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A Control Technology Evaluation of State-of-the-Art, Perchloroethylene Dry-Cleaning Machines

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NIOSH researchers evaluated the ability of fifth-generation dry-cleaning machines to control occupational exposure to perchloroethylene (PERC). Use of these machines is mandated in some countries; however, less than 1 percent of all U.S. shops have them. A study was conducted at a U.S. dry-cleaning shop where two fifth-generation machines were used. Both machines had a refrigerated condenser as a primary control and a carbon adsorber as a secondary control to recover PERC vapors during the dry cycle. These machines were designed to lower the PERC concentration in the cylinder at the end of the dry cycle to below 290 ppm. A single-beam infrared photometer continuously monitors the PERC concentration in the machine cylinder, and a door interlock prevents opening until the concentration is below 290 ppm. Personal breathing zone air samples were measured for the machine operator and presser. The operator had time-weighted average (TWA) PERC exposures that were less than 2 ppm. Highest exposures occurred during loading and unloading the machine and when performing routine machine maintenance. All presser samples were below the limit of detection. Real-time video exposure monitoring showed that the operator had peak exposures near 160 ppm during loading and unloading the machine (below the OSHA maximum of 300 ppm). This exposure (160 ppm) is an order of magnitude lower than exposures with more traditional machines that are widely used in the United States. The evaluated machines were very effective at reducing TWA PERC exposures as well as peak exposures that occur during machine loading and unloading. State-of-the-art dry-cleaning machines equipped with refrigerated condensers, carbon adsorbers, drum monitors, and door interlocks can provide substantially better protection than more traditional machines that are widely used in the United States.

Keywords Dry cleaning, Perchloroethylene, Engineering Controls, Vapor Recovery, Exposure Reduction, Tetrachloroethylene, Technical Feasibility

There are over 30,000 commercial dry-cleaning shops and approximately 244,000 dry-cleaning workers in the United States.⁽¹⁾ Approximately 90 percent of these shops use perchloroethylene (PERC) as their primary solvent. Exposure to PERC is the primary health hazard for workers in dry-cleaning shops. 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 cancers^(7,8) among individuals who work in dry-cleaning establishments.

The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for PERC is 100 ppm as an 8-hour time-weighted average (TWA). The allowable ceiling concentration limit is 200 ppm for 5 minutes in any 3-hour period, not to exceed a maximum of 300 ppm.⁽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⁾ OSHA is currently reviewing the PEL for PERC and will likely lower it. The National Institute for Occupational Safety and Health (NIOSH) considers PERC to be a potential occupational carcinogen and recommends that exposure be reduced.^(12,13) PERC has been a known animal carcinogen since the early 1990s.⁽¹⁴⁾ In 1995, the International Agency for Research on Cancer (IARC) classified PERC in group 2A, meaning that it is probably carcinogenic to humans.⁽¹⁵⁾

This article describes a NIOSH study that evaluated control of worker exposure to PERC in a dry-cleaning shop that used state-of-the-art, fifth-generation dry-cleaning machines.

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THE EVOLUTION OF DRY-CLEANING MACHINE DESIGN

Over the past several decades, the dry-cleaning industry has made tremendous progress in reducing worker exposures and environmental releases of PERC. In particular, the dry-cleaning machines and solvents used have evolved over time. The development of dry-cleaning machines encompasses five "generations," which are all currently used in the United States. Table I provides an outline of each machine generation and its major design features.

The first generation of dry-cleaning machines are transfer machines with separate washers and dryers. Transfer machines, older and less expensive, require manual transfer of solvent laden clothing between the washer and dryer. The transfer activity involves high worker exposure to PERC. Transfer machines were used exclusively until the late 1960s. That is when the second-generation, nonrefrigerated, dry-to-dry machines, using a one-step process that eliminates clothing transfer, were introduced.

In dry-to-dry machines, clothes enter and exit the machine dry. Generally, worker exposure to PERC from dry-to-dry machines is less than exposure from transfer machines. Most second-generation machines are vented dry-to-dry machines that vent residual solvent vapors directly to the atmosphere or through some form of vapor recovery system during the aeration

process. The third generation of machines, dry-to-dry machines with refrigerated condensers, were introduced in the late 1970s and early 1980s. These machines are ventless dry-to-dry machines that are essentially closed systems, which are only open to the atmosphere when the machine door is opened. They recirculate the heated drying air through a vapor recovery system and back to the drying drum. There is no aeration step. Third-generation dry-cleaning machines provide considerable solvent savings over their predecessors.

Fourth-generation dry-cleaning machines are essentially dry-to-dry, nonvented machines having controls to reduce residual PERC concentrations in the machine cylinder at the end of the dry cycle. These dry-to-dry machines rely on both a refrigerated condenser and closed-loop carbon adsorber that does not vent to the atmosphere to recover PERC vapors during the dry cycle. They are designed to recover residual PERC vapors in the cylinder at the end of the dry cycle. More traditional machines generally emit higher concentrations of PERC into the environment and workers' breathing zones. Fifth-generation machines have the same features as fourth-generation machines; however, they are also equipped with a monitor inside the machine drum connected to an interlock to ensure that the concentration is below approximately 290 ppm before the loading door can be opened.

TABLE I
Categories of perchloroethylene dry-cleaning machines

Machine generation	Machine type	Machine introduced	Design features
First	Transfer	Pre 1960	Separate washer and dryer Manual transfer of wet garments
Second	Dry-to-dry vented to atmosphere	Late 1960s	Single machine for washing/drying Watercooled condenser Air vented to atmosphere during dry cycle
Third	Dry-to-dry nonvented	Late 1970s	Single machine for washing/drying Refrigerated condenser No venting to atmosphere during dry cycle Some third-generation machines have a small door vent activated during loading and unloading
Fourth	Dry-to-dry nonvented secondary control	Late 1980s	Single machine for washing/drying Refrigerated condenser and carbon adsorber Carbon adsorber lowers PERC concentration in the cylinder at the end of the dry cycle No venting to the atmosphere
Fifth	Dry-to-dry nonvented secondary control drum monitor door interlock	1990s	Single machine for washing/drying Refrigerated condenser and carbon adsorber Carbon adsorber lowers PERC concentration in the cylinder at end of the dry cycle No venting to the atmosphere PERC concentration monitored in machine cylinder, and door will not unlock until concentration reaches threshold

PLANT AND PROCESS DESCRIPTION

A diagram of the evaluated shop is shown in Figure 1. Two dry-cleaning machines that were approximately one year old were used in this shop: Boewe Models 536 and 546. These machines had 36- and 46-pound garment capacities, respectively. Both dry-cleaning machines were situated on top of a metal safety trough to provide protection against a solvent leak reaching the ground or ground water. There were no other dry-cleaning machines in the shop. A radial fan that brought air into the shop was located in the wall next to the two machines. Dry-cleaned clothing was pressed in a small room adjacent to the dry-cleaning room, and laundered items were pressed near the rear of the building. Several fans provided general ventilation for dilution and cooling. Pressed clothing was hung on a long, motorized clothing rack, which transported clothing to the storage area.

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. Generally, one person operated the dry-cleaning machines and performed spot removal.

Dry-cleaning is a three-step process, involving washing, extracting, and drying. At the start of the washing process, clothes were manually loaded through the front door into the cylinder of the machine. After the door was closed and the machine was activated, PERC was automatically pumped into the cylinder. Water-based detergent was automatically injected into each load. 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. After the solvent was removed, the fabric was tumbled dry. Garments removed from the machine were pressed to remove wrinkles and to restore their original shape. Once the garments were completely pressed, they were put on hangers, wrapped

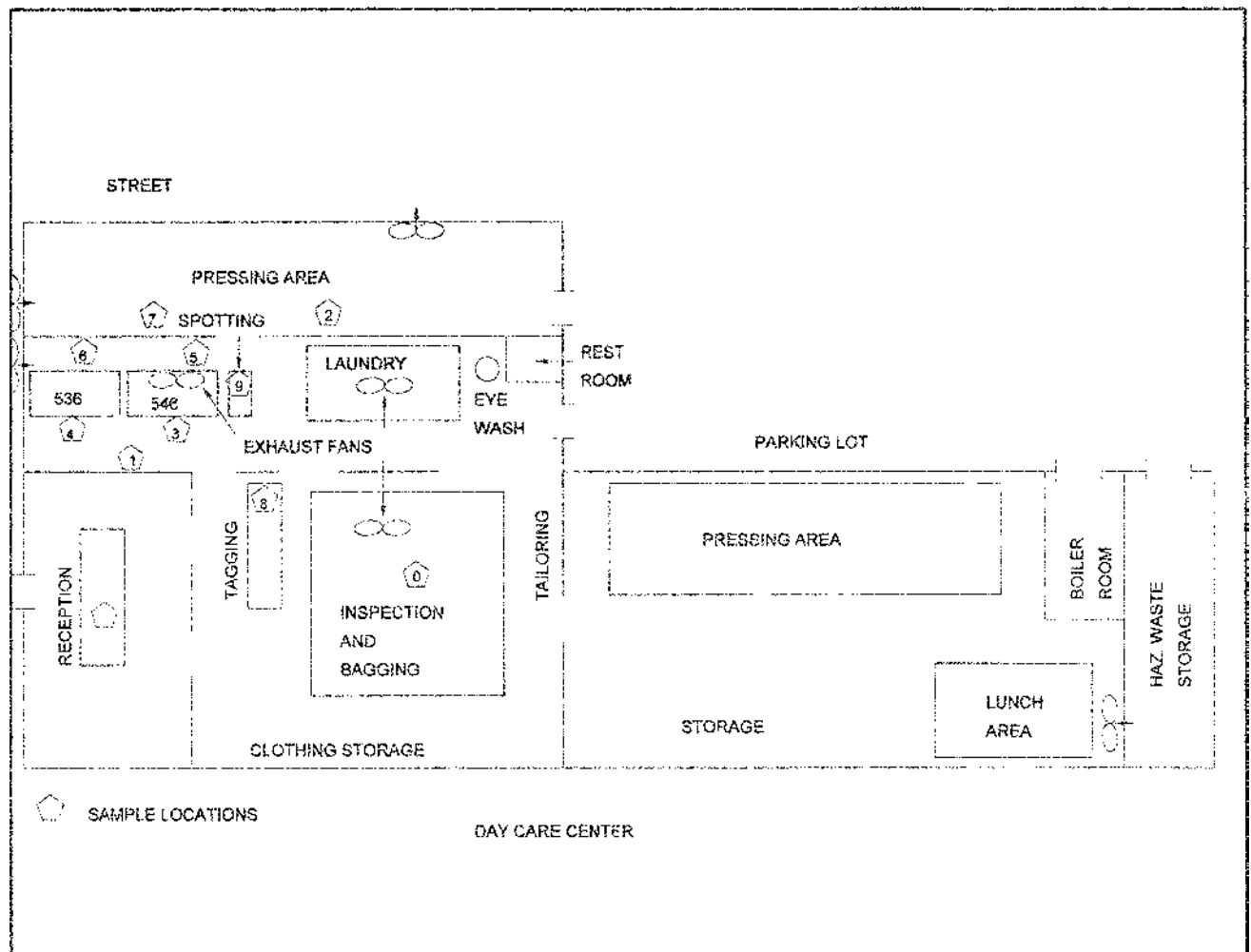


FIGURE 1
Shop layout.

in plastic, and stored on the overhead rack to await customer pick up.

Two fifth-generation PERC dry-cleaning machines were used. Each closed-loop, dry-to-dry machine had a refrigerated condenser and carbon adsorber to recover PERC vapors during the dry cycle. During the main drying cycle, the solvent-laden air recirculated through the refrigerated condenser, which vaporized and recovered most of the residual solvent. While passing through the cooling coil, PERC vapors condensed and were directed to the separator where the water was removed. Liquid PERC flowed back into the machine tank while the water was piped to an external container. A drying sensor located between the refrigerated condenser and water separator automatically switched the system to the cool-down/deodorize step. During this part of the cycle, the air was cooled in the refrigerated condenser and then passed through the carbon adsorber before returning to the drying drum. These machines did not vent to the atmosphere.

A single-beam infrared (IR) photometer continuously monitored the PERC concentration in the machine cylinder and the work environment. An interlock on the machine door did not allow the door to open unless the PERC concentration in the cylinder was below 290 ppm. As long as the concentration in the cylinder was above this limit, the drying/vapor recovery process continued to operate. This step relaxed the fabric fibers, helped to reduce wrinkles, and removed residual solvent from the garments. The carbon adsorption system used activated carbon to capture PERC in the airstream. The carbon was automatically desorbed, using hot air, during the subsequent dry cycle. Because steam was not used, there was no water vapor being retained in the carbon, and consequently the amount of hazardous waste generated was minimized.

These machines each had an enclosed still cleaning device that eliminated the need to rake out the still on a daily basis. Instead, automated still maintenance occurred daily, and the still was manually raked out approximately once every three weeks. The machines had a cleaning cycle of 35 to 40 minutes; however, the drying cycle was often increased for an additional 5 minutes to ensure that the PERC concentration in the cylinder was sufficiently low.

METHODS

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 liters/minute to achieve a volume of 12 liters. The limit of detection for this process was 0.01 mg/sample or approximately 0.12 ppm for a 2-hour sample.⁽¹⁶⁾ Area air samples were collected in front of and behind the dry-cleaning machine, in the pressing area located adjacent to the room containing the dry-cleaning machines, near the customer counter, and outside the building (Figure 1). TWA personal sampling was done for the machine operator and two pressers. For personal sampling,

workers were equipped with a sampling pump that clipped to a waist belt. The pump was used to draw air through a hose attached to a glass charcoal tube placed in the breathing zone of the worker. Most of the air sampling occurred when the dry-cleaning machines were in operation.

Real-time monitoring was used to study how specific manual tasks affected worker exposure to PERC. Some of these procedures occurred frequently throughout the day, such as loading/unloading the machine, while others were performed less often, such as machine maintenance. 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, Canada) with an 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 data logger (Rustrak Ranger, Gulton, Inc., East Greenwich, RI) 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 viewed 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 types of 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 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 by using the PID and data logger. The emitted PERC concentrations were summed. This value was used to determine the mass of PERC (mg) per kilogram of cloth. In all, approximately eight samples were collected and analyzed over a four-day period.

RESULTS

Air Sampling

Table II and Figure 2 summarize the daily TWA personal air samples. The machine operator had the highest TWA exposures to PERC, which ranged from 0.31 to 4.9 ppm on various days. The bulk of exposure to PERC resulted from loading and unloading the machine and performing machine maintenance. Almost all of the 2-hour samples of the operator were below 2 ppm, and most of them were below 1 ppm. The only exception to these low exposures occurred during the last morning of sampling, when the operator cleaned the stills on both machines.

TABLE II
Time-weighted average (TWA) PERC exposures

Worker	Day	Number of samples	Sampling period (min)	TWA concentration (ppm)
Operator	1	4	451	0.31
Presser	1	4	452	<LOD ^A
Operator	2	4	384	0.73
Presser	2	4	376	<LOD
Operator	3	4	396	1.09
Presser	3	4	374	<LOD
Operator	4	3	350	4.90
Presser	4	3	316	<LOD

^ALimit of Detection (LOD) = 0.12 ppm.

Still cleaning occurred approximately once every 3 weeks. During the last morning of sampling, the operator was exposed to approximately 12 ppm during a 2-hour period and 4.9 ppm full-shift TWA. This relatively high TWA exposure was a result of cleaning the still that morning. If cleaning the stills had not occurred, the TWA exposure probably would have been below 2 ppm.

The garment presser did not work as close to the dry-cleaning machines as the operator. All of the PERC concentrations measured near the presser's breathing zone, on each day, were at or below the limit of detection, which was 0.12 ppm per 2-hour sample. Concentrations this low indicate that there was very little PERC off-gassing from the clothing that was being pressed. Additionally, PERC, originating from the machine, was isolated from other areas of the shop.

There was almost no PERC detected on area air samples taken outside of the dry-cleaning room, except for a very small quan-

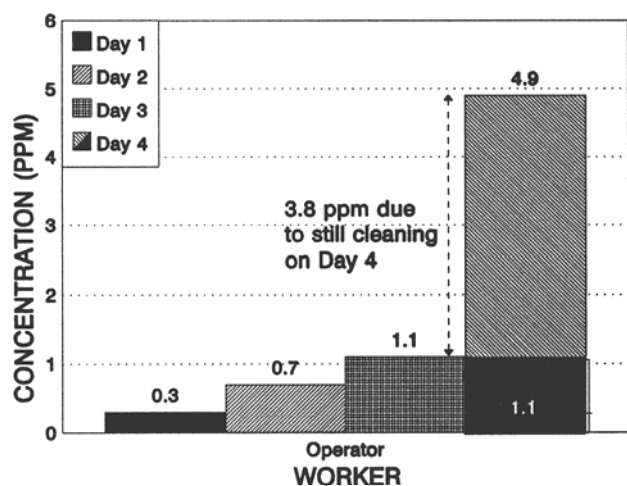


FIGURE 2

Time-weighted average worker exposure to PERC from fifth-generation dry-cleaning machines (four days of air sampling).

tity detected in the reception area on the final day of sampling. This nondetection of PERC can be attributed to the effective ventilation near the machines. The highest concentrations for area samples were detected near the Model 546 machine.

Real-Time Monitoring

Figure 3 shows real-time measurements taken at the operator's breathing zone during the first cycle of the day when dry-cleaning machine loading occurred. The empty machines had been turned on for approximately 10 minutes, and dirty clothing was added to the cylinder. During this time, there was a potential for contaminated air to be emitted from the machine cylinder into the worker's breathing zone. This exposure is characterized by a rapid increase and almost instantaneous peak, which approaches 160 ppm. The concentration in the worker's breathing zone dissipated over the next 10 to 20 seconds and then returned to below the limit of detection.

Figure 4 shows operator exposure while unloading and loading both machines. During some of these activities, average operator exposure and total dose were higher during loading than unloading. During unloading and loading the Model 536, operator exposure for loading the machine was significantly higher than for unloading, with average exposures of 101 and 34.6 ppm, respectively. When operator exposure was higher during loading than unloading, the machine sat idle for several minutes prior to the opening of the machine door.

During most evaluated cycles, the average PERC exposure while the operator loaded the machine with dirty clothing was less than the average PERC exposure while the garments that had been cleaned in PERC were unloaded. For the Model 536, the average exposure during loading was 58.7 ppm; the average exposure during unloading was 45.9 ppm. For the Model 546, the average exposure during loading was 20.2 ppm; the average exposure during unloading was 35.4 ppm. The total dose was

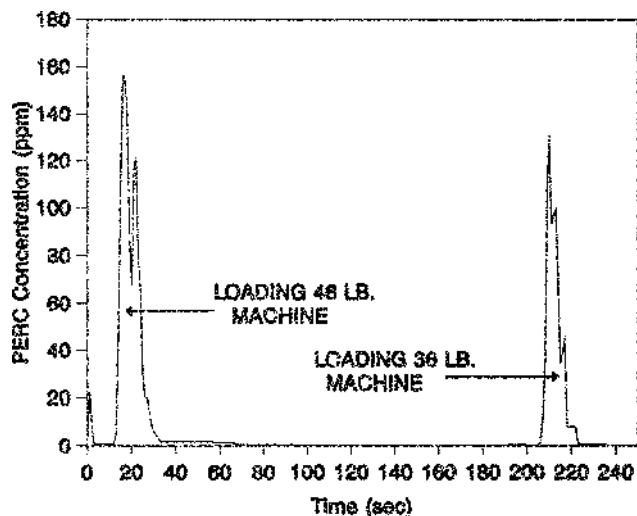


FIGURE 3

Operator exposure during the first cycle of the day.

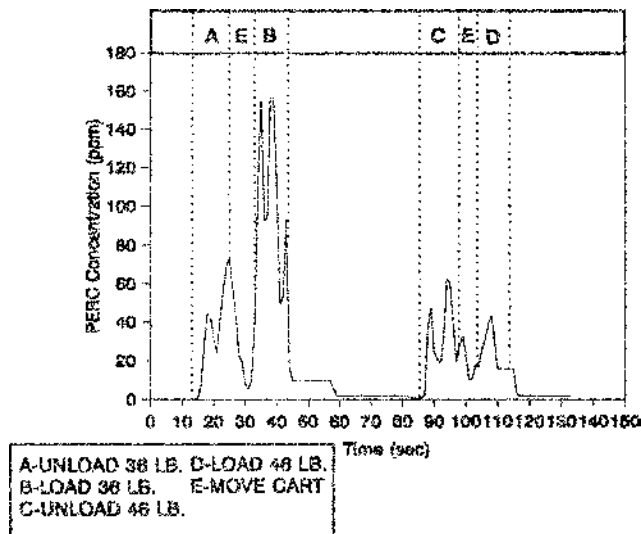


FIGURE 4
Operator exposure during unloading/loading.

usually higher during unloading than loading both machines, on average: 466 ppm*sec versus 401 ppm*sec.

Operator exposure while raking the Model 546 still averaged 156 ppm, and exposure while raking the Model 536 still averaged 35 ppm. Figure 5 shows a comparison of typical swatch off-gassing from a refrigerated, dry-to-dry, dry-cleaning machine versus one of the fifth-generation, dry-to-dry, dry-cleaning machines evaluated. The total PERC off-gassed was approximately 31.8 mg PERC/kg cloth and 1.34 mg PERC/kg cloth, respectively. During an average cycle, both fifth-generation machines were extremely effective at recovering solvent from the garments.

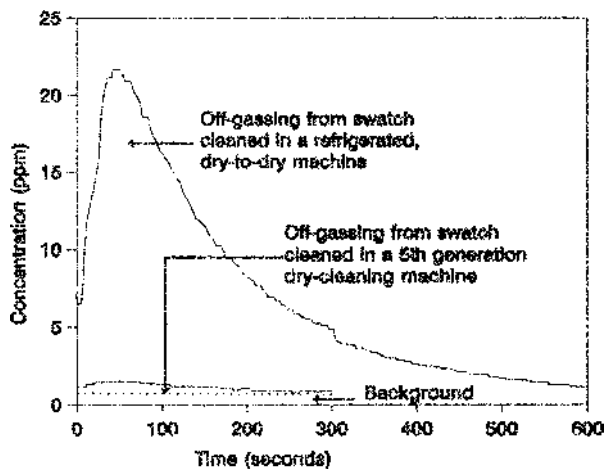


FIGURE 5
A comparison of typical swatch off-gassing from a refrigerated, dry-to-dry, dry-cleaning machine versus a fifth-generation, dry-to-dry, dry-cleaning machine. The total PERC off-gassed was approximately 31.8 mg PERC/kg cloth and 1.34 mg PERC/kg cloth, respectively.

DISCUSSION

Previous NIOSH studies have shown that worker exposures occur from three primary dry-cleaning machine sources: solvent vapors expelled from the machine cylinder during loading/unloading, residual solvent off-gassing from garments, and exposure during machine maintenance. The modern machines used at this shop were able to reduce peak exposures during loading and unloading the machine and reduce the TWA exposures more than traditional dry-cleaning machines that are widely used in the United States. Real-time monitoring and air sampling data demonstrated that although exposures during loading and unloading were dramatically reduced, loading and unloading still accounted for a substantial percentage of TWA exposures because these processes occurred so frequently.

The most important factor affecting PERC exposure in dry-cleaning shops is the design of the dry-cleaning machine. The vapor recovery system is of particular importance because it will determine the concentration of PERC remaining in the cylinder at the end of the dry cycle and the amount of PERC remaining in the garments that off-gas inside the shop.

A refrigerated condenser and carbon adsorber were used to recover PERC vapors on these machines. Refrigerated condensers use a refrigerant to cool the solvent-laden air below the dew point of the vapor to recover the PERC. The process can achieve 95 percent vapor control in dry-to-dry machines. The residual concentration is reduced to the saturation concentration, based on the temperature. The lowest condensation temperature is -22°C (-8°F); however, in practice, machines operate at a minimum of -20°C (-4°F). At this temperature, the air still contains approximately 2000 ppm, although concentrations could be higher depending on air temperature (Figure 6). Because of that limitation, it is important for dry-cleaning machines also to have a well-maintained, closed-loop carbon adsorber.

Carbon adsorbers can achieve a 95-99 percent vapor reduction by removing PERC molecules from the air. Solvent-laden

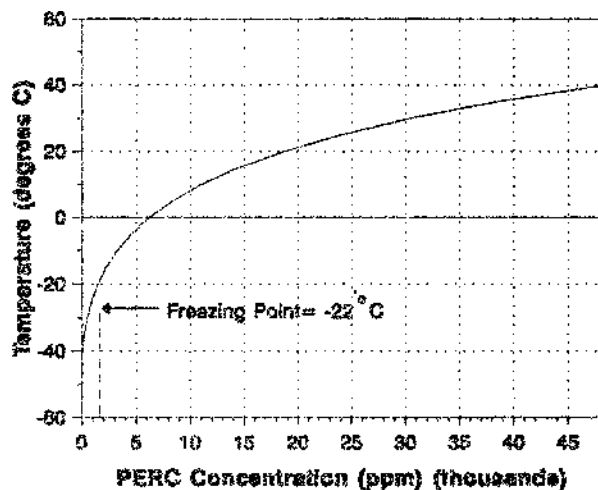


FIGURE 6
Concentration of PERC in saturated air.

vapors pass through activated carbon having a high adsorption capacity. Carbon adsorption systems can handle high volumes of air with relatively low solvent concentrations and maintain a high removal efficiency. The potential drawbacks of carbon adsorbers are the need for frequent desorbing, the possible generation of solvent contaminated wastewater, and the potential for high emissions and exposures if the carbon is not properly maintained. Fortunately, with the modern design of these carbon adsorbers that incorporate automatic thermal desorption, those drawbacks were not a problem; however, they do typically increase the dry cycle by 5 to 10 minutes to ensure that the PERC concentration in the drum is sufficiently low. The current study demonstrated that the two technologies used together dramatically lowered exposures.

In addition to the machine's vapor recovery system, several other design factors may affect worker exposures to PERC. For example, machines having a larger capacity can clean more garments in fewer cycles than machines having smaller capacities, thus reducing the number of times the machine must be loaded and unloaded and thereby reducing exposure. Another relevant factor is the number of dry-cleaning machines at each shop, which is a function of the quantity of garments being processed. Each machine is a generation source. The number of machines and quantity of garments processed will determine the number of times the machines must be loaded and unloaded and will therefore impact exposure.

In many shops, exposures originate from residual solvent vapors in insufficiently dried garments during pressing, hanging, or storage. Machines that do not sufficiently dry the garments can permit clothing to off-gas into the work environment for days. In most shops, pressers are exposed to PERC concentrations that are approximately two to three times less than that for machine operators. In this shop, presser exposures were below the limit of detection. Garment off-gassing tends to increase background concentrations of PERC within the shop, but as demonstrated by the air sampling results at this shop, garment off-gassing was not a major factor increasing operator exposure.

When the machine sat idle for a short period of time before the door was opened, higher exposures were observed while the operator loaded the machine. Variations between the time the dry cycle ended and the machine door was opened may have caused this problem. PERC vapors from the vapor loop were able to migrate down into the machine cylinder, and when the door was opened for clothes loading, air displacement forced residual vapors from the cylinder into the worker's breathing zone.

CONCLUSIONS AND RECOMMENDATIONS

Engineering controls on the dry-cleaning machines at this shop were determined to be effective. This study found that fifth-generation PERC machines reduced TWA worker exposures to PERC to below 5 ppm.^(17,18) On most days, operator exposure was near or below 1 ppm TWA. Similarly, exposures during loading and unloading on fifth-generation machines were dramatically lower than exposures on earlier models. Table III pro-

TABLE III

Dry-cleaning machine operator exposures to PERC associated with each generation of dry-cleaning machine

Machine generation	TWA exposure (ppm)	Peak exposure (ppm)
First	40-60	500-1500 during transfer 1000-4000 load/unload dryer
Second	20-30	1000-4000
Third	15-25	1000-4000
Fourth	< 10	< 290
Fifth	< 5	< 290

vides a summary of dry-cleaning machine operator TWA exposures to PERC associated with each generation of dry-cleaning machines based on the current and prior NIOSH studies.

The primary source of PERC exposure to the workers in all shops studied was the dry-cleaning machine. Real-time evaluation showed that machine loading and unloading had the greatest impact upon exposures because of the high PERC concentrations and frequency of occurrence. These exposures are directly related to machine design. Operator exposures can be dramatically reduced during loading/unloading by controlling the concentration in the machine cylinder at the end of the dry cycle and by controlling where the air in the machine cylinder goes during loading/unloading. There are basic distinctions between types of dry-cleaning machines and the physical principles that dictate the level of exposure to expect from each machine design. Those distinctions include the type of vapor recovery system, whether the machine is transfer or dry-to-dry, and whether the machine is vented or nonvented.

Based on these findings, it is recommended that dry-cleaning machine owners purchase the most advanced dry-cleaning machine that the budget permits. Because modern designs enabling vapor recovery can reduce TWA exposures to PERC to less than 5 ppm, the shop owner will save money in solvent costs, and the facility will more easily comply with safety and health/environmental regulations that will likely become more stringent in the future. At present, the fifth-generation dry-cleaning machines represent state-of-the-art technology, capable of controlling PERC exposures to concentrations well below those demonstrated by earlier models.

ACKNOWLEDGMENTS

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DISCLAIMER

Mention of any company or product does not constitute endorsement by the Centers for Disease Control and Prevention (CDC) or the National Institute for Occupational Safety and Health (NIOSH).

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