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Evaluation and Control of Perchloroethylene Exposures During Dry Cleaning

Gary S. Earnest

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

A study was conducted at a large, commercial dry cleaner to evaluate the control of worker exposure to perchloroethylene (PERC) and provide recommendations to reduce exposure. This shop used a dry-to-dry machine that had a refrigerated condenser, which operated during the dry cycle, as the primary vapor recovery device. A small fan that was ducted to a carbon canister was the secondary vapor recovery device. When the machine door was opened, a microswitch energized the fan to draw PERC-laden air from the cylinder through activated carbon. These two controls operated independently. Three of the six employees were sampled. The machine operator, who had the highest exposures, was exposed to between 13 and 19 ppm time-weighted average (TWA) PERC, primarily from loading/unloading the dry cleaning machine. Real-time monitoring revealed that average PERC exposure while loading the machine was much higher than while unloading (846 versus 271 ppm). Real-time measurements taken near the carbon canister showed that very high concentrations of PERC (approximately 1500 ppm) were blown into the work environment each time the machine door was opened. The carbon canister was ineffective at capturing PERC in the exhausted air. The average exposure to the operator during 7 minutes of maintenance was approximately 22 ppm TWA. The highest instantaneous maintenance exposures occurred during lint trap cleaning and peaked at over 200 ppm. Controls at this shop maintained exposures to PERC below 25 ppm TWA, the exposure concentration that the Occupational Safety and Health Administration encourages dry cleaners to follow. The National Institute for Occupational Safety and Health recommends controlling PERC to the lowest feasible concentration. Several measures could be taken to reduce exposures further. Modifications to the secondary vapor recovery device or use of local exhaust ventilation could drastically reduce exposure during loading/unloading (the main source of exposure). By controlling and eliminating exposure during loading and unloading, operator exposure could be reduced approximately two-thirds. Most of the findings and recommendations provided at this shop apply to many other dry cleaning shops across the country that use similar equipment and work practices. EARNEST, G.S.: EVALUATION AND CONTROL OF PERCHLOROETHYLENE EXPOSURES DURING DRY CLEANING. APPL. OCCUP. ENVIRON. HYG. 11(2):125–132; 1996.

The dry cleaning industry currently has over 30,000 commercial shops and approximately 244,000 employees in the United States.(1) Among these shops approximately 90 percent currently use perchloroethylene (PERC) as their primary solvent. 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 depression of the central nervous system; damage to the liver and kidneys; impaired memory; confusion; dizziness; headache; drowsiness; and eye, nose, and throat irritation.(2) PERC is a known animal carcinogen and a suspected human carcinogen. Some studies have shown an elevated risk of urinary tract,(3–5) esophageal,(2,6) and pancreatic cancer(7,8) among individuals who work in dry cleaning establishments. Repeated dermal exposure may result in dry, scaly, and fissured dermatitis.(1)

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.(9) OSHA had lowered the PEL to 25 ppm in 1989 under the Air Contaminants Standard; however, this standard was vacated in July 1992.(10) OSHA continues to encourage employers to follow the 25 ppm limit.(11) The National Institute for Occupational Safety and Health (NIOSH) considers PERC to be a potential occupational carcinogen and recommends that exposure be reduced to the lowest feasible concentration.(12,13)

This article describes a case study that evaluated control of worker exposure to PERC from a dry-to-dry dry cleaning machine with two independent vapor recovery systems. Dry cleaning machines with similar designs are used throughout the United States. Many of the findings and recommendations for reducing exposure to PERC in this case study are widely applicable to other dry cleaning facilities.

Plant and Process Description

This study was conducted at a commercial dry cleaning shop that 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 entrance for customers. One door, in the rear of the shop, was the entrance for workers, maintenance, and deliveries.

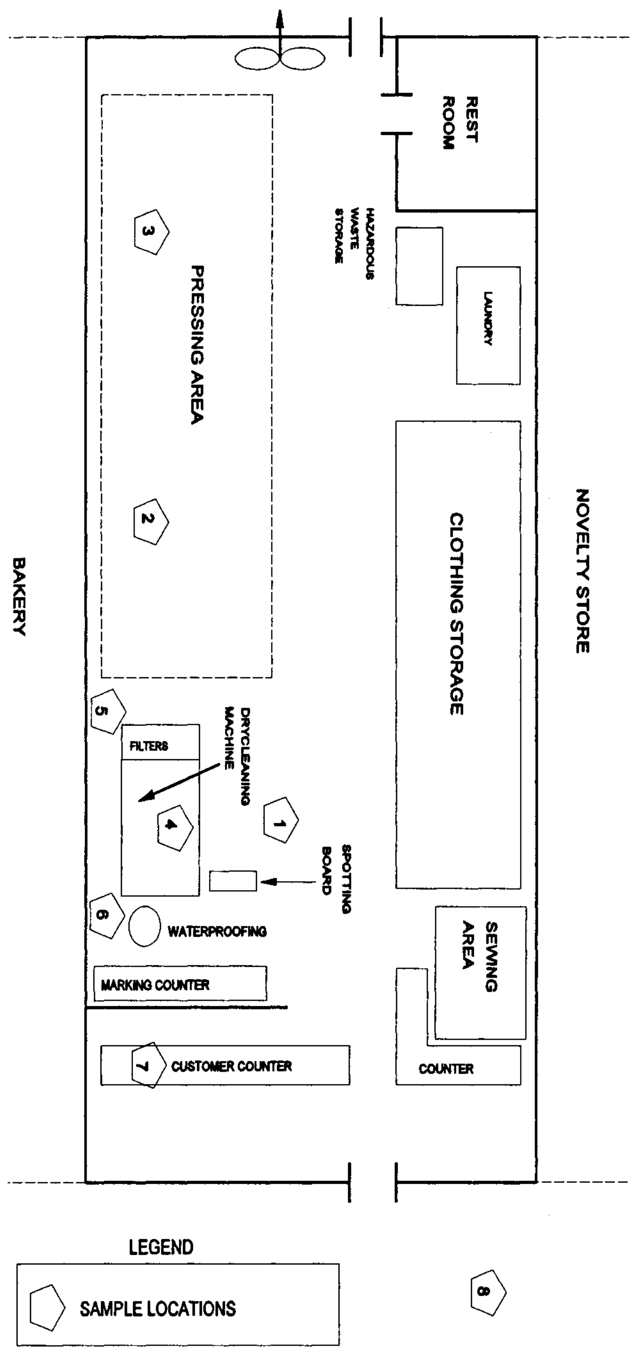

FIGURE 1. Shop layout.

There was one dry cleaning machine in the facility, located near the front left corner (Figure 1). A waterproofing drum was located near the left rear corner of the machine. A spotting board was near the front corner of the dry cleaning machine. Pressing was done along the wall adjacent to the bakery. Three small electric 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 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 next to the novelty store. Laundry was done behind and under the clothing racks. A restroom was in the rear corner of the shop, and hazardous waste storage barrels were next to the restroom. An eyewash station was in the restroom.

This shop did all of its own dry cleaning and did not receive clothing from any other store. The shop cleaned between 1400 and 1700 pounds of clothing per week. On Monday or Tuesday, the busiest days, eight or nine loads of clothing were cleaned, as opposed to an average of six or seven loads on other days. The load sizes varied between 25 and 45 pounds. There were six employees at this shop. Most employees worked approximately 8 hours per day. The shop was open for business 12 hours per day, Monday through Saturday.

Garments were brought to 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 dry cleaning machine and performed any spot removal that was necessary.

Various chemicals were used for spot removal, depending on the type of stain. Spotting chemicals and chemical mixtures were 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.

The dry cleaning process involves three steps: washing, extracting, and drying. At the shop, clothing was first weighed in a basket and then loaded into the dry cleaning 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 weighed less than 45 pounds, and a few were less than 35 pounds. The weight of every load was logged onto a daily record. The dry cleaning machine had a cleaning cycle of between 35 and 40 minutes.

Dry cleaning was done in an Omega® model CE-55, 55-pound, dry-to-dry machine that was about 6 years old. This machine had a refrigerated condenser as the primary vapor recovery device to condense PERC vapors during the dry cycle. The secondary vapor recovery device consisted of a small, centrifugal fan, rated at 110 ft^3/min at atmospheric pressure and ducted to an activated carbon canister. When the machine door was opened, a microswitch energized the fan to draw PERC-laden air from the machine's cylinder through the activated carbon. This was intended to recover residual PERC vapors in the cylinder during loading and unloading.

Solvent filters were on the right side of the machine. In lieu of solvent distillation used in most dry cleaning plants, clay and carbon filters were used to remove both soluble and insoluble soils from the solvent. There were four filters in two separate tubes. Distillation was eliminated, along with the need to clean the still or dispose of hazardous waste produced during distillation.

To begin the washing cycle, the store manager manually loaded the soiled clothes into the machine cylinder through the front door. After the door was closed, PERC was automatically pumped into the cylinder. Water-based detergent, based on the weight of the load, was automatically injected into the machine. The contents of the machine cylinder were then agitated for a period of time, allowing the solution to remove soils. Following this step, the clothes were spun at high speed to extract the solvent. After 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, and finally through a heating coil and back to the drum. While passing through the cooling coils, PERC vapors condensed to liquid form, and this liquid was 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 was bypassed and the temperature of the cooling coil was reduced to less than 0°F. This step relaxed the fabric fibers, helped to reduce wrinkles, and removed additional PERC.

Garments removed from the machine were pressed to remove wrinkles and to restore their original shape. Once the garments were completely pressed, they were wrapped in plastic and stored on the overhead rack to await customer pickup.

Methodology

Personal and area air sampling was conducted, using NIOSH Method 1003 for halogenated hydrocarbons. Analysis was done using a gas chromatograph with flame ionization detector. Samples were collected over a 120-minute period with a flow rate of 0.1 L/min to achieve a volume of 12 L. The limit of detection for this process was 0.01 mg/sample.(14)

Area samples were taken at various locations throughout the shop to evaluate exposure sources and air flow patterns. 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). TWA personal sampling was done for the machine operator and both pressers. Most of this sampling occurred when the dry cleaning machines were in operation. No air sampling was done for the spotting chemicals.

Real-time monitoring was used to study how specific manual tasks and maintenance operations affected worker exposure to PERC. Some of these procedures, such as loading/unloading the machine, occurred frequently throughout the day, while others, such as machine maintenance and waterproofing, occurred less often. Most of these tasks took less than 30 minutes. Real-time monitoring of PERC exposures was performed using a photoionization detector (PID; MicroTIP® IS3000 PHOTOVAC Inc., Thornhill, Ontario) with a 10.6-EV ultraviolet lamp. This instrument provides an analog output response proportional to the concentration of ionizable pollutants present in the air. The instrument was calibrated using 100 ppm isobutylene span gas and five standard concentrations of PERC gas. Instrument readings and actual PERC concentrations were used to construct a calibration curve.

Data were recorded on an electronic datalogger (Rustrak® Ranger, Gulton, Inc., East Greenwich, Rhode Island) and downloaded to a portable computer. During the gathering of real-time data, a video camera 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 PERC off-gassing from garments and provide a relative comparison of solvent recovery effectiveness of different dry cleaning machines. A test swatch approximately 5 inches by 6 inches, made of 51 percent rayon and 49 percent polyester, was introduced into the dry cleaning machine at the beginning of the wash cycle along with a typical load of clothing. When the dry cycle

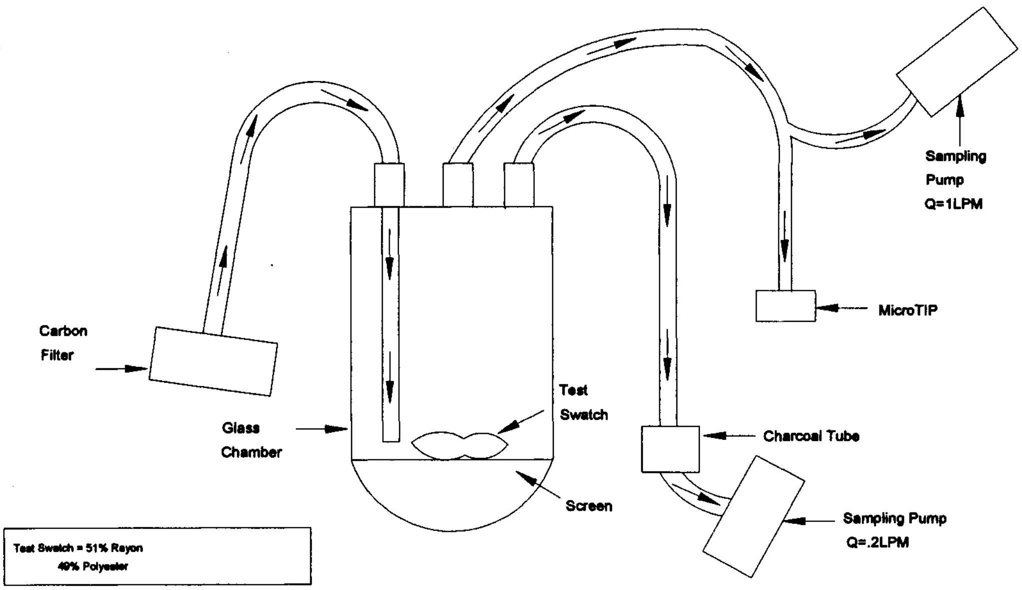

FIGURE 2. Apparatus for measuring garment off-gassing.

TABLE 1. TWA and Geometric Mean PERC Exposures

Worker	Number of Samples	Average Sampling Period (min)	Geometric Mean (ppm)	Geometric Standard Deviation (ppm)	TWA Concentration (ppm)	TWA Concentration Range (ppm)
Operator	7	364	14.7	1.5	15.8	13.2–18.6
Presser 2	7	328	4.0	2.1	4.9	2.2–6.5
Presser 3	7	319	2.1	1.7	2.5	1.4–3.0

had ended, the test swatch was placed in a small glass test chamber. As the PERC residuals vaporized, the emitted PERC concentrations were monitored and recorded using the PID and datalogger. The emitted PERC concentrations were summed. This value was used to determine the mass of PERC (milligrams) per kilogram of cloth. The apparatus for measuring off-gassing is depicted in Figure 2.

General ventilation measurements were taken with a hot-wire anemometer (Kurz® model 1440). Air flow near the dry cleaning machine was qualitatively evaluated using smoke tubes. The capacity and dimensions of general dilution ventilation systems were also recorded.

Measurement Error

The principal measurements in this study were the concentrations of PERC measured on coconut shell charcoal tubes using NIOSH Method 1003 for halogenated hydrocarbons and the real-time measurements. Charcoal tube analysis was performed using a gas chromatograph with flame ionization detector. According to the NIOSH method, measurements are expected to be accurate to within ±15.1 percent.(14) The other principal measure was the response of the PID with a 10.6-EV ultraviolet lamp. This instrument provides an analog output response proportional to the concentration of ionizable pollutants present in the air. This instrument was calibrated for PERC. Measurements made using the PID are expected to be accurate to within ±10 ppm or ±25 percent.(15)

Results

A summary of personal air samples is reported in Table 1. All of the individual personal samples taken at this shop were below 25 ppm. The TWA exposures were calculated based on the time the dry cleaning machine was in operation; typically, it was operated between 4 and 6 hours per day.

As expected, the operator of the machine had the highest exposure to PERC, which ranged from 13.2 to 18.6 ppm TWA on various days. The highest average exposure during a 2-hour period occurred to the operator while performing dip-tank waterproofing operations. The two pressers did not work in as close proximity to the machine as the operator (see Figure 1), but did work closely with dry-cleaned clothing and were exposed to between 1.4 and 6.5 ppm TWA on various days. The presser whose workstation was closest to the machine was consistently exposed to higher individual and TWA concentrations than the other presser.

Results of area air sampling are reported in Table 2. 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. The lowest concentrations measured were found in the reception area.

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 (846 ppm) was much higher than while unloading garments (271 ppm) that had been cleaned in PERC. The integrated exposure (area under the curve) was also higher during loading the machine, approximately 11,850 versus 7050 ppm*s. 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 blown into the work environment.

Operator exposure during waterproofing dip-tank operations was extremely high because the operator was working over an open tank of PERC and small quantities of other chemicals used 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 local ventilation during this task. The highest average exposures (approximately 150 ppm) occurred when the clothing was placed into the dry cleaning machine. Some of the

TABLE 2. Area Sample Concentrations of PERC

Location	Number of Samples	Average Sample Time (min)	Geometric Mean (ppm)	Geometric Standard Deviation (ppm)	Range (ppm)
Behind left	7	122.50	4.7	1.8	1.9–9.0
Behind right	7	122.50	9.7	2.0	3.3–23.0
Above machine	7	121.40	6.7	1.6	3.3–10.1
Reception	7	121.05	2.3	1.7	1.0–4.5

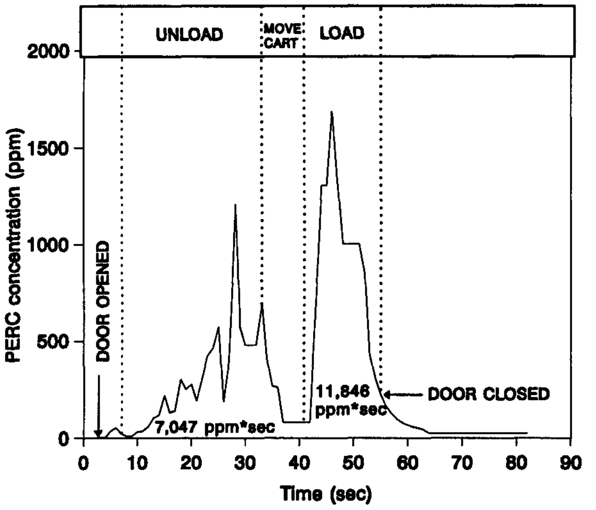

FIGURE 3. Operator exposure during loading/unloading machine.

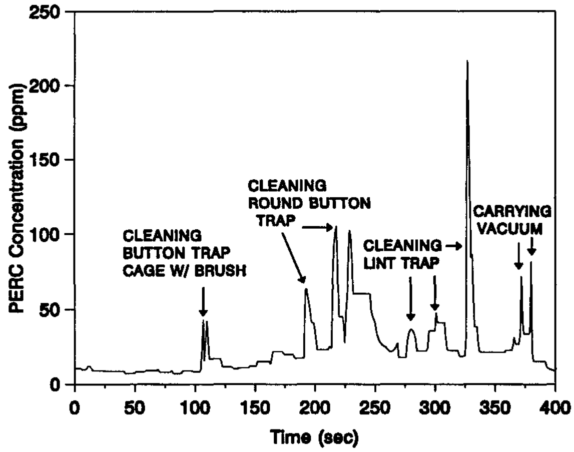

FIGURE 5. Operator exposure during maintenance on lint and button traps.

recorded real-time values were significantly lower than actual because the PID became saturated and was off scale. The greatest integrated exposure to PERC occurred when the clothing was scrubbed at the waterproofing barrel. Because this activity took longer than any other single task (approximately 140 seconds), the average exposure was relatively high (approximately 100 ppm).

Figure 5 shows exposure during machine maintenance. Machine maintenance occurred on a daily basis and involved cleaning the lint and button traps and disposing of the hazardous waste. Normally, maintenance was performed on the machine before the boilers were heated in the morning. There was no still to be cleaned on this machine. The highest exposure occurred while workers cleaned the lint trap. The average exposure during all of the maintenance on this machine was approximately 22 ppm.

The results of the garment off-gassing experiment are shown in Figure 6. 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 3800 ppm*s or 31.8 mg PERC/kg cloth. The average PERC concentration in the off-gas was 6 ppm.

Ventilation at the dry cleaning machine door was negligible. Air velocity measurements 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 44-inch diameter propeller fan, located in the rear wall of the building, exhausted approximately 6500 ft^3/min. Smoke tubes indicated significant air movement approximately 8 ft in front of the fan. No liquid solvent leaks were detected in this shop; however, general maintenance and housekeeping appeared to be a problem. A large vapor leak detected on the vapor recovery housing panel resulted from overtightening the retaining bolts.

Discussion

Video recording and real-time monitoring showed that the most significant source of exposure to the operator occurred during the loading and unloading of the machines. Brief exposures during this procedure peaked at near 1800 ppm. More

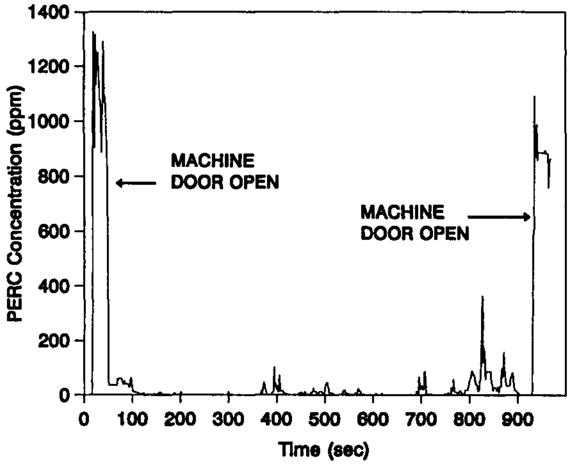

FIGURE 4. Real-time measurements near carbon canister exhaust.

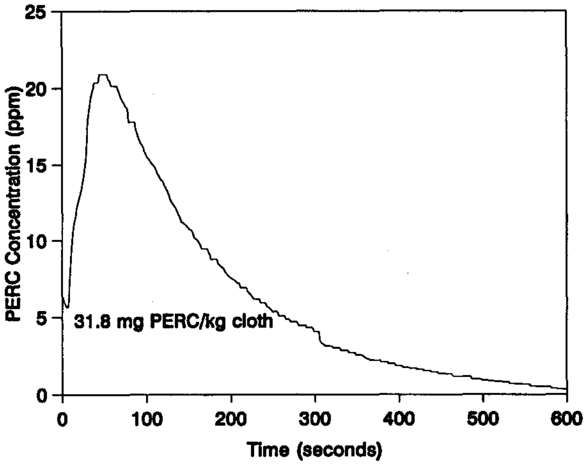

FIGURE 6. Typical off-gassing of test swatch.

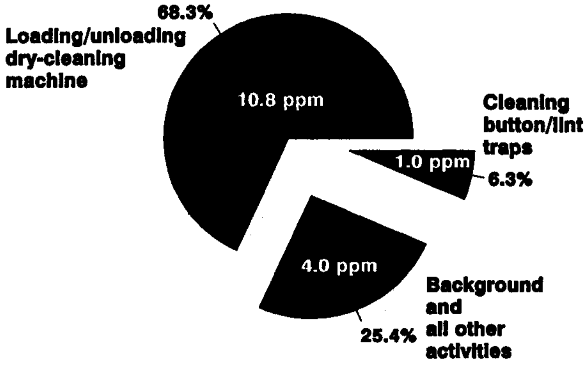

FIGURE 7. Sources of operator TWA exposure to PERC on a typical day.

importantly, loading and unloading occurred frequently, approximately six to ten times a day, depending on volume of business. Exposure from machine maintenance normally occurred only once a day; other high exposure activities, such as waterproofing, occurred even less frequently.

Operator exposure could be reduced two-thirds by eliminating the exposure during loading and unloading. The operator's TWA exposure during the workday based on air sampling data was 270,000 ppm★s (17,040 seconds ★ 15.82 ppm), whereas the exposure during loading/unloading, using real-time data, was 184,100 ppm★s/day (23,010 ppm★s ★ 8 times/day). If exposure during loading/unloading were reduced near 0, then the operator's total 8-hour TWA exposure would be reduced from approximately 15.8 ppm to approximately 5 ppm. Figure 7 shows the percentage that various activities contribute to the machine operator's TWA exposure during a typical day. Waterproofing was not included in this figure because it does not occur on a daily basis.

Figure 3 shows real-time measurements taken in the operator's breathing zone during unloading and loading. During unloading, the PERC concentration increased gradually as off-gassing garments were removed from the machine. Greater exposures occurred during loading than during unloading because residual PERC in the cylinder was ejected by air displacement when a large quantity of uncleaned clothing was placed in the empty cylinder. This air displacement was characterized by a rapid increase in PERC concentration, an almost instantaneous peak which approached 1800 ppm. The concentration in the worker's breathing zone dissipated over the next 10 to 20 seconds and then returned to 0. The machine cylinder was not fully isolated from the other sources of PERC within the machine, and it was not evacuated immediately prior to the door being opened. This allowed PERC vapors, which diffused into the cylinder, to be ejected when the door was opened. The secondary control on this machine was ineffective for the following two reasons:

- The activated carbon did not adsorb the PERC in the air exhausted by the fan.
- The 110-ft^3/min centrifugal fan provided insufficient air flow (capture velocity) at the face of the machine door to prevent escape of PERC vapors.

The small carbon canister was ineffective for a variety of reasons. Factors such as 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/or age of the carbon all affect adsorption. Generally, air flow rate and carbon bed capacity are the most important factors, and this was probably the case for this machine.(16)

Theoretical calculations (Appendix) indicated that at least one-tenth of a pound of carbon was needed per load if the concentration in the cylinder was 2000 ppm when the fan activated.(16–18) This was based upon the fact the 17-ft^3 cylinder contained approximately 0.96 L of PERC (gas phase) or 6.47 g 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 to be effective. At this shop the carbon in the canister was changed infrequently. Although there were no records, maintenance personnel estimated that the carbon was changed monthly.

Even if there had been sufficient carbon in the canister and the machine operated at optimal efficiency, the PERC effluent would tend to remain in the 50 to 150 ppm range. This concentration translates to approximately 95 to 99 percent efficiency. When the working capacity of the carbon is approached, breakthrough occurs and the concentration of PERC in the effluent stream increases dramatically. Even if the carbon canister were operating at optimal efficiency, the design of the secondary vapor recovery device would have permitted PERC-laden air to be exhausted into the work environment.

Because the centrifugal fan provided inadequate air flow, this secondary control on the machine failed to prevent vapors in the cylinder from escaping into the operator's breathing zone. Inadequate air flow was the most important factor contributing to the operator's daily TWA exposure. Much of the literature recommends an open-door face velocity of approximately 100 ft/min;(19–21) however, air velocity measurements at the face of this machine door were negligible.

Consequently, much of the residual PERC gas in the machine cylinder was permitted to escape directly into the operator's breathing zone during loading and unloading of the machine and later diffuse throughout the building.

Personal protective equipment at this shop consisted of a half-face respirator with organic vapor cartridges, and 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. There was no personal protective equipment training or respirator fit testing.

Conclusions and Recommendations

Nominally, this shop had adequate controls to maintain PERC TWA exposures below 25 ppm, which is the exposure concentration beneath which OSHA encourages dry cleaners to remain. NIOSH recommends controlling PERC to the lowest feasible concentration. The primary source of exposure to the workers in this shop was the dry cleaning machine. Loading and unloading of the machine had the greatest impact upon exposures, and if this were effectively controlled, TWA exposures could be reduced by approximately 66 percent.

Several measures could be taken to reduce exposures during loading and unloading. Local exhaust ventilation could be used by modifying the current system or by adding simple, inexpensive, external local exhaust ventilation consisting of an exhaust fan, ductwork, and hood. The 110-ft^3/min centrifugal fan and carbon canister were ineffective at controlling escape of residual PERC in the cylinder after the dry cycle. The fan provided insufficient air flow, 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 air flow and capture the residual PERC escaping from the cylinder. 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 present carbon canister would have to be changed almost every day.

Finally, the exhaust of the current system, which exhausted PERC into the work environment, should be ducted outside of the shop. This change would reduce some of the background concentrations of PERC in the shop. It is better to duct this PERC outside of the shop where it can dissipate, rather than to keep it inside the work environment where workers are exposed.

A simple, inexpensive, external local ventilation system with a separate exhaust fan, ductwork, and hood is another option. The captured air could then be exhausted outside the building or to a vapor recovery unit. Exposures during unloading have been shown to be reduced from 1000 to 28 ppm by use of a fan which operated at 990 ft^3/min with a slotted hood design.(22)

Controls should be implemented to reduce exposures during waterproofing operations. 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. Although no 5-minute peak or 15-minute short-term exposure was measured, it is highly likely that both peak and short-term limits of 300 and 200 ppm, respectively, were exceeded during waterproofing. Equipment is also available to perform waterproofing in the machine itself. Although waterproofing is performed infrequently, on an as-needed basis, it is a very significant source of exposure when it does occur.

Because the machine was 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 held the panel to the housing had been overtightened and caused the panel and seal to deform. This maladjustment was probably the cause of the high concentrations found near the right side of the machine. As machines age, leaks may develop and should be repaired promptly. Proper maintenance can be instrumental in reducing leakage.

Over the past decade, significant improvements have occurred in the dry cleaning industry to reduce occupational exposures and environmental emissions of PERC. This study, using real-time monitoring, suggests that a number of simple, inexpensive changes may be expected to result in dramatic exposure reductions to dry cleaning workers using similar equipment.

Disclaimer

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

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Appendix

17 $\text{ft}^3 \times 28.32\ \text{L/ft}^3 = 481.4$ L of air

2000 ppm $= (P/481.4) \times 10^6$, therefore: $P = 0.963$ L of PERC (gas phase)

0.963 L PERC/24.5 L/gmol $\times$ 166 g/gmol $=$ 6.52 g of PERC

6.52 g (1 lb./454 g) $= 1.43 \times 10^{-2}$ lb. PERC

1.43×10^{-2} lbs. PERC (1 gal/13.55 lbs.) $= 1.06 \times 10^{-3}$ gal PERC

1.06×10^{-3} gal PERC (66 lbs. carbon/1 gal PERC) $= 7.0 \times 10^{-2}$ lbs. carbon/load of clothing