleaning, disinfection, and proper storage
- medical review of the health and condition of the respirator user
- use of certified respirators which have been designed according to standards established by competent authorities [16]

It is recommended that at a minimum, proper respirators and gloves be used during machine maintenance and waterproofing operations by the operator

Gloves and goggles should be used to reduce exposure to hazardous chemicals such as PERC Gloves provide limited dermal protection and should be made of solvent resistant materials, such as Viton® fluoroelastomer, polyvinyl alcohol, or unsupported nitrile When a specific glove is chosen, factors such as permeation, durability, dexterity, and cost should be considered Viton® and polyvinyl alcohol have a PERC breakthrough time in excess of eight hours [17] A 1987 study showed that unsupported nitrile was impervious to PERC after a two-hour challenge period [18] Some of the drawbacks associated with these materials are that Viton® is expensive, polyvinyl alcohol significantly reduces dexterity, and unsupported nitrile has a high permeation rate

Whenever swelling or softening of the gloves or seepage of PERC into the glove is observed, the gloves should be replaced Gloves should also be regularly checked for perforations and cuts

Chemical splash goggles should be worn to prevent eye injury when workers are using hazardous chemicals Accidental contamination of the eye could result in minor irritation or complete loss of vision Use of chemical splash goggles is particularly important during maintenance operations, waterproofing, and spotting Additionally, location of the eye wash station in the restroom is unacceptable An unobstructed eye wash station should be installed in the vicinity of the dry cleaning machine and spotting station to provide prompt eye irrigation in the event it is needed If chemical contamination of the eye does occur, prompt irrigation for at least 15 minutes can play a deciding role in limiting the extent of damage

Controls at this facility were capable of maintaining exposures below 25 ppm TWA Control methods discussed previously could aid in reducing exposures further

APPENDICES

APPENDIX A BACKGROUND

The National Institute for Occupational Safety and Health (NIOSH), located in the Centers for Disease Control and Prevention (CDC), under the Department of Health and Human Services (DHHS) (formerly the Department of Health, Education, and Welfare), was established by the Occupational Safety and Health Act of 1970 This legislation mandated NIOSH to conduct 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 and develop engineering controls and assess their impact on reducing occupational illness Since 1976, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to document and evaluate control techniques and to determine their effectiveness in reducing potential health hazards in an industry or at specific processes

In the late 1970s and early 1980s, a NIOSH sponsored engineering control technology study was conducted in the dry cleaning industry [19] Since that study, significant changes involving equipment, processes, and work practices have occurred within the industry Many of these changes were initiated by new epidemiologic, toxicologic, and environmental data for the primary solvent, perchloroethylene (PERC) This industry currently has in excess of 30,000 commercial shops and approximately 244,000 employees in the United States [20]

Some studies have shown that in addition to the numerous adverse health effects already known for PERC exposure, there is evidence of carcinogenicity [21] PERC is a known animal carcinogen[22], but there is inadequate evidence of human carcinogenicity [23] In December 1991, the Environmental Protection Agency began regulating PERC as a hazardous air pollutant under Section 112 of the Clean Air Act This regulation was based on environmental research that PERC was a toxic air pollutant [24]

The industry has responded with increased research into alternative solvents and cleaning methods, a shift from transfer machines to closed loop, dry-to-dry machines, and innovations in vapor recovery equipment and other devices to reduce occupational exposures and environmental emissions Many of the exposure problems identified during studies in the late 1970s and early 1980s still exist because transfer equipment is still being used, many controls developed by industry are cost prohibitive, and some work practices are inadequate

Data from the OSHA Integrated Management Information System (IMIS), from 1984-1988, indicates that approximately 20 percent of samples taken at dry cleaning shops exceeded 100 ppm [25] More recent and comprehensive data gathered by the

International Fabricare Institute's (IFI) vapor monitoring service using passive monitoring badges is shown in Table 4

Table 4[26]
IFI'S Passive Monitoring Results

	Before 1/1/87	1/1/87 - 9/30/89	After 10/1/89
TRANSFER (AVG TWA PPM)	55 3 ppm	46 4 ppm	42 ppm
%>25 ppm	76 2%	59 9%	56 8%
%>100 ppm	7 7%	5 6%	7 0%
DRY-TO-DRY*** (AVG TWA PPM)	20 5 ppm	16 1 ppm	17 2 ppm 16 9 ppm* 16 7 ppm**
%>25 ppm	24 3%	18 5%	18 6%* 17 2%**
%>100 ppm	1 0%	8%	1 3%* 8%**

* Denotes dry-to-dry refrigerated with small vent to purge cylinder at end of dry cycle
** Denotes dry-to-dry refrigerated with no vent whatsoever
*** Denotes standard dry-to-dry with water-cooled condenser and vent at end of dry cycle

In 1988, the OSHA Director of Federal-State Operations conducted a nationwide query of the OSHA State Consultation Programs asking for high risk small businesses in need of occupational safety and health research The dry cleaning industry was the second most mentioned small business, falling behind autobody repair shops [27] Preliminary information gathered by the NIOSH,

Division of Surveillance, Hazard Evaluations, and Field Studies has shown a high incidence of back pain among laundry and dry cleaning workers [28] This information has not been gathered exclusively for dry cleaning, and, additional research and analysis are needed

Based upon the preceding information, a preliminary hazard analysis (PHA) was performed for the dry cleaning industry For this PHA, a hazard was defined as an activity or condition that poses a threat of loss During this analysis, the hazards listed below were identified

- inhalation of PERC vapors
- ergonomic hazards
- exposure to hazardous chemicals used in the spotting process
- fire/explosion hazards
- direct (dermal) exposure to PERC
- thermal burns
- heat stress

- mechanical hazards
- electrical hazards
- slips/trips/falls

These hazards are listed from top to bottom in decreasing order of risk The degree of risk was based upon two factors

1) likelihood of occurrence

2) severity of consequence

Each risk ranking is of a qualitative nature

APPENDIX B DRY CLEANING TECHNOLOGY

Two types of machines are generally used in dry cleaning transfer and dry-to-dry Transfer machines are older, less expensive, and require manual transfer of solvent laden clothing between the washer and dryer This is the point of highest worker exposure Transfer machines process twice as much clothing as comparably sized dry-to-dry machines because the process time is half that of a dry-to-dry machine Some owners of dry-to-dry machines reduce the cycle time or exceed the load capacity to increase productivity Unfortunately, this practice increases exposure due to residuals left in the clothing [29]

Because of the high exposures that occur during transfer, transfer machines are no longer manufactured in the United States, however, used or reconditioned ones can still be purchased Seventy percent of machines today are dry-to-dry machines using a one step process that eliminates clothing transfer [1] Clothes enter and exit the machine dry PERC exposure from dry-to-dry machines is considerably less than exposure from transfer machines Most federal and state regulations do not require the use of dry-to-dry machines, however, a few states, such as California and New York, have introduced legislation to eliminate use of transfer machines Worker exposures below 25 ppm are much more difficult to achieve using a transfer machine Most shops are moving or have moved to replace transfer machines with dry-to-dry machines because of the trend toward stricter regulations from both state and federal OSHA and the EPA

Among dry-to-dry machines, there are two general types in use today vented and ventless dry-to-dry machines Vented dry-to-dry machines vent residual solvent vapors directly to the atmosphere or through some form of vapor recovery system during the aeration process Ventless dry-to-dry machines are essentially closed systems which are only open to the atmosphere when the machine door is opened or closed They recirculate heated drying air through a vapor recovery system and back to the drying drum There is no aeration step

Two primary technologies are used to recover PERC vapors the carbon adsorber and the refrigerated condenser Carbon absorbers remove PERC molecules from the air by passing solvent laden vapors over activated carbon, which has a high adsorption capacity The PERC is then recovered in a condenser, separated from the water, and returned to the storage tank Desorption typically occurs daily, if not done regularly, the carbon bed will become ineffective for carbon recovery Refrigerated condensers use a refrigerant to cool the solvent laden air below the dew point of the vapor to recover the PERC

Tests have shown that several new technologies are more effective than a carbon adsorber or refrigerated condenser alone They are the Boewe® Consorba® and Dow TVS® technology Both of these are a subset of ventless dry-to-dry machines, which reduce occupational exposure by lowering solvent residuals in the cylinder The Boewe® Consorba® has a refrigerated condenser and carbon adsorber in series Air passes through the refrigerated condenser where solvent is extracted A drying sensor in the machine switches to a cool-down cycle During this phase, the cooled air leaves the refrigerated condenser and passes through the carbon adsorber

Dow's TVS® technology has eliminated the need for condensation equipment and returns the vapors directly to the machine cylinder A polymeric adsorbent has been developed by Dow which has a high capacity for PERC, even at high vapor concentrations The polymer is desorbed by hot air, thereby eliminating any waste water stream which would result if steam were used This system can be used as a primary control and retrofitted to existing, vented, dry-to-dry machines, converting the machine to a closed-loop, no vent system This system can also be used as a secondary control on closed-loop, refrigerated, dry-to-dry machines to lower residuals in the cylinder

Dry cleaners use filtration and distillation to recover and purify the solvent Filtration is used to remove insoluble soils, nonvolatile residues, and loose dyes from the solvent Filtration is usually a continuous process in which the solvent passes through either an adsorbent powder or filter cartridge, both of which must be replaced periodically Additionally, powderless, spin-disc filters[30] and a no filtration process[31] have been developed that significantly reduce the generation of hazardous waste

Distillation, which is used by 90 percent of the industry, separates soluble oils, fatty acids, and greases not removed by filtration [32] Distillation occurs by heating PERC to its boiling point so that it vaporizes and later is condensed back to liquid form During this process, nonvolatile impurities, which cannot be boiled off, remain at the bottom of the still and are discarded as hazardous waste Both filtration and distillation produce solid wastes containing PERC residue

APPENDIX C POTENTIAL HAZARDS

Exposure to PERC is the primary health hazard for workers in dry cleaning facilities today PERC can enter the human body through both respiratory and dermal exposure Symptoms associated with respiratory exposure include the following depression of the central nervous system, damage to the liver and kidneys, impaired memory, confusion, dizziness, headache, drowsiness, and eye, nose, and throat irritation [1] Repeated dermal exposure may result in dry, scaly, and fissured dermatitis [33]

Over the past 15 years, studies conducted by the National Cancer Institute (1977) and the National Toxicology Program (1986) have established a link between PERC exposure and cancer in animals Other studies have shown an elevated risk of urinary tract,[34 35,36] esophageal,[33 37] and pancreatic cancer[38 39] among individuals who work in dry cleaning establishments Most of these studies involved exposure to a variety of solvents and have not been linked to PERC exposure Cancer mortality research is continuing at NIOSH and other research organizations

Spotting involves the selective application of a wide variety of chemicals and steam to remove specific stains Some of the chemicals and chemical families that are used on a fairly regular basis for spotting in addition to PERC are as follows other chlorinated solvents, amyl acetate, petroleum naphtha, oxalic acid, acetic acid, esters, ethers, ketones, dilute hydrofluoric acid, hydrogen peroxide, and aqueous ammonia Individuals who perform the spotting process could be exposed to toxic chemicals through skin or eye contact or inhalation of vapors Use of dilute hydrofluoric acid, which is found in rust removal spotting agents, poses the greatest risk from acute dermal exposure, however, many of the chemicals used can cause occupational dermatoses from chronic exposure to the skin

Previous studies have shown that inhalation exposures are minimized due to the limited quantities of chemicals and the intermittent nature and short duration of the task [19] During personal sampling by the Arthur D Little Company at the International Fabricare Institute's Analysis Laboratory,[40] PERC exposures during spotting were many times lower than OSHA standards and some chemicals being used were below detection limits [41] The primary hazard posed by the majority of chemicals used in the spotting process is skin damage resulting from chronic or acute exposure or injury to the eyes, however, chemicals that readily vaporize and have a high toxicity could pose a risk from inhalation Vapor pressure, toxicity, ventilation, manner and frequency of use, and air concentration should all be considered when assessing the risk from inhalation

APPENDIX D
RESPIRATORY PROTECTION
(Code of Federal Regulations, 29 CFR 1910 134)

(a) Permissible practice (1) In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors, the primary objective shall be to prevent atmospheric contamination This shall be accomplished as far as feasible by accepted engineering control measures (for example, enclosure or confinement of the operation, general and local ventilation, and substitution of less toxic materials) When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators shall be used pursuant to the following requirements

(2) Respirators shall be provided by the employer when such equipment is necessary to protect the health of the employee The employer shall provide the respirators which are applicable and suitable for the purpose intended The employer shall be responsible for the establishment and maintenance of a respiratory protective program which shall include the requirements outlined in paragraph (b) of this section

(3) The employee shall use the provided respiratory protection in accordance with instructions and training received

(b) Requirements for a minimal acceptable program (1) Written standard operating procedures governing the selection and use of respirators shall be established

1910 134(b)(2)

(2) Respirators shall be selected on the basis of hazards to which the worker is exposed

(3) The user shall be instructed and trained in the proper use of respirators and their limitations

(4) [Reserved]

(5) Respirators shall be regularly cleaned and disinfected Those used by more than one worker shall be thoroughly cleaned and disinfected after each use

(6) Respirators shall be stored in a convenient, clean, and sanitary location

(7) Respirators used routinely shall be inspected during cleaning Worn or deteriorated parts shall be replaced Respirators for emergency use such as self-contained devices shall be thoroughly inspected at least once a month and after each use

(8) Appropriate surveillance of work area conditions and degree of employee exposure or stress shall be maintained

(9) There shall be regular inspection and evaluation to determine the continued effectiveness of the program

(10) Persons should not be assigned to tasks requiring use of respirators unless it has been determined that they are physically able to perform the work and use the equipment The local physician shall determine what health and physical conditions are pertinent The respirator user's medical status should be reviewed periodically (for instance, annually)

1910 134(b)(11)

(11) Approved or accepted respirators shall be used when they are available The respirator furnished shall provide adequate respiratory protection against the particular hazard for which it is designed in accordance with standards established by competent authorities The U S Department of Interior,

Bureau of Mines, and the U S Department of Agriculture are recognized as such authorities Although respirators listed by the U S Department of Agriculture continue to be acceptable for protection against specified pesticides, the U S Department of the Interior, Bureau of Mines, is the agency now responsible for testing and approving pesticide respirators

(c) Selection of respirators Proper selection of respirators shall be made according to the guidance of American National Standard Practices for Respiratory Protection Z88 2-1969

(d) Air quality (1) Compressed air, compressed oxygen, liquid air, and liquid oxygen used for respiration shall be of high purity Oxygen shall meet the requirements of the United States Pharmacopoeia for medical or breathing oxygen Breathing air shall meet at least the requirements of the specification for Grade D breathing air as described in Compressed Gas Association Commodity Specification G-7 1-1966 Compressed oxygen shall not be used in supplied-air respirators or in open circuit self-contained breathing apparatus that have previously used compressed air Oxygen must never be used with air line respirators

1910 134(d)(2)

(2) Breathing air may be supplied to respirators from cylinders or air compressors

(i) Cylinders shall be tested and maintained as prescribed in the Shipping Container Specification Regulations of the Department of Transportation (49 CFR Part 178)

(ii) The compressor for supplying air shall be equipped with necessary safety and standby devices A breathing air-type compressor shall be used Compressors shall be constructed and situated so as to avoid entry of contaminated air into the system and suitable in-line air purifying sorbent beds and filters installed to further assure breathing air quality A receiver of sufficient capacity to enable the respirator wearer to escape from a contaminated atmosphere in event of compressor failure, and alarms to indicate compressor failure and overheating shall be installed in the system If an oil-lubricated compressor is used, it shall have a high-temperature or carbon monoxide alarm, or both If only a high-temperature alarm is used, the air from the compressor shall be frequently tested for carbon monoxide to insure that it meets the specifications in paragraph (d)(1) of this section

(3) Air line couplings shall be incompatible with outlets for other gas systems to prevent inadvertent servicing of air line respirators with nonrespirable gases or oxygen

1910 134(d)(4)

(4) Breathing gas containers shall be marked in accordance with American National Standard Method of Marking Portable Compressed Gas Containers to Identify the Material Contained, Z48 1-1954, Federal Specification BB-A-1034a, June 21, 1968, Air, Compressed for Breathing Purposes, or Interim Federal Specification GG-B-00675b, April 27, 1965, Breathing Apparatus, Self-Contained

(e) Use of respirators

(1) Standard procedures shall be developed for respirator use These should include all information and guidance necessary for their proper selection, use, and care Possible emergency and routine uses of respirators should be anticipated and planned for

(2) The correct respirator shall be specified for each job The respirator type is usually specified in the work procedures by a qualified individual supervising the

respiratory protective program The individual issuing them shall be adequately instructed to insure that the correct respirator is issued

(3) Written procedures shall be prepared covering safe use of respirators in dangerous atmospheres that might be encountered in normal operations or in emergencies Personnel shall be familiar with these procedures and the available respirators

1910 134(e)(3)(i)

(i) In areas where the wearer, with failure of the respirator, could be overcome by a toxic or oxygen-deficient atmosphere, at least one additional man shall be present Communications (visual, voice, or signal line) shall be maintained between both or all individuals present Planning shall be such that one individual will be unaffected by any likely incident and have the proper rescue equipment to be able to assist the other(s) in case of emergency

(ii) When self-contained breathing apparatus or hose masks with blowers are used in atmospheres immediately dangerous to life or health, standby men must be present with suitable rescue equipment

(iii) Persons using air line respirators in atmospheres immediately hazardous to life or health shall be equipped with safety harnesses and safety lines for lifting or removing persons from hazardous atmospheres or other and equivalent provisions for the rescue of persons from hazardous atmospheres shall be used A standby man or men with suitable self-contained breathing apparatus shall be at the nearest fresh air base for emergency rescue

(4) Respiratory protection is no better than the respirator in use, even though it is worn conscientiously Frequent random inspections shall be conducted by a qualified individual to assure that respirators are properly selected, used, cleaned, and maintained

1910 134(e)(5)

(5) For safe use of any respirator, it is essential that the user be properly instructed in its selection, use, and maintenance Both supervisors and workers shall be so instructed by competent persons Training shall provide the men an opportunity to handle the respirator, have it fitted properly, test its facepiece-to-face seal, wear it in normal air for a long familiarity period, and, finally, to wear it in a test atmosphere

(i) Every respirator wearer shall receive fitting instructions including demonstrations and practice in how the respirator should be worn, how to adjust it, and how to determine if it fits properly Respirators shall not be worn when conditions prevent a good face seal Such conditions may be a growth of beard, sideburns, a skull cap that projects under the facepiece, or temple pieces on glasses Also, the absence of one or both dentures can seriously affect the fit of a facepiece The worker's diligence in observing these factors shall be evaluated by periodic check To assure proper protection, the facepiece fit shall be checked by the wearer each time he puts on the respirator This may be done by following the manufacturer's facepiece fitting instructions

(ii) Providing respiratory protection for individuals wearing corrective glasses is a serious problem A proper seal cannot be established if the temple bars of eye glasses extend through the sealing edge of the full facepiece As a temporary measure, glasses with short temple bars or without temple bars may be taped to the wearer's head

Wearing of contact lenses in contaminated atmospheres with a respirator shall not be allowed Systems have been developed for mounting corrective lenses inside full facepieces When a workman must wear corrective lenses as part of the facepiece, the facepiece and lenses shall be fitted by qualified individuals to provide good vision, comfort, and a gas-tight seal

1910 134(e)(5)(iii)

(iii) If corrective spectacles or goggles are required, they shall be worn so as not to affect the fit of the facepiece Proper selection of equipment will minimize or avoid this problem

(f) Maintenance and care of respirators (1) A program for maintenance and care of respirators shall be adjusted to the type of plant, working conditions, and hazards involved, and shall include the following basic services

(i) Inspection for defects (including a leak check),

(ii) Cleaning and disinfecting,

(iii) Repair,

(iv) Storage

Equipment shall be properly maintained to retain its original effectiveness

(2) (i) All respirators shall be inspected routinely before and after each use A respirator that is not routinely used but is kept ready for emergency use shall be inspected after each use and at least monthly to assure that it is in satisfactory working condition

(ii) Self-contained breathing apparatus shall be inspected monthly Air and oxygen cylinders shall be fully charged according to the manufacturer's instructions It shall be determined that the regulator and warning devices function properly

1910 134(f)(2)(iii)

(iii) Respirator inspection shall include a check of the tightness of connections and the condition of the facepiece, headbands, valves, connecting tube, and canisters Rubber or elastomer parts shall be inspected for pliability and signs of deterioration Stretching and manipulating rubber or elastomer parts with a massaging action will keep them pliable and flexible and prevent them from taking a set during storage

(iv) A record shall be kept of inspection dates and findings for respirators maintained for emergency use

(3) Routinely used respirators shall be collected, cleaned, and disinfected as frequently as necessary to insure that proper protection is provided for the wearer Respirators maintained for emergency use shall be cleaned and disinfected after each use

(4) Replacement or repairs shall be done only by experienced persons with parts designed for the respirator No attempt shall be made to replace components or to make adjustment or repairs beyond the manufacturer's recommendations Reducing or admission valves or regulators shall be returned to the manufacturer or to a trained technician for adjustment or repair

1910 134(f)(5)

(5) (i) After inspection, cleaning, and necessary repair, respirators shall be stored to protect against dust, sunlight, heat, extreme cold, excessive moisture, or damaging chemicals Respirators placed at stations and work areas for emergency use should be quickly accessible at all times and should be stored in compartments built for the purpose The compartments should be clearly marked Routinely used respirators, such as dust respirators, may be placed in plastic bags Respirators

should not be stored in such places as lockers or tool boxes unless they are in carrying cases or cartons

(ii) Respirators should be packed or stored so that the facepiece and exhalation valve will rest in a normal position and function will not be impaired by the elastomer setting in an abnormal position

(iii) Instructions for proper storage of emergency respirators, such as gas masks and self-contained breathing apparatus, are found in "use and care" instructions usually mounted inside the carrying case lid

(g) Identification of gas mask canisters (1) The primary means of identifying a gas mask canister shall be by means of properly worded labels The secondary means of identifying a gas mask canister shall be by a color code

1910 134(g)(2)

(2) All who issue or use gas masks falling within the scope of this section shall see that all gas mask canisters purchased or used by them are properly labeled and colored in accordance with these requirements before they are placed in service and that the labels and colors are properly maintained at all times thereafter until the canisters have completely served their purpose

(3) On each canister shall appear in bold letters the following

(i) - Canister
for ______________________________
(Name for atmospheric contaminant)
or
Type N Gas Mask Canister

(ii) **In addition**, essentially the following wording shall appear beneath the appropriate phrase on the canister label "For respiratory protection in atmospheres containing not more than _______ percent by volume of ______________________ "
Name of atmospheric contaminant)

1910 134(g)(4)

(4) Canisters having a special high-efficiency filter for protection against radionuclides and other highly toxic particulates shall be labeled with a statement of the type and degree of protection afforded by the filter The label shall be affixed to the neck end of, or to the gray stripe which is around and near the top of, the canister The degree of protection shall be marked as the percent of penetration of the canister by a 0 3-micron-diameter dioctyl phthalate (DOP) smoke at a flow rate of 85 liters per minute

(5) Each canister shall have a label warning that gas masks should be used only in atmospheres containing sufficient oxygen to support life (at least 16 percent by volume), since gas mask canisters are only designed to neutralize or remove contaminants from the air

(6) Each gas mask canister shall be painted a distinctive color or combination of colors indicated in Table I-1 All colors used shall be such that they are clearly identifiable by the user and clearly distinguishable from one another The color coating used shall offer a high degree of resistance to chipping, scaling, peeling, blistering, fading, and the effects of the ordinary atmospheres to which they may be exposed under normal conditions of storage and use Appropriately colored pressure sensitive tape may be used for the stripes

TABLE I-1

Atmospheric contaminants to be protected against	Colors assigned(1)
Acid gases	White
Hydrocyanic acid gas	White with 1/2-inch green stripe completely around the canister near the bottom
Chlorine gas	White with 1/2-inch yellow stripe completely around the canister near the bottom
Organic vapors	Black
Ammonia gas	Green
Acid gases and ammonia gases	Green with 1/2-inch white stripe completely around the canister near the bottom
Carbon Monoxide	Blue
Acid gases and organic vapors	Yellow
Hydrocyanic acid gas and chloropicrin vapor	Yellow with 1/2-inch blue stripe completely around the canister near the bottom
Acid gases, organic vapors, and ammonia gases	Brown
Radioactive materials, excepting tritium and noble gases	Purple (Magenta)
Particulates (dusts, fumes, mists, fogs, or smokes) in combination with any of the above gases or vapors	Canister color for contaminant, as designated above, with 1/2-inch gray stripe completely around the canister near the top
All of the above atmospheric contaminants	Red with 1/2-inch gray stripe completely around the canister near the top

Footnote(1) Gray shall not be assigned as a main color for a canister designed to remove acids or vapors

NOTE Orange shall be used as a complete body, or stripe color to represent gases not included in this table The user will need to refer to the canister label to determine the degree of protection the canister will afford

(Approved by the Office of Management and Budget under control number 1218-0099) [39 FR 23502, June 27, 1974, as amended at 43 FR 49748, Oct 24, 1978, 49 FR 5322, Feb 10, 1984, 49 FR 18295, Apr 30, 1984]

APPENDIX E RAW AIR SAMPLING AND REAL-TIME DATA

TUCHMAN CLEANER'S CHARCOAL TUBE SAMPLES

DATE	DAY	SAMPLE #	TYPE	SAMPLE LOCATION	SAMPLE TIME (min)	FLOW RATE (LPM)	VOLUME (liters)	PERC DET LIMIT	PERC MASS (mg)	PERC CONC (mg/m3)	PERC CONC (ppm)
05/09/94	MAY_9	681 00	AREA	OFF GAS	87 00	0 2	17 4	0 01	0 07	3 9	0 57
05/10/94	MAY_10	662 00	PERSONAL	OPERATOR	124 00	0 1	12 4	0 01	1 60	129 0	19 03
05/10/94	MAY_10	747 00	AREA	RECEPTION	123 00	0 1	12 3	0 01	0 28	22 8	3 36
05/10/94	MAY_10	587 00	AREA	ABOVE MACH	124 00	0 1	12 4	0 01	0 79	63 7	9 40
05/10/94	MAY_10	646 00	AREA	BEHIND LF	128 00	0 1	12 8	0 01	0 47	36 7	5 41
05/10/94	MAY_10	782 00	AREA	BEHIND RT	128 00	0 1	12 8	0 01	1 80	140 6	20 74
05/10/94	MAY_10	599 00	PERSONAL	PRESSER 2	90 00	0 1	9 0	0 01	0 60	66 7	9 83
05/10/94	MAY_10	555 00	PERSONAL	PRESSER 3	83 00	0 1	8 3	0 01	0 18	21 7	3 20
05/10/94	MAY_10	647 00	AREA	OFF GAS	37 00	0 2	7 4	0 01	0 07	9 2	1 36
05/10/94	MAY_10	655 00	PERSONAL	OPERATOR	120 00	0 1	12 0	0 01	1 20	100 0	14 75
05/10/94	MAY_10	652 00	AREA	RECEPTION	125 00	0 1	12 5	0 01	0 18	14 4	2 12
05/10/94	MAY_10	651 00	AREA	ABOVE MACH	122 00	0 1	12 2	0 01	0 54	44 3	6 53
05/10/94	MAY_10	731 00	AREA	BEHIND LF	120 00	0 1	12 0	0 01	0 34	28 3	4 18
05/10/94	MAY_10	760 00	AREA	BEHIND RT	117 00	0 1	11 7	0 01	0 78	66 7	9 83
05/10/94	MAY_10	667 00	PERSONAL	PRESSER 2	115 00	0 1	11 5	0 01	0 42	36 5	5 39
05/10/94	MAY_10	595 00	PERSONAL	PRESSER 3	112 00	0 1	11 2	0 01	0 24	21 4	3 16
05/10/94	MAY_10	669 00	PERSONAL	OPERATOR	120 00	0 1	12 0	0 01	1 80	150 0	22 12
05/10/94	MAY_10	611 00	AREA	RECEPTION	117 00	0 1	11 7	0 01	0 13	11 1	1 64
05/10/94	MAY_10	649 00	AREA	ABOVE MACH	121 00	0 1	12 1	0 01	0 76	62 8	9 26
05/10/94	MAY_10	604 00	AREA	BEHIND LF	121 00	0 1	12 1	0 01	0 72	59 5	8 77
05/10/94	MAY_10	624 00	AREA	BEHIND RT	123 00	0 1	12 3	0 01	0 63	51 2	7 55
05/10/94	MAY_10	633 00	PERSONAL	PRESSER 2	123 00	0 1	12 3	0 01	0 42	34 1	5 04
05/10/94	MAY_10	607 00	PERSONAL	PRESSER 3	124 00	0 1	12 4	0 01	0 18	14 5	2 14
05/11/94	MAY_11	663 00	PERSONAL	OPERATOR	118 00	0 1	11 8	0.01	1 70	144 1	21 25
05/11/94	MAY_11	780 00	AREA	RECEPTION	118 00	0 1	11 8	0 01	0 32	27 1	4 00
05/11/94	MAY_11	619 00	AREA	ABOVE MACH	117 00	0 1	11 7	0 01	0 75	64 1	9 45
05/11/94	MAY_11	617 00	AREA	BEHIND LF	120 00	0 1	12 0	0 01	0 73	60 8	8 97
05/11/94	MAY_11	735 00	AREA	BEHIND RT	122 00	0 1	12 2	0 01	1 90	155 7	22 97
05/11/94	MAY_11	627 00	PERSONAL	PRESSER 2	114 00	0 1	11 4	0 01	0 22	19 3	2 85
05/11/94	MAY_11	584 00	PERSONAL	PRESSER 3	118 00	0 1	11 8	0 01	0 14	11 9	1 75
05/11/94	MAY_11	631 00	PERSONAL	OPERATOR	130 00	0 1	13 0	0 01	0 70	53 8	7 94
05/11/94	MAY_11	754 00	AREA	RECEPTION	127 00	0 1	12 7	0 01	0 09	6 9	1 01
05/11/94	MAY_11	653 00	AREA	ABOVE MACH	130 00	0 1	13 0	0 01	0 29	22 3	3 29
05/11/94	MAY_11	621 00	AREA	BEHIND LF	127 00	0 1	12 7	0 01	0 18	14 2	2 09
05/11/94	MAY_11	516 00	AREA	BEHIND RT	125 00	0 1	12 5	0 01	0 28	22 4	3 30
05/11/94	MAY_11	751 00	PERSONAL	PRESSER 2	57 00	0 1	5 7	0 01	0 03	5 3	0 78
05/11/94	MAY_11	767 00	PERSONAL	PRESSER 3	75 00	0 1	7 5	0 01	0 04	5 3	0 79
05/12/94	MAY_12	625 00	PERSONAL	OPERATOR	120 00	0 1	12 0	0 01	1 50	125 0	18 43
05/12/94	MAY_12	588 00	AREA	RECEPTION	118 00	0 1	11 8	0 01	0 36	30 5	4 50
05/12/94	MAY_12	758 00	AREA	ABOVE MACH	118 00	0 1	11 8	0 01	0 81	68 6	10 12
05/12/94	MAY_12	613 00	AREA	BEHIND LF	121 00	0 1	12 1	0 01	0 60	49 6	7 31
05/12/94	MAY_12	799 00	AREA	BEHIND RT	122 00	0 1	12 2	0 01	1 30	106 6	15 71
05/12/94	MAY_12	770 00	PERSONAL	PRESSER 2	124 00	0 1	12 4	0 01	0 37	29 8	4 40
05/12/94	MAY_12	790 00	PERSONAL	PRESSER 3	115 00	0 1	11 5	0 01	0 35	30 4	4 49
05/11/94	MAY_11	623 00	AREA	OFF GAS	41 00	0 2	8 2	0 01	0 09	10 5	1 55
05/12/94	MAY_12	683 00	PERSONAL	OPERATOR	120 00	0 1	12 0	0 01	0 64	53 3	7 86
05/12/94	MAY_12	603 00	AREA	RECEPTION	120 00	0 1	12 0	0 01	0 10	8 3	1 22
05/12/94	MAY_12	561 00	AREA	ABOVE MACH	120 00	0 1	12 0	0 01	0 29	24 2	3 56
05/12/94	MAY_12	737 00	AREA	BEHIND LF	121 00	0 1	12 1	0 01	0 16	13 2	1 95
05/12/94	MAY_12	783 00	AREA	BEHIND RT	120 00	0 1	12 0	0 01	0 37	30 8	4 55
05/12/94	MAY_12	788 00	PERSONAL	PRESSER 2	37 00	0 1	3 7	0.01	0 15	40 5	5 98
05/12/94	MAY_12	684 00	PERSONAL	PRESSER 3	130 00	0 1	13 0	0 01	0 14	10 8	1 59

Level	Sample size	Average	Median	Mode	Geometric mean
Open door	5	9.19544	2.51700	2.51700	3.86274
Unload	26	271.055	204.380	478.566	155.573
Load	14	846.120	1003.11	1003.11	584.427
Shut door	28	60.4500	26.1768	26.1768	42.1811
Other	10	237.890	171.324	82.5576	113.228

Level	Variance	Standard deviation	Standard error	Minimum	Maximum
Open door	243.168	15.5938	6.97378	1.67800	37.0838
Unload	69236.0	263.127	51.6035	12.0816	1209.00
Load	261967.	511.827	136.792	82.5576	1689.75
Shut door	4713.18	68.6526	12.9741	26.1768	308.584
Other	51596.2	227.148	71.8305	2.51700	689.490

Level	Range	Lower quartile	Upper quartile	Interquartile range	Skewness
Open door	35.4058	2.18140	2.51700	0.33560	2.23335
Unload	1196.92	59.9046	424.534	364.629	1.90196
Load	1607.19	431.246	1305.48	874.238	-0.33127
Shut door	282.407	26.1768	61.9182	35.7414	2.52188
Other	686.973	82.5576	406.747	324.190	0.91393

Level	Standardized skewness	Kurtosis	Standardized kurtosis	Coefficient of variation	Sum
Open door	2.03876	4.99037	2.27778	169.582	45.9772
Unload	3.95925	5.32304	5.54040	97.0752	7047.43
Load	-0.50602	-0.81167	-0.61992	60.4911	11845.7
Shut door	5.44789	6.38176	6.89309	113.569	1692.60
Other	1.17987	-0.02804	-0.01810	95.4844	2378.90

Level	Sample size	Average	Median	Mode	Geometric mean
Open door	31	1003.25	1078.95	1078.95	0.00000
Closed doo	51	103.240	39.9364	35.4058	54.1281
Other	15	0.00589	0.00000	0.00000	0.00000

Level	Variance	Standard deviation	Standard error	Minimum	Maximum
Open door	119518.	345.714	62.0921	0.00000	1327.30
Closed doo	42551.2	206.279	28.8849	30.2040	940.687
Other	0.00052	0.02280	0.00589	0.00000	0.08832

Level	Range	Lower quartile	Upper quartile	Interquartile range	Skewness
Open door	1327.30	955.789	1206.48	250.693	-2.20906
Closed doo	910.483	35.4058	60.0724	24.6666	3.43453
Other	0.08832	0.00000	0.00000	0.00000	3.87298

Level	Standardized skewness	Kurtosis	Standardized kurtosis	Coefficient of variation	Sum
Open door	-5.02125	4.40659	5.00815	34.4593	31100.9
Closed doo	10.0133	10.7128	15.6165	199.806	5265.23
Other	6.12372	15.0000	11.8585	387.298	0.08832

Level	Sample size	Average	Median	Mode	Geometric mean
Open lid	6	0.00000	0.00000	0.00000	0.00000
Load barre	38	109.489	123.249	174.176	0.00000
Scrub	139	99.2671	94.1861	172.784	83.3208
Unload bar	30	84.1562	55.0552	32.8385	62.6014
Transport	23	88.8443	62.2706	76.9866	72.6219
Load m/c	9	152.651	174.176	174.193	149.094
Close door	4	165.723	174.185	174.193	165.026
Away	120	19.4887	14.3469	9.34646	0.00000
Drain xs	87	84.4208	78.8492	17.1324	67.9152
Other	215	48.3576	22.3006	22.3006	0.00000
Open sq tr	5	7.48724	7.13150	6.71200	7.42376
Remove cg	25	13.0320	8.64170	8.64170	10.6571
Clean trp	99	20.5006	10.7056	11.3768	12.7910
Remove rd	27	77.8244	72.8252	65.4420	60.7680
Clean rd	105	11.5680	6.44352	6.44352	7.33311
Idle	57	7.69819	6.12470	5.40316	7.08028
Close sq t	1	8.64170	8.64170	8.64170	8.64170

Level	Variance	Standard deviation	Standard error	Minimum	Maximum
Open lid	0.00000	0.00000	0.00000	0.00000	0.00000
Load barre	3989.03	63.1587	10.2457	0.00000	174.176
Scrub	2450.52	49.5027	4.19876	9.83308	172.817
Unload bar	3573.10	59.7754	10.9134	8.92696	178.590
Transport	3162.01	56.2317	11.7251	25.6231	188.825
Load m/c	1073.10	32.7582	10.9194	103.281	174.193
Close door	286.565	16.9282	8.46411	140.331	174.193
Away	286.770	16.9343	1.54588	0.00000	108.315
Drain xs	2368.57	48.6680	5.21776	17.1324	174.193
Other	3155.65	56.1751	3.83111	0.00000	174.210
Open sq tr	1.25853	1.12184	0.50170	6.46030	9.24578
Remove cg	95.1658	9.75529	1.95106	5.95690	40.0371
Clean trp	992.558	31.5049	3.16636	6.86302	174.176
Remove rd	1678.67	40.9716	7.88498	6.09114	146.959
Clean rd	678.648	26.0509	2.54231	4.58094	189.480
Idle	17.1482	4.14104	0.54849	5.38638	24.5827
Close sq t	0.00000	0.00000	0.00000	8.64170	8.64170

Level	Range	Lower quartile	Upper quartile	Interquartile range	Skewness
Open lid	0.00000	0.00000	0.00000	0.00000	0.00000
Load barre	174.176	45.1718	174.176	129.005	-0.31293
Scrub	162.984	60.4919	157.262	96.7703	0.00597
Unload bar	169.663	32.8385	144.241	111.402	0.51427
Transport	163.202	42.6883	150.433	107.744	0.63762
Load m/c	70.9123	122.192	174.193	52.0012	-0.95564
Close door	33.8620	157.254	174.193	16.9394	-2.00000
Away	108.315	9.34646	22.0070	12.6605	1.89051
Drain xs	157.061	39.5840	119.071	79.4869	0.32470
Other	174.210	7.29930	67.8080	60.5087	1.25978
Open sq tr	2.78548	6.71200	7.88660	1.17460	1.15333
Remove cg	34.0802	7.29930	16.8136	9.51426	1.59755
Clean trp	167.313	7.34964	12.2662	4.91654	3.34390
Remove rd	140.868	55.8438	111.486	55.6425	-0.11591
Clean rd	184.899	5.88978	7.06438	1.17460	5.90124
Idle	19.1963	5.40316	8.96052	3.55736	3.05256
Close sq t	0.00000	8.64170	8.64170	0.00000	0.00000

Level	Standardized skewness	Kurtosis	Standardized kurtosis	Coefficient of variation	Sum
Open lid	0.00000	0.00000	0.00000		0.00000
Load barre	-0.78753	-1.50427	-1.89283	57.6852	4160.57
Scrub	0.02875	-1.22135	-2.93929	49.8682	13798.1
Unload bar	1.14994	-1.45242	-1.62386	71.0291	2524.69
Transport	1.24838	-1.16455	-1.14003	63.2925	2043.42
Load m/c	-1.17042	-1.30723	-0.80051	21.4595	1373.86
Close door	-1.63299	4.00000	1.63299	10.2147	662.894
Away	8.45463	5.40762	12.0918	86.8929	2338.65
Drain xs	1.23644	-0.97031	-1.84742	57.6493	7344.61
Other	7.54118	0.08311	0.24877	116.166	10396.9
Open sq tr	1.05284	0.74291	0.33909	14.9834	37.4362
Remove cg	3.26098	1.54672	1.57862	74.8563	325.800
Clean trp	13.5830	11.0692	22.4817	153.678	2029.56
Remove rd	-0.24589	-0.66465	-0.70497	52.6462	2101.26
Clean rd	24.6867	35.8442	74.9734	225.198	1214.64
Idle	9.40861	9.60582	14.8036	53.7924	438.797
Close sq t	0.00000	0.00000	0.00000	0.00000	8.64170

Level	Sample size	Average	Median	Mode	Geometric mean
Open sq bt	6	8.13830	8.13830	8.89340	8.10319
Remove cg	3	7.38320	7.38320	7.38320	7.38320
Clean cg	63	12.1855	8.89340	17.1156	10.8847
Replace cg	11	12.0206	12.0816	12.0816	11.9814
Close lid	12	15.1719	15.1020	15.1020	15.1515
Open rd bt	5	21.8140	21.8140	21.8140	21.8140
Remove cg	18	19.7724	19.9682	19.9682	19.7161
Clean cg	24	32.5113	23.1564	22.9886	29.5730
Replace cg	11	62.2233	49.5010	45.1382	57.4617
Close lid	13	60.4080	60.4080	60.4080	60.4080
Open lt ft	7	48.1826	45.8094	60.4080	47.4459
Remove ftr	18	25.5709	25.2539	21.9818	25.3988
Clean ftr	42	29.7046	30.6235	22.3174	28.3815
Replace ft	16	33.8746	22.4852	22.4852	24.8369
Clean lt	8	81.9284	71.3989	38.2584	69.8858
Transport	22	32.0498	29.1972	33.7278	29.0470
Open barre	22	11.1816	9.90020	15.2698	10.8206
Dispose of	10	9.76596	9.90020	9.90020	9.73449
Close barr	50	12.8501	11.9977	11.7460	12.6052
Others	61	9.63337	9.22900	8.89340	9.54602
Stand idle	37	16.8888	21.4784	21.4784	15.9983
Over vacuu	31	28.0009	21.4784	9.06120	18.5599

Level	Variance	Standard deviation	Standard error	Minimum	Maximum
Open sq bt	0.68421	0.82717	0.33769	7.38320	8.89340
Remove cg	0.00000	0.00000	0.00000	7.38320	7.38320
Clean cg	55.2169	7.43080	0.93619	7.21540	43.1246
Replace cg	1.13907	1.06727	0.32179	11.0748	14.9342
Close lid	0.68835	0.82967	0.23950	13.4240	17.2834
Open rd bt	0.00000	0.00000	0.00000	21.8140	21.8140
Remove cg	2.32625	1.52521	0.35949	17.6190	21.8140
Clean cg	231.741	15.2230	3.10739	17.6190	63.7640
Replace cg	667.322	25.8326	7.78881	27.6870	102.526
Close lid	0.00000	0.00000	0.00000	60.4080	60.4080
Open lt ft	84.9157	9.21497	3.48293	36.4126	60.4080
Remove ftr	9.84210	3.13721	0.73945	21.9818	33.2244
Clean ftr	78.3083	8.84920	1.36546	17.9546	47.6552
Replace ft	2384.62	48.8326	12.2082	18.7936	216.630
Clean lt	2567.91	50.6745	17.9162	38.2584	175.519
Transport	267.544	16.3568	3.48727	15.2698	81.5508
Open barre	8.97947	2.99658	0.63887	7.21540	15.2698
Dispose of	0.68077	0.82509	0.26092	8.72560	11.2426
Close barr	6.53594	2.55655	0.36155	8.55780	17.1156
Others	1.79676	1.34043	0.17162	7.38320	12.0816
Stand idle	29.0488	5.38969	0.88606	10.5714	22.6530
Over vacuu	874.789	29.5768	5.31216	7.21540	105.211

Level	Range	Lower quartile	Upper quartile	Interquartile range	Skewness
Open sq bt	1.51020	7.38320	8.89340	1.51020	0.00000
Remove cg	0.00000	7.38320	7.38320	0.00000	2.44949
Clean cg	35.9092	8.39000	15.6054	7.21540	2.72000
Replace cg	3.85940	11.0748	12.0816	1.00680	2.22296
Close lid	3.85940	15.1020	15.1859	0.08390	0.77795
Open rd bt	0.00000	21.8140	21.8140	0.00000	0.00000
Remove cg	4.19500	17.9546	20.6394	2.68480	-0.20909
Clean cg	46.1450	22.9886	41.5305	18.5419	0.93943
Replace cg	74.8388	45.1382	87.9272	42.7890	0.49369
Close lid	0.00000	60.4080	60.4080	0.00000	-1.13545
Open lt ft	23.9954	41.6144	60.4080	18.7936	0.48392
Remove ftr	11.2426	22.9886	27.5192	4.53060	0.95362
Clean ftr	29.7006	22.3174	35.7414	13.4240	0.10712
Replace ft	197.836	18.7936	22.4852	3.69160	3.97308
Clean lt	137.260	38.2584	111.168	72.9091	1.04568
Transport	66.2810	22.6530	33.7278	11.0748	1.96071
Open barre	8.05440	8.72560	15.2698	6.54420	0.55519
Dispose of	2.51700	8.72560	10.2358	1.51020	0.05299
Close barr	8.55780	11.5782	15.1020	3.52380	0.39437
Others	4.69840	8.89340	10.5714	1.67800	0.71534
Stand idle	12.0816	11.0748	21.4784	10.4036	-0.16141
Over vacuu	97.9952	9.06120	25.0022	15.9410	1.73881

Level	Standardized skewness	Kurtosis	Standardized kurtosis	Coefficient of variation	Sum
Open sq bt	0.00000	-3.33333	-1.66667	10.1639	48.8298
Remove cg	1.73205	0.00000	0.00000	0.00000	22.1496
Clean cg	8.81381	8.17510	13.2452	60.9808	767.685
Replace cg	3.00990	6.36079	4.30627	8.87872	132.226
Close lid	1.10019	5.68134	4.01731	5.46845	182.063
Open rd bt	0.00000	0.00000	0.00000	0.00000	109.070
Remove cg	-0.36215	-1.02565	-0.88824	7.71380	355.904
Clean cg	1.87886	-0.49163	-0.49163	46.8239	780.270
Replace cg	0.66846	-1.36001	-0.92073	41.5159	684.456
Close lid	-1.67134	-2.40000	-1.76635	0.00000	785.304
Open lt ft	0.52269	-1.11176	-0.60042	19.1251	337.278
Remove ftr	1.65172	0.62703	0.54303	12.2687	460.275
Clean ftr	0.28342	-1.38723	-1.83513	29.7907	1247.59
Replace ft	6.48801	15.8441	12.9367	144.157	541.994
Clean lt	1.20744	0.11418	0.06592	61.8523	655.427
Transport	3.75448	4.35406	4.17827	51.0355	705.096
Open barre	1.06311	-1.50096	-1.43706	26.7992	245.995
Dispose of	0.06841	-0.34377	-0.22190	8.44861	97.6596
Close barr	1.13845	-0.74589	-1.07660	19.8951	642.506
Others	2.28086	-0.52741	-0.84082	13.9145	587.636
Stand idle	-0.40084	-2.05323	-2.54937	31.9128	624.887
Over vacuu	3.95236	1.81102	2.05825	105.628	868.029

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