CHAPTER 4
RELEASE AND EXPOSURE

CHAPTER CONTENTS

This chapter addresses the releases to the environment and human and environmental exposures to chemicals that may result from dry and machine wetcleaning operations. Section 4.1 contains an introduction to the chapter. Section 4.2 contains information on environmental releases of chemicals used in various fabricare processes. In this section, potential releases to air, water, and for off-site recovery or disposal are discussed for each applicable chemical. These estimates are used as inputs for general population exposure estimation where monitoring data do not exist. Section 4.3 provides an overview of exposure assessment principles, including definitions of the types of estimated exposures. Section 4.4 examines potential exposures. Both worker exposure and general population (non-worker) exposure are assessed. Both dermal (skin) and inhalation exposure are assessed for workers, when applicable. Inhalation, ingestion, and dermal exposure are presented where applicable for the general population. Additionally, surface water concentration estimates are made, when possible, to support assessment of risks to aquatic organisms. The methodologies and models used for estimating releases and exposures are described along with the associated assumptions and uncertainties. Additional information related to this chapter is provided in Appendix E.

4.1 INTRODUCTION

For the assessments of economics of the processes and risks to the chemicals used in commercial clothes cleaning, this chapter characterizes releases of and exposures to chemicals used in the clothes cleaning processes covered by the CTSA. Section 2.4 discussed which chemicals this Cleaner Technologies Substitutes Assessment (CTSA) examines for each of the processes. Releases occur when chemicals are no longer contained within the process and are no longer under the control of the facility using those chemicals. The assessment of releases is the estimation of magnitude, frequency, and media (e.g., to air, to water, in solid waste for off-site disposal to landfill, incineration, or recovery processes) of releases. Exposure is defined by USEPA as the contact of a chemical with the outer boundary of a person. The assessment of exposure is the estimation of the magnitude, frequency, duration, and route of exposure. The exposure assessment describes who contacts the chemicals used in the various cleaning processes and thus who may experience the effects related to the chemicals.

4.2 ENVIRONMENTAL RELEASE ASSESSMENTS

In this CTSA, chemical release estimates serve two primary purposes. Some release estimates are used as inputs for estimating general population and environmental exposures, and process economics when other data are not available. Release estimates may also be used for rough comparisons between different fabricare processes. A summary of environmental release issues and comparisons is located in the Executive Summary.

Chemical release is essentially equivalent to chemical consumption, and the cleaning facility must pay a cost to replace a chemical which is released. Some releases also result in the cleaning facility paying to dispose a waste stream. Releases may also have regulatory implications for facilities. Chemical releases to the environment can result in exposures to humans and other living organisms. The media of release determines how the exposures may occur.

Release of a chemical to air can result in exposure to workers who may inhale workplace air containing the chemical, to the general population who may inhale air containing the chemical, and to the environment, where animals and plants may also be exposed to the chemical. Releases to water can result in exposure to the general population who may drink, bathe, and/or shower in water containing the chemical or eat aquatic organisms containing the chemical released, and to the aquatic environment, where aquatic animals and plants may be exposed to the chemical. Releases to non-hazardous landfills can leach to groundwater, resulting in exposure to the general population who may drink, bathe, and/or shower in water containing the chemical or eat aquatic organisms containing the chemical released, and to the aquatic environment, where aquatic animals and plants may be exposed to the chemical. Releases to licensed hazardous waste landfills are assumed to result in no significant human or environmental exposure. Some factors that affect the transport of a released chemical to those exposed are discussed in more detail in the exposure section of this chapter.

To allow for comparison of processes on an equal basis, all release estimates were based on a CTSA "model facility" annual throughput of 53,333 pounds of clothes cleaned. Each model facility was also assumed to clean 100% of the clothes using a single process. Model facilities are all assumed to operate for 312 days per year. Each release estimate in this report is an "if-then" estimate, which is an estimate of release that is determined by postulating a release scenario with specific hypothetical or actual combinations of factors. "If-then" estimates are used when actual release data and distributions cannot be determined, and these estimates do not give information about how likely the release estimates are to be representative of actual releases from "real world" facilities.

Various sources were used to gather data needed to generate release estimates. The most recent sources found were used, although recent research and data could not be found for some important parameters used to estimate releases. Published emission rates and emission factors, which are often estimated as amount released per amount of articles cleaned, were used to estimate environmental releases of solvents from drycleaning facilities. Where such data were unavailable, estimates were calculated from release-related data or assumptions. For example, releases of solvents to water were estimated using estimated amounts of water released from facilities and estimated solubilities of solvents.

Two primary references used to estimate perchloroethylene processes' emissions were the California EPA's Air Resources Board (CARB) Staff Report (CEPA, 1993) and USEPA's PCE Drycleaning NESHAP Background Document (USEPA, 1991). Most of the data for hydrocarbon processes' release estimates were found in USEPA's document on Control of Volatile Organic Compound Emissions from Large Petroleum Drycleaners (USEPA, 1982). Estimates of releases of cleaning and processing aid formulations used in aqueous-based processes were based on estimated formulations' use rates and the simplifying assumption that all of the formulations are released with waste water. Specific information and details regarding release estimates are provided in the Release Assessment section for each process.

4.2.1 Drycleaning Technologies

PCE Process Release Assessment

Release Sources and Media

Drycleaners can release perchloroethylene (PCE) to the air, as both vented and fugitive emissions, and to water, mainly as separator wastewater. PCE is also disposed from drycleaners in solid wastes such as distillation still bottoms and used cartridge filters. Numerous factors affect the amounts of these releases from individual facilities. These factors include, but are not limited to, equipment differences, such as cleaning machine type, capacity, vapor recovery device(s), operating temperatures, separator size, filter type, number of cleaning machines, and still type; differences in operating conditions, such as number of articles cleaned per load, level of soil in articles cleaned, number of loads per day, drying time, and residence time in water separator; and differences in maintenance and general housekeeping.

Vented air emissions include exhausts from the aeration step of the drying process, from still and muck cooker condensers, and from inductive door fans that vent the cylinder when a machine's door is open. Fugitive air emissions result from vapor escaping from the open door of a machine, leaking equipment, off-gassing of residual in clothes after drying, evaporative losses during article transfer, button trap cleaning, filter changes, and when containers with liquid PCE such as waterproofing "third" tanks and storage drums are open to the workplace. Additional emissions may also come from carbon adsorber (CA) exhausts, particularly if the adsorber is not properly maintained, and from the evaporation of wastewater from the water separator.

PCE-containing wastewater from drycleaning collects in the water separator. The sources of this wastewater are condensate from the direct contact steam desorption of CAs, still and muck cooker condensate, condensate from the machine's conventional or refrigerated condenser, and condensate from steam presses. Following separation from PCE, these wastewaters are generally discharged to sewers and may leak to groundwater before reaching a Publicly Owned Treatment Works (POTW) for treatment (Wolf, 1992). A California well contamination study indicates that historical practices of drycleaners have caused groundwater contamination, but that the effect of current practices cannot be determined (Radian, 1993).

Additionally, PCE is released indirectly from drycleaners in solid wastes removed from the drycleaning facility. These PCE-containing solid wastes include spent filter cartridges, distillation bottoms or muck, and, spent carbon. These solid wastes are defined as a hazardous waste under the Resource Conservation and Recovery Act (RCRA), and facilities generating more than 220 pounds per month of such waste are required to dispose of such waste through RCRA-approved waste handlers. Some facilities also dispose of separator water as hazardous waste.

Release Estimates

Because other sources of exposure information are available, release estimates from PCE drycleaning facilities are not needed for this CTSA's general population and environmental exposure assessments. Because PCE technologies are the dominant method for commercial clothes cleaning, releases of PCE from drycleaning facilities have been estimated for the purpose of illustrating potential differences in releases from PCE machines of a given capacity using different controls (i.e., refrigerated condensers [RCs] and carbon adsorbers [CAs]) for reducing emissions. Another emission control is an azeotropic unit (AU), which is discussed in Chapter 2; however, because AUs are not commonly used, releases from AUs are not assessed in this CTSA. It may be noted that these AUs may be less efficient than CAs (i.e., AUs do not lower emissions as effectively as CAs), but when used in conjunction with CAs, the combination are more effective than a CA alone (i.e., CA/AU combination results in higher emission reduction than CAs alone).

As mentioned previously in this chapter, release amounts of PCE and PCE-containing wastes were estimated, and spotting chemical releases and detergents used in PCE processes were not estimated. PCE release estimates in this section are based on data from several sources, primarily USEPA sources (e.g., NESHAP documents) and the CARB Staff Report (CEPA, 1993). These data are combined with some assumptions to generate the release estimates. The machines assessed here are either transfer or dry-to-dry machines with or without CAs or RCs. Estimates of releases are made for eight PCE machine configurations utilizing emission control technologies in different combinations. These configurations are described below.

- *PCE-A1: Transfer with No Carbon Adsorption or Refrigerated Condenser:* Washing and extraction in one machine, drying in a second machine (i.e., first generation equipment). At the end of the drying cycle, aeration air leaving the drying tumbler vents to atmosphere.

- *PCE-A2: Transfer with Carbon Adsorber Vent Control:* Washing and extraction in one machine, drying in a second machine (i.e., first generation equipment). At the end of the drying cycle, aeration air leaving the drying tumbler vents to a carbon bed, which may remove much of the PCE before emitting the air stream.

- *PCE-A3: Transfer with Refrigerated Condenser Control:* Washing and extraction in one machine, drying in a second machine (i.e., first generation equipment). By the end of the drying cycle, the refrigerated condenser will have removed more of the PCE from the drying air stream, resulting in lower emissions than would occur from a machine with a non-refrigerated condenser.

- *PCE-B1: Dry-to-Dry with No Carbon Adsorption or Refrigerated Condenser:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment). At the end of the drying cycle, aeration air vents to atmosphere after leaving the tumbler.

- *PCE-B2: Dry-to-Dry with Carbon Adsorber Vent Control:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment). At the end of the drying cycle, aeration air leaving the tumbler vents to a carbon bed, which may remove much of the PCE before emitting the air stream.

- *PCE-B3: Dry-to-Dry Converted to Closed-Loop:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment converted to third generation). Two common conversions are an internal conversion or an add-on. Internal conversion includes converting the internal condenser from air- or water-cooled condenser to a refrigerated condenser and ducting the exhaust back to the machine as input air. The add-on includes ducting the vent to an add-on refrigerated condenser, which supplements the original condenser, and ducting the exhaust from the condenser back to the machine as input air.

- *PCE-C: Dry-to-Dry Closed-Loop with No Carbon Adsorber or with Door Fan and Small Carbon Adsorber:* Washing, extraction, and drying operations all in one cylinder/one machine. Built-in internal refrigerated condenser that exhausts drying air back to the machine as input air in a “closed-loop” cycle (i.e., third generation equipment). On some machines, when the machine door is opened after the drying cycle ends, a fan draws air through the open door into the machine, and the air is exhausted elsewhere, sometimes to a small carbon adsorber. These small adsorbers, sometimes known as “OSHA fans,” are not believed to have much effect on emissions.

- *PCE-D: Dry-to-Dry Closed-Loop with Unvented Integral Secondary Carbon Adsorber Control:* Washing, extraction, and drying operations all in one cylinder/one machine. Built-in internal refrigerated condenser that exhausts back to the machine as input air. After the drying cycle ends while the door is closed, air from the drum circulates to a large CA (50-pound or greater carbon capacity), which may remove most of the PCE before the door is opened (i.e., fourth generation equipment). Some machines may have an integral PCE sensor that will not allow the door to be opened until an allowable PCE level is reached (i.e., fifth generation machine).

Exhibit 4-1 presents estimates of air, water, and hazardous waste releases that may result from each of the eight PCE technologies evaluated. Assumptions and data used are noted in the footnotes to the exhibit.

There are numerous uncertainties regarding the estimates in Exhibit 4-1, several of which are identified here. There are uncertainties in the accuracy of the numerous assumptions and parameters used to generate release estimates. The accuracy of some data gathered for the NESHAP is uncertain, and it is not known whether data from the CARB survey of California facilities represents facilities nationally. The assumptions used by the CARB to estimate emissions are unknown. The CARB Staff Report presents average emissions estimates collected prior to the PCE drycleaning NESHAP, and the NESHAP has likely decreased average emissions following its promulgation. There are also many variables that may affect releases from a facility or that account for differences among facilities, and some of these variables are listed at the beginning of this section. There is limited information on the extent to which these variables contribute to differences among facilities. Exhibit 4-1 shows that machine type can affect releases significantly. Operating practices can also increase or decrease emissions by up to a factor of four between facilities with a particular machine configuration (CEPA, 1993). Also, because the releases estimated in Exhibit 4-1 are intended to reflect relative averages and do not account for many site-specific factors, releases from a specific facility in the real world may not compare well with the estimates.

Data on mileages of the various machine configurations relative to mileages that may be calculated from the release estimates in Exhibit 4-1 indicate that many facilities with the same throughput as the

Exhibit 4-1. Estimated Releases from PCE Model Facilities with Various Machine Types and Emission Controls

	Releases					
	PCE			Total Volume		
Machine Type and Control Technology	To Air[a] (gal/year)	To Water[b] (gal/year)	In Hazardous Waste[c] (gal/year)	Total PCE Loss (gal/year)	Total Wastewater Volume[b] (gal/year)	Total Hazardous Waste Volume[c] (gal/year)
Transfer						
No RC or CA - Option PCE-A1	501	0.007	127	627	75	658
With CA - Option PCE-A2	342	0.1	127	469	1,500	667
With RC - Option PCE-A3	290	0.014	127	417	150	658
Dry-to-Dry						
No RC or CA - Option PCE-B1	434	0.007	127	561	75	658
With CA - Option PCE-B2	228	0.1	127	355	1,500	667
Converted to closed-loop - Option PCE-B3	176	0.014	127	303	150	658
Closed-loop with no CA or with door fan and small CA - Option PCE-C	83	0.014	127	210	150	662
Closed-loop with unvented integral secondary CA - Option PCE-D	51[d]	0.014	127	178	150	662

RC = refrigerated condenser; CA = carbon adsorber; see text for further explanation of equipment.

[a] Based on Table 4 of CEPA 1993 (see Exhibit E-1 in Appendix E) assuming that the transfer and vented dry-to-dry emission estimates would be representative of CA-controlled machines. Total air emissions are the sum of vented emissions and fugitive emissions. For transfer machines with no CA or RC, vented emissions were assumed to be 50% of fugitive emissions, and for dry-to-dry machines with no CA or RC, vented emissions were assumed to be equal to fugitive emissions. Vent control efficiencies were assumed to be 95% for CA. The difference in emissions between transfer with CA and transfer with RC was assumed to be the same as the difference between dry-to-dry with CA and dry-to-dry converted to closed-loop. Average “model” and California facilities are estimated to clean 53,333 and 51,460 pounds/year clothes, respectively, and CEPA emissions data were scaled proportionally from California throughput to “model” facility throughput.

[b] Based on 150 gal/year for RCs (USEPA, 1997a) and 1,500 gal/year for CAs (USEPA, 1993), and assuming water-cooled condenser generates 50% of volume generated by RC; also, based on 150 ppm PCE average in wastewater and 3.78 kg/gal water and 6.1 kg/gal PCE.

[c] Based on the International Fabricare Institute estimate of 3.2 lb of PCE per 100 lb clothes cleaned is lost in hazardous wastes from filters and distillation residues (CEPA, 1991), plus CA waste, as applicable, of less than 10 lb PCE annually, based on average 275 lb carbon bed (USEPA, 1991), spent carbon is 10% PCE by weight (assumed based on CEC, 1992), and a carbon change out frequency of 5 years for CAs used without RCs and 10 years for CAs used as integral secondary controls. Hazardous waste is assumed to average 40% PCE by weight (based on Safety Kleen, 1986, and PEI, 1985) and to average 2.94 kg/gal (assume non-PCE portion has a density of diatomaceous earth, 0.834 kg/gal).

[d] CEPA 1993 estimates that secondary control reduces emissions for a closed-loop machine by almost 40% (drum levels of 300 ppm for secondary control versus 8,600 ppm for no secondary control is 96.5% removal; emissions from drum is 40% of total facility emissions).

"model" facility may have lower releases than those shown in Exhibit 4-1, indicating inaccuracies in data and assumptions used for Exhibit 4-1 estimates. However, no better data sources or bases for assumptions could be found, nor did peer review of an earlier draft of this CTSA document identify additional improvements to these release estimates. Despite these uncertainties, Exhibit 4-1 is expected to fairly accurately reflect *relative* differences in releases between the configurations.

Hydrocarbon Processes Release Assessment

Release Sources and Media

Drycleaners can release hydrocarbons (HC) to the air, as both vented and fugitive emissions, and to water, mainly in separator wastewater. HC is also disposed from drycleaners in solid wastes such as distillation still bottoms and used cartridge filters. Numerous factors affect the amounts of these releases from individual facilities. These factors include, but are not limited to, equipment differences, such as cleaning machine type, capacity, vapor recovery device(s), operating temperatures, separator size, filter type, number of cleaning machines, and still type; differences in operating conditions, such as number of articles cleaned per load, level of soil in articles cleaned, number of loads per day, drying time, and residence time in water separator; and differences in maintenance and general housekeeping.

Vented air emissions include exhausts from the drying process, from still condensers, and from inductive door fans that vent the cylinder when a machine's door is open. Fugitive air emissions result from vapor escaping from the open door of a machine, leaking equipment, off-gassing of residual in clothes after drying, evaporative losses during article transfer, button trap cleaning, filter changes, and when containers with liquid HC tanks and storage drums are open to the workplace.

HC-containing wastewater from drycleaning comes from three main sources. First, some water may be added to articles in the cleaning process to remove water-soluble soils. Second, water is used in the distillation and reclamation process. Finally, air pollution control processes can create wastewater, including condensate from refrigerated condensers. These waters are generally discharged to sewers and may leak to groundwater before reaching a POTW for treatment (Wolf, 1992). The California well contamination study of PCE drycleaners indicates that historical practices of drycleaners have caused groundwater contamination by solvents, but the effect of current practices cannot be determined (Radian, 1993).

Additionally, HC is released indirectly from drycleaners in solid wastes removed from the drycleaning facility. These HC-containing solid wastes include spent filter cartridges and distillation bottoms or muck. Some of these solid wastes are defined as a hazardous waste under the Resource Conservation and Recovery Act (RCRA). Section 8.4.5 discusses the criteria for determining whether HC-containing solid wastes are hazardous. Facilities generating more than 220 pounds per month of hazardous waste are required to dispose of such waste through RCRA-approved waste handlers. Some facilities also dispose of separator water as hazardous waste.

Release Estimates

Because other sources of exposure information are not available, release estimates from HC drycleaning facilities are used for this CTSA's general population and environmental exposure assessments. Because HC technologies are the second dominant method, after PCE, for commercial clothes cleaning, releases of HC from drycleaning facilities have been estimated for the sole purpose of illustrating potential differences in releases from HC machines of a given capacity using different controls (i.e., RCs and dry-to-dry type machines) for reducing emissions.

As mentioned previously in this CTSA, release amounts of HC and HC-containing wastes were estimated, and spotting chemical releases and detergents used in HC processes were not estimated (see Section 1.2). Very little information is available to determine solvent releases to the various media (e.g., air, water, landfill, incineration). HC release estimates in this section are based on data from several sources, primarily one USEPA source, a 1982 Control Guideline document, which documented studies on large petroleum drycleaning facilities. No newer emissions and release factor data could be located. These data are combined with some assumptions, including analogy to PCE machines, to generate the release estimates. The machines assessed here are either transfer and dry-to-dry machines with or without RCs. For more details regarding these "model" machines, see Chapter 7. Estimates of releases are made for three HC machine configurations utilizing emission control technologies in different combinations. These configurations are described below.

- *HC-A1: Transfer with Standard Dryer (with No Condenser):* Washing and extraction in one machine, drying in a second machine. Throughout the entire drying cycle, fresh air is drawn into the tumbler, removes HC from the wet clothes, and exits the drying tumbler directly to atmosphere. (All HC that is not extracted from the clothes is emitted to air.)

- *HC-A2: Transfer with Recovery Dryer (with Condenser):* Washing and extraction in one machine, drying in a second machine. During the drying cycle, drying air leaving the tumbler passes through a condenser. The condenser cools the air and recovers some of the HC from the drying air stream, which is reheated and returned to the tumbler. At the end of the drying cycle, aeration air vents to atmosphere after leaving the tumbler.

- *HC-B: Dry-to-Dry Closed-Loop with Condenser:* Washing, extraction, and drying operations all in one cylinder/one machine (i.e., second generation equipment). During the drying cycle, drying air leaving the tumbler passes through a condenser. The condenser cools the air and recovers some of the HC from the drying air stream, which is reheated and returned to the tumbler. At the end of the drying cycle, aeration air vents to atmosphere after leaving the tumbler.

Exhibit 4-2 presents estimates of air, water, and hazardous waste releases that may result from each of the three HC technologies evaluated. Assumptions and data used are noted in the footnotes to the exhibit.

There are numerous uncertainties regarding the estimates in Exhibit 4-2, several of which are discussed below. The emissions factors from the primary reference (USEPA, 1982) used to estimate releases were based on case studies of only a few large petroleum facilities. Those emission factors may not be representative of smaller facilities, which are expected to generally use solvent less efficiently (i.e., lower solvent mileages) than larger facilities. Some data and information used to make assumptions represent different time periods that may not be representative of current conditions and improved

Exhibit 4-2. Estimated Releases from HC Model Facilities with Various Machine Types and Emission Controls

Machine Type and Control Technology	**Releases**					
	HC Solvent			**Total Volume**		
	To Air[a] (gal/yr)	To Water[b] (gal/yr)	In Solid Waste[c] (gal/yr)	Total HC Loss (gal/yr)	Total Waste Water Volume[b] (gal/yr)	Total Solid Waste Volume[c] (gal/yr)
Transfer						
w/ Standard dryer - Option HC-A1	1,839	< 10^{-5}	320	2,159	415	1,415
w/ Recovery dryer - Option HC-A2	678	10^{-5}	320	998	829	1,415
Dry-to-Dry						
Closed-loop w/ condenser - Option HC-B	194	10^{-5}	320	514	829	1,415

[a] Based on emission factors in USEPA, 1982. Total air emissions are the sum of vented emissions and fugitive emissions. The CTSA's "model facility" throughput of 53,333 lb/year clothes was used to estimate these releases. Emission factors from USEPA 1982 and other assumptions are shown in Appendix E. Air release from dry-to-dry closed-loop is based on air release from transfer with recovery dryer multiplied by the ratio of PCE dry-to-dry closed-loop to PCE transfer with refrigerated condenser.
[b] Based on 3.4 lb water recovered per 100 lb clothes for a system with a recovery dryer, and same recovery assumed for dry-to-dry; HC losses based on 0.036 ppm HC average in wastewater, 3.78 kg/gal water and 3.0 kg/gal HC, and 10% of total water volume recovered from a system with no condenser relative to recovery from a system with a condenser.
[c] Based on emission factors in USEPA, 1982. Total solid waste loss includes spent cartridge filters and vacuum still bottoms. Hazardous waste is assumed to average 40% HC by weight (USEPA, 1982) and to average 1.71 kg/gal (assuming that non-HC portion has a density of diatomaceous earth, 0.834 kg/gal).

technology. Operating practices can also increase or decrease emissions by up to a factor of four between facilities with a particular machine configuration (CEPA, 1993). Also, because the releases estimated in Exhibit 4-2 are intended to reflect averages and do not account for many site-specific factors, releases from a specific facility in the real world may not compare well with the estimates. Both the method of calculating HC fugitive emissions (see Appendix E) and the use of emission ratios from PCE machines to estimate HC dry-to-dry air releases introduce additional uncertainties into the release estimates. There is limited information on the extent to which these variables contribute to differences among facilities.

Data on mileages of the various machine configurations relative to mileages that may be calculated from the release estimates in Exhibit 4-2 indicate that many facilities with the same throughput as the "model" facility may have lower releases than those shown in Exhibit 4-2, indicating inaccuracies in data and assumptions used for Exhibit 4-2 estimates. However, no better data sources or bases for assumptions could be found, nor did peer review of an earlier draft of this CTSA document identify additional improvements to these release estimates. Despite these uncertainties, Exhibit 4-2 is expected to fairly accurately reflect *relative* differences in releases between the configurations.

4.2.2 Machine Wetcleaning Release Assessment

Release Sources and Media

Clothes cleaners using the machine wetcleaning (MWC) process are expected to release various MWC formulations such as detergents, finishes, water softeners, and other cleaning and processing aids, primarily to water during wash and rinse cycles of the machines. Of these MWC formulations, only detergents have been assessed in this CTSA as discussed in section 2.4. However, non-detergent formulations may have more of an environmental impact from MWC than from drycleaning processes due to the potential releases of these formulations to water.

Most chemical constituents in the various MWC formulations are likely to be non-volatile and would remain in solution throughout the MWC process. Releases of chemical constituents such as fragrances to air are expected to be relatively insignificant. Releases of chemicals from the formulations in solid wastes, such as emptied formulation bottles and lint from dryers and from water recycling, are also expected to be relatively small. Releases of MWC formulations are expected to vary between individual facilities, and these variations may be affected by a number of factors including equipment differences, such as machine capacity; differences in operating conditions, such as amount of articles cleaned, number of loads per day, load types, percentages of load capacities, and dosages of MWC formulations; and differences in cleaning procedures, formulations used and general housekeeping.

Release Estimates

Release estimates from machine wetcleaning (MWC) facilities are needed for this CTSA's estimation of process costs and assessment of general population and environmental exposures. Compared to drycleaning machines, MWC machines do not have a variety of machine configurations that affect releases. Only a few studies of MWC were found in the literature, and from these studies only one primary variable affecting release quantities could be found. This variable is the percent of clothes cleaned by immersion in water. This variable was 100 percent in one study and not quantified but stated to be less than 100 percent in another study. Therefore, detergent releases have been estimated for only two MWC model facilities.

Because no environmental release data are available for MWC processes, releases have been estimated based on expected average formulation use rates and simplifying assumptions. For this release assessment, two studies were found which contained enough information to calculate formulation use rates for MWC model facilities. "If-then" modeling was used to estimate releases of detergents from the two model facilities using MWC processes. An estimated 29.5 gallons per year of detergent are estimated to be released from the model facility which machine washes less than 100 percent of clothes "cleaned." An estimated 95.4 gallons per year detergent are estimated to be released from the model facility that machine washes 100 percent of clothes cleaned. It is not known whether these estimated releases are representative of the potential universe of machine wetcleaning processes.

The following data and assumptions were used to calculate release estimates from the MWC model facilities. The MWC model facility machine washing less than 100 percent of clothes used 0.0213 gallons per day detergent for 2.7 loads per day and 100 garments per 7 loads (Environment Canada 1995). This use rate was scaled up to 53,333 pounds per year clothes assuming 1 pound per garment (Gottlieb et al., 1997) to estimate the release rate. The MWC model facility machine washing 100 percent of clothes used 48.8 ounces combined formulations per 100 garments. Spotting agents were 3 ounces of the 48.8 ounces, and the detergent and finish formulations were assumed to be equal volumes of the remaining 45.8 ounces. This use rate was applied to 53,333 pounds per year clothes assuming 1 pound per garment (Gottlieb et al., 1997) to estimate the release rate.

These MWC model facilities' release estimates assume that all detergent formulations are in the wastewater released from the wash and rinse cycles, and that insignificant amounts of the formulations remain on the clothes after rinsing. MWC wastewater from the wash and rinse cycles would normally be expected to be discharged to a municipal sewer, which route the wastewater to publicly owned treatment works (POTW). These releases are assumed to occur over 312 days per year, the estimated number of operating days annually for a CTSA model facility.

Reuse of water is an optional feature that, when used, is typically only done with the final rinse. Reuse of water is not expected to significantly affect releases of formulations. The formulations used in MWC processes are either of unknown or proprietary composition. Detergents account for 30–50% of the total MWC formulations released based on the two studies used to estimate MWC model facilities' releases. For the purpose of assessing potential risks from wetcleaning processes, the two example detergent formulations discussed in Section 2.4.2 were assumed to be released in the amounts estimated for the two MWC model facilities. The releases of individual chemical constituents in those example detergents are provided in Appendix E, Exhibits E-3 and E-4. It is not known whether these example detergent constituents or their estimated releases are representative of the potential universe of MWC processes.

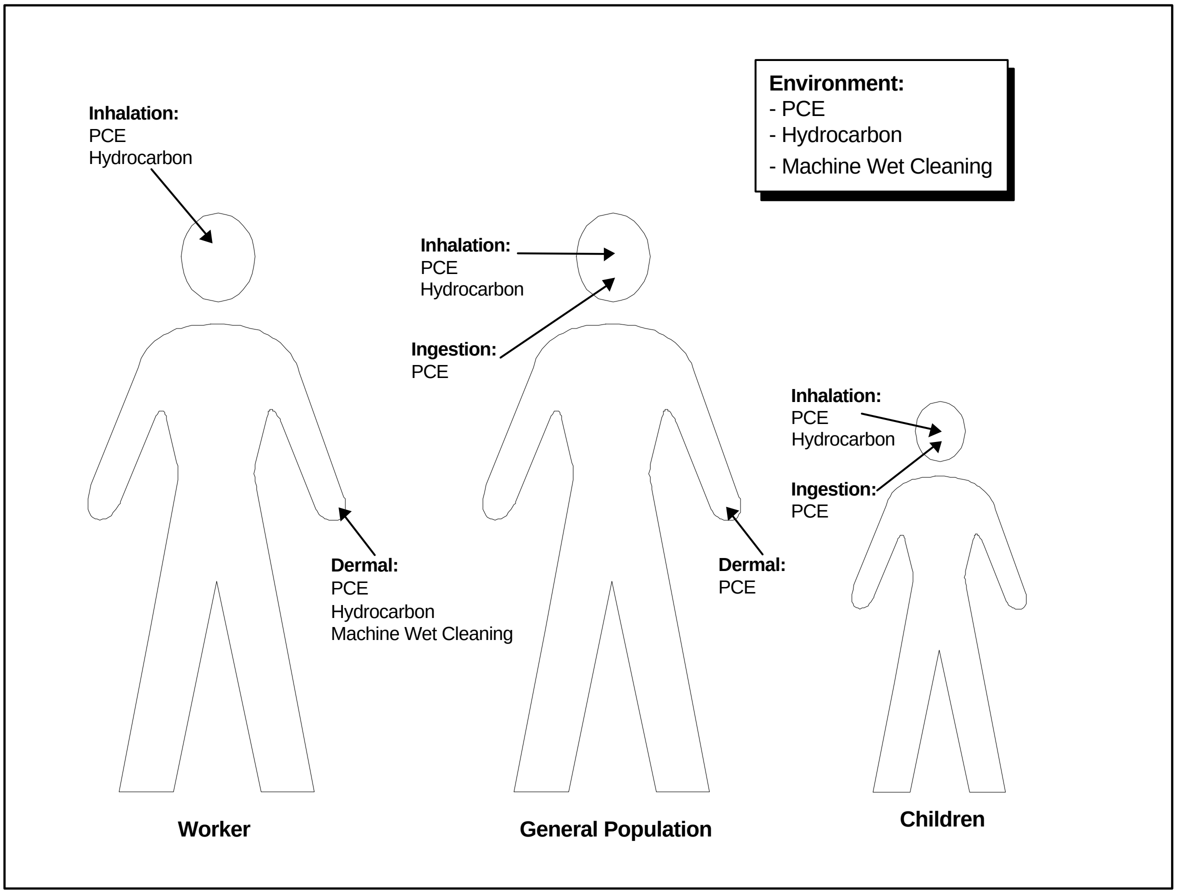
4.3 EXPOSURE OVERVIEW

4.3.1 Background and Definitions

Exposure is defined by USEPA as the contact of a chemical with the skin, nose, or mouth of a person over a given period of time. This includes the magnitude, duration, and route of exposure. There are a number of ways in which people and the environment can come into contact with the chemicals used in clothes cleaning and become subjected to the effects of the chemicals. The populations generally thought to be exposed include workers and the general population, including specific sub-populations of co-located residents and children. This assessment is not comprehensive and examines only those populations and pathways that appear most relevant to the specific technologies or for which appropriate data and methods were available. Exhibit 4-3 illustrates the exposures covered.

This CTSA assesses two primary routes of worker exposure. Inhalation exposure, or workers breathing workplace air containing significant concentrations of volatile solvents, is expected to be the most significant route in drycleaning processes. Dermal exposure, or workers getting solvent and detergents on the skin during various work activities, is expected to be the significant route of exposure for non-volatile chemicals, such as most detergent components. Therefore, this route of exposure is examined for machine wetcleaning. Dermal exposure is also a route of worker exposure for solvents, thus it is also assessed for both PCE and HC technologies.

Exhibit 4-3. Pathways Covered in the CTSA



The general population is exposed to the solvents used in drycleaning technologies and the detergents used in the aqueous processes in several ways. Studies have measured exposures to individuals residing in apartment buildings that are co-located with PCE drycleaning facilities. The CTSA provides information on many exposure scenarios for this group, including inhalation exposures to residents, exposure to wearers of drycleaned clothing, and exposures to nursing infants. Ingestion of PCE-contaminated drinking water and dermal exposure during showering are also discussed.

PCE and HC exposures among members of the general population who do not live in co-located residences are also assessed for the inhalation pathway. Dermal exposure to the detergents from machine wetcleaning has been assessed for the general population; however, no other exposures related to the other aqueous-based technologies have been examined.

In assessing exposures, the specific effects of a chemical, such as acute (short-term) effects or chronic (long-term) effects, determine what period(s) of exposure were considered. For long-term effects, such as carcinogenicity, it is often more helpful to have a central tendency of exposures, since the effect is typically estimated from the cumulative exposure.

In this document, exposures are expressed as exposure concentrations, potential doses, or potential dose rates. In order to simplify the presentations of exposures for each technology, both the expression of exposure and the units of measure are those most commonly presented for the chemical in studies and reports documenting exposure data in the literature. Some descriptions of the methods and assumptions used to calculate these exposure expressions, as well as sample calculations, are contained in Appendix E.

Inhalation exposures are usually expressed as exposure concentrations in units of parts per million (ppm) or milligrams per cubic meter (mg/m^3). Potential dose is the amount of the chemical substance available for inhalation, ingestion, or dermal absorption. These estimates are referred to as Lifetime Average Daily Concentrations (LADCs). These exposures incorporate the measured concentration of the chemical in air in mg/m^3 and the estimated exposure duration. LADCs, which are averaged over a lifetime, are used to assess the risks of cancer. For the dermal and ingestion exposure routes, potential dose rates (PDRs) are presented. PDRs are the amounts of chemical either applied to the skin or ingested. PDR units of measurement are mass per unit of time (and sometimes, per body weight as well) and are often presented as mg/day or mg/kg/day. Occupational dermal PDRs are presented in mg/day, and general population dermal and ingestion exposures are presented in mg/kg/day.

4.3.2 Exposure Descriptors

USEPA has published Guidelines for Exposure Assessment in the *Federal Register* (USEPA, 1992c). These guidelines provide the basic terminology and principles by which the Agency conducts exposure assessments. The guidelines indicate that *exposure descriptors* describe or characterize numerical expressions of exposure that can be made for a given population of concern. The guidelines suggest that if the exposure assessment methodology allows an assessor in some way to quantify the spectrum of exposure, the assessor should estimate central tendency exposures, as well as high-end or bounding exposures.

Central tendency exposures are average or median estimates of exposure to a particular substance. **High-end** exposures are exposures that are higher than those received by 90% of the people who are exposed to the substance. Central tendency and high-end estimates are presented together when possible to show the **variability** of the estimated exposures. **Bounding** exposures are exposure estimates that, in the assessor's judgement, are higher than those incurred by the person in the population with the highest exposure. Each of these exposure descriptors is used for at least one exposure scenario in the CTSA, although estimates with some of each of these descriptors are often unavailable for many scenarios in this CTSA.

In many cases, however, it is possible to calculate only an estimate of what the exposure would be under a given set of circumstances, without a characterization of the probability of those circumstances. These estimates are called **"what-if"** estimates, and they do not try to judge where on the exposure distribution the estimate actually falls. Where insufficient information is available to provide central tendency, high-end, or bounding estimates of exposure, what-if estimates are provided.

4.3.3 Exposure Comparisons

Comparing exposure data for different populations and for different studies entails more than simple numeric comparisons. Different populations may have different exposure factors that have impacts on their risks. These exposure factors may include, but are not limited to, volumes of air inhaled, durations and frequencies of exposure, and body weights. It may be more appropriate to compare risks when they can be calculated, rather than exposures, since some of these factors are included in risk. Also, different studies of similar populations may have different collection methods, purposes, or sources of bias that may cause their data sets to be incomparable. Finally, comparing measured exposure data to modeled exposure estimates must be considered very carefully.

4.4 EXPOSURE ASSESSMENTS

4.4.1 Drycleaning Technologies: Perchloroethylene Processes

People are exposed to PCE primarily as a result of PCE releases to the air, water, and land following commercial drycleaning. Workers are exposed to PCE solvent both from inhalation and dermal exposure. The non-worker population is exposed to PCE from inhalation, ingestion, and dermal contact. Inhalation is the most significant route of exposure for several reasons. PCE has a relatively high vapor pressure and therefore volatilizes readily (see Appendix A). This sometimes leads to elevated concentrations in both indoor and outdoor air, especially in locations close to drycleaners. Inhalation is also a physiologically significant means of exposure because PCE is well absorbed from the lungs.

Oral exposure to PCE may occur from ingestion of contaminated drinking water, contaminated foods (not evaluated here), or from ingestion by infants of breast milk from PCE-exposed mothers. PCE is well absorbed from the gastrointestinal tract following ingestion. Metabolism of absorbed PCE is expected to be low, roughly 20% (USEPA, 1985).

Absorption of PCE through the skin appears to vary depending upon the type of dermal exposure (i.e., in water, as a vapor, or as a liquid). For the general population, one important means of dermal exposure is from showering in water containing PCE. An exposure scenario is presented for dermal contact during showering.

Occupational Exposures

This section examines issues regarding PCE exposures to the workers in the drycleaning industry. Data sources include those that are readily available in published literature or through on-line access.

Some regulatory and recommended limits have been established for worker exposure to PCE. In January 1989, the U.S. Occupational Safety and Health Administration (OSHA) adopted a 25 ppm (170 mg/m^3) time weighted average (TWA) permissible exposure limit (PEL) to replace the pre-1989 PEL of 100 ppm (680 mg/m^3) TWA. However, all new 1989 PELs were vacated via a court decision, and the pre-1989 PEL for PCE is currently in effect. In addition to the PEL, OSHA requires a ceiling limit of 200 ppm (five minute average in any three hours) and a maximum peak of 300 ppm (never to be exceeded during the workday). Some states may maintain the 1989 PEL or other levels as state regulatory limits. Section 8.6 presents more details on OSHA requirements.

The American Conference of Government Industrial Hygienists (ACGIH) sets its Threshold Limit Value (TLV) for PCE at 25 ppm (170 mg/m^3)(ACGIH, 1994). The National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) is the lowest feasible level. NIOSH recognizes PCE as a potential carcinogen and lists the level of quantification as 0.4 ppm (3 mg/m^3). NIOSH also has established 150 ppm as a concentration immediately dangerous to life and health (IDLH)(NIOSH, 1997a).

The National Occupational Exposure Survey (NOES) estimates that 61,724 workers may have potential for exposure at 6,924 sites using PCE for all industries in the Standard Industrial Classification (SIC) Code 72 (NIOSH, 1982). Commercial drycleaners are included as one of many industries in SIC 72. Other information gathered for this CTSA indicate that NOES estimates of numbers of workers and sites are underestimates.

For this CTSA, it has been estimated that there are 30,600 commercial facilities that dryclean clothes in PCE (excluding drop-off/ pick-up sites) in the United States. NIOSH recently published a study of commercial drycleaners which included data on numbers of workers and sites (American Business Information, 1994). These BA data include drop-off/ pick-up sites that do no cleaning and include all process types (PCE, hydrocarbon, etc.). In order to estimate numbers of workers in PCE drycleaning facilities nationwide, the BA data needed to be adjusted, and the BA data and assumptions used to adjust them are shown in Exhibits E-5 and E-6 of Appendix E.

As a result, it is estimated that 119,000 to 278,000 workers are employed in facilities that dryclean clothes using PCE in the U.S. The midpoint of this range suggests an average of 6.5 workers per facility. It is not known how representative these estimates are of the industry due to the uncertainties in the data and assumptions used to adjust them.

The population of drycleaning workers may be categorized into various job titles, such as operator or presser, based on worker activities. However, typical activities and exposures may be difficult to characterize because workers may have rotating responsibilities and overlapping activities, which often vary from facility to facility. In a previous study, USEPA estimated the number of workers by job description (PEI, 1985). Based on those estimates, the drycleaning workers may be categorized into the following job titles with the corresponding percentage of the total drycleaning population: 3.8% managers/ administrators, 18.5% clerks, 9.9% tailors, 15.5% pressers, 48.7% operators, and 3.6% for all others combined. It is assumed that the job descriptions of “(dry)cleaner” and “operator” are equivalent, and include those workers who operate the drycleaning washing and drying equipment. For risk assessment in Chapter 5, it is assumed that the workers may normally be exposed for 8 hours/day and 250 days/year. Some worker subpopulations (e.g., some owner/operators and workers who work overtime) could be exposed for up to 312 days/year or more and more than 8 hours/day, although no data were found to support estimated average numbers of hours/day and days/year.

Occupational Inhalation Exposure

Many studies and data sets are available to characterize inhalation exposures to PCE for drycleaning workers. The four data sets presented in this section illustrate variations in worker inhalation exposures due to factors such as jobs, machine types and controls, numbers of machines, and time period in which monitoring was performed. These data sets consist of OSHA monitoring data, a compilation of published data sets, data collected by the International Fabricare Institute, and survey data from a NIOSH report. These data sets include measured TWA exposure concentrations (ECs) of PCE; for risk screening later in this report, it is assumed that these data are representative of 8-hour (full-shift) TWAs.

The first data set consists of OSHA workplace personal exposure concentrations (ECs) for PCE in drycleaning from 1991 to 1993 (OCIS, 1994) and 1997 (OCIS, 1998). ECs from these data are summarized by job title in Exhibit 4-4. Distributions of data for four worker subpopulations (i.e., drycleaner, spotter, presser, and manager) were generated from the 1991 to 1993 data; worker subpopulations were not available for the 1997 data. Other subpopulations could not be distinguished due to multiple job descriptions for individual workers. Because OSHA often monitors for compliance or in reaction to complaints, ECs generated from OSHA data may be higher than actual ECs for the total population of workers. Exhibit 4-4 shows the following order of exposures from highest to lowest:

Exhibit 4-4. Summary of TWA ECs Based on OSHA Personal Monitoring for PCE Drycleaning[a]

Job Description	EC Units	Geometric Mean EC± SD	Arith. Average EC ± SD	Maximum EC
1990 to 1993				
All Jobs [386]	mg/m^3	69±62	280±530	5,000
	ppm	10±9.2	41±79	740
Cleaner [157]	mg/m^3	80±76	330±630	5,000
	ppm	12±11	49±93	740
Spotter[b] [37]	mg/m^3	53±77	180±240	1,100
	ppm	7.8±11	27±35	160
Manager [43]	mg/m^3	250±31	620±820	4,300
	ppm	38±4.6	91±120	630
Presser [41]	mg/m^3	37±39	97±130	470
	ppm	5.4±5.7	14±19	69
1997				
All Jobs [40]	mg/m^3	42±51	190±410	2,500
	ppm	6.2±7.5	28±60	360

Source: OCIS (1994) and OCIS (1998).
[a] Number of measurements [n] are in brackets for each job title. All concentrations are reported as means and, when applicable, ± standard deviation (SD). For 1990 to 1993, 39 of the 386 measurements (10%) exceed the current OSHA permissible exposure limit of 100 ppm TWA; for 1997, two of the 40 measurements (5%) exceed the OSHA PEL.
[b] A majority with the job title “spotter” had the associated job title of “cleaner” (e.g., spotter/cleaner).

manager, cleaner, spotter, and presser. No information was available to determine why manager exposures were higher than operator exposures in this data set, although it could be hypothesized that these managers may perform many of the same activities that operators perform. Data on factors such as machine type and controls, and numbers of machines were not available. The data show that exposure levels and OSHA PEL excursions may be dropping over time, although the data were not examined for statistical significance. This drop over time could be due to regulatory, economic, and other factors.

A second set of data is a compilation of data from several studies and sources on workplace PCE concentrations in drycleaning facilities (Thompson and Evans, 1993). This compilation presented average TWA concentrations for two worker subpopulations (operator and non-operator) working in facilities with either of the two machine types (transfer and dry-to-dry). The ECs presented in Exhibit 4-5 are from three studies/sources. Like Exhibit 4-4, Exhibit 4-5 shows that operator/cleaners generally have higher exposures than most non-operators (e.g., pressers, spotters). This exhibit also shows that workers in facilities with transfer machines may be expected to have higher exposures than workers in facilities with dry-to-dry machines.

Exhibit 4-5. Central Tendencies of TWA Concentrations of PCE Reported in Some US Occupational Studies for Drycleaning Workers by Job Type and Machine Type[a]

Machine Type	TWA PCE Concentrations (n =number of samples) for				Data Source Code[b]
	Operators		Non-operators		
	ppm	mg/m^3	ppm	mg/m^3	
Dry-to-Dry	17	115 (n=1301)	12	79 (n=497)	1
	11±12	73±81 (n=3)	6±3	39±22 (n=8)	2
	8±6	56±38 (n=9)	2±1	11±10 (n=26)	3
Transfer	48	328 (n=1027)	26	179 (n=508)	1
	58±30	396±206 (n=9)	16±14	107±96 (n=19)	2
	22±18	152±123 (n=16)	5±5	33±34 (n=20)	3

[a] Excerpts of Table 2 from Thompson and Evans, 1993. All concentrations are reported as arithmetic averages and, when available, ± standard deviation; studies which reported only geometric mean concentrations or which monitored from other than random sampling are not included.
[b] Source Codes: 1=IFI, 1990; 2=Solet, 1990; 3=Toutonghi, 1992.

The third set of data was collected by the International Fabricare Institute (NIOSH, 1997). These data, presented in Exhibit 4-6, are average worker TWA ECs and are differentiated by machine type and time period. The data from Exhibit 4-6, which are not referenced in the NIOSH source, appear to be from the same original IFI source document as the data associated with Data Source Code 1 in Exhibit 4-5. Like Exhibit 4-5, Exhibit 4-6 shows that workers in facilities with transfer machines may be expected to have higher exposures than workers in facilities with dry-to-dry machines. Relative to facilities with transfer machines, facilities with dry-to-dry machines had a higher percentage of samples in Exhibit 4-6 that complied with the OSHA PEL for PCE of 100 ppm TWA. Exhibit 4-6 also shows a general decrease in exposure levels over time. Possible explanations for such decreases over time may include improvements to machinery and workplace practices brought on by PCE regulations and economics.

Exhibit 4-6. Passive Air Monitoring Results for PCE Drycleaning Workers by Machine Type Collected by the International Fabricare Institute[a]

Machine Type		Before 1/1/87	1/1/87 - 9/30/89	After 10/1/89
Transfer	ppm	55.3	46.4	42
	mg/m^3	375	315	285
	% > 25 ppm[b]	76.2%	59.9%	56.8%
	% > 100 ppm[c]	7.7%	5.6%	7.0%
Dry-to-Dry	ppm	20.5[d]	16.1[d]	17.2[d] 16.9[e] 16.7[f]
	mg/m^3	139[d]	109[d]	117[d] 115[e] 113[f]
	% > 25 ppm[b]	24.3%	18.5%	18.6%[e] / 17.2%[f]
	% > 100 ppm[c]	1.0%	0.8%	1.3%[e] / 0.8%[f]

[a] Table is taken in its entirety from NIOSH, 1997. All concentrations are TWA.
[b] The ACGIH TLV is 25 ppm.
[c] The OSHA PEL is 100 ppm.
[d] Denotes standard dry-to-dry with water-cooled condenser and vent at end of dry cycle.
[e] Denotes dry-to-dry refrigerated with small vent to purge cylinder at end of dry cycle.
[f] Denotes dry-to-dry refrigerated with no vent.

The fourth set of data was from a recent NIOSH study (NIOSH, 1997). These data, presented in Exhibit 4-7, are average worker TWA ECs and are differentiated by machine type and control, job title, and number of machines. Like Exhibits 4-4 and 4-5, Exhibit 4-7 shows that operators tend to have higher exposures than non-operators and that operators in facilities with transfer machines tend to have higher exposures than workers in facilities with dry-to-dry machines. NIOSH concluded, and Exhibit 4-7 shows, that as the number of machines increases, exposure levels also increase. NIOSH determined that closed-loop machines with integral CA (fifth generation) result in statistically significantly lower worker exposures than all other machine configurations currently available. Compliance with the OSHA PEL for PCE of 100 ppm was 100% for 148 samples taken in the NIOSH surveys.

Exhibit 4-7. TWA ECs for PCE Drycleaning Workers by Machine Type and Control and Job Title Collected by the National Institute for Occupational Safety and Health[a]

Machine Type/Control	Number of Machine s	Worker Job Title (n = number of samples)	TWA PCE Concentration, in ppm [in mg/m^3]		SS D
			Arith. Mean	Geom. Mean ± GSD	
Transfer: Dryer with Refrigerated Condenser	1	Operator (n=13)	19.5 [132]	16.1±1.7 [109±12]	A
		Presser 1	3.8 [26]	-	-
		Presser 2	3.3 [22]	-	-
Dry-to-Dry Closed- Loop/ Door Fan exhausted to Small Carbon Adsorber	1	Operator (n=7)	15.8 [107]	14.8±1.7 [100±12]	A
		Presser 1	5.0 [34]	-	-
		Presser 2	2.5 [17]	-	-
	2	Operator (n=15)	21.6 [146]	19.3±13.1 [131±89]	A
		Spotter	8.3 [56]	-	-
Dry-to-Dry Closed Loop	2	Operator (n=8)	7.8 [53]	7.0±2.0 [47±14]	A
		Presser	0.6 [4]	-	-
Dry-to-Dry Closed Loop/ Integral Carbon Adsorber	2	Operator (n=15)	1.6 [11]	0.4±1.6 [3±11]	B
		Presser	ND [ND]	-	-

[a] Taken entirely from NIOSH, 1997. All concentrations are average TWA taken from five NIOSH surveys. GSD is the geometric standard deviation. The reference did not present numbers of samples, geometric means, GSDs, and SSDs (see note below) for non-operators.
ND = Below the detection limit.
Where available, n = number of samples. Total n = 148 for the five NIOSH surveys used in the reference.
SSD: This Statistically Significant Difference (SSD) column presents letter indicators for the operator data. The NIOSH reference states that different letters indicate a statistically significant difference using the least significant difference test (α = 0.05).

A number of factors make it difficult to associate the NIOSH data in Exhibit 4-8 with the CTSA's PCE model facilities. The four machine types and controls studied by NIOSH and shown in Exhibit 4-8 correspond to the machine types and controls for four of the eight PCE model facilities studied. However, only two of the five facilities in the NIOSH study used only one dry cleaning machine, which was the basis for a model facility. Also, the clothes cleaning throughputs for the facilities in the NIOSH studies were unknown and the machine sizes of the facilities in the NIOSH study are significantly larger than those of the CTSA's model facilities. As a result of these factors, the data in Exhibit 4-8 are not associated with particular model facilities in this CTSA.

This NIOSH study explored a number of factors affecting worker exposures. NIOSH found that loading and unloading of the machines accounted for over half of the operator's TWA exposures. Another factor that affected worker exposures at several facilities was the presence of small, inadequately sized (1- to 2-pound carbon capacity) and inadequately maintained carbon canisters to which air from the cylinder is purged at the end of the dry cycle when the machine door is opened. NIOSH estimated that these canisters should be changed daily in order to be effective, and if steam desorbed, the carbon must be fully dried before reuse. Also at some facilities, the operation of waterproofing dip-tanks was found to result in very high instantaneous exposures to PCE. NIOSH recommended that, ideally, this type of waterproofing be eliminated; otherwise, when these dip tanks are operated, adequate local exhaust ventilation, respirators, and gloves must be used. A detailed examination and discussion of these and other factors affecting exposure, exposure reduction options, and other worker health and safety issues in commercial drycleaning may be found in the NIOSH report (NIOSH, 1997).

The NIOSH study also examined instantaneous and short-term worker exposures to PCE. Exposures during unloading, transfer, and loading of a transfer machine reached instantaneous levels between 1,000 ppm and 1,500 ppm, and the highest average exposures of 500 ppm to 600 ppm occurred during the 1-minute garment transfer from the washer to the reclaimer. Real-time monitoring by NIOSH at facilities using dry-to-dry machines yielded measurements of 1,500 to 2,000 ppm during machine loading and unloading of the machines (NIOSH, 1997).

In summary, the following are five primary findings from the four exhibits summarizing worker inhalation of PCE:

1. Operator/cleaners generally have higher exposures than most non-operators (e.g., pressers, spotters).
2. There appears to have been a general decreasing trend in exposure levels and PEL excursions over time.
3. Operators in facilities with transfer machines tend to have higher exposures than workers in facilities with dry-to-dry machines.
4. As the number of machines increases, exposure levels also increase.
5. Closed-loop machines with integral CA (fifth generation) result in significantly lower worker exposures than all other machine configurations currently available.

Interpretation and comparison of the data sets summarized in this CTSA raise some uncertainties related to the data and the studies in which they were collected. It is not known whether the measured concentrations in these data sets are representative of the distributions of concentrations to which the populations of drycleaning workers are actually exposed nationwide. The smaller the observed numbers of facilities, workers, and samples, the higher the degree of uncertainty regarding representativeness. Nor is it known whether the measured TWA concentrations, if not adjusted to represent full-shift (i.e., normally assumed as 8-hour shifts) values, are representative of full-shift TWA concentrations. Variations in machinery and plant layout, exposure controls such as ventilation, work practices and procedures, amounts of clothes cleaned daily, and many other factors affect an individual drycleaning worker's exposure. As a result, an individual worker's exposure may or may not be well-represented by the data summarized in this CTSA. The data in these exhibits may only compare qualitatively. Details about the facilities, the worker activities, the monitoring studies, and other relevant details behind the monitoring data presented in the exhibits were not available to allow for a detailed understanding and analysis of the ECs in the different data sets and how they may be quantitatively compared. The sets of data in the exhibits do appear to support one another generally. For instance, the arithmetic averages of larger data sets for a given population or subpopulation appear to be within an order of magnitude and often compare closely.

Occupational Dermal Exposure

Drycleaning workers may also experience dermal exposure to PCE. No studies or data were available that quantify dermal exposures to PCE for drycleaning workers; however, dermal exposures to PCE can be modeled. Estimates presented here are based upon the Occupational Dermal Exposure Model of the Office of Pollution Prevention and Toxics (OPPT ODEM; USEPA, 1991a). The model relies on a two-hand contact or immersion in a liquid without any protective clothing and use of pure PCE. This model is believed to present bounding estimates of amounts of solvent available for absorption on the skin surface (see Section 4.3.2). Hence, these estimates are larger than the exposures that workers would be expected to receive. This model assumes that the surface area for two hands is up to 1,300 cm^2. No model is available to estimate dermal exposures from vapors.

The OPPT ODEM is normally used to estimate potential dose rates (PDRs). However, in this case, the volatility of PCE makes PDRs relatively meaningless because most of the PCE that workers get on their skin would be expected to volatilize before absorption. Also, the absorption rates available for PCE in the literature are in units of mass per area per time. Therefore, the ODEM was used to estimate the potential dose available for a given worker activity to demonstrate that a significant quantity of PCE is available for absorption before the PCE evaporates. Evaporation time is roughly estimated using the quantity available for absorption into skin and a model that estimates a rate of evaporation from a pool of liquid with the same area as the estimated skin contact area. This method introduces additional uncertainties to the assessment, but no better method could be found.

Operators are the primary workers expected to perform activities that result in dermal exposures to liquid PCE, and these activities are shop and equipment dependent. Some of these activities occur at least once per day (routine) and others occur on a less frequent basis (non-routine), such as changing cartridge or rag filters and open-tank waterproofing. Routine activities include, but are not limited to, transferring wet articles from the washer to the dryer and cleaning the button trap and still (or muck cooker). For the wet article transfer activity, the OPPT ODEM immersion data were chosen to be applicable for exposure modeling; for all other activities, the OPPT ODEM contact data were chosen to be applicable for exposure modeling.

Based on the OPPT ODEM, the estimated dermal potential dose for workers performing wet article transfer is 18,000 mg PCE available for dermal absorption per transfer. This activity is expected to take approximately 1 to 2 minutes, and after this activity is completed, most of the PCE on the skin would be expected to evaporate within 2 minutes as estimated roughly by the method described above. The total maximum duration of dermal exposure to liquid PCE from transfer of wet clothing would be expected to average 18 to 24 minutes per day, based on 3 to 4 minutes of total PCE dermal exposure per transfer and six transfers per day. The estimated dermal potential dose for workers performing other activities is less than 3,900 mg PCE per event available for dermal absorption, and most of the PCE on the skin from these contacts would be expected to evaporate in less than one minute. In most shops, PCE liquid can be contacted during routine and non-routine activities other than wet article transfer, and the duration of dermal contact with liquid PCE for these activities is estimated to average up to 8 minutes per day (see Appendix E for details).

Non-Worker Populations

Inhalation Exposure

Releases to air are caused by evaporation of chemicals during the clothes cleaning process. Activities include removing clothes from the cleaning machine (dry or wet). These vapors are then carried by and mixed with outside air. The resulting air concentration will depend on weather conditions. Stagnant conditions will not move vapors away quickly, so local concentrations of the chemical will be higher than the concentrations farther from the facility. Under windy conditions, the vapors will be carried away faster, reducing the local concentrations. The number of people exposed at varying distances from the facility may be larger or smaller depending on urbanization and the distance the vapor travels.

Within the non-worker population, those most highly exposed are persons living in the same building as a drycleaner that cleans clothes on the premises. This population is referred to as “co-located residents” and includes children, adults, and the elderly. The next most exposed are persons living in close proximity to drycleaners, or those who work in buildings very close to drycleaners. Other exposed populations include people bringing drycleaned clothes home and the families of workers in drycleaning plants.

Throughout Chapter 4, different estimates of exposure duration are provided for the general population exposure scenarios. In most cases, exposure to PCE is not expected to occur over an individual’s entire lifetime. For example, apartment residents in buildings that contain drycleaners can be exposed to elevated levels of PCE. It is assumed that exposed individuals live in their apartments between about 2.5 and 8 years. This assumption is made based on estimates of average and upper-end apartment residence times provided in USEPA (1997b).

The exception is exposure to ambient levels of PCE. This exposure is assumed to occur over an individual’s entire lifetime. This assumption is made because PCE has been detected in ambient air at many different locations (Wallace, 1989).

Exposures Received by Co-located Residents

The results of a number of monitoring studies indicate that the highest concentrations of PCE in indoor air are found in workplaces and in apartments or condominiums located in the same building as drycleaners. PCE concentrations in apartments above drycleaners have been measured in New York, San Francisco, Germany, and the Netherlands (Staub et al., 1992; USEPA, 1992a; BAAQMD, 1993; Fast, 1993; Schreiber et al., 1993; Consumers Union, 1995).

Investigations carried out by the New York State Department of Health in 1989 and 1990 revealed high concentrations of PCE in apartments above drycleaners (Schreiber et al., 1993). Elevated concentrations of PCE were found in an apartment in Mahopac, New York; the highest measured concentration was 197 mg/m^3. The drycleaning machine in this building was in very poor condition. This facility was closed while improvements to the machine were made. Later sampling showed much lower concentrations (although still elevated over ambient levels). Another investigation showed elevated PCE concentrations in West Seneca, New York. These results prompted the first of the studies described below (Schreiber et al., 1993). Expanded descriptions are in Appendix E.

Capital District Survey (Schreiber et al., 1993). The Capital District Survey was conducted by the New York State Department of Health in the summer of 1990. PCE concentrations were measured in the six apartments above drycleaners in the Capital District of Albany, New York. These apartments were located in six different buildings; each building contained one drycleaning machine. Three of the drycleaning facilities used transfer machines. Two used vented dry-to-dry machines, and one used a non-vented dry-to-dry machine. Samples were taken in the room expected to have the highest PCE levels. PCE concentrations ranged from 0.100 to 55.0 mg/m^3. The highest concentrations were measured above an old dry-to-dry unit “in poor operating condition” (Schreiber et al., 1993).

Samples at six control apartments were taken at the same time. Each control residence was located at least 100 meters from one of the six drycleaning facilities. Controls were chosen based on their similarity in building type, age, and neighborhood to the co-located apartments. In three of the control apartments, average measured concentrations were less than 0.0067 mg/m^3. Concentrations in the other control residences ranged from 0.022 to 0.103 mg/m^3. A resident of one control apartment worked in a chemical laboratory; a resident of another apartment worked at a drycleaner (Schreiber et al., 1993).

Consumers Union (Wallace et al., 1995). In 1995, Consumers Union published a study of PCE concentrations in 29 apartments above dry-to-dry non-vented machines. These apartments were located in 12 residential apartment buildings, each with one drycleaner. Measurements were taken from December 1994 to May 1995. Single-day measured concentrations ranged from 0.0007 mg/m^3 to 38.0 mg/m^3. Four-day average concentrations ranged from 0.007 mg/m^3 to 25.1 mg/m^3 (Wallace et al., 1995).

The highest PCE concentrations were measured above a drycleaner using a dry-to-dry vented machine that had been modified to function like a non-vented machine. Consumers Union concluded that the machine “had been described as an unvented dry-to-dry machine, but probably did not represent the modern equipment that was our focus” (Wallace et al., 1995). The lowest measured concentrations were found in apartments on the other side of the building from the drycleaning facility.

Concentrations in the control apartments were much lower, ranging from less than 0.0007 mg/m^3 to 0.0305 mg/m^3 for the single-day average values. The overall average PCE concentration, based on values from all control apartments, was 0.006 mg/m^3 (Wallace et al., 1995).

New York State Health Department Data, Unpublished. Data on PCE concentrations have been collected in New York State by the New York City and State Departments of Health in response to residential complaints. These data consist mainly of 4-hour samples taken during the daytime, although a few sets of 24-hour samples are also available. Because these results have not been published by their collectors, they were accompanied by minimal descriptive information. More than 50 samples above 23 machines were taken in New York in response to residential complaints from 1991 to 1993 (NYSDOH, 1993). Machine types included transfer and dry-to-dry. Machine conditions varied quite substantially. PCE concentrations ranged from less than 0.02 mg/m^3 to 2.5 mg/m^3.

San Francisco Bay Area (BAAQMD, 1993). In 1993, the Bay Area Air Quality Management District in San Francisco, California, published a study of measured PCE concentrations in the hallways of apartments above four non-vented dry-to-dry machines. These measurements were made to determine if new machines with advanced controls also produced elevated levels of PCE inside the building. These samples were taken over two 40-minute periods; the arithmetic mean was reported (BAAQMD, 1993). PCE concentrations ranged from 0.00224 mg/m^3 to 0.673 mg/m^3. The highest PCE concentration was measured above a drycleaner that was the subject of a prior PCE odor complaint. This facility did not have room enclosures or fans.

Concentrations Measured in Germany and Netherlands (Staub et al., 1992; USEPA, 1992a; Fast, 1993). Additional data are available on PCE concentrations in residences above drycleaners in Germany and the Netherlands. Unlike the U.S. data, which appear to show that PCE concentrations are lower above non-vented dry-to-dry machines than above transfer and vented dry-to-dry machines, the European data showed no difference in PCE concentrations above vented and non-vented dry-to-dry machines. The European measurements ranged from less than 1 mg/m^3 to 130 mg/m^3, with most measurements between 0.1 and 50 mg/m^3 (Staub et al., 1992; USEPA, 1992a; Fast, 1993).

Uncertainties (BAAQMD, 1993, Schreiber et al., 1993; Wallace et. al, 1995). The Capital District Survey was a census-based assessment, in which each co-located facility in the Albany area was located and all were tested (Schreiber et al., 1993). Only six apartments were co-located, however, far fewer than would be found in most major cities.

Samples taken by the New York City and State Departments of Health were based on complaints. That means that sampling was not carried out based on machine characteristics, which varied tremendously.

Residents of the apartments tested by Consumers Union volunteered for the study. It is possible that residents who thought their apartments were polluted with PCE were more likely to volunteer for the testing. However, Consumers Union concluded that there is nothing about the buildings or cleaners chosen to suggest that there were more likely to be PCE problems in the tested buildings than any other locations (Wallace et al., 1995).

The San Francisco Bay Area assessment measured concentrations above non-vented dry-to-dry machines. The sample size was very small, and concentrations were measured in the hallways, not in the actual apartments (BAAQMD, 1993).

In all cases, sampling occurred over short periods ranging from 4 hours to a few days. One would expect the measurements prompted by complaints to be higher than PCE levels which are not related to complaints. This effect is not seen. The small sample sizes, however, make it difficult to draw general conclusions. Additionally, PCE concentrations were generally measured at one location. It is not known whether PCE concentrations might vary throughout an apartment.

In the Capital District and Consumers Union studies, apartment residents were asked not to bring newly drycleaned items into the home in the week prior to sampling. Most residents complied with this request. However, there may have been some individuals who did not. Measured concentrations for such individuals' residences could be higher than for others. Additionally, because sampling occurred during the summer, residents were not asked to keep their windows closed. In two of the Capital District study homes, windows were open during the sampling period (Schreiber et al., 1993). This could have lowered measured concentrations by introducing a downward bias.

Concentrations have been measured above both older and newer machine types. A wide range of machine conditions is also represented. However, the data presented here only go up to 1995. It is not known whether concentrations would be lower above the very best and most well-maintained machines. Both Consumers Union and San Francisco have found elevated concentrations in buildings containing non-vented dry-to-dry machinery (BAAQMD, 1993; Wallace et al., 1995).

Apartment location within the building can also affect concentration measurements. Both the Capital District survey and Consumers Union measured higher PCE concentrations in the lower and upper floors of multistory buildings than in the middle floors (Schreiber et al., 1993, Wallace et al., 1995).

Summary Statistics. Exhibit 4-8 provides summary statistics for the results obtained in the Capital District, Consumers Union, and San Francisco studies, as well as the previously unpublished data gathered by the New York City and State Departments of Health. Results are grouped for residences above transfer machines as well as above vented and non-vented dry-to-dry facilities. Concentrations from each study are presented separately. Analyzing the data separately in this way does introduce some uncertainties, in that conclusions are being drawn based on smaller sample sizes. It prevents, however, differences in study circumstances from masking similarities in results. The exposure assessment does reflect a fairly good database on the whole, which includes several different monitoring studies. Note that Exhibit 4-8 contains entries for number of apartments, number of buildings, and number of samples. PCE concentrations were sometimes sampled in one co-located residence per building and sometimes in several different apartments in the same building. There was generally one drycleaning machine in a co-located building.

Different machine types tend to produce different levels of fugitive emissions. In general, the more sophisticated the type of machine, including associated controls, the lower the fugitive emissions. Machine condition is important as well. As the Consumers Union study shows, even relatively advanced dry-to-dry machines can produce moderate to high PCE concentrations in co-located apartments (Wallace et al., 1995).

The highest measurements shown in Exhibit 4-8 reflect machine type and machine condition. The highest concentration, 62 mg/m^3, was measured by the New York Health Department above a transfer machine. The arithmetic means were also highest for these results. The high measurements above the vented dry-to-dry machine in the Capital District survey reflect poor machine condition.

The influence of considering complaints in characterizing typical measured values is unclear. For example, the arithmetic mean of the measurements taken in response to complaints concerning non-vented dry-to-dry facilities is lower than the mean results found in the Consumers Union study. Both, however, are close to the odor threshold of PCE in air, which has been reported at one ppm (ATSDR, 1993).

Exhibit 4-8. Summary Statistics for PCE Concentrations in Air in Co-located Residences

Study	No. of Apartments	No. of Buildings	No. of Samples	PCE Concentrations in Air (mg/m^3)			
				Range	Arithmetic Mean	Standard Deviation	Median
Residences Above Transfer Machines							
Capital District	3	3	3	1.35-17	7.72	7.72	6.12
New York State	5	1	10	0.4-62	15.5	22.4	5.95
New York State	7	6	7	0.02-2.47	0.85	0.92	0.48
Residences Above Vented Dry-to-Dry Machines							
Capital District	1	1	2	0.16-0.44	0.3	0.28	0.3
Capital District[a]	1	1	2	36.5-55	45.7	18.5	45.7
New York State	10	10	19	0.06-15.5	3.94	5.18	2.05
Residences Above Non-vented Dry-to-Dry Machines							
Capital District	1	1	2[a]	0.1-0.3	0.2	0.2	0.2
New York State	1	1	4	0.2-1.9	0.75	0.68	0.56
Consumers Union[b]	29	12	116	0.0007-38.0	1.85	4.79	0.441
San Francisco	4 hallways	4	4	0.0022-0.67	0.25	0.31	0.17

[a] The authors of the Capital District study describe this machine as old and in poor condition.
[b] These results include concentrations measured above a vented dry-to-dry machine that had been modified to function as a non-vented machine. Consumers Union included these results in its statistical analysis. Four observations were taken above this machine, with a mean of 25.1 mg/m^3, a standard deviation of 9.51, and a median value of 22.7.

Co-located Residents: Assumptions. The total number of co-located residents in the United States is unknown. Information collected in New York State indicates that there are more than 70,000 co-located individuals in the state (NYSDOH, 1993). In New York City, about 30% of drycleaners are estimated to be in buildings with co-located apartments; statewide, the authors estimate that 6% of drycleaners are located in the same building as apartments. Similar information for other cities is not available. Co-located living situations occur in many urban areas throughout the United States.

One estimate of the average time in residence at an apartment is 2.35 years (Israeli and Nelson, 1992, as cited in USEPA, 1997b). This duration was used in calculating the average LADCs. Israeli and Nelson estimate that 5% of apartment dwellers are still living in the same apartment after 8 years (USEPA, 1997b). This upper-end duration of 8 years was used in estimating the high-end LADCs for adult co-located residents. Adults have been estimated to spend about 16 hours a day indoors at home (USEPA, 1997b).[1] This factor was multiplied by the measured concentration in air and the estimated fraction of the lifetime spent living in the apartment above a drycleaning facility. A lifetime of 70 years was assumed.

PCE concentration data were taken from monitoring studies (BAAQMD, 1993; NYSDOH, 1993; Schreiber et al., 1993). Some of these monitoring studies reported A.M. and P.M. concentrations. The A.M. concentrations generally were taken between 7:00 A.M. and 7:00 P.M., and the PM concentrations between 7:00 P.M. and 7:00 A.M. These A.M. and P.M. concentrations were averaged to provide the arithmetic mean concentration for the day. This was done because monitoring patterns and activity pattern reports do not provide data that are readily combined across a day (USEPA, 1997b). If more than one set of A.M. and P.M. measurements were taken, overall arithmetic mean concentrations were calculated based on the daily average values.

LADCs were estimated from the arithmetic mean of the measured concentrations. Medians were provided to help characterize the bulk of the observations. The median values potentially underestimate exposure by lessening the importance of exposures at the high end of the distribution.

These assumptions were used to estimate long-term concentrations received by co-located residents (LADCs). The results are presented in Exhibit 4-9.

Exposures Received by Special Co-located Populations

The exposures shown in Exhibit 4-9 are based on measured PCE concentrations in air as well as a factor for exposure duration. The 90th percentile value for time spent indoors at one's residence is 23.3 hours per day (USEPA, 1997b). This represents 97% of the day spent indoors at home. This highly exposed group of people clearly would not work outside the home and could include infants, children, and the elderly. In general, adults are assumed to spend 68% of their time (16.4 hours per day) indoors at home.

Estimated exposures received by persons at home 97% of the time would be less than double the values presented in Exhibit 4-9. The estimates for this highly exposed subpopulation would range from 0.007 to 5 mg/m^3. This is probably a bounding estimate, which overestimates actual exposures. The

[1] The median value based on 9,343 24-hour diary responses is 16.4 hours in an activity study of 9,386 respondents by Tsang and Klepeis (1996) as cited in USEPA (1997); the 25th percentile was 13.25 hours, the 75th percentile 20.6 hours.

activity pattern data were collected on a short-term basis, and it is difficult to appropriately use the 90th percentile estimate of time indoors at home to predict the amount of time spent at home over a period of years.

Activity pattern data gathered specifically for children indicate that children ages 3 to 11 spend 19 hours per day indoors during the week and 17 hours per day indoors during the weekend (USEPA, 1997b). These values are not necessarily for time indoors at the child's residence, and could include time indoors at other locations (such as school). For this reason, quantitative exposure estimates based on these activity pattern data have not been calculated.

Exhibit 4-9. Estimated Exposures Received by Co-located Residents

Study (Number of Residences)	Arithmetic Mean PCE Concentration (mg/m^3)	LADC (mg/m^3)[a]	
		Average Time in Residence = 2.4 years	High End Time in Residence = 8 years
Residences Above Transfer Machines			
Capital District (N=3)	7.72	0.18	0.60
New York State (N=1)	15.5	0.36	1.21
New York State (N=7)	0.85	0.02	0.07
Residences Above Vented Dry-to-Dry Machines			
Capital District (N=1)	0.3	0.007	0.02
Capital District (N=1)	45.7	1.05	3.56
New York State (N=9)	3.94	0.09	0.31
Residences Above Non-vented Dry-to-Dry Machines			
Capital District (N=1)	0.2	0.005	0.02
New York State (N=1)	0.75	0.020	0.06
Consumers Union (N=29)	1.85	0.040	0.14
San Francisco (N=4)	0.25	0.006	0.020

[a] LADC (mg/m^3) = Arithmetic Mean PCE Concentration (mg/m^3) x Exposure Duration (ED)/Lifetime (LT)
ED = 16.4 hours/day x 365 days/year x 2.35 years (average)
ED = 16.4 hours/day x 365 days/year x 8 years (high end)
LT = 24 hours/day x 365 days/year x 70 years

Please note that other differences between children and adults, such as inhalation rates and body weights, are not relevant to the calculations above because these inhalation exposures represent PCE concentrations in air prior to inhalation.

Uncertainties:

The most significant uncertainty in this exposure assessment is the assumption that these concentrations in air will remain constant over a period of years. Another important uncertainty involves the assumed exposure duration. Although USEPA (1997b) information indicates that 8 years is an appropriate upper-end value for time in residence at an apartment, it has been pointed out that residents in New York City could live in the same apartment for a much longer period of time (Wallace et al., 1995). Consumers Union found that residents of 15 apartments (out of the 29 apartments studied) had lived in their present residence for 10 or more years. Several residents had lived in the same apartment for more than 20 years (Wallace et al., 1995).

Exposures Received by People Working Near Drycleaners.

Data gathered by the New York State Department of Health shows elevated concentrations of PCE in some locations next door to dry cleaners. A total of ten samples were taken in buildings located next door to drycleaners in strip malls. Nine of the ten measurements showed elevated PCE concentrations, which ranged from 0.2 to 50.4 mg/m^3, with a median value of 11.8. The tenth sample showed a PCE concentration of 0.008 mg/m^3 (NYSDOH, 1993). This small data set shows that there is potential for exposure to elevated levels of PCE for people working next door to drycleaners.

Exposures Received by the General Population

One study was carried out at four sites across the country to reflect exposures consequent to a variety of exposure patterns. The Total Exposure Assessment Methodology (TEAM) study reported 24-hour concentrations of PCE from close to 1,000 personal samples of persons living in New Jersey, California, Maryland, North Dakota, and North Carolina (Wallace, 1989). The monitored persons were chosen to represent members of the general population in these cities. No persons in co-located residences were included in the study.

Each study participant carried a personal sampler for a 24-hour period, collecting both daytime and evening samples. Identical samplers were set up near some participants' homes to measure concentrations in outdoor air. The arithmetic mean 24-hour personal exposure across all locations was 0.017 mg/m^3, as opposed to 0.003 mg/m^3 measured outdoors (Wallace, 1989).

Wallace concluded that if these concentrations represent the rest of the country, and if in the absence of other sources outdoor concentrations will equal indoor concentrations, then "outdoor ambient air is responsible for at most 20% of the risk due to tetrachloroethylene" (Wallace, 1989).

Wallace noted that there was one unusually high measured concentration of 1.6 mg/m^3 in North Dakota, which increased the overall average; without that single measurement, the mean personal exposure received by residents of all cities was 0.012 mg/m^3. Four sources of exposure were listed by the authors to explain why personal exposures (without the North Dakota measurement) were an average of 0.009 mg/m^3 higher than the measured outdoor concentrations of 0.003 mg/m^3 (Wallace, 1989):

1. Exposure in the drycleaning shop while picking up or dropping off clothes (commercial drycleaners) or while using coin-operated drycleaning facilities. The author estimated that these visits to drycleaners contributed less than 0.001 mg/m^3 toward the higher indoor concentrations.

2. Exposure in the car or at home while transporting or storing drycleaned clothes. These exposures were estimated to contribute 0.005 mg/m^3.

3. Exposure at work to one's own or fellow workers' drycleaned clothes. Exposures at work were estimated to contribute 0.002 mg/m^3.

4. Exposure to nonambient, non-drycleaning sources (e.g., paints, solvents, cleaning materials). This was estimated to contribute the remaining 0.001 mg/m^3 toward personal exposures.

Based on these results, an average LADC can be estimated for persons in New Jersey, California, Maryland, North Carolina, and North Dakota. For the CTSA, we shall assume that the concentration measured from personal sampling will remain constant over the individuals' lifetimes. Therefore, the estimated LADC received by the general population would be 0.017 mg/m^3. A limited data set compiled by the State of New York (NYSDOH, 1993) suggests the PCE is present at low concentrations above pressing only/drop stores, which do not use PCE on the premises. Measured concentrations ranged from 0.008 to 0.016 mg/m^3.

Uncertainties:

The TEAM data are relatively old and also include PCE concentrations from other sources (although, as stated above, other sources are estimated to contribute only 0.001 mg/m^3 toward the total). As in the co-located scenario, short-term concentrations are used in this CTSA to predict long-term exposures. Information on the fluctuations of PCE concentrations over time is not available. The NYSDOH data above pressing only/drop stores are limited to two samples.

Other Studies Measuring Elevated Concentrations in the Home

Several studies have been published relating to consumer exposure to drycleaned clothes. They relate to bringing clothing home as well as wearing newly drycleaned outfits. As described in the previous section, arithmetic mean values from the TEAM study have been used in estimating general population exposures. The following shows how additional information relates to those concentration measurements.

Exposures from Bringing Drycleaned Clothing Home. USEPA data show that the presence of newly drycleaned clothes in the home will elevate PCE concentrations (Tichenor et al., 1990). In this study, a polyester/wool suit, a wool skirt, and two polyester/wool blouses were drycleaned and then brought into a building constructed as a test home. PCE concentrations were measured in the den, bedroom, and closet. Measured concentrations were less than 1 mg/m^3 in the den and bedroom, but approached 3 mg/m^3 in the closet (Tichenor et al., 1990). Concentrations dropped off slowly over the nine-day study duration; the authors believe that sink effects (i.e., adsorption and re-emission of PCE) were responsible for this phenomenon (Tichenor et al., 1990).

Thomas et al. (1991) also examined the impact of drycleaned clothing on PCE concentrations in indoor air. Newly drycleaned clothes were brought into nine New Jersey test homes. PCE concentrations were measured in the living room and bedroom. Personal air and breath samples were also taken. Elevated PCE concentrations were observed in seven of the nine homes, with a maximum indoor air concentration of 0.3 mg/m^3. Indoor air concentrations remained at elevated levels for at least 48 hours in all seven homes. Personal air and breath samples also showed higher PCE concentrations, with breath samples elevated two- to six-fold. Thomas et al. state that "Indoor air, personal air, and breath tetrachloroethylene concentrations were significantly related (0.05 level) to the number of garments introduced divided by the home volume" (Thomas et al., 1991).

Exposures Received by Families of Drycleaning Workers. Families of drycleaning workers may also experience elevated PCE concentrations in the home (Aggazzotti et al., 1994; Thompson and Evans, 1993). Aggazzotti et al. (1994) measured PCE concentrations in the homes of 50 Italian drycleaning workers and found a median PCE concentration of 0.3 mg/m^3, compared to 0.006 mg/m^3 in control homes.

Thompson and Evans "consider the hypothesis that workers introduce Perc into their homes via their exhaled breath" (Thompson and Evans, 1993). They note that most inhaled PCE is exhaled as PCE, and they cite results from Wallace (1989) showing elevated PCE concentrations in workers' exhaled breath and in the homes of drycleaning workers (Thompson and Evans, 1993). Model results for the eighth consecutive week of worker exposure showed that weekly time-weighted PCE averages in the home ranged from 0.04 to 0.08 mg/m^3 (Thompson and Evans, 1993). Modeled weekend concentrations in the home ranged from 0.04 to 0.09 mg/m^3 (on Saturday) and 0.03 to 0.06 mg/m^3 (on Sunday). Thompson and Evans state that "workers' families may represent one of the most highly exposed non-occupational subgroups of the population" (Thompson and Evans, 1993).

Exposures Resulting from Wearing Drycleaned Clothes. Consumers Union asked 24 volunteers to measure breathing zone PCE concentrations emitted by newly drycleaned garments. The garments included six charmeuse blouses, six men's cotton sweaters, six silk blouses, and six women's blazers. These clothes were cleaned at non-vented dry-to-dry facilities (Wallace, 1995). Measured concentrations ranged from 4.8 mg/m^3 to below detection limits (Wallace, 1995). The median concentrations were 0.032 mg/m^3 for charmeuse blouses, 0.043 mg/m^3 for men's cotton sweaters, 0.094 mg/m^3 for silk blouses, and 0.22 for women's blazers. "Although average concentration follows this order: charmeuse blouse < men's sweater < silk blouse < blazer, the scatter is so wide for each garment type that the differences are not statistically significant except that between the charmeuse blouses and the blazers. The same garment type cleaned at the same cleaner in the same run often yielded vastly different concentrations" (Wallace, 1995).

Consumers Union also examined the influence of machine type on measured PCE residues. Twenty volunteers measured breathing zone concentrations from newly drycleaned wool blazers. Drycleaner facilities included five transfer machines as well as five vented and five non-vented dry-to-dry machines. Five distributor (drop-off) facilities were also included in the study. Consumers Union stated that "the only trend we could detect is that blazers cleaned at distributors yielded generally lower concentrations than those cleaned at either type of on-site cleaner" (Wallace, 1995). They also concluded that "the same cleaner could yield vastly different results on different days or even between two different blazers cleaned during the same round. These results suggest that consumers cannot guarantee low perc exposure by choosing a cleaner with new equipment" (Wallace, 1995). A larger study is needed to provide information on PCE residues on various types of garments and cleaning machines (Wallace, 1995).

Consumers Union used these results to estimate low, moderate, and high exposures received by persons wearing drycleaned clothes (Wallace, 1995). The low-exposure scenario involves the assumption that a consumer wears drycleaned clothes a few times a year, and the drycleaner "does a typical job of extracting perc from cleaned garments" (Wallace, 1995). The moderate exposure scenario "represents a consumer who gets a few items of clothing drycleaned each month, and whose cleaner does a typical job of extracting perc" (Wallace et al., 1995). The high exposure scenario "represents a consumer who gets clothes drycleaned at least once a week, and whose cleaner sometimes leaves residues of perc in garments toward the high end of those we measured in our tests" (Wallace, 1995).

The author assumed that clothes are worn the day after they are cleaned, and that this exposure occurs over the estimated 40-year career duration (Wallace, 1995). The results are shown in Exhibit 4-10.

These estimates are presented for the general adult population. It is assumed that the elderly, infants, and children will not wear drycleaned clothing on a regular basis. It is possible, however, that some members of these subpopulations will occasionally wear drycleaned clothes. The low exposure scenario could be the most appropriate scenario for these individuals.

Uncertainties:

Brand et al. (1997) have examined PCE residues on acetate cloth. In contrast to the Consumers Union findings, Brand et al. found minimal variations in the amount of PCE residue on the cloth from different drycleaners. As Wallace et al. (1995) state, a larger study is needed to provide additional information on PCE residues. It is assumed for the CTSA that the PCE levels measured by Consumers Union will represent actual residues left on clothing continously over many drycleaning events.

The low exposure scenario could be an overestimate for people who very rarely wear drycleaned clothes. Conversely, the high exposure scenario could underestimate exposures to PCE for people who wear drycleaned clothing every day. A forty-year career duration has been assumed; this could be an overestimate for some individuals.

Estimated Concentrations in Surface Water

Releases to water are estimated for different types of drycleaning machines in Exhibit 4-1. Estimated releases range from 0.007 gallons/year (0.04 kg/year) to 0.1 gallons/year (0.61 kg/year). These releases are assumed to occur over the estimated 312 days of drycleaner operation each year. The estimated daily releases range from 0.00002 gallons/day (0.0001 kg/day) to 0.0003 gallons/day (0.002 kg/day). The maximum predicted PCE concentration in surface water resulting from these releases is 3 ppb.

Exhibit 4-10. Consumers Union Inhalation Exposure Estimates From Wearing Drycleaned Clothes

Exposure Scenario	Garment Type (PCE concentration description)	Number of Wearings per Year	Measured PCE Concentration (mg/m^3)	LADC (mg/m^3)
Low exposure	Blazer (median PCE concentration)	4[a]	0.5	0.002
	Blazer (low-end concentration), or silk blouse (median concentration), or sweater (high-end concentration)	6[a]	0.1	
	Silk blouse or sweater (low-end concentration)	6[a]	0.03	
Moderate exposure	Blazer (median concentration)	12[b]	0.5	0.005
	Blazer (low-end concentration), or silk blouse (median concentration), or sweater (high-end concentration)	12[b]	0.1	
	Silk blouse or sweater (low-end concentration)	12[b]	0.03	
High exposure	Blazer (average value for blazers cleaned with old equipment)	52[c]	0.7	0.03
	Blazer (low-end concentration), or silk blouse (median concentration), or sweater (high-end concentration)	26	0.1	
	Silk blouse or sweater (low-end concentration)	26	0.03	

Source: Wallace, 1995
[a] Based on an IFI survey indicating that 30% of drycleaning patrons clean clothes infrequently or seasonally (Wallace, 1995).
[b] The IFI survey indicated that 35% of the drycleaning patrons had clothes cleaned on a monthly basis.
[c] The IFI survey indicated that 21% had clothes cleaned weekly.

Uncertainties:

These estimated concentrations are highly dependent on the estimated per-site release values shown in Exhibit 4-1. Generic assumptions regarding streamflow data have been used to predict estimated concentrations in surface water (see Appendix E for more information). These assumptions tend to be conservative and could overestimate concentrations in surface water. PCE concentrations from spills and splashes are not taken into account in this assessment. As the following section shows, extensive PCE groundwater contamination has been found in locations close to drycleaners in California and New York.

Ingestion Exposure

Ingestion of Food

PCE has been detected in fatty foods (such as butter and milk) at low concentrations. Although ingestion of these foods will result in exposure to PCE, dietary intake is too variable to allow for a quantitative estimate of exposure via this pathway (NYSDOH, 1998).

Ingestion of Contaminated Groundwater

Information on PCE concentrations in groundwater is available from California and New York. Potential dose rates received by persons drinking contaminated groundwater are estimated based on measurements taken by the California Regional Water Quality Control Board (Izzo, 1992). Groundwater in more than 215 wells was contaminated by PCE. Most of these were large system municipal wells. The source of the PCE contamination has been identified for 21 wells. In 20 of these wells, the source of PCE is known to be drycleaners (Izzo, 1992). In many cases, concentrations in well water exceeded 0.8 parts per billion (ppb). Forty-seven wells contained PCE in excess of California's maximum contaminant level (MCL) of 5ppb (Izzo, 1992).

PCE is discharged in several forms. "The discharge from most drycleaning units contains primarily water with dissolved PCE, but also contains some pure cleaning solvent and solids containing PCE. Being heavier than water, PCE settles to the bottom of the sewer line and exfiltrates through it. This liquid can leak through joints and cracks in the line. PCE, being volatile, also turns into gas and penetrates the sewer wall. . . The PCE then travels through the vadose zone to the ground water" (Izzo, 1992). The vadose zone, also known as the unsaturated zone, refers to the soft layers, which contain air and some water, above the groundwater level. A 1988 survey of drycleaners indicates that more than 50% discharge their separator water to a sewer (IFI, 1989).

The California Regional Water Quality Control Board believes that most PCE contamination in groundwater is due to drycleaners. PCE is used in other industries, including the auto/boat industry, telephone companies, furniture, and paint dealers, but typically the products contain less than 30% PCE (Izzo, 1992). Drycleaning uses 15 to 40 gallons per month of pure PCE solvent. In other industries, "many of the solvents used that contain PCE are in aerosol cans. The solvent is sprayed on the part to remove grease and as the part dries, the PCE volatilizes into the air. Most industries other than dry cleaners which use solvents have no daily discharge of waste liquids containing PCE." (Izzo, 1992).

Sewer sampling conducted near seventeen drycleaners in the California cities of Merced, Sacramento, Roseville, Turlock, and Lodi has revealed high concentrations of PCE. PCE concentrations in sewer water range from 0.6 ppb to 3,800 ppb, with the median reported concentration at 190 ppb and the average concentration at 748 ppb (Izzo, 1992). "Monitoring wells drilled adjacent to dry cleaners had concentrations from 12 ppb to 32,000 ppb" (Izzo, 1992).

The New York State Department of Health has reported PCE concentrations in soil and groundwater in areas in close proximity to drycleaners (Stasiuk, 1993). High concentrations have resulted from "either direct discharges of PCE from drycleaner operations or from indirect contamination as a result of improper disposal of wastes from drycleaner operations" (Stasiuk, 1993).

Monitoring of areas near 30 drycleaners revealed that PCE has been found in groundwater at concentrations ranging from 5 to 28,000 ppb. These samples were taken at various time periods between the mid-1970s and the early 1990s. Eighty-five private wells were contaminated, with concentrations ranging from 5 to 6,000 ppb. PCE has also been detected in six public wells at concentrations ranging from 41 to 640 ppb (Stasiuk, 1993). After cleanup, PCE concentrations in public wells were at or below the New York state standard of 5 ppb.

The PCE levels in groundwater can be used to develop an exposure assessment for household residents, who ingest PCE in their drinking water. As described above, PCE has been reported in public wells at concentrations ranging from 0.8 to 640 ppb (Izzo, 1992; Stasiuk, 1993). For the CTSA, it is assumed that cleanup will occur and that PCE levels in excess of the New York and California standards of 5 ppb would not be present in drinking water on a long-term basis. It is also assumed that PCE levels in drinking water over an extended period of time could range from 0.8 to 5 ppb. The estimated what-if exposures resulting from drinking water containing these levels of PCE range from 2×10^{-6} mg/kg/day (at 0.8 ppb) to 1×10^{-5} mg/kg/day (at 5 ppb).

These estimates are based on the assumption that exposed individuals drink 1.4 L of water per day, which is an average value for tap water ingestion (USEPA, 1997b). A body weight of 72 kilograms is assumed (USEPA, 1997b). The assumed exposure duration is 9 years, which is the average residence time reported in USEPA, (1997b). For the purposes of this assessment, it is assumed that when residents move, they would move to an area in which the water supply is no longer contaminated with PCE.

Infants and children would also be exposed to PCE in household water supplies. Average values for tap water intake range from 0.3 liters per day for infants to 0.97 liters per day for children ages 11 to 19 (USEPA, 1997b). Exposure scenarios are developed for infants and 11-year-old children. The assumed body weight for infants is 10 kg, which is based on the 50th percentile values for male and female infants at twelve months of age (USEPA, 1997b). A body weight of 41.1 kg is used for 11-year-old children (USEPA, 1997b). Daily PCE intake ranges from 2×10^{-5} to 1×10^{-4} mg/kg/day for infants. The estimated range for 11-year-olds is 2×10^{-5} to 1×10^{-4} mg/kg/day. Please note that these are daily values, unlike the scenario for adults which provides chronic values.

Additional information on PCE concentrations in groundwater has been obtained by performing a search of Dialog, STORET, and the Internet. These concentrations of PCE are accompanied by minimal descriptive information, and it is not certain that the contamination source is dry cleaners. For this reason, these data have not been included in the exposure assessment. A summary of the search results in shown in Appendix E.

Uncertainties:

These estimates were obtained from an analysis of a number of contaminated sites in California and New York. It is assumed for the purposes of the CTSA that the concentrations in municipal wells as reported above are representative of PCE concentrations in household water supplies. This could be a conservative assumption if public water supplies are drawn from a number of different wells, which could cause PCE concentrations to be diluted. Another uncertainty involves the assumption that removal in drinking water treatment does not occur. In some cases, well water is treated before it is supplied to households. If PCE is removed during such treatment, these assumed concentrations could be conservative.

An important assumption that could lead to underestimates of exposure is that PCE concentrations in excess of the 5 ppb regulatory level will not be present in household drinking water over a period of years. The New York State investigations were prompted either by routine sampling or by taste and odor complaints. The author states, however, that “we have not systematically sampled private drinking water supplies near dry cleaners” (Stasiuk, 1993). It is possible that PCE could be present at higher levels in some water supplies because sampling has not been done.

Ingestion of PCE in Breast Milk

Several authors have described the pathway of infant exposure to PCE via ingestion of their mothers’ milk (Fisher et al., 1997; Schreiber, 1997). The maternal exposures result from inhalation of PCE. The breast milk concentrations may be measured; the amounts reaching infants are modeled.

Most inhaled PCE is exhaled as PCE (Schreiber, 1997). A small percentage of inhaled PCE, however, is stored in adipose tissue and contaminates breast milk (Schreiber, 1997). Nursing infants then ingest PCE from the mother’s milk. A survey of 17 nursing mothers showed that 63% had PCE in their breast milk at concentrations ranging from 0.15 to 43 µg/L. (Sheldon et al., 1985). Schreiber used a physiologically based pharmacokinetic model to estimate infant doses from ingestion of breast milk (Schreiber, 1997). Maternal inhalation exposure scenarios were developed for occupationally exposed women, persons living in apartments above drycleaners, and women inhaling a “residential background concentration of 27 µg/m^3” (Schreiber, 1997).

The residential PCE exposure “results in a predicted breast milk PCE concentration of 1.5 µg/L, similar to the mean PCE breast milk concentration of 6.2 µg/L found by Sheldon et al. (1985) in a study of 17 nursing mothers in the Elizabeth-Bayonne, New Jersey, area” (Schreiber et al., 1993). Predicted infant exposures ranged from 0.0001 to 0.82 mg/kg/day (Schreiber, 1997). Schreiber assumed that the infant weighs 7.2 kg (Schreiber, 1997).

Byczkowski and Fisher also developed a model for estimating infant exposure to volatile organic chemicals (VOCs) from breast milk ingestion (Fisher et al., 1997). Results were in agreement with Schreiber’s predictions (Fisher et al., 1997). More recently, Fisher et al. (1997) revised this model to improve the estimate of milk production and incorporate measured values for milk and blood partition coefficients. The authors predicted that if a mother inhales PCE at the OSHA PEL of 25 ppm (170 mg/m^3) for 8 hours per day, the infant will ingest 1.36 mg of PCE per day (Fisher et al., 1997). In a similar exposure scenario with 8 hours of maternal exposure at the PEL (25 ppm), followed by 16 hours of exposure at 27 mg/m^3, Schreiber predicted an infant exposure of 2.4 mg (0.34 mg/kg/day). These results are comparable, recognizing that Schreiber (1997) included 16 hours of maternal inhalation exposure at background levels while Fisher et al. (1997) assumed no maternal exposure outside the workplace.

Uncertainties:

These scenarios are based on measured PCE concentrations in air; however, the amount of PCE reaching the infant is based on modeling. Maternal inhalation exposures could vary widely even within the co-located population. Schreiber (1997) has estimated exposures based on a wide range of exposures, from maternal occupational exposure to inhalation of background levels.

PCE exposures to the fetus:

Very little information is available on fetal exposures to PCE. Fisher et al. (1989) developed data to assess the feasibility of building a physiologically based pharmacokinetic model of exposure of pregnant rats to trichloroethylene (TCE), a structurally similar chemical. Pregnant rats were exposed to TCE via inhalation, gavage, and drinking water. Their data were compared to outcomes of the model which diverged by no more than a factor of two, leading the authors to believe the approach was worth further validation. We do not, however, have a comparable study for PCE. Fisher et al. did conduct a similar exercise for estimates of lactational transfer for TCE. A later parallel simulation for PCE by Byczkowski et al. (1994) indicated the compartmental models for lactational transfer for the two compounds are not exactly parallel. Consequently, it may not be appropriate to use the findings on rat fetal exposure to TCE to calculate human fetal exposure to PCE. This study does, however, suggest that further examination of the potential for human fetal exposure to PCE should be included in any future assessment.

Dermal Exposure

Exposures would also result from bathing and showering in water contaminated with PCE. Dermal uptake of PCE in bath water has been estimated to equal the dose received from drinking 2 liters of water a day, for any given level of chemical contamination (Keifer, 1998). Therefore, if PCE is present in bath water at concentrations ranging from 0.8 to 5 ppb, the estimated dermal uptake from bathing would be slightly greater than the ingestion exposure for adults, which assumes a drinking water ingestion rate of 1.4 liters per day.

Uncertainties:

The assumption that dermal uptake is equivalent to ingesting an equivalent amount of PCE in two liters of water per day is based on modeling results (see Appendix E for more information). In addition to the uncertainties with the groundwater results, it is possible that dermal uptake could be higher or lower.

4.4.2 Drycleaning: Hydrocarbon Solvents

General

People are exposed to HC solvents (including Stoddard solvent and 140°F solvent) primarily as a result of HC releases to the air, water, and land following commercial drycleaning. Workers are exposed to HC solvents both from inhalation and dermal exposure. Hydrocarbon solvents are used much less often than PCE in commercial drycleaning, and very little information is available on them. The exposure analysis is therefore much less detailed than that performed for PCE.

Occupational Exposure

This section examines issues regarding HC exposures to the workers in the drycleaning industry. The HC solvents for which data were available were Stoddard solvent and 140°F solvent. Data sources include those that are readily available in published literature or through on-line access.

Some regulatory and recommended limits have been established for worker exposure to Stoddard solvent. In January 1989, the U.S. Occupational Safety and Health Administration (OSHA) adopted a 525 mg/m^3 (100 ppm) TWA permissible exposure limit (PEL) to replace the pre-1989 PEL of 2,900 mg/m^3 (500 ppm) TWA. However, all new 1989 PELs were vacated via a court decision, and the pre-1989 PEL for Stoddard solvent is currently in effect. Some states may maintain the 1989 PEL or other levels as state regulatory limits. Section 8.6 presents more details on OSHA requirements.

The American Conference of Government Industrial Hygienists (ACGIH) sets its Threshold Limit Value (TLV) for Stoddard solvent at 525 mg/m^3 (100 ppm) (ACGIH, 1994). The National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit (REL) is 350 mg/m^3 (100 ppm) TWA, and NIOSH recommends a ceiling of 1,800 mg/m^3 (300 ppm) for a 15-minute TWA (NIOSH, 1997a). NIOSH also has established 20,000 mg/m^3 (3,600 ppm) as a concentration immediately dangerous to life and health (IDLH) (NIOSH, 1997a).

For this CTSA, it has been estimated that there are 5,400 commercial facilities that dryclean clothes using hydrocarbon solvents (excluding drop-off/pick-up sites) in the United States. NIOSH recently published a study of commercial drycleaners that included data on numbers of workers and sites (American Business Information, 1994). These BA data include drop-off/pick-up sites that do no cleaning and include all process types (PCE, hydrocarbon, etc.). In order to estimate numbers of workers in PCE drycleaning facilities nationwide, the BA data needed to be adjusted, and the BA data and assumptions used to adjust them are shown in Exhibits E-5 and E-6 of Appendix E.

As a result, it is estimated that 21,000 to 49,000 workers are employed in commercial facilities that dryclean clothes using HC in the U.S. The midpoint of this range suggests an average of 6.5 workers per facility. It is not known how well these estimates represent the industry due to the uncertainties in the data and assumptions used to adjust them. National Occupational Exposure Survey (NOES) data for numbers of workers in the HC drycleaning industry were not found and therefore could not be compared to the numbers of workers estimated for this CTSA.

The population of drycleaning workers may be categorized into various job titles, such as operator or presser, based on worker activities. However, typical activities and exposures may be difficult to characterize because workers may have rotating responsibilities and overlapping activities, which often vary from facility to facility. In a previous study, USEPA estimated the number of workers by job description (PEI, 1985). Based on those estimates, the drycleaning workers may be categorized into the following job titles with the corresponding percentage of the total drycleaning population: 3.8% managers/administrators, 18.5% clerks, 9.9% tailors, 15.5% pressers, 48.7% operators, and 3.6% for all others combined ("spotter" was not a job title in the classification list). It is assumed that the job descriptions of "(dry) cleaner" and "operator" are equivalent, and include those workers who operate the drycleaning washing and drying equipment. For risk assessment in Chapter 4, it is assumed that the workers may normally be exposed for eight hours per day and 250 days per year (days/yr). Some worker subpopulations (e.g., some workers in "mom and pop shops") could be expected to be exposed for up to 312 days per year or more and more than eight hours per day, although no data were found to support estimated average numbers of hours per day and days per year.

Occupational Inhalation Exposure

Few studies and data sets are available to characterize inhalation exposures to HC for drycleaning workers. Two data sets are presented in this section that illustrate variations in worker inhalation exposures due to the one factor that could be differentiated from the data: job title. These data sets consist of OSHA monitoring data and survey data from a NIOSH report. These data sets include measured TWA exposure concentrations (ECs) of Stoddard solvent; for risk screening later in this report, it is assumed that these data are representative of 8-hour (full-shift) TWAs.

The first data set is post-1990 monitoring data from OSHA's Computerized Information System (OCIS, 1994 and 1998). ECs from these data are summarized by job title in Exhibit 4-11. Distributions of data for two worker subpopulations (drycleaner and presser) could be generated from these data. Because OSHA often monitors for compliance or in reaction to complaints, mean ECs generated from OSHA data may be higher than actual ECs for the total population of workers. Exhibit 4-11 indicates that cleaners have higher exposure than pressers. Factors such as machine type and controls and numbers of machines were not available for these data.

Exhibit 4-11. Summary of TWA Exposure Concentrations (ECs) for Inhalation of Stoddard Solvent by Job Title Based on OSHA Personal Monitoring Data

Job Description[a]	Geometric Mean EC (mg/m^3 TWA)	Arithmetic Mean EC (mg/m^3 TWA)	Maximum EC (mg/m^3 TWA)
1990 to 1993			
All jobs [n = 28]	17±7	92±190	720
Cleaner [n = 16]	25±6	99±200	720
Presser[b] [n = 7]	3.5	3.5	3.5
1997			
All jobs [n=11]	41±1	150±200	550

Source: OCIS (1994) and OCIS (1998).
[a] Number of data points [n] is in brackets. Mean concentrations ± standard deviations are presented. For both OCIS data sets, none of the measurements exceeds the current OSHA permissible exposure limit of 2,900 mg/m^3 TWA for Stoddard Solvent.
[b] All observations were below the detection limit.

The second data set is a limited amount of personal monitoring data available from the study conducted by NIOSH (1988) that included six industrial (several very large) and commercial drycleaners using petroleum solvents. Monitoring data were collected from job categories with monitoring lasting at least one hour. These data form the basis for the mean concentrations for inhalation of petroleum solvents presented in Exhibit 4-12. Again, as does Exhibit 4-11, Exhibit 4-12 shows that the cleaner has higher mean exposures than all other worker categories. Compliance with the OSHA PEL for Stoddard solvent of 2,900 mg/m^3 was 100% for all 56 samples taken in the NIOSH surveys.

Exhibit 4-12. Summary of TWA ECs for Inhalation of Petroleum Solvents by Job Title Based on NIOSH Data

Job Category[a]	Arithmetic Mean EC (mg/m^3 TWA)	Geometric Mean EC (mg/m^3 TWA)	Maximum EC (mg/m^3 TWA)
All jobs [n=56]	260 ± 350	93 ± 5	1,246
Cleaner [n=35]	380 ± 400	170 ± 5	1,246
Cleaner assistant [n=4]	24 ± 31	14 ± 3	70
Customer service [n=1]	3	3	3
Pants folder [n=1]	63	63	63
Inspector [n=4]	83 ± 43	74 ± 2	131
PCE cleaner[b] [n=6]	27 ± 15	21 ± 2	48
Supervisor [n=5]	120 ± 54	100 ± 2	160

Source: NIOSH (1980). Based on six case studies conducted by NIOSH on industrial and commercial facilities cleaning with petroleum solvents (Stoddard solvent and 140°F solvent).
[a] Number of data points [n] is in brackets. Mean concentrations ± standard deviations are presented. None of the 56 measurements exceeded the current OSHA permissible exposure limit of 2,900 mg/m^3 TWA for Stoddard solvent.
[b] These cleaners operated the PCE machines in a facility that had both PCE and HC machines. The value is their HC exposure.

In summary, the primary finding from the two exhibits summarizing worker inhalation of HC is that operator/cleaners generally appear to have higher exposures relative to most non-operators (e.g., pressers, spotters). No other conclusions could be drawn due to the limited amount of data and information available for this subpopulation of the industry. A comparison of the levels in the two exhibits indicates a general decrease in exposure levels over time, although the mean values in the tables do not conclusively verify this apparent decrease.

Interpretation and comparison of the data sets summarized in this CTSA raise some uncertainties related to the data and the studies in which they were collected. It is not known whether the measured concentrations in these data sets are representative of the distributions of concentrations to which the populations of drycleaning workers are actually exposed nationwide. The smaller the numbers of facilities, workers, and samples, the higher the degree of uncertainty regarding representativeness. It is also not known whether the measured TWA concentrations, not adjusted to represent full-shift values (i.e., no scaling from observed period to 8-hour shifts), are representative of full-shift TWA concentrations. Variations in machinery and plant layout, exposure controls such as ventilation, work practices and procedures, amounts of clothes cleaned daily, and many other factors affect an individual drycleaning worker's exposure. As a result, an individual worker's exposure may or may not be well-represented by the data summarized in this CTSA. The data in these exhibits may only compare qualitatively. Specifics of the facilities, the worker activities, the monitoring studies, and other relevant details behind the monitoring data presented in the exhibits were not available to allow for a detailed understanding and analysis of the ECs in the different data sets and how they may be quantitatively compared. The sets of data in the exhibits do appear to support one another generally. For example, the arithmetic averages of larger data sets for a given population or subpopulation are within an order of magnitude and often compare closely.

Occupational Dermal Exposure

Drycleaning workers may also experience dermal exposure to HC. No studies or data were available which quantify dermal exposures to HC for drycleaning workers; however, dermal exposures to HC can be modeled. Estimates presented here are based upon the OPPT Occupational Dermal Exposure Model (USEPA, 1991a). The model relies on a two-hand contact or immersion in a liquid without any protective clothing and use of pure HC. This model is believed to present bounding estimates of amounts of solvent available for absorption on the skin surface (see Section 4.3.2). Hence, these estimates are larger than workers would be expected to receive. This model assumes the surface area for two hands is up to 1,300 cm^2. No model is available to estimate dermal exposures from vapors.

Operators are the primary workers expected to perform activities that result in dermal exposures to liquid HC, and these activities are shop and equipment dependent. Some of these activities occur at least once per day (routine) and others occur on a less frequent basis (non-routine), such as changing cartridge or rag filters and open-tank waterproofing. Routine activities include, but are not limited to, transferring wet articles from the washer to the dryer and cleaning the button trap and still. For the wet article transfer activity, the OPPT ODEM immersion data were chosen to be applicable for exposure modeling; for all other activities, the OPPT ODEM contact data were chosen to be applicable for exposure modeling.

The estimated dermal PDR for workers performing wet article transfer is 18,000 mg/day HC available for dermal absorption. This PDR for transfer assumes essentially pure HC solvent, 1,300 cm^2 two-hand surface area, and up to 14 mg/cm^2 surface density of HC solvent on the skin. The estimated dermal PDR for workers performing other activities is less than 3,900 mg/day HC available for dermal absorption. This PDR for other activities assumes essentially pure HC solvent, 1,300 cm^2 two-hand surface area, and up to 3 mg/cm^2 surface density of HC solvent on the skin. These estimates are not used for risk calculation in this document.

Non-worker Exposure

Members of the general population are exposed to HC solvents as a result of releases to the air, water, and land following commercial drycleaning. HC solvents are used less frequently in commercial drycleaning than PCE, and information on measured concentrations in air and water is not available. The exposure analysis is therefore much less detailed than that performed for PCE.

Inhalation Exposure

An inhalation exposure scenario is presented for inhalation of HC solvents by the general population. Studies providing monitoring data on concentrations were not available, so exposure from inhalation of HC solvents was modeled by distance from a hypothetical facility. A 9-year exposure duration, which is the average residence time reported in USEPA (1997b), is assumed for exposure to HC solvents. It is assumed that residence time adequately accounts for exposure duration. It is expected that exposures to HC solvents will decrease with increased distance from the facility. The estimates of HC solvents releases used to calculate exposure concentrations (potential doses) are presented earlier in the release section of this document. Using these releases, several estimates of Lifetime Average Daily Concentrations (LADCs) are developed and presented in Exhibit 4-13. They are differentiated by distance from the hypothetical facility and assumptions regarding the degree of emission controls on the HC machines. Further details on the assumptions involved in these calculations can be found in Appendix E.

These estimates are based on conditional release ranges and therefore are “what-if” LADC estimates.

Exhibit 4-13. Hydrocarbon LADCs by Distance from a Hypothetical Facility (mg/m^3)

Distance (meters)	Transfer Machines		Dry-to-Dry Machine
	Conventional Dryer	Recovery Dryer	
100	0.002	0.0008	0.0002
200	0.0009	0.0003	0.0001
400	0.0003	0.0001	0.00004

LADC (mg/m^3) = Modeled Hydrocarbon Concentration (mg/m^3) x Exposure Duration (ED)/Lifetime (LT)
ED = 16.4 hours/day x 365 days/year x 9 years (average residence time from USEPA, 1997b)
LT = 24 hours/day x 365 days/year x 70 years

The most sensitive value in the estimation of these values is probably the release concentration. This concentration will vary with facility-specific machine type, controls, and ventilation systems. Therefore, the distribution of expected HC solvent concentrations cannot be appropriately defined at present.

These exposure estimates are generated for adults spending about 70% of the time at home (16.4 hours/day). As discussed in the case of PCE, children and members of other populations who spend more time at home could receive higher exposures. However, the increased time spent at home for these populations would contribute an additional factor of less than two to these estimated exposures.

Ingestion of Contaminated Drinking Water

The projected releases of HC solvents to surface water are very low, on the order of 5×10^{-8} to 1×10^{-7} kg/site/day. The HC solvent concentration in surface water resulting from these releases is estimated at less than 1 ppb. The estimated drinking water exposure is much less than 1 mg/kg/day.

Uncertainties (these are applicable to both the inhalation and ingestion scenarios):

These exposure scenarios are highly dependent upon the estimated hydrocarbon releases to air and to water. These release estimates may or may not be characteristic of actual facilities, and for this reason the exposures are what-if. Exposures to water have been calculated with the use of generic streamflow information because the information on the specific release sites is not available. These HC exposure estimates are based on modeling and therefore could be considered more uncertain than estimates of exposure to PCE, which are generally based on monitoring.

4.4.3 Machine Wetcleaning Process

Occupational Exposure

Workers in machine wetcleaning facilities (MWC) are exposed to formulations of the MWC detergents and other cleaning agents. The primary route of exposure to workers for these formulations, which are expected to be liquids, is the dermal route. Inhalation exposure is not expected for most of the chemicals in these liquid formulations, most of which are relatively non-volatile. If powdered MWC formulations are developed, small inhalation exposures to airborne powders could be expected. However, because no such formulations are known to exist for commercial applications, this CTSA assumes that workers are not significantly exposed to chemical constituents in MWC formulations via the inhalation route.

There are no regulatory limits for chemical constituents in MWC formulations that would be expected to limit or affect worker exposures to these formulations.

There are approximately 38 dedicated MWC facilities in the U.S. Two studies of facilities that used MWC processes noted numbers of workers at those facilities: four to five workers at one site (Gottlieb, 1997), and five to seven workers at another site (Patton et al, 1996). Both of these sites cleaned fewer clothes via MWC than the clothes cleaning throughput of 53,333 lb/yr for this CTSA's "model facility."

As mentioned above, potential occupational dermal exposure to liquid MWC formulations exists among drycleaning workers. There are no studies or data that quantify occupational dermal exposures to these formulations; however, dermal exposures to MWC formulations can be modeled. Estimates presented here are based upon the OPPT Occupational Dermal Exposure Model (USEPA, 1991a). The model relies on a two-hand contact or immersion in a liquid without any protective clothing and use of pure or diluted MWC formulations. This model is believed to present bounding estimates of amounts of formulation(s) available for absorption on the skin surface (see Section 4.3.2). This model assumes a surface area for two hands of 1,300 cm^2. Operators are the primary workers expected to perform activities that result in dermal exposures to liquid MWC formulations, and these activities are shop- and equipment-dependent. Some of these activities occur at least once per day (routine) and others occur on a less frequent basis (non-routine). Routine activities include, but are not limited to, transferring wet articles from the washer to the dryer; and non-routine activities include, but are not limited to, connecting the formulation container to the dispensing pump line. For the wet article transfer activity, the OPPT ODEM immersion data were chosen to be applicable for exposure modeling; for all other activities, the OPPT ODEM contact data were chosen to be applicable for exposure modeling.

The estimated dermal potential dose rate (PDR) for workers performing wet article transfer is up to 2.5 mg/day of combined MWC formulations available for dermal absorption, and the frequency of this exposure would be daily for up to 250 days per year for most workers. This PDR assumes a maximum concentration of 0.01% MWC formulations (e.g., detergents, finishes, water softeners) remaining in the rinse water, 1,300 cm^2 two-hand surface area, and up to 14 mg/cm^2 surface density of detergent.

The estimated dermal PDR for workers connecting formulation containers to dispensing lines or performing other activities that may result in contact with undiluted formulation(s) is less than 3,900 mg/day of one or more MWC formulations available for dermal absorption. This PDR assumes undiluted MWC formulations (e.g., detergents, finishes, water softeners), 1,300 cm^2 two-hand surface area, and up to 3 mg/cm^2 surface density of detergent. The frequency of exposure for changing out formulation containers (e.g., detergent or finish) would be approximately 29 days per year for the "model facility" assuming 20 L (5 gallon) containers, 0.15 L/load detergent, 0.15 L/load finish, 6 loads/day, and 312 days per year operation. It is not known whether these PDR estimates are representative of actual PDRs for machine wetcleaning workers. PDRs of individual chemical constituents in two sample detergent formulations are provided in Exhibits E-13 and E-14 in Appendix E.

Non-worker Exposure

Human Exposure

Machine wetcleaning processes are expected to result in exposures to the general population primarily as a result of contamination of surface waters. Ingestion and dermal exposure can result from showering in and drinking this contaminated water. A few of these machine wetcleaning chemicals are expected to cause irritation; however, large dermal exposures among the general population are not expected.

Concentrations in Surface Water

Estimated releases of machine wetcleaning chemicals to water are shown in Exhibit 4-3. Releases to surface water are discharged through a drain at a dry or machine wetcleaning facility and end up going to public sewers or POTWs. This discharge is treated before being released. The effectiveness of the treatment is estimated so that the amount reaching the receiving water body can be calculated. Because the receiving water will dilute the discharge from the POTW, stream flow information is used to calculate surface water concentrations. Stream in this context means the receiving body of water and includes creeks and rivers as well as streams.

There is concern for the effect that a chemical may have on aquatic organisms, from algae to fish. If the food chain is broken in a stream, the consequences are dire (i.e., no algae, no fish). A healthy stream with many organisms will have a better ability to handle chemical releases than one whose quality is already compromised. Since contaminant concentrations will vary with the stream flow, periods of lower flow conditions may cause problems where regular flow conditions would not. Stream flow data are used to predict how often this will happen.

Since these chemicals could be released from many drycleaning sites, site-specific data are not available. Generic assumptions based on releases from single sites have been used to estimate surface water concentrations (USEPA, 1995). Streamflow values for POTWs have been used in this assessment. This provides a conservative estimate of surface water concentrations and is appropriate for use when the specific locations of the sites are unknown (USEPA, 1995). See Appendix E for more information.

As an illustration, surface water concentrations were estimated for the constituents of the two example machine wetcleaning formulations. Estimated surface water concentrations for "example detergent #1" range from 40 to 130 ppb. For "example formulation #2," estimated surface water concentrations range from 40 to 430 ppb.

Uncertainties:

As in the HC assessment, the accuracy of these surface water concentrations is dependent upon the estimated releases. Two example formulations have been assessed; these may or may not be representative of other machine wetcleaning formulations. Assumptions were made for a hypothetical facility, and for this reason the exposure scenarios are what-if. As described above, generic streamflow assumptions have been used because site-specific data are not available.

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