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Cleaner Technologies Substitutes Assessment: Professional Fabricare Processes

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ACRONYMS AND ABBREVIATIONS

AATCC	American Association of Textile Chemists and Colorists
ABD	American Business Directory
ACGIH	American Conference of Government Industrial Hygienists
ADC	Average Daily Concentration
AFCEE	Air Force Center for Environmental Excellence
ALP	Alkaline Phosphatase
ALT	Alanine Aminotransferase
API	American Petroleum Institute
AQUIRE	Aquatic Toxicity Information Retrieval Database
AST	Aspartate Aminotransferase
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
AU	Azeotropic Unit
AWWA	American Water Works Association
BAAQMD	Bay Area Air Quality Management District
BCF	Bioconcentration Factor
BLS	Bureau of Labor Statistics
CA	Carbon Adsorber
CAA	Clean Air Act
CAPB	Cocoamidopropyl Betaine
CARB	California EPA’s Air Resources Board
CAS	Chemical Abstracts Service
CBH	City of Beverly Hills
CC	Concern concentration
CCRIS	Chemical Carcinogenesis Research Information System
CEB	Chemical Engineering Branch, OPPT, USEPA
CEC	Center for Emissions Control
CED	Certified Environmental Drycleaner
CEPA	California Environmental Protection Agency
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CESQG	Conditionally Exempt Small Quantity Generator
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CG	Cellulose Gum
CGA	Compressed Gas Association
CIR	Cosmetic Ingredient Review
CMC	Carboxymethylcellulose
CNT	Center for Neighborhood Technologies
CO_2	Carbon Dioxide
CRWQCB	California Regional Water Quality Control Board
CTFA	Cosmetic, Toiletry and Fragrance Association
CTSA	Cleaner Technologies Substitutes Assessment
CU	Consumers Union
CWA	Clean Water Act

DC	Drycleaning
DCA	Dichloroacetic acid
DDT	Dichlorodiphenyltrichloroethane
DEA	Diethanolamide
DfE	Design for the Environment
DL	Detection Limit
DMBA	Dimethylbenz[a]anthracene
DO/PU	Drop-off/Pick-up
EC	Effective Concentration
ED	Exposure Duration
ED_{10}	Expected Dose at which 10% of the group will respond
EEG	Electroencephalogram
EIA	Energy Information Administration
EPI	Estimation Programs Interface
EWCC	European Wetcleaning Committee
FDA	Food and Drug Administration
FEL	Frank Effect Level
FKDA	Federation of Korean Drycleaners Associations
FTC	Federal Trade Commission
GEMS	Graphical Exposure Modeling System
GGT	Gamma Glutamyltransferase
GRAS	Generally Recognized As Safe
GSD	Geometric Standard Deviation
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HEC	Hydroxyethylcellulose
HPC	Hydroxypropylcellulose
HPMC	Hydroxypropylmethylcellulose
HQ	Hazard Quotient
HSDB	Hazardous Substances Data Bank
HSIA	Halogenated Solvents Industries Alliance
IARC	International Agency for Research on Cancer
IDEM	Indiana Department of Environmental Management
IDLH	Immediately Dangerous to Life and Health
IFI	International Fabricare Institute
IRIS	Integrated Risk Information System
ISCLT	Industrial Source Complex Long Term
KSBEAP	Kansas Small Business Environmental Assistance Program
LADC	Lifetime Average Daily Concentration
LADD	Lifetime Average Daily Dose
LAE	Linear Alcohol Ethoxylate
LC	Lethal Concentration
LD	Lethal Dose
LDH	Lactic Acid Dehydrogenase
LEL	Lower Explosive Limit

LOAEL	Lowest-Observed-Adverse-Effect Level
LOWWT	Low Weight
LQG	Large Quantity Generator
LT	Lifetime
MACT	Maximum Available Control Technology
MC	Methylcellulose
MCL	Maximum Contaminant Level
MDEQ	Michigan Department of Environmental Quality
MHS	Municipal Health Service
MNNG	N-methyl-N’-nitro-N-nitrosoguanidine
MOE	Margin of Exposure
MPBPVP	Melting Point, Boiling Point, Vapor Pressure
MWC	Machine Wetcleaning
NAG	n-acetyl-glucosaminidase
NCAI	Neighborhood Cleaners Association International
NCI	National Cancer Institute
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emission Standard for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NHOU	North Hollywood Operable Unit
NIOSH	National Institute for Occupational Safety and Health
NMRI	Strain of mouse (U.S. Naval Medical Research Institution)
NOAEL	No-Observed-Adverse-Effect Level
NOEC	No-Observed-Effect Concentration
NOES	National Occupational Exposure Survey
NPDES	National Pollutant Discharge Elimination System
NSPS	New source performance standard
NTP	National Toxicology Program
NU	Nucleotidase
NYCDOH	New York City Department of Health
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OAQPS	Office of Air Quality Planning and Standards, USEPA
OCIS	OSHA Computerized Information System
ODEM	Occupational Dermal Exposure Model
ODEQ	Oregon Department of Environmental Quality
OPPT	Office of Pollution Prevention and Toxics, USEPA
ORD	Office of Research and Development, USEPA
OSH	Occupational Safety and Health Act
OSHA	Occupational Safety and Health Administration
PCE	Perchloroethylene
PDR	Potential Dose Rate
PEL	Permissible Exposure Limit
PGME	Propylene Glycol Monomethyl Ether
POTW	Publicly Owned Treatment Works

ppb	parts per billion
PPERC	Pollution Prevention Education and Research Center
PPI-CE	Producer Price Index for Capital Equipment
PPI-Chem	Producer Price Index for Chemicals and Allied Products
ppm	parts per million
PRP	Potentially Responsible Party
QA	Quality Assurance
QC	Quality Control
QSAR	Quantitative Structure-Activity Relationship
RC	Refrigerated Condenser
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
RfC	Reference Concentration
RfD	Reference Dose
RTECS	Registry of Toxic Effects of Chemical Substances
RTL	Research Testing Laboratories
SAB	Science Advisory Board
SAR	Structure-Activity Relationship
SARA	Superfund Amendments and Reauthorization Act
SBAP	Small Business Assistance Program
SD	Standard Deviation
SDWA	Safe Drinking Water Act
SGOT	Serum Glutamate Oxaloacetate Transaminase
SGPT	Serum Glutamate Pyrurate Transaminase
SIAM	SIDS Information Assessment Meeting
SIAR	SIDS Initial Assessment Report
SIC	Standard Industrial Classification
SIDS	Screening Information Data Set
SIU	Significant Industrial User
SLI	Sodium Lauryl Isethionate
SQG	Small Quantity Generator
SRC	Syracuse Research Corporation
SRI	Stanford Research Institute
SRRP	Source Reduction Research Partnership
SSD	Statistically Significant Difference
STEL	Short-term Exposure Limit
STORET	Storage and Retrieval of U.S. Waterways Parametric Data System
STP	Sewage Treatment Plant
SWDA	Solid Waste Disposal Act
TCA	Trichloroacetic Acid
TCE	Trichloroethylene
TCLP	Toxicity Characteristic Leaching Procedure
TCVC	Trichlorovinylcysteine
TCVG	Trichlorovinylglutathione
TEAM	Total Exposure Assessment Methodology
TLV	Threshold Limit Value

TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
TURI	Toxic Use Reduction Institute
TWA	Time-Weighted Average
UCLA	University of California at Los Angeles
UEL	Upper Explosive Limit
UF	Uncertainty Factor
UIC	Underground Injection Control
USDHHS	United States Department of Health and Human Services
USEPA	United States Environmental Protection Agency
UST	Underground Storage Tank
UV	Ultraviolet
VOC	Volatile Organic Chemical
WC	Wetcleaning
WEF	Water Environment Federation
WHO	World Health Organization

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INTRODUCTION

Chemical solvents have been used for cleaning clothes since the mid-19th century. Perchloroethylene (PCE) has been the solvent of choice for commercial clothes cleaning applications since the 1960s, although the volume used by drycleaners has declined significantly over the last decade. Despite this decline, a variety of health and safety issues associated with PCE use and increased regulation of the chemical have compelled the U.S. Environmental Protection Agency (USEPA), industry, and environmental groups to address concerns about PCE emissions. As part of an effort to explore opportunities for pollution prevention and reduce exposure to traditional drycleaning chemicals, the EPA's Design for the Environment (DfE) Garment and Textile Care Program has developed the *Cleaner Technologies Substitutes Assessment* (CTSA)*: Professional Fabricare Processes*.

The goal of the CTSA is to provide comparative cost, risk, and performance information on professional fabricare technologies. The audience for the CTSA is technically informed and might consist of individuals such as environmental health and safety personnel, owners, equipment manufacturers, and other decision makers. It is expected to be used as a technical supplement by USEPA and stakeholders to develop information products suitable for a broad audience. These products will help professional cleaners make informed technology choices that incorporate environmental concerns.

The CTSA is based upon readily available information and uses simplifying assumptions and conventional models to provide general conclusions about various cleaning technologies. It is not a rigorous risk assessment of chemicals used in the fabricare industry and should not be used to describe the absolute level of risk associated with a particular clothes cleaning operation to specific populations or individuals. Results often represent case studies, however, these case study scenarios may not be representative of or generalizable to common practices. For instance, data on performance are reported from real world performance demonstrations conducted in model clothes cleaning facilities that may or may not be representative of a cleaner's specific operation. Additionally, there is not a consistent level of performance information available across all technologies. Cost information, developed from literature and through contact with industry representatives, is generalized and may overestimate or underestimate costs for a specific operation. Exposure, hazard, and risk assessments for the chemical components of the cleaning technologies were made by USEPA based on available data and/or modeling. Assumptions used in developing the information in the CTSA are presented throughout to assist users in determining the applicability of the information to various clothes cleaning operations. It is reasonable to expect that actual risks, costs, and performance may vary for specific clothes cleaning operations.

DESIGN FOR THE ENVIRONMENT GARMENT AND TEXTILE CARE PROGRAM

The CTSA is a small part of DfE's Garment and Textile Care Program. The Program's mission is to assist in providing the professional garment and textile cleaner with a wider range of environmentally friendly options which they can offer to their customers, while maintaining or increasing economic viability. The objective is to promote not only cleaner production in the manufacture of garments and textiles, but also to promote production of garments and textiles that will facilitate the use of clean technologies by the professional fabricare provider in meeting consumer needs.

USEPA's interest in PCE exposures from drycleaning developed after learning about air emissions and water releases of the chemical. PCE has been documented in air, soil, and sediments and has been found in 771 out of 1,190 National Priorities List sites (ATSDR, 1995). In May 1992, USEPA convened the International Roundtable on Pollution Prevention and Control in the drycleaning Industry. One of the outcomes of the International Roundtable on Drycleaning was recognition of the need to both prevent pollution and reduce exposures to PCE in the drycleaning industry. USEPA has published some materials that examine pollution prevention in the drycleaning industry. Included is *The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes*, which evaluates the "...possibility of dramatic reductions in toxic chemical releases by focussing on safe substitutes..." (USEPA, 1994) and which contains sections specific to PCE. In this document, CTSA builds on that approach and introduces additional information on PCE and alternative technologies that is useful for examining alternatives for pollution, exposure, and risk reduction in a business environment.

CTSA RESULTS

Several technology alternatives to PCE drycleaning are available for commercial fabricare (generally referred to as clothes cleaning throughout). They are categorized as dry and wet cleaning processes, distinguished by the type of solvent used. Drycleaning refers to technologies based on non-aqueous solvents, while wetcleaning refers to processes based on water as a solvent. The CTSA covers PCE, hydrocarbon (HC) (including Stoddard, 140°F, and DF-2000 solvents), and machine wetcleaning (MWC) processes.

Several alternative modifications and machine configurations for the most prevalent technologies, PCE and HC dry cleaning, are also examined in the CTSA. They are compared on the basis of relative releases of solvent and costs to provide information to current PCE or HC users on the trade-offs associated with reducing solvent emissions, and possibly exposure, through process modifications.

The information in the CTSA is primarily focused on the use of chemicals in the various cleaning processes. Therefore, lifecyle considerations are not a part of the CTSA. Spotting chemicals, although used in many commercial clothes cleaning operations, are not included in this document, nor are chemicals in other formulations, such as fabric finishes and water softeners. An exception is coverage of detergents used in the machine wetcleaning process. USEPA has developed example formulations for which individual chemical components are examined in the CTSA. These formulations and component chemicals are presented for illustrative purposes. Numerous detergent formulations are currently available, and it is not clear how representative USEPA's sample may be.

Effects

Possible health, environmental, and safety concerns are described for each of the clothes cleaning processes. These possible effects range from cancer for PCE to a variety of noncancer effects, such as neurotoxicity for HC, and skin irritation for the several components of the sample detergent. The CTSA does not, nor is it intended to, represent the full range of hazards that could be associated with clothes cleaning technologies. These effects have been associated with these chemicals in laboratory tests and they may not occur in humans.

Environmental effects data are reviewed, and an environmental hazard ranking for aquatic toxicity of the individual solvents and detergent chemicals is included where data allow. The rankings range from low to high concern. Those of high concern include the HC solvents (Stoddard, 140°F, and DF-2000 solvents). While water, the primary solvent in machine wetcleaning, is not of concern for aquatic toxicity, there is concern for the detergents used. While used in small amounts (e.g. approximately 1% of total volume of solvent and additives [Industry Contacts, 1998]) relative to the process solvent, water, based upon EPA's sample formulation, some detergent components of the example detergents may be associated with aquatic toxicity. Some characteristics of detergent components, such as ability to biodegrade and chemical persistence, will affect whether actual detergents are associated with aquatic toxicity.

Three chemicals are of additional concern due to fire hazard. These chemicals are Stoddard solvent, 140°F solvent, and DF-2000, although the concern is lessened for 140°F solvent and DF-2000 due to their high flashpoints.

Releases

The CTSA presents estimated environmental releases of CTSA covered chemicals from facilities that clean clothes. These estimates are used in evaluating health and environmental impacts of the chemicals released and in examining the costs of the the processes. The CTSA relies heavily upon information in published literature to generate release estimates. However, published literature contains very limited information on most factors affecting chemical releases, including process type and operating procedures. Therefore, it was not possible to examine the relative impact that many of these factors have on releases. As a basis for comparing processes, theoretical "model facilities" were developed. Releases were estimated for eight PCE, three HC, and two machine wetcleaning model facilities.

The HC model facilities generally release the highest average volumes of solvent and solvent-containing wastes, followed by the PCE model facilities[1]. The PCE and HC model facilities with the fewest pollution control technologies release the highest volumes of chemicals to the air. These PCE and HC model facilities also generate solid wastes that in many cases are considered to be hazardous. PCE and HC model facilities release very small volumes of solvent into water. MWC model facilities generally release the lowest average volume of chemicals, and almost all of these releases are into water.

Exposures

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[1] Releases for machine wetcleaning cover only detergent chemicals, not solvent (i.e. water).

There are a number of ways that people and the environment can be exposed to the chemicals from clothes cleaning processes. Exposed populations include workers, co-located residents, and the general population.

Workers in PCE and HC drycleaning facilities are exposed to solvents primarily by inhalation and dermal (skin) pathways. Workers in MWC facilities are exposed to detergents primarily by the dermal pathway. To characterize drycleaning worker inhalation exposures to the solvents, the CTSA has relied heavily upon personal monitoring data in published literature. Published literature contains limited information on most of the factors that affect exposure, including process type and operating procedures. Therefore, it was not possible to examine the relative impact that all factors have on worker exposures. All dermal exposures were modeled.

The inhalation data for PCE workers show several trends. There appears to be a general decreasing trend in exposure levels and PEL excursions over time. As expected, operators in facilities with transfer machines tend to have higher exposures than workers in facilities with dry-to-dry machines, and increases in the number of machines increases exposure levels. Closed-loop machines with integral carbon adsorbers (fifth generation) result in statistically significantly lower worker exposures than all other machine configurations currently available. Finally, the inhalation data for HC workers support the PCE data in showing that operators in drycleaning facilities generally receive higher average exposures than non-operators.

Workers in drycleaning facilities who transfer wet garments generally have higher dermal exposure potential than other workers, although PCE evaporates from the skin relatively quickly, limiting the potential dermal doses. HC evaporates from the skin more slowly than PCE, and the dermal doses of HC that drycleaning workers receive are potentially greater. MWC workers receive lower and less frequent potential dermal doses of detergents relative to potential dermal doses of solvents received by drycleaning workers.

Within the non-worker population, those most highly exposed to PCE are persons living in the same building as a drycleaner that cleans clothes on the premises (i.e., co-located residents). Monitoring studies show that the machine type and condition are important factors in the level of exposure. Generally, more sophisticated machines, with associated controls, produce lower fugitive emissions. However, even relatively advanced dry-to-dry machines can produce moderate to high PCE concentrations in co-located apartments (Wallace et al., 1995). PCE emissions from drycleaners are not expected to substantially increase exposures to the general population. Other types of general population exposure to PCE can occur from ingestion of contaminated drinking water and from wearing drycleaned clothes.

Monitoring data on HCs were not available, so exposures were modeled. The general population's exposure to HCs is expected to be low. General population dermal (skin) exposure to machine wet cleaning detergents was also modelled, and significant exposure is not expected.

Risk Estimates

The risk assessments were conducted at a "screening level" of review, using readily available information and standard analyses for completion. The risk assessments and characterizations give an idea of the potential risks to human health and the environment associated with each of the processes, however, careful interpretation is necessary given that the extent and type of hazard and exposure data and uncertainties associated with each process differ widely.

Perchloroethylene Solvent

There is a reasonable basis to conclude that there can be a health risk for cancer and some non-cancer effects to workers from the relatively high PCE exposures observed on average in the drycleaning industry. Based upon upper bound estimates, cancer concerns may also extend to residents living in co-location with drycleaning establishments, particularly if they live in such dwellings for more than several years. Non-cancer effects may also be a concern for co-located residents. In addition to their exposures related to co-location with drycleaning facilities, co-located residents are also at risk through a variety of PCE exposures that the general public experience, such as drinking PCE-contaminated water, or wearing dry-cleaned clothes. Adult risk does not translate directly to infants, children, and the elderly, although in scenarios where high risk levels have been determined for adults, there should be a concern for sub-populations exposed by similar routes at similar levels.

Given the release estimates developed in the CTSA, it does not appear that there is a concern for risk to aquatic species for the majority of dry cleaners who send their wastewater effluents to a publicly-owned treatment work.

Hydrocarbon Solvents

A major hazard identified with the HC solvents considered in the CTSA is their potential flammability. The National Fire Protection Association (NFPA) gives them a grading of “2” for flammability indicating that they must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. For comparison, PCE receives a grade of “0” for flammability which indicates that it will not burn. Data are not available to evaluate the risks of fire in drycleaning facilities due to use of these HC solvents. However, based on the NFPA’s low flammability ranking, the risk of fire from HC use can be considered greater than the risk of fire due to PCE. In addition, the varying flashpoints of the three HC solvents examined suggests that the fire potential is lessened as one employs a higher flashpoint HC solvent. Of the HC chemicals examined in the CTSA, DF-2000 has the highest flashpoint, followed by 140°F solvent, and Stoddard solvent.

The health risk conclusions for the HC solvents in the CTSA are based upon findings for Stoddard solvent, however, there are no data suitable for drawing conclusions concerning carcinogenic potential. Worker exposures to HC solvents, especially the high end exposures, are indicative of a concern for non-cancer risk for workers. Although HCs can be toxic to aquatic organisms, they are not expected to be released in quantities that would pose a risk.

Machine Wetcleaning

Based upon the example detergent, there may be a risk to aquatic organisms from some of the constituents in detergents used in machine wetcleaning formulations. Potential risks are dependent on the local streamflow and water treatment conditions, as well as the specific chemicals used in actual detergent formulations. There is no expected health risk to the general public based on low expected exposures. Risk estimates could not be developed for workers due to lack of sufficient toxicity data.

SELECTED FEDERAL REGULATORY REQUIREMENTS

Professional clothes cleaners may be subject to numerous federal requirements. In addition, cities and municipalities have enacted numerous zoning restrictions that may affect all types of fabricare operations, and many localities have adopted some, or all, of the National Fire Protection Association's standards for drycleaning equipment and operations (NFPA-32). These restrictions and requirements have the potential to affect costs and liabilities of cleaning operations.

Exhibit ES-1 summarizes the federal regulations that may affect clothes cleaning operations covered in the CTSA. State and other requirements are not included. Requirements that pertain to the use of spotting chemicals and chemicals such as fabric finish and water softeners are not included, however, they should not be overlooked for their impact on a fabricare operation's regulatory compliance activities. Absence of regulatory requirements identified within the CTSA does not mean that federal, state, and local regulations are not applicable or will not apply in the future.

Exhibit ES-1. Summary of Regulations Related to Fabricare Technologies[a]

Fabricare Option	CAA	CWA	RCRA	CERCLA	OSH	Care Labeling Rule	Other
PCE cleaning	✓	✓	✓	✓	✓	✓	NFPA 32
HC cleaning	✓	✓	✓	✓	✓	✓	NFPA 32
Machine wetcleaning	NA	✓	NA	NA	NA	✓	NA

✓ Indicates that a technology is regulated specifically in statute.
NA Indicates that although the statutes apply to the technology there are no specific regulatory requirements.
[a] The list of regulations covered in this exhibit should not be considered exhaustive and may not cover all regulated aspects of the fabricare industry.

The two most prevalent technologies, PCE and HC drycleaning, are most affected by provisions of federal regulations. Machine wetcleaning currently has fewer requirements that are directly applicable. It is unclear how requirements may change as industry use of these technologies changes.

The Care Labeling Rule relates to all cleaning methods, although it does not contain specific requirements for cleaning garments. The rule requires manufacturers to label garments identifying acceptable cleaning methods. Garments that are cleaned in a manner other than that specified by the manufacturer and are subsequently damaged, are the responsibility of the cleaner. Manufacturers may cautiously label garments as "dryclean only" (Wentz, 1996; Riggs, 1998). In effect, this may constrain the cleaner interested in avoiding liability from utilizing wetcleaning processes.

Under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), potentially responsible parties that contribute to chemical contamination of a particular site, regardless of the intent or involvement of that party, are held strictly liable. Many sites with past and present PCE drycleaning operations are already contaminated to levels that will limit future uses of the property leading to liability considerations that may affect decisions regarding technology choices. Other liability concerns could result from worker claims for health effects resulting from chemicals used in clothes cleaning processes or from garment damage resulting from the various cleaning processes.

COSTS

The costs of running a professional clothes cleaning business include rent, basic operating expenses, and equipment. The equipment capacity, equipment type, and the location of the facility will also affect the costs and economic viability of a professional cleaning operation. The CTSA has focused on a subset of costs associated with operating clothes cleaning facilities.

Exhibit ES-2 summarizes the estimated process dependent cost components for the cleaning technologies covered in the CTSA. Cost figures are presented in constant 1997 dollars in order to allow direct comparisons among the process options.

Machine wetcleaning equipment, on average, is expected to cost less to purchase that PCE or HC drycleaning equipment. The average total operating cost per pound is expected to be higher for PCE and HC than for machine wetcleaning. One of the more significant operating costs for the drycleaning technologies is the cost of hazardous waste disposal. These costs are estimated to be highest for HC because of the volume of hazardous wastes released. However, wastes from certain HC processes, particularly those using the higher flashpoint solvents such as DF-2000 and 140°F solvents, are less likely to have significant amounts of hazardous waste generated from the cleaning process. Therefore, HC costs, on average, are likely to be close to those for PCE. No hazardous waste costs are assumed for machine wetcleaning, however, certain components of detergents or spotting chemicals may be hazardous waste in actual machine wetcleaning facilities.

PERFORMANCE CHARACTERISTICS

Several factors may affect the performance of a cleaning process, including soil chemistry, textile fiber type, transport medium (aqueous vs. non-aqueous), chemistry of additives (e.g., detergents) use of spotting agents, and process controls (time, temperature, and mechanical actions). These factors work interactively to provide a range of cleaning abilities for all clothes cleaning processes. In addition, customer perceptions of a “clean” garment will vary. Finally, variations in technology and the knowledge base of operators may also affect performance of the clothes cleaning process.

Exhibit ES-2. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technologies[a]

Fabricare Technology[b]	Capital Cost of Base Equipment[c]	Capital Cost Total[d]	Annualized Cost of Equipment[e]	Annual Cost of Solvent[f]	Annual Energy Cost[g]	Regulatory Compliance Costs[h]	Annual Cost of Hazardous Waste[i]
PCE	$38,511	$38,511	$4,228	$1,434	$136	$3,680	$4,594
HC	$37,432	$37,432	$4,110	$2,236	NA	NA	$9,820
Machine Wetcleaning	$11,102	$11,102	$1,219	$763	$788	NA	NA

Exhibit ES-2. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technologies (Cont'd)

Fabricare Technology	Annual Cost of Filters and Detergent[j]	Annual Cost of Maintenance[k]	Total Annual Operating Cost[l]	Total Annual Cost[m]	Total Annual Cost/Pound
PCE	$1,913	$6,000	$14,077	$18,305	$0.34
HC	$1,551	$6,000	$19,607	$23,717	$0.44
Machine Wetcleaning	$3,162	$376	$5,089	$6,308	$0.12

NA means cost category not applicable for technology or that data are not available at this time.

[a] The values include the price of equipment, labor and services directly related to the various drycleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333 pound (24,191) annual volume of clothes cleaned per facility. Costs are meant to provide relative comparisons and may differ for specific fabricare operations.

[b] Configurations for fabricare technology include: PCE dry to dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (PCE-C), as required by the PCE NESHAP regulation; HC Transfer with Recover dryer and condenser (HC-A2); and Unimac UW30 washer and DTB50 dryer.

[c] List price of 35 pound PCE drycleaning system includes control equipment, distillation unit, and filters; List price 35 to 40 pound HC drycleaning system includes control equipment, filters, and an explosion kit.

[d] Base machine costs (actual or implied) are added to cost of control capital.

[e] Annual cost of drycleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[f] PCE solvent cost based on $6.83 per gallon for PCE in 1997 dollars (BLS, 1997; USEPA, 1993a) and "mileage" from EPA engineering estimates; HC solvent cost based on $2.24 per gallon for hydrocarbon solvent and "mileage" based on engineering estimates; wetcleaning solvents cost based on $3.06/100 feet^3 for water (BLS, 1997; USEPA, 1993a).

[g] All technology energy costs are based (USEPA, 1991a) on $0.0764/kWh national average electricity cost (BLS, 1997).

[h] Regulatory compliance costs for PCE are based on 1.84% of total annual revenues of $200,000 (Gottlieb et al., 1997; NCAI, 1998).

[I] Hazardous waste disposal costs for PCE and HC based on $6.94 per gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates, excluding disposal cost for potentially hazardous spotting chemicals. Hazardous waste associated with PCE-based machines includes filters, distillation residues, and spent carbon. Hazardous waste associated with HC-based machines includes spent cartridge filters and vacuum still bottoms.

[j] Cost includes of cleaning detergents, spotting chemicals, and replacement filters (Hill, Jr., 1994; USEPA, 1993a).

[k] Annual maintenance cost for PCE and HC based on 3.0% of total revenues of $200,000 annually; costs for machine wetcleaning based on 3.39% of total capital costs (Murphy, 1994).

[l] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[m] Includes all operating costs and annual capital costs.

Although there is insufficient information to characterize the cleaning performance of each of the cleaning technologies considered in this document, some general comparisons are possible between drycleaning and wetcleaning processes. Drycleaning processes are more effective at dissolving oils and fatty stains (non-polar soils), while wetcleaning processes tend to dissolve sugar, salt, and perspiration (polar stains) with greater success. It is unclear whether particulate soils are better handled by one process type or the other. The cleaning ability of both wet and drycleaning processes may be enhanced with the use of spotting agents, detergents, surfactant additives, and other process modifications (time, temperature, mechanical action).

These two types of cleaning processes also excel at cleaning different kinds of materials. Drycleaning processes are most effectively used with textiles that contain water-loving (hydrophilic) fibers (such as wool), low twist yarns, low count fabrics, and polar colorants. Wetcleaning processes are effective with textiles containing water-hating (hydrophobic) fibers (such as polyester and nylon), high twist yarns, high count fabrics, and non-polar colorants. Wetcleaning methods tend to cause expansion of natural and cellulose fibers, leading to a loss of strength, wrinkling, color loss, and dimensional change (shrinkage, stretching). However, textile manufacturers have developed a number of fiber treatments and modifications (resin preparation, shrink prevention preparation, wool felt prevention) that may minimize such cleaning impacts on clothing. Such alterations are not necessarily apparent when synthetic fibers are subjected to similar water-based cleaning methods. Drycleaning methods, however, may not be appropriate for synthetic fibers due to potential fiber deterioration.

OTHER FACTORS

Because different cleaning processes are more effective with certain types of materials and/or certain types of soils, and because the effectiveness of all cleaning processes may be enhanced by certain process modifications, it is difficult to draw any general conclusions concerning the relative performance of the cleaning technologies considered in this document.

There are several other factors that may affect a clothes cleaner's decision. These may include consumer issues beyond performance, such as odor in clothing, liability concerns, and the current state and availability of alternatives. These factors can affect the costs faced by the cleaner, customer satisfaction, or ability to select alternatives.

PCE has been known to leave an odor in drycleaned clothing. Similar odor concerns exist for several of the HCs, however; the manufacturer of DF-2000 claims that it leaves no odor. Machine wetcleaning processes do not have odor problems associated with them.

SUMMARY OF TRADE-OFF CONSIDERATIONS

Each of the factors summarized above may affect the technology choices made by clothes cleaners. Cleaners must consider the costs of running an operation and the service that they can provide to consumers. Choices may be limited by regulatory requirements and levels of necessary capital investment. The effects of technology choice on the health and well-being of the environment and individuals exposed to the chemicals and to the cleaning process are also important factors. Many of these considerations are summarized in the CTSA and are organized and presented in Exhibit ES-4.

EMERGING TECHNOLOGIES

Several fabricare processes are currently under various stages of commercial development. As a result of their emerging status, information on them ranges from anectdotal study to results. The CTSA presents some information on these technologies, describing processes, estimated capital costs, and claims about technology performance. However, the developmental nature of these process alternatives does not allow for comparison with the existing technologies. The emerging technologies covered include liquid carbon dioxide (CO_2) drycleaning, propylene glycol ether (Rynex) solvent, ultrasonic wetcleaning, and Biotex solvent. Much of the information comes from vendors and can not be independently verified at this time; however, it is useful in providing an indication of fabricare technologies that may become viable alternatives for drycleaners.

CONCLUSIONS

During the time that this CTSA has been under development, the fabricare industry has gone through major changes. Drycleaners have significantly reduced PCE consumption, established a new commercially viable cleaning process, machine wetcleaning, developed lower flashpoint hydrocarbon solvents, and witnessed the development of a number of emerging technologies. As would be expected, the CTSA, which is based on available information, includes a significant amount of information on PCE and HC technologies, less on machine wetcleaning, and almost nothing on the emerging technologies. As new information becomes available, EPA will make it publicly available through case studies and fact sheets from its DFE Garment and Textile Care Program.

The CTSA demonstrates that each of the fabricare processes may have health and environmental implications associated with their use. It does not provide estimates of risks from individual fabricare operations, but identifies the most significant health and environmental concerns associated with each process. Clearly identified are the possibility of risks of cancer to individuals highly exposed to PCE, flammability hazards from some of the HC solvents, and possible considerations for the environmental release of detergents from machine wetcleaning (depending upon the actual chemical components). Cost data in the CTSA show which factors may contribute most to the costs of a particular technology choice, and how these costs may compare relative to the costs of other technologies. The CTSA relates the results of performance studies that describe customer satisfaction and effectiveness of the Machine Wetcleaning process. The information on emerging technologies is general, reflecting what is known at this time about liquid CO_2 and ultrasonic cleaning, and Rynex and Biotex solvents.

Exhibit ES-3. An Overview of Alternative Cleaning Technologies' Trade-Off Factors[a]

Characteristic	PCE	HC	Machine Wetcleaning
Health and Environmental Risks	**Health:** Risk of cancer to workers, co-located residents. Risks of non-cancer effects, including potential for developmental and reproductive effects for workers. May be cancer and non-cancer risks to co-located children. **Environmental:** Potential risk to aquatic organisms for effluent not treated by a POTW.	**Health:** Risk of neurotoxic effects and skin and eye irritation for workers. **Fire:** Highest for Stoddard solvent, less for 140°F and DF-2000, based on flashpoint **Environmental:** Potential to contribute to smog and global warming.	**Health:** Risk not evaluated quantitatively. Potential risks of skin and eye irritation for workers. **Environmental:** Potential risk to aquatic organisms from specific detergent component releases.
Costs[b]			
Potential liability costs	Groundwater contamination and worker illness.	Fire damage.	Damaged clothing labeled "Dryclean Only."
Capital costs[c]	$38,511	$37,432	$11,102
Hazardous waste disposal[d]	$4,594	$9,820	NA
Annual operating costs[e]	$14,077	$19,607	$5,089
Total annual costs[f]	$18,305	$23,717	$6,308
Market Considerations			
State of technology	Dominant in market.	Well-established in market; use of some HCs may be limited by local fire codes.	Commercial use since 1994 in U.S.; numerous detergent suppliers.
Consumer Issues			
Odor	Yes	Yes, maybe less for particular HCs	No
Cleaning Performance	Wide range of clothes.	Wide range of clothes.	Wide range of clothes.

NA means cost category not applicable for technology.

[a] Configurations for fabricare technology include: PCE dry-to-dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (PCE-C), as required by the PCE NESHAP regulation; HC Transfer with Recover dryer and condenser (HC-A2); and Unimac UW30 washer and DTB50 dryer.

[b] The values include the price of equipment and services directly related to the various fabricare cleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333 pound (24,191) annual volume of clothes cleaned per facility.

[c] List price of 35-pound PCE drycleaning system includes control equipment, distillation unit, and filters; list price of 35- to 40-pound HC drycleaning system includes control equipment, filters, and an explosion kit.

[d] Hazardous waste disposal costs for PCE and HC based on $6.94-per-gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates; HC solvent waste may not be considered hazardous waste under the Resource Conservation and Recovery Act. Therefore, this is a high-end estimate. Hazardous waste costs associated with spotting chemicals or certain detergent components are not included.

[e] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[f] Includes all operating costs and annual capital costs.

The CTSA offers guidance on the most important factors for comparing technologies. Individual cleaners would need to apply these general considerations to the specifics of their operation in order to make reasoned technology choices. Since the information contained in the CTSA is highly technical, additional information products are expected to be developed to assist in dissemination of the results. Currently, DfE's Garment and Textile Care Program is developing a condensed version of the CTSA.

Through its DfE Garment and Textile Care Program, EPA also plans to continue work in the fabricare industry. Plans are to expand the Program's core base of stakeholders by increasing representation from upstream industries such as textile and garment designers and manufacturers. The broader circle of stakeholders will continue to work collaboratively to further integrate pollution practices into the fabricare industry. EPA hopes that the CTSA, as well as future efforts, will encourage improvement and expansion of new fabricare choices and remove barriers that prevention adoption of economically competitive and environmentally sound processes.

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CHAPTER 1
INTRODUCTION

CHAPTER CONTENTS

This chapter introduces the Design for the Environment (DfE) Cleaner Technologies Substitutes Assessment (CTSA) for Professional Fabricare Processes. Section 1.1 describes the background for the CTSA and its relationship to the broader Garment and Textile Care Program. Section 1.2 discusses the CTSA's approach, including scope of coverage, focus on certain technologies, and why particular information may be relevant. A brief description of the intended use of this document concludes this chapter.

1.1 PROJECT BACKGROUND

The use of chemical solvents for cleaning clothes began in France in the mid-19th century. In 1925, a petroleum solvent (Stoddard) was developed and used for this purpose, and in the 1960's perchloroethylene (PCE) became the solvent of choice for commercial clothes cleaning because it was considered less flammable than petroleum. PCE is now used by a majority of clothes cleaners and has since been shown to have a variety of health and safety issues associated with it. As a result, it has been subject to increased regulation, taxation, and liability costs. While drycleaners have significantly reduced the use of PCE over the last decade (Rissoto, 1997), it is still released to the environment. For example, PCE has been found in 38% of 9,232 surface water sampling sites throughout the United States. It has also been documented in air, soil, and sediments (ATSDR, 1995). PCE has been found in at least 771 National Priorities List (NPL) sites. The NPL consists of 1,416 hazardous waste sites identified by USEPA as the most serious in the nation (ATSDR, 1995) and they are targeted for long-term federal clean-up. It is unknown how many NPL sites have been evaluated for this compound. As USEPA looks at more sites, the number of sites known to have PCE contamination may increase (ATSDR, 1995).

In May 1992, the Office of Pollution Prevention and Toxics of the U.S. Environmental Protection Agency (USEPA) convened the International Roundtable on Pollution Prevention and Control in the Drycleaning Industry. Researchers, industry representatives, and government officials met to exchange information on the drycleaning industry. Issues discussed included exposure reduction, regulation, and information dissemination. Numerous other topics, such as potential health and environmental considerations related to exposure from drycleaning solvents, were also discussed.

USEPA created the DfE Program the following year and selected drycleaning as the subject of a pilot project. USEPA made this selection in consideration of concerns identified at the Roundtable and based on discussions with the Neighborhood Cleaners Association-International, Greenpeace, the New York State Department of Health, the Fabricare Legislative and Regulatory Education organization, and EcoClean. Dow Chemical, the Center for Emissions Control (currently the Halogenated Solvents Industries Alliance), American Clothing and Textiles Workers Union (now the Union of Needletrades, Industrial, and Textile Employees), the Center for Neighborhood Technologies (CNT), the International Fabricare Institute (IFI), the Federation of Korean Drycleaners Associations (FKDA), and the Toxic Use Reduction Institute at the University of Massachusetts also became active stakeholders. Alliance members

What is Design for the Environment?

"Design for the Environment" means building in pollution prevention aspects when industry is developing a product or process. The Design for the Environment (DfE) Program harnesses USEPA's expertise and leadership to facilitate information exchange and research on risk reduction and pollution prevention efforts. DfE works with businesses on a voluntary basis, and its wide-ranging projects include:

- Encouraging businesses to incorporate environmental concerns into decision-making processes in their general business practices.
- Working with specific industries to evaluate the risks, performance, and costs of alternative chemicals, processes, and technologies.
- Helping individual businesses undertake environmental design efforts through the application of specific tools and methods.

DfE partners often include:
Industry # Professional Institutions # Academia # Labor
Environmental Groups # Public Interest Groups # Other Government Agencies

were committed to exploring ways to prevent pollution, choose safer substitutes, and reduce exposure to traditional drycleaning chemicals.

The fabricare industry is characterized by small companies that rarely have the time or resources to gather information on alternatives to their current processes. As a result, few companies have access to sufficient information to choose safer or lower risk chemicals, work practices, or technologies. DfE prepared the CTSA to help fill this information gap. Specifically, the *CTSA for Professional Fabricare Processes* is a compilation of information on the relative risks, costs, and performance of clothes cleaning operations. USEPA anticipates that this information will be used to develop information products for cleaners so that they may be better equipped to examine trade-offs and incorporate environmental concerns into their day-to-day and long-term business decisions.

What is a *Cleaner Technologies Substitutes Assessment*?

This technical document, referred to as a *Cleaner Technologies Substitutes Assessment* (CTSA), is intended to develop and compile the information needed to systematically compare the trade-offs associated with traditional and alternative products, processes, and technologies. Specifically, these trade-offs include the cost, performance, and environmental concerns (such as risk and environmental releases) associated with a product or technology. This CTSA addresses fabricare alternatives and serves as the repository for technical information developed by the DfE Garment and Textile Care Project on clothes cleaning technologies. It is only one of the products developed for use as part of the Project, including those that may be suitable for a wider audience such as pamphlets and cost accounting worksheets, and those that may pertain to other segments of the textile and garment care industries.

The CTSA is a small part of DfE's Garment and Textile Care Program. The Program's mission is to assist in providing professional garment and textile cleaners with a wide range of environmentally friendly options that they can offer to their customers, while maintaining or increasing economic viability. The core of the Program stems from the fact that drycleaning is at the terminal end of an elaborate chain of industries in the garment and textile industry sectors. Thus, so-called "upstream" industries, such as fabric and garment manufacturing, directly affect the options available to garment and textile care providers. Whether a garment or textile product can be cleaned by a particular method or alternative technology depends largely on decisions made by the upstream industries regarding garment, fabric, and textile design and construction.

As a result, the Garment and Textile Care Program is taking a "systems" or industrial ecology approach to pollution prevention and is soliciting participation from a wider group of stakeholders than is involved in the CTSA. Recent efforts of the Program have focused on expanding the core stakeholder group to include representatives from the upstream industries and beginning development of a long-term plan for change and increased incorporation of pollution prevention practices along the entire value chain. The objective is to promote not only cleaner production in the manufacture of garments and textiles, but also production of garments and textiles that will facilitate the use of clean technologies by the professional fabricare provider.

1.2 CTSA APPROACH

An outcome of the International Roundtable on Drycleaning was the recognition of the need to prevent pollution and reduce exposures to perchloroethylene (PCE) in the drycleaning industry. USEPA has already published materials that examine pollution prevention in the drycleaning industry, including "The Product Side of Pollution Prevention: Evaluating the Potential for Safe Substitutes." This report evaluates the "...possibility of dramatic reductions in toxic chemical releases by focusing on safe substitutes..." (USEPA, 1994) and contains sections specific to PCE.

"The Product Side of Pollution Prevention" identifies existing substitutes for PCE in drycleaning and examines their efficiency and impact on reducing the generation of hazardous waste and the release of toxic chemicals. The report describes priority toxic chemicals generally, as those chemicals that are part of USEPA's 33/50 Program. The report concludes that safe substitute approaches for reducing PCE releases from drycleaning include reducing the use of garments requiring drycleaning, reducing the use of water-sensitive fabrics, altering the drycleaning process to eliminate or reduce organic solvent use, and substituting a safe solvent for PCE (USEPA, 1994).

The CTSA builds on this approach and introduces additional information on PCE and substitute processes that is useful in business decision making. Many of the approaches identified in "The Product Side of Pollution Prevention" such as the reduction in numbers of garments requiring drycleaning and the use of water-sensitive fabrics in garment manufacture, are not within the CTSA's scope. However, the CTSA takes a broad view of the substitutes for PCE, within the context of factors controllable by the drycleaner. Rather than focusing only on reducing hazardous waste generation and release of toxic chemicals, which is the approach of "The Product Side of Pollution Prevention," the CTSA incorporates additional considerations of risk, cost, regulatory environment, and performance.

For instance with “The Produce Side of Pollution Prevention” looks at reducing toxic releases, the CTSA incorporates information on the risks of chemical releases. Therefore, possible substitutes may differ between documents.

1.2.1 Coverage of Fabricare Alternatives

Several technology alternatives are available for commercial fabricare. The CTSA generally categorizes these as dry and wetcleaning alternatives. These categories are distinguished by the primary solvent used. Drycleaning refers to those technologies using non-aqueous solvents, although it is recognized that water may be a part of these processes. The CTSA covers PCE and hydrocarbon (HC) drycleaning alternatives. The other process covered uses water as a solvent and is referred to as machine wetcleaning in the CTSA. The extent to which each technology is covered in the CTSA is a function of the amount of data available.

The CTSA includes evaluations on a subset of chemicals used in fabricare processes, for instance, solvents and detergents (in the case of wetcleaning). Spotting chemicals and chemicals in other formulations, such as fabric finishes and water softeners, are not covered in the CTSA. Also, the report does not take an industrial ecology approach and evaluate lifecycle issues surrounding the chemicals and does not fully consider issues related to garment labeling. These important issues may be evaluated outside of this document and will likely be mentioned as considerations in the information products developed from the CTSA for use by cleaners. Finally, the CTSA compiles much of the known information on the cleaning technologies but does not generally develop new conclusions based upon that information. For instance, the CTSA adopts USEPA’s current classification of the carcinogenicity of PCE, although USEPA is due to reassess this finding in the near future. Thus, most of what is found in this document will be familiar to the studied reader.

The information in the CTSA shows a range of alternative processes for reducing exposures to drycleaning solvents, (primarily PCE). These range from minor equipment modifications or changes (e.g., adding an emission control) to complete adoption of a new cleaning technology. For the PCE and HC drycleaning technologies, the CTSA evaluates a set of alternative equipment modifications (e.g., changing from a transfer to a dry-to-dry machine). This information is intended to provide a comparison of alternatives that move toward a greater reduction in drycleaning solvent use, recognizing that a complete technology change-over may not be an economically viable alternative for many of the businesses in the short-run.

The evaluation of machine wetcleaning risks focuses mainly on the detergents used in this process. Within the process, detergents are small percentage of the total volume of the solvent (i.e. water) and additive mix, accounting for approximately 1% (Industry Representatives, 1998). Numerous detergent formulations are currently available (Mains, 1996; Starr, 1998), complicating the review of this technology. Therefore, in preparing the CTSA, USEPA contacted wetcleaning product formulators to obtain information (chemical constituents and their weight percentages) on detergent formulations used. As expected, much of this information was deemed proprietary by the manufacturers. Based upon the information received, USEPA constructed an example formulation composed of chemicals (and their weight percentages) that may reasonably represent the chemicals (and percentages in formulation) found in actual formulations. It is not known how representative the selected chemicals and their concentrations are of those found in the myriad detergents available. Therefore, information reported for specific detergent components is intended only to illustrate the range of effects that could be associated with detergents in general. To account for the variety of constituents that could be found in a detergent product, the CTSA attempts, where possible, to identify the functions of chemicals found in detergents (e.g., surfactants) and to generally identify considerations related to chemicals that can be used in those functions.

The CTSA contains a general section in Chapter 2 describing the market status of each technology. The evolution of some of the technologies is briefly covered. Although some of the material covered in the CTSA addresses older equipment (e.g., transfer machines), the information will provide perspective and be useful to those cleaners who may currently be using this equipment or may be more familiar with it.

Process descriptions of the various technologies are also provided. These descriptions are useful as background information and are general in nature. The reader should understand that specific machine configurations within a given facility may differ.

To present information that is useful for comparison, the CTSA establishes a baseline against which alternatives can be compared. Since the CTSA stakeholders are committed to pollution prevention and solvent exposure reduction and because PCE is the dominant solvent used in the clothes cleaning industry, the PCE technologies are used as the baseline.

1.2.2 Description of Health and Environmental Risks

The CTSA organizes information on the health and environmental risks of clothes cleaning processes so that they can be compared. Characterizing these risks involves gathering a variety of information. This process, known as risk assessment, generally requires the following components of an analysis: hazard assessment, dose-response assessment, exposure assessment, and risk characterization.

As a first step in risk assessment, the CTSA provides a review of the human health, environmental, and other (e.g., flammability) hazards (effects) of various fabricare technologies. This step provides a basic description of the potential effects of exposure to the chemicals and processes. Effects can relate to health and well-being, such as the ability of a chemical to cause cancer, respiratory illness, or injury such as repetitive stress injury. They can also be environmental in nature, such as the ability of a chemical to cause harm to aquatic organisms. Additionally, the CTSA describes effects related to flammability resulting from chemical use. In its description of the hazards of individual chemicals, the CTSA generally maintains the findings of USEPA, when available, and thus, does not present additional analysis of hazard data. It does, however, provide a reasonable summary of relevant literature on hazards. Hazard descriptions are summarized in Chapter 3, and a more detailed summary is found in Appendix C.

In addition to the hazards associated with the various cleaning technologies, it is also important to identify who is exposed to the chemicals used in the various processes and thus, who may experience the effects related to the chemical or process. This is the next stage in risk assessment. There are a number of ways in which people and the environment can be subjected to the effects of the processes or individual chemicals used therein. The CTSA limits its coverage of these exposures to those most relevant for the specific technologies and presents these in Chapter 4.

In evaluating exposures, the CTSA primarily uses the results of existing studies as a basis of exposure estimates. These studies include monitoring data, where available, on chemical concentrations in air and water. These concentration data are then incorporated into models typically used by USEPA with standard assumptions, in order to present ranges of estimates for chemical exposures. The CTSA also describes reported exposure estimates from studies that use modeling.

In some cases, reported concentration data or modeled estimates of exposures are not available. In these cases, it is necessary to develop estimates of chemical releases from various processes to serve as a basis for estimating exposures. The CTSA presents release estimates for multiple media, air, water, and solid waste, depending on the chemical and exposure pathways and populations of concern. Release estimates are primarily developed for the analysis of exposures from wetcleaning operations and are based upon the example detergent formulation developed by USEPA.

The CTSA also presents solvent release estimates from 11 PCE and HC machine configurations. These estimates are intended to illustrate the relative differences in releases due to alternative machine configurations and control technologies. They are not used in risk assessments; however, they are presented in Chapter 10 to provide some information on how PCE and HC solvent reductions can be made.

The health and environmental risks associated with the cleaning technologies and the chemicals used within them are characterized in Chapter 5. Information on the hazards of the chemicals or associated with the technologies is combined with exposure and dose-response information to provide assessments of potential risks. The risk characterization is conducted at a “screening level” and developed using standard approaches. Estimated risks are not meant to predict actual risks to a particular individual; rather, they are meant to give a sense of the significance of the risk. Particular attention is paid to characterizing the uncertainty of the information. Similar to other information collected for this document, the extent of information presented on risk of the individual technologies is a function of the amount of information available on the technologies. Absence of information on a technology does not mean that risks are not associated with it.

The CTSA presents both cancer and non-cancer health risks for humans. It also evaluates environmental effects to aquatic species. Risks to terrestrial species are not considered. Quantitative measures are presented, in some cases, to provide a sense of the magnitude of potential risks. However, since the assessments for the individual technologies vary in the amount and type of hazard and exposure information, type of health concern, and uncertainties, the information is not directly comparable across technologies. Therefore, the comparison of risks is limited to a qualitative presentation in Chapter 10.

1.2.3 Performance Data

In addition to providing information on risks, in Chapter 6 the CTSA aims to provide information on the performance characteristics of alternative clothes cleaning processes. Several performance demonstrations and laboratory studies have been conducted to assess wetcleaning technologies in both the U.S. and Canada. While independent of the CTSA, these demonstrations and studies have provided useful information comparing wetcleaning to more traditional drycleaning technologies. Several studies have been summarized and incorporated into the CTSA. These studies contain information on consumer perceptions of the cleaning process (as it pertains to garments they have had cleaned) as well as information on the costs to run the performance demonstration sites. The CTSA, however, does not derive conclusions about the suitability for individual drycleaners of the alternatives that have undergone the performance testing.

1.2.4 Analysis of the Costs of the Alternative Clothes Cleaning Technologies

A cost analysis was developed for the alternative technologies by using data supplied by industry and publicly available information. Cost information from the performance demonstrations was not incorporated into the cost analysis. The cost information in the performance studies was not developed for machine configurations similar to the model plant configurations in the CTSA and could not, therefore, be applied in the cost analysis. The cost analysis considers a subset of the costs of running a professional clothes cleaning business: the private costs to the business. The CTSA includes estimates of some of these costs, including capital equipment, solvent, energy, hazardous waste disposal, filters, and maintenance costs. The CTSA uses this information to assess the relative costs of alternatives for a cleaning technology.

The concept of social costs is introduced in Chapter 10. These costs could include the costs to human and environmental health resulting from various technology choices. These costs are not quantified in the same manner as the private or business costs in this document, but are presented qualitatively.

1.2.5 Selected Federal Regulations

Professional clothes cleaners are affected by the requirements of many federal air, water, waste management, and occupational health and safety regulations. State, local, and other requriements may also pertain to clothes cleaning operations, however, are not covered in detail in the CTSA. Compliance with regulatory requirements can affect the choice of technology by limiting available alternatives or by increasing costs through compliance or liability. Chapter 6 summarizes many of the requirements faced by cleaners, and encourages them to investigate additional federal, state, and other requirements that may affect their operation. However, due to the variation in requirements across localities and operations, specific cost estimates are not included.

1.2.6 Environmental Improvements

Individual drycleaning shops have unique circumstances that impinge upon their ability to make certain process and technology changes. Therefore, in Chapter 9 the CTSA provides a listing of management practices and improvements that can be used at drycleaning shops to prevent pollution, reduce chemical consumption (and possibly exposure), and minimize waste. These opportunities can contribute to a facility’s ability to reduce drycleaning solvent use.

1.2.7 Evaluation of Trade-Off Issues

For alternative technologies, the CTSA considers private costs (costs to the cleaner), such as operating and regulatory costs. It also considers *external* costs, including environmental damage and the risk of illness to the general public or workers. These are described qualitatively in the CTSA in Chapter 10. In addition, other factors such as performance and state-of-the-art technology are included as factors necessary in comparing alternatives. This material is presented in several frameworks that demonstrate how useful comparisons can be made, including cost-benefit and cost-effectiveness analyses.

1.2.8 Emerging Technologies

Chapter 11 of the CTSA provides some information on emerging technologies, liquid carbon dioxide (CO_2), and ultrasonic processes, in addition to Rynex and Biotex solvents. Information is generally limited due to the pre-commercial status of most, and they have therefore not been compared to existing technologies.

1.2.9 Additional Information

Several appendices are added to the CTSA to provide detailed information on various aspects. Appendix A details chemical and physical properties of chemicals evaluated in the CTSA. Appendices providing more technical coverage of hazard and dose-response (Appendices B, C, and D) are included. Release and exposure methodology and data are found in Appendix E. Finally, a description of the peer review process that the CTSA underwent is included in Appendix F.

1.3 HOW TO USE THIS DOCUMENT

1.3.1 Clothes Cleaners

While a CTSA contains the technical information developed about a use cluster (in this case, professional fabricare processes), it is not intended to guide the small business in making decisions. This document should be used by technically informed decision makers. USEPA will develop user-friendly information products based on the technical information in the CTSA and disseminate them to interested parties. After reviewing these more targeted information products, clothes cleaners may choose to return to the CTSA to obtain technical details on a specific alternative that is of interest to their operation.

The methods used to evaluate the technologies in this project may also be of interest to clothes cleaners. These individuals may use the methodologies described in this document to conduct their own evaluations of alternative projects or processes specific to their operation.

1.3.2 Other Readers

For technical assistance programs, the CTSA can provide background information on fabricare, the applicable technologies, and the DfE Garment and Textile Care Project. The comparative information on the cost, risk, and performance of alternative clothes cleaning technologies can be useful when working with cleaners to move toward reducing risks or pollution. Comparative risk information in the CTSA can be disseminated to workers and the general public so that they can better understand the risks associated with the various cleaning technologies.

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CHAPTER 2
OVERVIEW OF PROFESSIONAL FABRICARE TECHNOLOGIES

This chapter provides an overview of the professional fabricare technologies covered in the Cleaner Technologies Substitutes Assessment (CTSA). The technologies evaluated in the CTSA are listed in Section 2.1.1. Section 2.2 gives background information on clothes cleaning. Section 2.3 describes the clothes cleaning processes equipment. Section 2.4 gives the chemical characterization of the technologies evaluated in the CTSA. The chapter closes with Section 2.5, a market profile of the commercial fabricare industry.

CHAPTER CONTENTS

2.1 TECHNOLOGIES EVALUATED IN THE CTSA

Several technology alternatives are available for clothes cleaning, and can generally be categorized into dry and wetcleaning alternatives. These categories are distinguished by the primary type of solvent used. Drycleaning refers to processes that use predominately non-aqueous solvents. The term “drycleaning” is a misnomer because clothes are actually immersed in a liquid solvent, and some water may be included in the solution. Wetcleaning processes are those that use predominately water as a solvent.

Drycleaning chemicals are chosen for their ability to dissolve organic materials that soil fabrics. Two drycleaning solvents currently dominate the market in the United States, perchloroethylene (PCE) and hydrocarbon solvents, which include Stoddard solvent, 140°F solvent and DF-2000. These are generally referred to as hydrocarbon (HC) solvents throughout the document. The CTSA discusses the risks associated with these solvents. PCE drycleaning is prevalent in the industry, and there are numerous machine configurations that can affect costs, risks, and other considerations. The CTSA examines several alternative modifications and machine configurations for PCE and HC cleaning, primarily for the difference in releases and costs.

In addition to drycleaning, “wet” or aqueous-based cleaning is a possible process substitute that may accomplish many of the same functions as drycleaning. The term “wet” refers to the use of a quantity of water during the process, but garments may never be fully immersed or saturated with water in some processes. Certain aqueous-based processes can be used on many garments, and are potential substitutes for drycleaning. Others are designed only for certain types of garments, and may become an alternative for a part of the total clothes cleaning volume.

USEPA originally sponsored testing of an approach to wetcleaning called “multiprocess wetcleaning”; however, this technique is no longer practiced in the commercial field. It has been replaced by a variety of combinations of machine wetcleaning and, therefore, machine wetcleaning is included in the CTSA. For this process, the CTSA discusses the risks associated with sample detergents.

2.2 CLOTHES CLEANING PROCESS

Clothes go through several steps at professional fabricare facilities. The following steps generally apply to cleaners using dry or wetcleaning processes. However, steps and procedures may vary considerably depending upon the facility, and there are some distinctions between dry and wetcleaning processes. The professional cleaning process begins with the sorting of clothes into similar fabric weights, colors, and finishes. Clothes are examined for stains. When stains are found, spotting agents are applied to remove stains from the clothes. Clothes are then loaded into the cleaning machine (CARB, 1993; Gottlieb, 1997; NIOSH, 1997).

The clothes are washed in the machine by immersion and spin-agitation in a solvent-detergent solution. The machine then drains and spin-extracts the solution from the clothes. Cleaners occasionally add second washing and extraction steps for better cleaning (CARB, 1993). After the final solvent extraction from the clothes, the clothes are tumble-dried using heated air. The dry clothes are then removed from the cleaning machine (CARB, 1993; Gottlieb, 1997; NIOSH, 1997). The equipment used to clean clothes is discussed in Section 2.3.

After cleaning, clothes are rechecked for stains. If stains are found, spotting agents will be applied. The final major step in the clothes cleaning process is pressing. Pressing uses steam and physical pressure to remove wrinkles and reshape clothes as needed (CARB, 1993). A variety of pressing equipment is available (NIOSH, 1997). Wetcleaners who process 100% of garments may be more inclined to purchase specially-designed pressing equipment that uses tension (Gottlieb, 1997). However, pressing equipment is not covered in this CTSA.

2.3 PROCESS EQUIPMENT DESCRIPTIONS

This section describes the primary equipment used to clean garments for the technologies covered in this CTSA. This equipment and their functions affect the environmental releases, human and environmental exposures, and economic assessments within the CTSA.

The description is not a complete listing and description of all cleaning equipment but, is intended to generally cover many of the important aspects of much of the cleaning equipment.

2.3.1 Perchloroethylene Processes Equipment

PCE use in drycleaning became prevalent in the 1960s, and several of PCE’s desirable characteristics have helped it to become the most common drycleaning solvent in the United States. As the use of PCE in drycleaning has proliferated, a combination of financial factors, regulations, and environmental concerns have given drycleaners incentives to reduce the loss of PCE. As a result, PCE drycleaning equipment has evolved considerably. With the variety of drycleaning equipment has come a variety of terms to describe it. This CTSA attempts to describe the equipment using the most commonly-used terminology, although specific terms may have different meanings to various people.

The following equipment comprises most PCE drycleaning machines: rotating cylinders or drums for washing, extracting, and drying; condensers; charged and pure solvent tanks; a still; filters; a lint trap; a water separator; and solvent vapor recovery devices, including carbon adsorbers, refrigerated condensers, and/or other devices. Some facilities have other equipment. Some PCE equipment variations, features, and functions are described below. Special emphasis is given to equipment that particularly affects exposures and releases of PCE.

Machine Types

Machines used to clean garments and other articles may be classified into two types: transfer and dry-to-dry. Like home clothes washing equipment, transfer machines have a unit for washing/extracting and another unit for drying. Following PCE extraction, articles which had been immersed in PCE are transferred by a worker from the washer/extractor to the dryer, sometimes called a reclaimer. Dry-to-dry machines wash, extract, and dry the articles in the same cylinder in a single machine, so the articles enter and exit the machine dry. Transfer machines are sometimes called “first generation” machines. Dry-to-dry machines may be called “second”, “third”, “fourth”, or “fifth” “generation”, and each machine’s designation depends upon its internal PCE vapor recovery machinery. Exhibit 2-1 presents process flow diagrams for dry-to-dry and transfer machines.

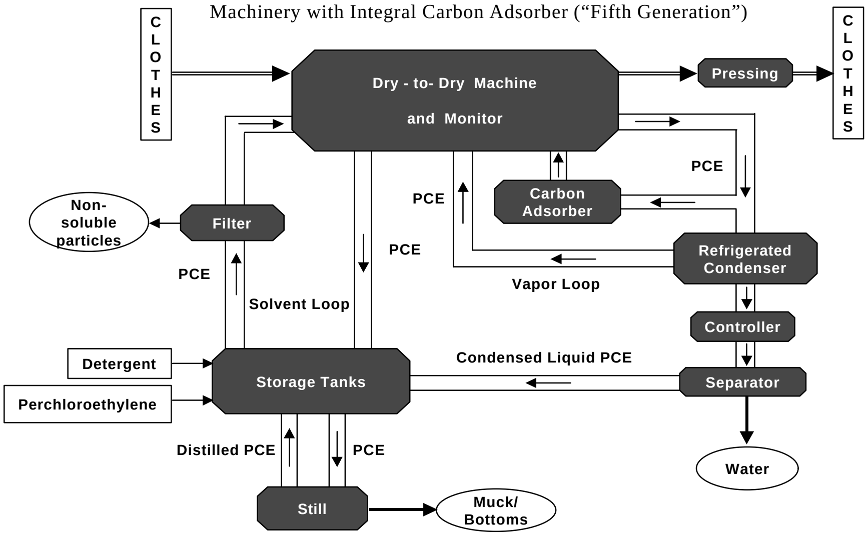
Equipment for Vapor Recovery in the Machine

Vapor recovery of PCE in the drycleaning machine occurs during the drying of the articles. During the drying cycle, heated air is forced into the cylinder containing the wet articles and PCE vaporizes into the heated air. The heated air containing PCE vapor passes through a lint bag and enters a condenser. The condenser cools the air and condenses some of the PCE, which is recovered. The air from the condenser is reheated and cycled back to the cylinder until the condenser no longer condenses much PCE from the heated air stream. Some machines have drying sensors, that control the drying cycle duration (CEPA, 1993).

Two types of condensers are used to perform this initial PCE vapor recovery: conventional and refrigerated. Conventional condensers are usually cooled using water. This cooling water may be circulated or once-through. Circulated water would pass through a cooling circuit such as a cooling tower or a water chiller. Some conventional condensers may use air for cooling rather than water. Refrigerated condensers (RCs) usually operate at lower temperatures than conventional condensers, and the lower the condenser’s operating temperature, the more PCE the condenser will recover from the air. USEPA’s PCE drycleaning National Emission Standard for Hazardous Air Pollutants (NESHAP) requires an RC exhaust-side temperature of no more than 45°F. At the end of the cool-down cycle, conventional water-cooled condensers can reduce PCE concentrations in the cylinder to 25,000 to 75,000 parts per million (ppm), while RCs can reduce PCE concentrations in the cylinder to 2,000 to 8,600 ppm (CEPA, 1993; NIOSH, 1997).

Exhibit 2-1. Simplified Process Flow Diagram for PCE Dry-to-Dry Closed-Loop Machinery with Integral Carbon Adsorber ("Fifth Generation")[a]

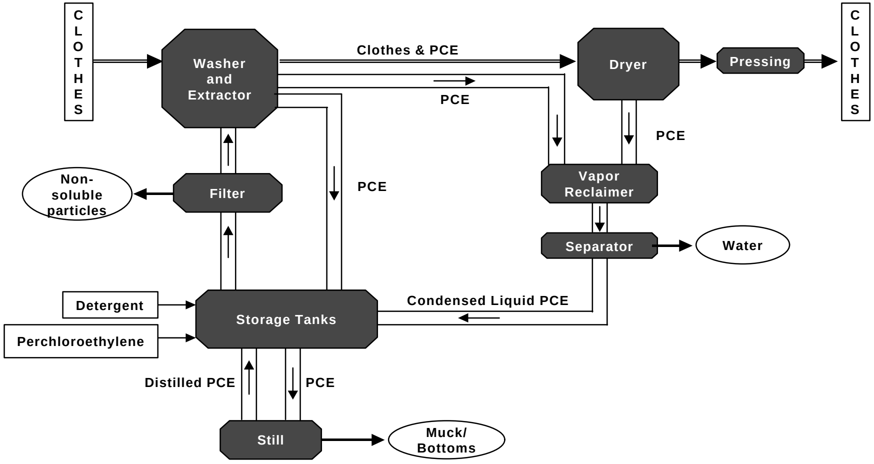
EXHIBIT 1: Simplified Process Flow Diagram for PCE Dry-to-Dry Closed Loop Machinery with Integral Carbon Adsorber ("Fifth Generation")



Source: Adapted from NIOSH, 1997.
With consultation from Hill,Jr., 1998.

Simplified Process Flow Diagram for PCE Transfer Machinery ("First Generation")

EXHIBIT 2
Simplified Process Flow Diagram for PCE Transfer Machinery ("First Generation")



Source: Adapted from USEPA, 1991b for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics.
With consultation from Hill, Jr., 1998.

[a] The simplified process flow diagrams in this CTSA have been developed from various sources. These diagrams may therefore have differences in appearance, components, and flows. The reader is cautioned not to interpret all these differences as having significance due to the issues presented in this CTSA. These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations which are not represented on these diagrams.

Machines with conventional condensers have an aeration cycle following the drying cycle. Dry-to-dry machines with conventional condensers are sometimes called “second generation” machines. During the aeration step, fresh air is forced into the cylinder containing the clean, dry clothes to remove the odor of residual PCE from the clothes. The aeration air leaving the cylinder contains PCE and may be vented to atmosphere or may enter another vapor recovery device. When vented to the atmosphere, the aeration air is a primary source of “vented emissions” from drycleaning machines, subject to the NESHAP.

A device that can either recover PCE from vented aeration air or eliminate the aeration step from first and second generation machines is sometimes called a “primary control.” RCs and carbon adsorbers (CAs) are the most commonly used primary controls. Once the CA reaches its capacity for adsorbing PCE from the aeration stream (e.g., daily), the PCE is usually removed (desorbed) from the CA by passing steam through the CA. Steam containing PCE exits from the CA and is routed to a condenser, which liquefies the PCE and water vapors. The liquid PCE and water mixture from the condenser is routed to the water separator. The CA must dry thoroughly before it is ready for reuse.

An azeotropic device is another device for recovering PCE from aeration air. An azeotrope is a mixture of liquids with a boiling point that is lower or higher than any of its components. PCE and water can be mixed to form a low boiling azeotrope. In azeotropic devices used in PCE drycleaning, the aeration air containing PCE is bubbled through water, forming an azeotrope in the aeration air. This azeotrope condenses at a lower temperature than PCE itself would condense, so more PCE can be recovered using the azeotropic device than could be recovered without it. The aeration air circulates in the machine until the condenser can no longer recover the PCE/water azeotrope. The condensed PCE and water are routed to the water separator. Because azeotropic units are not widely used, they will not be discussed further.

Machines with RCs do not have an aeration step since they remove more PCE from the drying air than machines with conventional condensers do. The dry-to-dry machines with RCs are sometimes called “closed-loop” machines because they do not vent aeration air. Machines with RCs have a cool-down cycle following the drying cycle. Air is no longer heated, but continues to circulate between the cylinder containing the clothes and the condenser, which cools the air and recovers more PCE. At the end of the cool-down cycle, the condenser no longer recovers much PCE from the unheated air stream.

Some machines with RCs have no additional equipment for emission or exposure reduction at the end of the drying cycle although significant PCE concentrations remain in the cylinder of the machine. Other machines with RCs may have a fan that is intended to reduce worker exposures by drawing air into the cleaning cylinder when the door is opened at the end of the drying cycle. The air brought into the cylinder by this “door fan” or “OSHA fan” may be vented into the facility, outside the facility, or to a small (one- or two-pound capacity) CA. The National Institute for Occupational Safety and Health (NIOSH) has found that these small CAs are ineffective in capturing PCE unless the carbon is either changed or desorbed daily (NIOSH, 1997). The air vented from a machine’s “door fan” into the facility either directly or indirectly through a small, ineffective CA may contribute to increased PCE concentrations in the facility. The various dry-to-dry machines described in this paragraph are sometimes called “third generation” machines.

Some closed-loop dry-to-dry machines have a large, “integral” CA (usually 50- to 60-pound carbon capacity or greater [NIOSH, 1997]) that is activated at the end of the cool-down step to reduce the PCE concentration in the cylinder. These machines are sometimes called “fourth generation” machines. Air containing PCE from the cylinder passes through the CA where PCE is adsorbed to the carbon and returns to the cylinder. CAs used in this configuration are sometimes called “secondary controls.” Some fourth generation machines may have a sensor to monitor PCE concentration in the air in the cylinder and control the adsorption until a desired PCE concentration (e.g., 290 ppm) is achieved.

Some other machines have the features of the “fourth generation” machine just described and an additional door lock. This lock will not open until the PCE monitor detects the desired PCE concentration “set point” in the cylinder. Reaching this set point indicates that the PCE recovery cycle is complete. Thus, the door lock assures that the PCE recovery cycle is completed before the door may be opened. These machines are sometimes called “fifth generation” machines. The PCE adsorbed by the CAs in these fourth and fifth generation machines is removed (desorbed) from the CA by non-contact steam or electrical heating (desorption) of the CA. Most of the desorbed PCE is then recovered by the RC.

Liquid PCE Reclamation Equipment

Filtration and distillation allow drycleaners to clean and reuse PCE. Careful equipment use and on-site recovery of PCE reduces the amount of PCE lost per volume of articles and reduces the need to purchase replacement PCE. To remove insoluble materials from PCE, four primary filter types are used: cartridge, tubular, disk, and regenerative. The two most common filter types are disk (also called spin disk) filters and cartridge filters (Murphy, 1994). Polishing filters and filter additives sometimes supplement filters to improve PCE purity (CEPA, 1993).

The spin disk filter consists of fine-mesh disks in a tube. Some disk filters are made to use filter powder to aid the filtration process. Powder is not needed for powderless disk filters. For those that use powder, the powder is coated on the disks’ surfaces, and that coating is maintained by a constant flow of PCE through the filter. Powders such as diatomaceous earth (i.e., clay) and carbon are added to the PCE that passes through the outer parts of the tube and is deposited on the outer sides of the disks. During filtration, PCE contaminated with insolubles passes into the tube, depositing the insolubles on the outside of the disk. When the pressure across the disk increases to a certain level, filtration ends and the filter is spun. The insolubles (and powder, if used) spin off the disks and into the PCE, which is then sent to distillation. Powderless disk filters may require a finishing or polishing filter to remove extremely small insolubles such as dyes that pass through these filters (CEPA, 1993).

Tubular filters are cylindrical screens on the outside of which diatomaceous earth and carbon are coated. During filtration, PCE contaminated with insolubles passes through the screen, depositing the insolubles on the outside of the screen. At the end of the day, the filter is back washed with PCE to remove the insolubles and powder sludge from the filter, and the sludge in the PCE is sent to distillation (CEPA, 1993).

Regenerative, or “bump-style,” filters are modified tubular filters that are “regenerated” after each load of clothes (CEPA, 1993). At the end of each wash load, the regenerative filter coating is "bumped" from the filter by stopping the flow of PCE through the filter (IFI, 1994). The coating redeposits on the filter when the PCE flow is restarted before the next load.

Cartridge filters are used and discarded, while all other filter types are reusable. PCE containing insoluble impurities passes through the cartridge filter's perforated outer shell, through paper, carbon, and a fine mesh that collectively remove the insolubles from the PCE, which then exits the filter. Several indicators may be used to determine when cartridges need to be replaced and may include pressure drop across the filter; numbers of loads or amounts of clothes cleaned using the filter. Spent filters are drained, and some drycleaners use steam to strip additional PCE from the filters. Usually, the spent filters are then removed from the facility as hazardous waste (CEPA, 1993).

The main advantage of cartridge filters is the ease and simplicity of operation and changing, requiring less labor and skill relative to other filter types, which usually require special start-up, cleaning, and handling of powder and carbon. The main disadvantage with cartridge filters is the increased hazardous waste disposal cost (IFI, 1994) and the higher loss of PCE (CEPA, 1993) relative to other filter types.

Most drycleaners use distillation to keep the solvent clean enough to avoid odors and darkening articles. Without distillation, oils, soils, dyes, detergents, and other PCE-soluble impurities would build up in the solvent. Distillation generates concentrated waste material sometimes called "still bottoms," which contain PCE-soluble impurities. The still bottoms are often composed of 20% to 80% PCE, although steam injection or PCE/water azeotropic distillation can lower this PCE concentration to 5% in the still bottoms. The newest stills can reduce the PCE to below 1% (USEPA, 1997). Still bottoms are usually removed and treated by the same firms providing other hazardous waste disposal services to drycleaners (CEPA, 1993).

To begin the distillation process, impure PCE is pumped from the charge tank to a still. This impure PCE is boiled in a still using steam coils, and PCE vapors flow to a condenser where the PCE condenses. Two types of PCE stills are batch and flash (continuous). Condensed PCE and water flow to a water separator, that separates water from the PCE. PCE leaving the separator flows to a PCE storage tank, and in some facilities flows through a "rag" filter before entering the storage tank. Some facilities use steam or air sweeping or steam injection to remove additional PCE from the still bottoms near the end of the distillation process. At the end of this process, the still bottoms are drained before becoming cool enough to thicken (IFI, 1994).

A special type of still called a muck cooker is used with machines that use powder filters. Muck cookers have several features that stills do not: a special intake opening and valve from the filter; an agitator with a universal joint; a sight glass; and a large bottom clean out door. Muck cookers use a distillation step, then a "cook down" step, and a final air or steam sweeping step, that results in a "dry" powder muck. The "dry" muck, that contains used filter powder and other soluble and insoluble impurities from the PCE, is then removed from the cooker (IFI, 1994).

The water separator may receive PCE/water mixtures from many sources, several having been described previously: direct steam desorption of carbon adsorbers, distillation and muck cooker condensates, condensate from machines' conventional and refrigerated condensers, and condensate from steam presses. These mixtures are received into the separator, which works using the immiscibility and density differences of PCE and water. The mixtures enter the separator and separate into PCE and water layers, with the heavier PCE settling to the bottom. The water phase is usually drained from the top of the separator into a container for later evaporation or disposal as a hazardous waste. The PCE is usually drained from the bottom of the separator to either the PCE storage tank or the machine cylinder. The water from the separator usually contains less than 150 ppm PCE, unless the capacity of the separator is insufficient to allow proper settling time for the water and PCE phases to fully separate or the water contains detergents or other impurities (CEPA, 1993).

Wastewater Evaporation Equipment

Evaporators are used in some facilities to evaporate PCE-contaminated waste water rather than dispose of it through hazardous waste haulers or release it to the sewer. Prior to evaporation, most facilities will separate PCE from wastewater in the separator, and some facilities will pass the water through carbon for adsorption and removal of more PCE from the water. If this carbon is changed according to the manufacturer's instructions, PCE in the evaporated water can be minimized (CEPA, 1993). Vapor is vented from the evaporator to either the inside or outside of the facility. If vented inside, the PCE in this vapor will increase PCE concentrations in the facility.

Water-Repelling Equipment

Three primary methods are used to apply water-repelling or waterproofing solutions to articles. One method uses an additional storage tank, sometimes called a third tank, in which a PCE/water repellent mixture is stored. This mixture is pumped from this storage tank into the machine's cleaning cylinder, where clothes are immersed in the mixture. The mixture is then returned to the storage tank for later reuse. A second method employs hand-pumped spraying of a commercial repellent mixture (usually non-PCE based) onto articles. The third method uses a dip tank containing a PCE/water repellent mixture. Cleaned articles are placed into a wire basket that is immersed into the repellent mixture. After immersion, the basket is raised and excess liquid drips from the articles before the articles are manually transferred to a dryer.

Spill Containment

Spill containment is another control that reduces PCE losses and ground contamination due to spills. Two options for spill containment are safety troughs and floor coatings. Safety troughs are shallow rectangular tanks in which all drycleaning equipment and auxiliaries that contain solvent reside. These tanks are designed to allow for containment of the entire volume of the largest storage tank. The tank generally contains a drain that can be connected to a pump for removal of spilled solvent, or for smaller spills, rags may be used to absorb the spill and later cleaned in the drycleaning equipment. Floor coatings in conjunction with a diked area or containment lip can function similarly to a trough, although the effectiveness of these coatings has yet to be determined (CEPA, 1993).

Fugitive Emissions Control

A variety of fugitive emissions recovery, ventilation, and containment systems have been employed to reduce emissions and/or exposure to PCE vapor in the facility. The "door fan" described above under *Equipment for Vapor Recovery in the Machine* is one of these systems. Other local and general exhaust systems may be used to remove and sometimes recover PCE vapor from air in the facility. Floor vents can be effective at removing and recovering PCE, especially in the event of spills. In some of these systems, air containing PCE can be directed to CAs to recover some of the PCE vapor (CEPA, 1993).

PCE emissions and migration within and from drycleaning facilities can also be reduced through the use of enclosures sometimes called vapor barriers. Vapor barriers can contain some or all drycleaning equipment that uses PCE and can be used to achieve minimum ventilation rates or other requirements. The walls and ceiling are made of materials that are impermeable to PCE. The enclosures have negative air pressure relative to the surrounding facility to prevent PCE migration. The air collected from the vapor barrier may be exhausted outside the facility or to a control device such as a CA to recover some of the PCE vapor (CEPA, 1993). Similarly, particular coatings and wallpapers used as PCE diffusion barriers in Germany appear to have achieved some effectiveness, although significant numbers of defective applications have been found (Hohenstein, 1994).

In facilities with transfer machines, the transfer of clothing from the washer/extractor to the dryer may result in a significant fugitive emission that does not occur in facilities with only dry-to-dry machines. Under the NESHAP, a dry-to-dry machine used in conjunction with a dryer/reclaimer is considered to be a transfer machine. Articles are damp with PCE when they are physically transferred from the washing machine to the dryer, and some evaporation occurs during this transfer. The NESHAP identifies three control technology options for reducing transfer losses: hamper enclosures, room enclosures (a particular variation of the vapor barriers described above), and replacement with dry-to-dry machines.

The most effective alternative for reducing fugitive emissions from clothing transfer is to replace the transfer machine with a dry-to-dry unit. By definition, this eliminates transfer losses, since the transfer process is eliminated. The new dry-to-dry machine would likely include process controls providing additional reductions in total PCE emissions relative to the older transfer machine. Another alternative to reduce transfer emission is to enclose the space surrounding washing and drying machines with a vapor barrier (described above) and to vent air from the enclosure to a control device, usually a CA. This alternative is sometimes called a “room enclosure.” The least effective of these alternatives is a hamper enclosure, which consists of a hood or canopy that encloses the transfer basket and doors of the washer and dryer during loading and unloading and covers the hamper during movement from the washer to the dryer. The operator reaches into slits in the hamper enclosure to load and unload the PCE damp articles. A fan can draw room air into the enclosure, and air and PCE vapor are routed to a control device, usually a CA, attached to the hamper enclosure.

2.3.2 Hydrocarbon Processes Equipment

HCs were once the dominant drycleaning solvents used in the U.S. before PCE, which now predominates. The most commonly used hydrocarbons are two petroleum solvents: Stoddard solvent and 140°F solvent (IFI, 1994). However, synthetic HC and other alternatives to petroleum solvents are being marketed. Regarding the process equipment, HC equipment has not undergone the evolution that PCE machinery has, so fewer variations and options exist in HC equipment. Also, HC processes and equipment seem to have received little attention as indicated by scant coverage in literature. Therefore, information presented in this CTSA is based on older literature sources and some more recent personal contacts.

Machine Types

Machines used to clean garments and other articles may be classified into two types: transfer and dry-to-dry. Like home clothes washing equipment, transfer machines have a unit for washing/extracting and another unit for drying. Following HC extraction, articles that have been immersed in HC are transferred by a worker from the washer/extractor to the dryer, sometimes called a reclaimer. Dry-to-dry machines wash, extract, and dry the articles in the same cylinder in a single machine, so the articles enter and exit the machine dry. Exhibit 2-2 presents process flow diagrams for dry-to-dry and transfer machines.

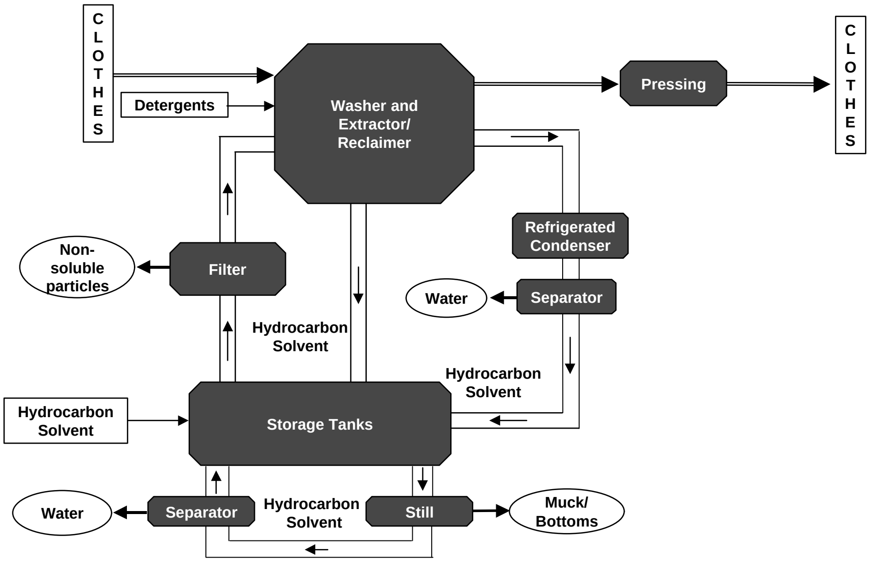
Equipment for Vapor Recovery in the Machine

As with the PCE process equipment, HC vapor can be recovered during the drying of the articles. Some HC transfer machines have standard dryers, which do not recover any vapor during drying. Heated air is forced into the cylinder containing the wet articles, and HC vaporizes into the heated air. The heated air containing HC vapor leaves the cylinder and is then vented from the standard dryer to atmosphere.

However, machines with recovery dryers and dry-to-dry machines have condensers, which can recover HC during article drying. During the drying cycle of these machines, heated air is forced into the cylinder containing the wet articles, and HC vaporizes into the heated air. The heated air containing HC vapor leaves the cylinder, passes through a lint bag, and enters a condenser. The condenser cools the air and condenses some of the HC vapor, which is recovered. The cooled air from the condenser is reheated and cycled back to the cylinder until the condenser no longer condenses much HC from the heated air stream. For water-cooled condensers, an exhaust/cool-down cycle follows the drying cycle. In this exhaust/cool-down cycle, fresh air is forced through the tumbling clothes, removing residual HC, and is then exhausted to the atmosphere. It is not clear whether HC machines with RCs, like PCE machines with RCs, have a cool-down cycle following the drying cycle.

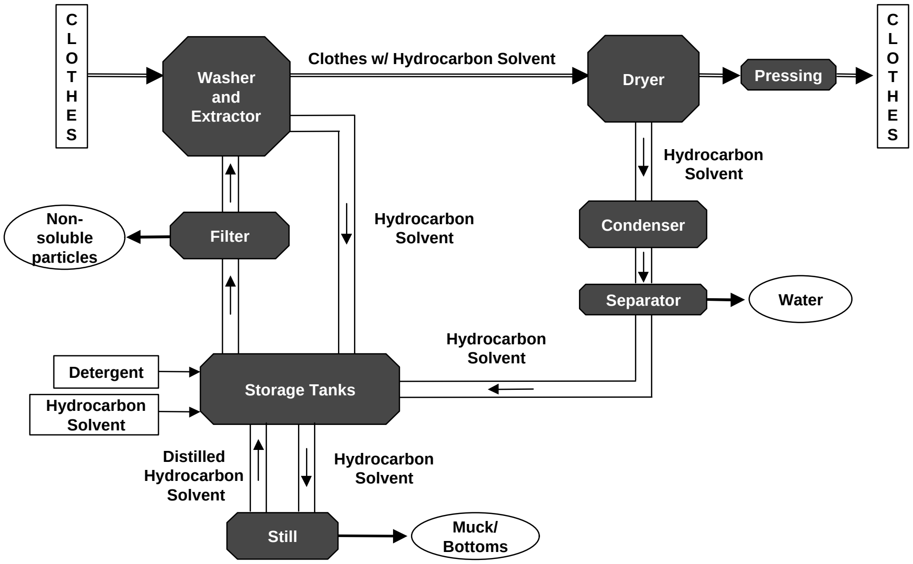
Two types of condensers are used to perform this HC vapor recovery: refrigerated and conventional. Conventional condensers are usually cooled using water. This cooling water may be circulated or once-through. Circulated water would pass through a cooling circuit such as a cooling tower or a water chiller. Some conventional condensers may use air for cooling rather than water.

Exhibit 2-2. Simplified Process Flow Diagram for Hydrocarbon Dry-to-Dry Solvent Machinery[a]



Sources: Adapted from OTEC, Swiss Clean Hydrocarbon Drycleaning Instruction Handbook.
With consultation from Hill Jr., 1998.

Simplified Process Flow Diagram for Hydrocarbon Transfer Solvent Machinery



Source: Adapted from USEPA, 1991b for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics.
With consultation from Hill Jr., 1998.

[a] The simplified process flow diagrams in this CTSA have been developed from various sources. These diagrams may therefore have differences in appearance, components, and flows. The reader is cautioned not to interpret all these differences as having significance due to the issues presented in this CTSA. These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations which are not represented on these diagrams.

Refrigerated condensers (RCs) usually operate at lower temperatures than conventional condensers, and the lower the condenser's operating temperature, the more HC the condenser will recover from the air.

Liquid HC Reclamation Equipment

As with PCE, filtration and distillation allow drycleaners to clean and reuse HC. Careful equipment use and on-site recovery of HC reduces the amount of HC lost per volume of articles and reduces the need to purchase replacement HC. Filters remove insoluble materials from HC, and one source states that the filter options available for PCE are also available for HC (peer review comment 1-196). The four primary filter types are cartridge, tubular, disk, and regenerative. These options are discussed in detail under the *Liquid PCE Reclamation Equipment* header in the previous PCE processes equipment description section and will not be repeated here.

Most drycleaners use a distillation process to keep the solvent clean. Without distillation, oils, soils, dyes, detergents, and other HC-soluble impurities would build up in the solvent. The distillation process generates a concentrated waste material sometimes called "still bottoms" that contains HC-soluble impurities. The still bottoms normally contains a significant fraction of HC. Still bottoms are usually removed and treated by the same firms providing other hazardous waste disposal services to drycleaners (CEPA, 1993).

Vacuum stills are used to distill impure HC. The vacuum reduces the steam pressure required for HC distillation. To begin the distillation process, impure HC is pumped to a still. The steam coils in the still transfer heat to the HC, which boils, and HC vapors flow to a condenser where the HC condenses. Condensed HC and water flow to a water separator. At the end of this process, the still bottoms are drained before becoming cool enough to thicken (IFI, 1994).

The water separator may receive HC/water mixtures from several sources, some having been described previously: distillation and muck cooker condensates; condensate from machines' conventional and refrigerated condensers; and condensate from steam presses. These mixtures are received into the separator, which works using the immiscibility and density differences of HC and water. The mixtures enter the separator and separate into HC and water layers, with the heavier water settling to the bottom. The water phase is usually drained from the bottom of the separator into a container for evaporation or disposal to the sewer or as a hazardous waste. The HC decanted from the separator flows to a HC storage tank, and in some facilities flows through a "rag" filter before entering the storage tank. The water from the separator usually contains less than one part per million HC unless, as with PCE/water separation in PCE processes, the phases do not fully separate or the water contains detergents or other impurities (CEPA, 1993).

Flammability Controls

Two dry-to-dry equipment variations have been developed to reduce the likelihood of explosion by reducing the oxygen concentration in the machine. These variations are nitrogen injection and oxygen vacuum systems. No information was found in the literature for these systems. The following descriptions are based upon limited personal contacts and assumptions. The nitrogen injection and oxygen vacuum is expected to be used only during the drying cycle when air containing HC vapor is heated.

Drycleaning equipment with nitrogen injection injects nitrogen gas into the cleaning chamber in combination with HC. The addition of nitrogen lowers the concentration of oxygen, reducing the chance of explosion (Abt, 1994).

Drycleaning equipment with oxygen vacuum lowers the pressure in the cleaning chamber. The partial vacuum resulting from the reduced pressure reduces the concentration of oxygen, which greatly lowers the flashpoint of the solvent and reduces the chance of explosion (Abt, 1994).

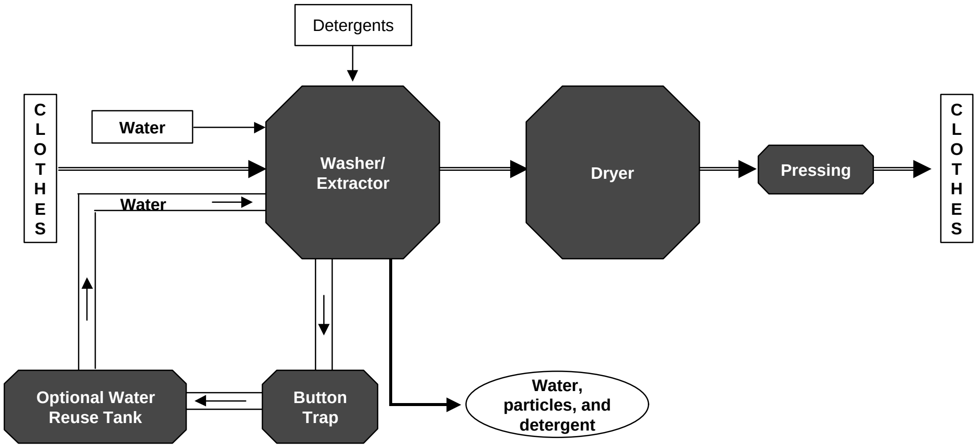
2.3.3 Machine Wetcleaning Process Equipment

In the 1990s, several aqueous-based processes have been explored as substitutes for drycleaning of some garments. One of these processes, sometimes called “multiprocess wetcleaning,” relied heavily on hand labor to “clean” garments. This process used a variety of different techniques depending on the individual characteristics of the garment in need of cleaning. These techniques include steaming, immersion and gentle hand washing in soapy water, hand scrubbing, tumble drying, air drying. This process also used spotting and pressing as in any of the fabricare technologies. The spotter/cleaner determined which technique was most appropriate for each garment, given the fabric, construction, and degree of soiling. A number of different techniques may have been used on any one garment (Abt, 1994). Multiprocess wetcleaning has not gained acceptance as a marketable primary cleaning method. However, some of its techniques have been used to supplement the second, more widely-accepted aqueous process, which is sometimes called machine wetcleaning (Environment Canada, 1995).

The machine wetcleaning process differs from the multiprocess wetcleaning by using machinery instead of hand labor in the washing process. The basic difference in the machinery from traditional laundering units is that the agitation applied to the clothes is reduced (Abt, 1994). The following example of machine wetcleaning process equipment is particular to a Miele/Kreussler system, one of the earliest systems developed for this process. Although the equipment specifics mentioned in this section are particular to this example system, the process equipment functions for this system are expected to be generally applicable to other machine wetcleaning systems.

The example system consists of a washer/extractor and a separate dryer, which both control mechanical action and temperature (Patton et al., 1996). The principle of the system is that “spinning” clothes during both water-based washing and drying can thoroughly clean and dry the clothes without incurring the damage to delicate fabrics caused by agitation and tumbling. The washer/extractor developed for the example system has holes in its drum which have been devised to provide optimum protection for the garment being washed, and to facilitate chemical flow and active cleaning. The temperature and the water level are each monitored and controlled. The washing/extracting process is fully automated, and a liquid detergent is dispensed by two pumps at a predetermined time. After the garment washing step, the wash water containing soils, oils, and detergents is extracted and disposed to the sewer. After the garment rinsing step, rinse water may be disposed to the sewer or may be recovered and reused using storage and filtration systems (Patton et al, 1996). The dryer in the example system monitors the moisture of items in the drum, and air passes horizontally through the drum. A fraction of

Exhibit 2-3. Simplified Process Flow Diagram for Machine Wetcleaning[a]



Sources: Adapted from USEPA, 1997 for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics. Training Curriculum for Alternative Clothes Cleaning. With consultation from Star, 1998.

[a] The simplified process flow diagrams in this CTSA have been developed from various sources. These diagrams may therefore have differences in appearance, components, and flows. The reader is cautioned not to interpret all these differences as having significance due to the issues presented in this CTSA. These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations which are not represented on these diagrams.

drying air is recycled, and automatic drum reversal is intended to dry the load evenly and help prevent creasing (Abt, 1994). Exhibit 2-3 shows a flow diagram of the machine wetcleaning process with a separate washer/extractor/dryer.

2.4 CHEMICAL CHARACTERIZATION OF TECHNOLOGIES

The information on hazards, releases, exposures, and risks presented in the CTSA is primarily focused upon the chemicals as they are used in the various cleaning processes evaluated. Therefore, lifecycle considerations are not a part of the CTSA. For the PCE and HC technologies, the focus is upon effects associated with those chemicals as they are used as solvents. The portrayal of risks associated with wetcleaning focuses upon the chemicals contained in the detergent formulations used. While detergents may be used in other processes, the significant reliance upon these products in wetcleaning processes warrants their evaluation under that technology. Detergent use is not evaluated for the other technologies (i.e., PCE or HC processes) because their use is less significant. Spotting chemicals are another type of chemical common to all of the cleaning technologies; however, they are not evaluated in this document.

2.4.1 Drycleaning—Solvents

Drycleaning processes utilize solvents other than water to effect cleaning. The solvents covered in the CTSA are PCE and the HCs, Stoddard solvent, 140°F solvent, and DF-2000.

2.4.2 Machine Wetcleaning—Detergents

In preparing the CTSA, USEPA collected information on wetcleaning processes' formulations through the processes' developers and machine manufacturers. USEPA received little information following the requests, and most of the information received was deemed proprietary. However, from the non-proprietary information received, USEPA developed two example wetcleaning detergent formulations. These example formulations are primarily comprised of the chemicals listed in Exhibit 2-4, and the formulations themselves are shown in Exhibit 2-5. It is important to note that it is not known how representative the formulations considered in this report will be of the potential universe of detergent formulations available. While the chemicals included are commonly found in detergent formulations, actual formulations may vary considerably in terms of both constituents and concentrations. Therefore, information presented on the individual chemical constituents of the sample formulation is presented to illustrate possible considerations associated with these types of products.

Exhibit 2-4. Example Detergent Chemicals Included in the CTSA

Chemical Name	CAS No.	Chemical Synonyms	Function
Acetic acid	64-19-7	Acetic acid glacial; vinegar; ethanoic acid	Surfactant aid
Cellulose gum	9004-32-4	Sodium carboxymethylcellulose; CMC; carboxymethylcellulose, sodium salt; CM cellulose	Surfactant
Citric acid	77-92-9	1,2,3-Propane tricarboxylic acid; 2-hydroxy-hydroxytricarballylic acid	Surfactant aid
Cocamidopropyl betaine	61789-40-0	1-Propanaminium, 3-amino-N-(carboxymethyl)-N, N-dimethyl-, N-coco acyl derivates, inner salts; cocamidopropyl dimethyl glycine	Surfactant
Ethoxylated sorbitan monodecanoate	9005-64-5	Polyoxyethylene (20) sorbitan monolaurate; sorbitan, monodecanoate, poly(oxy-1, 2-ethanediyl) derivatives	Surfactant
Lauric acid diethanolamide	120-40-1	Lauramide DEA; N,N-bis (2-hydroxyethyl) lauramide	Surfactant
Methyl 2-sulfolaurate, sodium salt	4337-75-1	Sodium methyl 2-sulfolaurate; N-lauroyl-N-methyl-taurine, sodium salt; ethanesulfonic acid, 2-[methyl (1-oxododecyl) amino]-, sodium salt	Surfactant
Sodium carbonate	497-19-8	Carbonic acid; sodium salt; soda ash; Solvay soda	Surfactant aid
Sodium citrate	68-04-2	Trisodium citrate; 1,2,3-propane tricarboxylic acid; 2-hydroxy-trisodium salt	Surfactant aid
Sodium laureth sulfate	9004-82-4	Ethoxylated sodium laureth sulfate; ethoxylated sodium lauryl ethyl sulfate; poly(oxy-1, 2-ethanediyl)-sulfo-(dodecyloxy)-, sodium salt	Surfactant
Sodium lauryl isethionate	7381-01-3	Sodium ethyl 2-sulfolaurate; sodium dodecoylisethionate; dodecanoic acid, 2-sulfoethylester, sodium salt	Surfactant

Exhibit 2-5. Example Wetcleaning Detergent Formulations

Example Detergent #1		Example Detergent #2	
Constituent	**Weight Percent**[a]	**Constituent**	**Weight Percent**[a]
water	54	water	54
methyl 2-sulfolaurate, sodium salt	3.75	methyl 2-sulfolaurate, sodium salt	2.14
sodium lauryl isethionate	3.75	sodium lauryl isethionate	2.14
ethoxylated sorbitan monodecanoate	7.5	lauric acid diethanolamide	4.28
lauryl polyglucose	7.5	lauryl polyglucose	4.28
Aveda's fragrance	1	sodium laureth sulfate	4.28
sodium citrate	2.5	sodium citrate	2.5
cellulose gum	5	cocamidopropyl betaine	4.28
acetic acid	5	Aveda's fragrance (orange)	1
citric acid	2.5	citric acid	2.5
diazolidinyl urea	7.5	diazolidinyl urea	4.28
		cocoamphocarboxyproprionate	4.28
		sodium carbonate	10

[a] Assumed based on assumed function of constituent.

Four of these chemicals, Aveda's fragrance, lauryl polyglucose, cocoamphocarboxy proprionate,and diazolidinyl urea are not covered in the CTSA because information was lacking on their chemical identity.

The detergent chemicals in these example formulations can be grouped into several categories, such as surfactants and surfactant aids. Surfactants are used to reduce the surface tension of water so that it may more throughly wet the surface (Soap and Detergent Association, 1998) and are the primary chemicals found in the detergent formulation reviewed for this document. Surfactant aids may enhance the functions of the surfactant and can include components such as soil suspenders, pH adjusters, and solubilizers. The chemicals included as part of the machine wetcleaning detergent formulation in the CTSA are identified as either surfactants or surfactant aids.

2.5 COMMERCIAL FABRICARE INDUSTRY MARKET PROFILE

2.5.1 Introduction

The commercial fabricare industry, also called the professional clothes cleaning industry, includes approximately 36,000 facilities[1] that generate a total revenue of $7.2 billion[2] annually (Seitz, 1997; Faig, 1998; Wong, 1998). Clothes cleaning volume for these facilities is estimated to be 871 billion kg (1.9 billion pounds) of clothes per year[3] (Faig, 1998; Wolf, 1998). The majority (over 90%) of the 36,000 commercial fabricare facilities in the U.S. are small neighborhood stores that consist of a small storefront operation with customer pickup and delivery in the front, and cleaning and finishing in the back.

Although there are numerous fabricare processes under development, drycleaning and wetcleaning are the primary clothes cleaning processes commercially available at this time. Drycleaning uses organic solvents, such as perchloroethylene (PCE) and hydrocarbon (HC) solvents, to clean soils from clothing. HC solvents are a by-product of the distillation of petroleum and are often sold as either Stoddard solvent or 140°F solvent, in reference to its flashpoint. In 1994, Exxon introduced a synthetic HC solvent, called DF-2000, with a flashpoint above 140°F. Since then several other firms have either introduced or are testing synthetic petroleum solvents for the drycleaning market (DeSanto, 1998). Approximately 30,600 (85%) fabricare facilities in the U.S. use PCE drycleaning solvents, while approximately 5,400 (15%) use HC drycleaning solvents.

Wetcleaning is an alternative cleaning process that uses water as the primary solvent to clean fabrics. Wetcleaning is used exclusively at relatively few facilities but is used in combination with other methods at many more facilities. Exhibit 2-6 presents the solvent volume used by commercial cleaners distributed by solvent type and number of facilities. The commercial sector’s total consumption of solvents is also shown.

2.5.2 Perchloroethylene Market Share and Volume

The dominance of PCE in the professional clothes cleaning market is a function of its cleaning ability for a wide range of fabrics and the materials that soil them, and its inherent fire safety advantages as compared to many hydrocarbon solvents (i.e., PCE is not a flammable liquid).

In the U.S., 37% of the PCE produced is used by drycleaners (Mannsville, 1997). Mannsville estimates that 52.6 million kg of PCE is consumed by the drycleaning industry, while Risotto places this

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[1] The number of facilities is estimated from data provided by the California Air Resources Board (Wong, 1998).

[2] Based on an average facility revenue of $200,000 (Seitz, 1997; Faig, 1998).

[3] Based on $200,000 revenue per facility and $3/lb average revenue (Faig, 1998; Wolf, 1998).

Exhibit 2-6. Solvent Usage in the Commercial Sector of the Drycleaning Industry

Fabricare Solvent Type	PCE	HC Solvents	Wetcleaning
Number of Facilities	30,600[a]	5,400[a]	38[b]
Drycleaning Volume (kg/year)	741,818,181[c]	130,909,091[c]	NA
Solvent Consumption (MM kg/year)	45[d]	8.3 to 34[e]	NA

NA = not available

[a] Estimate based on 85% PCE and 15% HC use; data provided by the California Air Resources Board (Wong, 1998).

[b] There are 38 facilities using wetcleaning methods exclusively (Star, 1998). By the end of 1997, 3,000 wetcleaning machines had been sold in the U.S.; however, it is not known how many facilities combine wetcleaning with other methods (USEPA, 1998).

[c] Estimated from revenue (Seitz, 1997; Faig, 1998), and based on 85% PCE and 15% HC use.

[d] Estimate based on Textile Care Allied Trade Association survey, adjusted for brokered import volume (Risotto, 1997).

[e] Estimated from the range of mileages presented with the petroleum solvent options in Chapter 8.

estimate of consumption at 45 million kg (Risotto, 1997; Mannsville, 1997). The following three companies produce PCE in the U.S.: Dow Chemical in Plaquimine, Louisiana; PPG Industries in Lake Charles, Louisiana; and Vulcan Materials Company in Geismer, Louisiana (Chemical Marketing Reporter, 1997). In 1996 these plants produced approximately 136.4 million kg of PCE (see Exhibit 2-7) (Mannsville, 1997).

Exhibit 2-7. Total Volume of PCE (in million kg)

Year	1996
Capacity	184.9[a]
Production	136.4[a]
Imports	27.7[a]
Exports	21.8[a]
Consumption (Drycleaning)	52.6[b] (1996) 45[c] (1996)

[a] Mannsville, 1997.

[b] Based on 37% of PCE being used for drycleaning and in textile manufacturing (Mannsville, 1997).

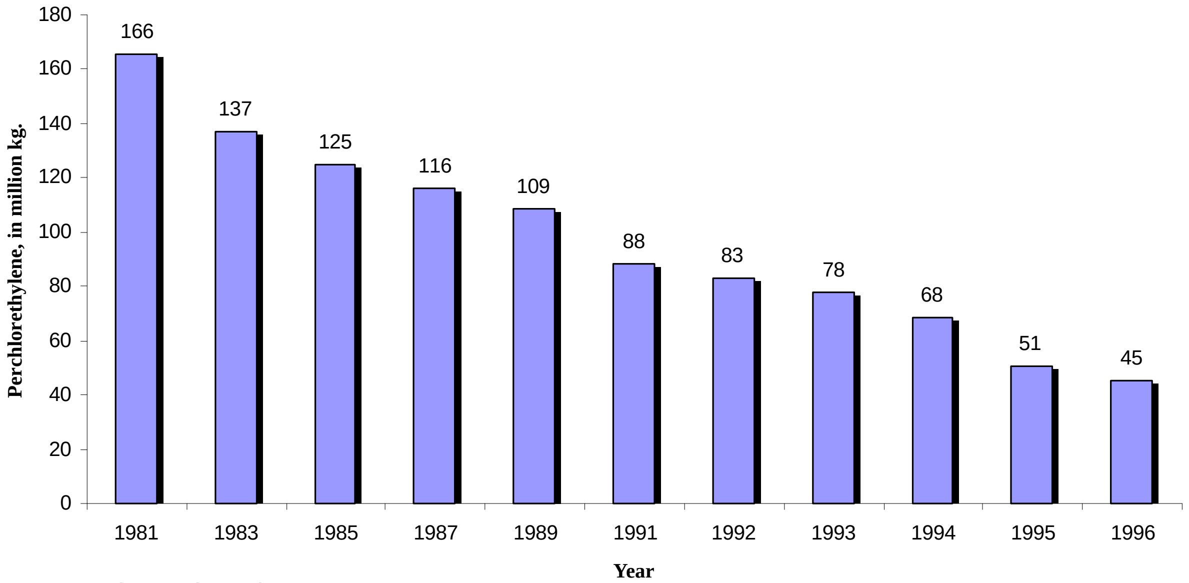
[c] Risotto, 1997.

Exhibit 2-8 provides a historical perspective of PCE use in the U.S. from 1981 to 1996 (Risotto, 1997). Although PCE holds the largest market share in the clothes cleaning industry, the consumption of this chemical by fabricare facilities has clearly declined since 1981. Exhibit 2-8 demonstrates that from 1981 to 1996 there has been a 72% decrease in PCE use by the fabricare industry. One of the primary reasons for this decline is the growth in the use of wash-and-wear fabrics by the garment industry (Levine, 1997). In addition, concerns regarding the human health and environmental hazards associated with PCE have placed pressure on fabricare professionals to reduce consumption and use more benign process alternatives. Initially, the drycleaning industry has focused on designing new equipment with more effective solvent recovery and recycling systems, as well as developing safer solvent alternatives.

2.5.3 Hydrocarbon Solvents Market Share and Volume

HC solvents dominated the drycleaning industry in the United States in the 1950s. However, their use gradually declined in the next three decades, primarily due to concerns about their inherent fire and explosion hazards and the increased use of PCE by the industry. HC solvents with lower flashpoints are desirable because of their cleaning ability and quickness in drying, when compared to HCs with higher flashpoints. Increasing regulatory pressures on PCE, the introduction of HC dry-to-dry machines, and the availability of higher flashpoint solvents in the 1990s have resulted in an increase in the number of facilities using HC solvents (Baker, 1996). The proportion of establishments that rely on HC solvents for clothes cleaning is approximately 15% of all commercial drycleaners (IFI, 1989; USEPA, 1991). The Neighborhood Cleaners Association International (NCAI) predicts that the proportion of HC-using establishments has the potential to increase to almost 25% in the future if stricter regulation of PCE is implemented (Seitz, 1998)

Exhibit 2-8. Perchloroethylene Use (Domestic and Import) in the U.S. Drycleaning Industry



Source: Risotto (1997).

The current producers of HC solvent include Exxon, Ashland Chemicals Inc., Texaco Chemical Co., Plaza Group (which sells only Stoddard solvent but not exclusively to the drycleaning industry), Citgo (formerly Unocal Chemicals Division), Sun Company, Inc., Calument Lubricants, and Shell Chemicals (OPD, 1992; Hinrich, 1998; Schreiner, 1998). Besides use as drycleaning agents, HC solvents are commonly used as degreasers in manufacturing and as paint thinners (Gosselin et al., 1984). No information was available to identify the relative volumes of HC in various uses.

HC solvents used in drycleaning are differentiated as Stoddard solvent, 140°F, and Naphtha. Stoddard solvent is estimated to be used by 25% to 30% of HC drycleaners, while 140°F solvent is used by 60% to 65% of HC drycleaners (Seitz, 1998). Greater use of the latter solvent is attributed to its higher flashpoint, and therefore greater safety threshold. Naphtha solvent is estimated to be used by 10% of HC drycleaners (Seitz, 1998).

The American Society for Testing and Materials (ASTM) has developed standard specifications for Stoddard solvent that cover 10 HC solvents. These specifications are currently being revised (ASTM, 1995, Hinrich, 1998). According to ASTM, Stoddard solvents include the following four types with flashpoints of 100°F or 142°F: Type I, Full Range Mineral Spirits; Type II, High Flashpoint; Type III, Odorless; and Type IV, Low Dry Point. Each of these types contain one to three different classes with varying ranges of percent aromatic content: Class A, 8% to 22%; Class B, 2% to 8%; and Class C, 0% to 2%.

Conventional Stoddard solvents with flashpoints of 100°F to 105°F (38°C to 41°C) are highly flammable and are banned in communities with strict fire codes. Many are regulated by local air pollution control districts because of their volatile organic compound (VOC) content, which contributes to the build-up of photochemical smog. The 140°F solvent was designed to reduce the flammability and VOC problems. Due to its higher flashpoint, 140°F solvent does not require the same level of explosion-proof equipment and building construction as conventional Stoddard solvent. It is likely that the combination of new dry-to-dry hydrocarbon drycleaning equipment and the use of 140°F solvent will meet many of the fire codes that previously forced cleaners to switch to PCE (Hill, Sr., 1997).

Several of the major producers of HC solvents have recently introduced, or are about to begin marketing, products with flashpoints of 140°F to 147°F (60°C to 64°C). New equipment available to HC drycleaners and a reassessment of the drycleaning market prompted the development of these products (Exxon, 1994; Shell, 1994). The DF-2000 solvent was introduced in 1994 and is a synthetic hydrocarbon solvent with a flashpoint of 147°F. It is designed for use in petroleum drycleaning machines, such as the new dry-to-dry systems, and may also be used in PCE machines that have been properly converted (Exxon, 1998). One of the major advantages of DF-2000 is that chemical residuals are not considered hazardous wastes under the Resource Conservation and Recovery Act, (RCRA), which results in lower waste disposal costs. Manufacturers also report that pressing times associated with using DF-2000 are reduced when compared to other HC solvents (Exxon, 1998). However, DF-2000 is still a flammable liquid and is classified as a VOC. Therefore, the following restrictions may apply to this HC solvent: local fire inspectors may have to pre-approve use; waste must by transferred by a licensed hazardous waste hauling company; a permit from a local air quality management district may be required; and facilities converting to DF-2000 may be required to follow the requirements of the NFPA Code 32 (Guidelines for Class III A drycleaning plants).

In response to the increased demand for HC drycleaning machines, equipment manufacturers have added several safety features to their designs to reduce the risk of fire and explosion. For example, a new dry-to-dry HC machine may include a mechanism that injects an inert gas, such as nitrogen, into the drycleaning equipment to reduce the concentration of oxygen and thus the explosion potential. A number of systems incorporate HC monitoring equipment, which measures the HC vapor concentration and automatically shuts down the system when the solvent stream reaches the Lower Explosive Limit. Another safety method is to reduce the oxygen supply during the dry cycle by applying a vacuum and an oxygen monitor to the system to reduce the oxygen level below 8%. HC dry-to-dry machines with nitrogen injection and oxygen vacuum have been used for about 1 year in the U.S. and 4 years in Germany. There are approximately 25 HC dry-to-dry machines with nitrogen injection or oxygen vacuum in use in the U.S. (Seitz, 1998).

The market for this equipment has supported an increase from a single supplier in 1993 to at least five suppliers in 1998. Because of local fire code restrictions, each facility that purchases a hydrocarbon dry-to-dry machine must apply for a zoning variance before using the new machine. There are now approximately 250 petroleum dry-to-dry machines in use in the United States (DeSanto, 1998).

2.5.4 Machine Wetcleaning

Fabricare professionals have always cleaned a portion of their clothing throughput using domestic washers and dryers. With the introduction of more advanced washers and dryers, that incorporate microprocessor controls, the percentage of clothing that can be effectively wetcleaned is expected to increase. Other improvements that have made wetcleaning a more viable and safer clothes cleaning process include the development of specialized detergents, fabric softeners, dye setting agents that reduce bleeding, mild bleaching agents, and fabric finishes (sizing chemicals) that restore fabric hand (Seitz, undated). In the U.S., wetcleaning is being used in combination with either PCE or HC at about 200 facilities and at 38 dedicated wetcleaning shops (Star, 1998). A survey by the Hohenstein Institute of Germany reported that approximately 40% of the professional clothes cleaning stream in that country is wetcleaned, while the remaining 60% is drycleaned using PCE (Seitz, undated). While the clothing stream in Germany may differ from that in the United States, the value indicates that a greater portion of the clothing steam can be wetcleaned.

Companies selling machine wetcleaning equipment in the U.S. include Aqua Clean Systems, Inc., AquaTex, Böwe Permac, Continental Girbau (plans to market a wetcleaning machine in 1998), Daewoo Electronics Company, Edrom, Marvel Manufacturing, Pellerin Milnor Corporation, and UniMac, (Star, 1998). In addition, domestic washer models such as the Maytag Neptune have been used in facilities for wetcleaning processes. Wetcleaning chemicals manufacturers selling products in the U.S. include Adco Inc., Aqua Clean Systems, Inc., AquaTex, Büfa, Caled-Signal Corporation, Daewoo Electronics Company, EnviroSafe Wetcleaning Technologies, Fabritec International, Gurtler Chemicals Inc., Laidlaw Corporation, Priaser, R.R. Street & Co.,Royaltone, and Seit (Mains, 1996; Star, 1998). The increased availability of these products (all wetcleaning chemicals were imported as recently as 1994) indicates a growing market (CNT, 1996).

2.5.5 Fabricare Industry Trends

Although PCE continues to dominate the professional fabricare industry in the U.S., the industry is undergoing significant change. Five years ago there were no hydrocarbon dry-to-dry machines or wetcleaning machines in use. Today, the major U.S. HC supplier is producing 60% HC drycleaning machines and 38 facilities perform dedicated wetcleaning. The development of alternative solvents and cleaning processes was motivated by concerns of stricter state and federal regulation of PCE, as well as increasing evidence of the chemical's negative impact on human health and the environment. In fact, many drycleaners are increasingly faced with financial liability associated with cleaning up PCE-contaminated soil and groundwater around their facilities. These concerns have made many property owners reluctant to renew leases or rent to PCE drycleaners (Lummis, 1996). In addition, several states have imposed taxes on PCE that double its price. The adoption of wetcleaning and petroleum solvents in Germany as a response to strict PCE regulation could presage the level of adoption that may occur in the U.S. However, direct comparisons among countries must be understood in the context of differences in fabric and garment type, lifestyle, geography, and climate. Different perceptions of cleaning quality among countries will also affect customer acceptance of alternative cleaning technologies.

Increasingly, fabricare professionals are proving that they can effectively wetclean many garments traditionally drycleaned. Most facilities have a washer and dryer that are being used for "wetcleaning" a larger fraction of the clothing stream than was done in 1990 (Seitz, 1995). The major challenge facing the industry is the decline in the total volume of clothing drycleaned. Several reasons have been cited for the decrease, including the increase in casual wear among office workers (Levine, 1997). The industry is addressing this by trying to broaden the services it offers to customers. For example, a cleaning facility may provide services that emphasize pressing and finishing over merely cleaning. The industry is also cooperating with clothing designers and apparel manufacturers to make professional fabricare an integrated part of the textile care process. By encouraging the use of fabrics and clothing construction compatible with professional fabricare techniques, the industry hopes to remain a viable aspect of the U.S. economy.

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CHAPTER 3
HAZARD SUMMARY

This chapter describes possible health, environmental, and safety concerns related to clothes cleaning processes and the chemicals used therein. It highlights some of the issues related to these chemicals, but it is not intended to represent the full range of hazards that could be associated with clothes cleaning technologies.

CHAPTER CONTENTS

The chapter provides data on each of the technologies and the individual chemicals used within those technologies as defined by this Cleaner Technologies Substitutes Assessment (CTSA). For each technology and/or chemical, the chapter presents summaries of human health and toxicological data, including exposure routes; toxicity endpoints (e.g., carcinogenicity, developmental toxicity, and neurologic effects); and hazard measures. More detailed discussions of the studies are presented in Appendix C. Environmental effects data on acute and chronic aquatic toxicity levels for fish, invertebrates, and algae and environmental hazard rankings for individual chemicals are included. The chapter also describes safety hazards that may be associated with the various technologies or chemicals.

3.1 INTRODUCTION

In understanding how the choice of alternative technologies may affect humans and the environment, it is important to consider the effects that could result from exposure to the clothes cleaning processes and the chemicals used in the various technologies under a specified set of conditions. Effects can relate to health and well-being, such as the ability of a chemical to cause cancer or respiratory illness. They can also be environmental in nature, such as the ability of a chemical to cause harm to aquatic organisms. These effects on human health and the environment are often described as the hazard associated with the chemicals and technologies. In its description of the potential hazards associated with the alternative fabricare technologies, the CTSA includes effects on physical property, such as those related to flammability

The chemistry and environmental fate of a substance also play important roles in determining both hazard and potential exposure. Appendix A provides the chemical/physical properties of each chemical and environmental fate summaries for some of the chemicals considered in the CTSA.

The data presented on chemical hazards focus on individual chemicals. Some technologies employ mixtures of chemicals or formulations. Examples include machine wetcleaning and hydrocarbon (HC) solvents. Ingredients (or components) of the formulations may differ from manufacturer to manufacturer or supplier to supplier. While information on the specific formulation would be preferable, it is not generally available. This section provides hazard data for chemicals among those typically used as components.

Certain hazards, common to all technologies, are not expected to be noticeably different across technologies. For instance, there are hazards of physical injury associated with the ergonomic environment of the fabricare operation. Fabricare requires that employees perform a variety of tasks, some to operate the cleaning equipment, some to carry out associated activities (e.g., pressing, clothes bagging). The highly repetitive nature of these tasks can generate musculoskeletal injury. In particular, shops where garment transfer is required entail such tasks as (1) moving carts with soiled items, (2) loading the washer, (3) unloading the washer/extractor and loading the reclaimer or dryer, (4) setting controls and turning on each machine, (5) sorting dried items for presser designations, and (6) moving dried items to a pressing area. These tasks are largely comprised of lifting and bending stresses. (Terminology and machine functions involved in transfer may differ from technology to technology; for instance, the machine wetcleaning process or a perchloroethylene (PCE) dry-to-dry machine may not require task 3.) Adding a hamper enclosure to a PCE operation to control fugitive emissions may increase lifting stress, through increasing the horizontal distance from the spine to the lifting activity of the hands, the most critical measurement in the multiplicative National Institute for Occupational Safety and Health (NIOSH) “lifting equation” for repetitive stress injuries (Waters et al., 1994). Because such injuries are more a function of the specific fabricare operation than the technology used, they are not examined further in the CTSA.

3.2 OVERALL SUMMARY

3.2.1 Human Health Hazard

Approach

The CTSA is intended to compile existing information on potential health effects resulting from exposures to clothes cleaning technologies. Literature searches were limited to such sources as USEPA’s Integrated Risk Information System (IRIS), the National Library of Medicine’s Hazardous Substances Data Bank (HSDB), TOXLINE, TOXLIT, GENETOX, and the Registry of Toxic Effects of Chemical Substances (RTECS). These sources are considered to be secondary sources, and a minimal attempt was made to verify the information contained therein. Additionally, toxicologic data developed under the Chemical Testing Program of USEPA’s Office of Pollution Prevention and Toxics (OPPT), where available, are incorporated in the human health hazard summaries.

Results

Exhibit 3-1 summarizes human health effects information obtained to date on chemicals used in the clothes cleaning industry. Later sections in the chapter provide a brief summary for each technology and the chemicals used within that technology.

The “Toxicity Endpoint” column in Exhibit 3-1 lists adverse toxicological effects by expected exposure routes reported in the literature for animal or human studies. This is simply a qualitative listing of reported observed effects. The list does not imply anything about the severity of the effects, nor the doses at which the effects occur. Furthermore, an entry in this column does not necessarily imply that USEPA has critically reviewed the reported studies or that USEPA concurs with the authors’ conclusions.

Exhibit 3-1. Human Health Hazard Summary[a]

Chemical Name	CAS No.	Expected Exposure Route	Toxicity Endpoint
Drycleaning Technology - Perchloroethylene			
Perchloroethylene[b]	127-18-4	Inhalation, dermal, oral	Liver and kidney toxicity, neurotoxicity, developmental and reproductive toxicity, and cancer.
Drycleaning Technology - Hydrocarbon Solvents			
Stoddard solvent (petroleum)[b,c]	8052-41-3	Inhalation, dermal	Irritation of the eye, skin, and respiratory tract, and neurotoxicity.
Machine Wetcleaning Technology - Detergent Component Examples[d]			
Surfactants			
Cellulose gum	9004-32-4	Dermal, inhalation	No significant adverse effects noted in animal and human studies.
Cocamidopropyl betaine	61789-40-0	Dermal, inhalation	Possible eye and skin irritant.
Ethoxylated sorbitan monodecanoate	9005-64-5	Dermal	Little or no skin irritation. May enhance tumor activity of carcinogenic compounds.
Lauric acid diethanolamide	120-40-1	Inhalation, dermal	Mild eye irritant.
Sodium laureth sulfate	9004-82-4	Dermal	Eye and skin irritant.
Sodium lauryl isethionate	7381-01-3	Dermal	Limited information suggests may not be an irritant.
Surfactant Aids			
Acetic acid	64-19-7	Inhalation, dermal	Eye injury.
Citric acid and sodium citrate	77-92-9 68-04-2	Inhalation, dermal	Eye and skin irritant.
Sodium carbonate	497-19-8	Inhalation, dermal	Eye and skin irritation; respiratory effects.

[a] Technical hazard summaries may be found in Appendix C. Hazards represent possible effects identified and do not indicate the likelihood of the effect occuring.

[b] Refer to Appendix D for a discussion of the doses used in the risk assessment (Chapter 5).

[c] Stoddard solvent hazard data are assumed to be representative for other hydrocarbon solvents (140°F solvent and DF-2000).

[d] Chemicals are based upon an example detergent formulation developed for presentation in the CTSA. Therefore, it is not clear how representative they may be of chemicals used in actual detergent formulations.

In the sections that follow, the most salient human health hazards associated with individual chemicals within each technology are summarized. The information includes route(s) of exposure, absorption and metabolism, human and animal toxicity information, irritation and sensitization potential, and carcinogenic potential. These sections represent brief summaries of applicable information. Appendix C contains a more detailed review of the hazard summaries for many of these chemicals, including citations and references. Appendix D contains the dose-response assessments for PCE and hydrcarbon (HC) solvents, which are used in the risk assessment (Chapter 5).

3.2.2 Environmental Hazard

Approach

The environmental hazard assessment of chemicals identifies effects that a chemical may have on organisms in the environment. An overview of this assessment process has been reported by Zeeman and Gilford (1993) and is summarized in Appendix B. The effects are expressed in terms of the toxicity of a chemical on the organisms and are generally given as the effective concentration (EC) that describes the type and seriousness of the effect for a known concentration of a chemical. A Hazard Profile or Toxicity Profile is created when the ECs for a range of species are tabulated for a chemical. A detailed discussion of a prototypic comprehensive Hazard Profile has been presented by Nabholz (1991).

The most frequently used Hazard Profile for the aquatic environment consists of three chronic and three acute effective concentrations as reported by Nabholz, et al. (1993). These are:

- A fish acute value (usually a fish 96-hour LC_{50} value) where LC_{50} represents the concentration that is lethal to 50 % of the tested organisms at the end of the exposure period;
- An aquatic invertebrate acute value (usually a daphnid 48-hour LC_{50} value);
- A green algal toxicity value (usually an algal 96-hour EC_{50} value) where EC_{50} represents the concentration at which a chemical inhibits algal growth (biomass) by 50% at the end of the exposure period;
- A fish chronic value (Chapter 5), calculated according to Nabholz et al. [1993]), which is often obtained from a fish 28-day early life stage study;
- An aquatic invertebrate chronic value (usually from a daphnid 21-day study); and
- An algal chronic value (usually from an algal 96-hour study for biomass).

USEPA obtained the ecological/environmental toxicity values used in the Hazard Profile from the results of standard toxicity tests reported to USEPA or published in the literature (i.e., measured values) or estimated them based upon Structure-Activity Relationships (SARs) (predictive equations). SARs are based on the assumption that chemicals with similar structural features will show similar toxic effects, and they use data from many chemicals to predict these effects.

For the CTSA, USEPA assessed discrete organic chemicals using predictive SAR equations. USEPA found no data that conflicted with these estimates; however, few of the specific chemicals, with the exception of PCE and Stoddard solvent, have studies reported.

Some products, such as detergents, softeners, surfactants, and hydrocarbon solvents are mixtures and do not lend themselves readily to the standard hazard assessment process using SARs. USEPA therefore evaluated the machine wetcleaning detergent formulations on a per constituent basis for this CTSA. Thus, the toxicity values are for the discrete chemical only; interactions between chemicals within a formulation are not considered.

Upon completion of a hazard profile, USEPA determined a concern concentration (CC). A CC is the concentration of a chemical in the aquatic environment that if exceeded, may result in a significant risk. Conversely, if the CC is not exceeded, it is assumed that the probability of a significant risk occurring is low. The CC for each chemical is determined by applying assessment factors (USEPA, 1984) to the effect concentrations in the Hazard Profile.

After assigning a CC, USEPA ranked chemicals according to hazard concern levels for the aquatic environment. This ranking can be based upon the acute toxicity values expressed in milligrams per liter (mg/L). The generally accepted scoring is as follows (Clements et al., 1993):

High Acute Concern (H)		≤ 1
Moderate Concern (M)	> 1 and	< 100
Low Concern (L)		> 100

This ranking can also be expressed in terms of chronic values as follows:

High Chronic Concern (H)		≤ 0.1
Moderate Concern (M)	> 0.1 and	< 10.0
Low Concern (L)		≥ 10.0

The chronic toxicity ranking takes precedence over the acute ranking.

Results

The results of the estimated aquatic toxicity determinations are summarized in Exhibit 3-2. For each chemical, the exhibit gives the estimated toxicity values in mg/L (ppm) for acute and chronic effects of fish, daphnid, and algae. The second-to-last column shows the CC set for the chemical in water. The last column notes the hazard rank using the method described above.

Exhibit 3-2. Estimated Aquatic Toxicity Values of Dry and Wetcleaning Chemicals Based on Measured Data and Struture Activity Relationship (SAR) Analysis (mg/L)[a]

Chemical Name	CAS Number	Acute Toxicity (mg/L)			Chronic Toxicity (mg/L)			Concern Conc. (mg/L)[b]	Hazard Rank
		Fish	Daphnid	Algal	Fish	Daphnid	Algal		
Drycleaning Technology - Perchloroethylene									
PCE (SAR)	127-18-4	5.9	7.0	4.8	0.96	0.66	1.07	0.07	moderate
PCE (measured data)	127-18-4	5	8.5	--	2.3	0.51	--	0.05	moderate
Drycleaning Technology - Hydrocarbon Solvents[c]									
Stoddard solvent (SAR)	8052-41-3	0.14	0.19	0.14	0.005	0.006	0.015	<0.001	high
Stoddard solvent (measured data)	8052-41-3	2.1	0.42	--	--	--	--	0.004	high
Machine Wetcleaning Technology - Detergent Component Examples									
Acetic acid (SAR)	64-19-7	>100	>100	>100	>10	>10	>10	>1	low[d]
Cellulose gum[e] (SAR)	9004-32-4	--	--	--	--	--	--	--	--
Citric acid (SAR)	77-92-9	>100	>100	5	>10	>10	1/30[f]	0.1/3[f]	moderate/ low[f]
Cocamidopropyl betaine (SAR)	61789-40-0	>10	>10	>10	>10	>10	>10	0.2	moderate
Ethoxylated sorbitan monodecanoate (SAR)	9005-64-5	20	20	20	3	3	3	0.3	moderate
Lauric acid diethanolamide (SAR)	120-40-1	6	6	6	0.6	0.6	1	0.06	high
Methyl 2-sulfolaurate, sodium salt (SAR)	4337-75-1	20	15	15	3.0	2.3	3.7	0.2	moderate
Sodium carbonate (SAR)	497-19-8	8300	2400	240	>100	>100	>60	6	moderate
Sodium laureth sulfate (SAR)	9004-82-4	40	30	30	6.2	4.6	8.0	0.46	moderate
Sodium lauryl isethionate (SAR)	7381-01-3	10	10	>10	2	2	3	0.2	moderate

[a] Aquatic toxicity values based on the use of SARs except where noted.

[b] Concern Concentration (CC) is derived by dividing the lowest chronic value by ten. If result is < 0.001 then CC is set at 0.001.

[c] For the CTSA, toxicity levels, concern concentrations, and hazard rankings for 140°F solvent and DF-2000 are assumed to be the same as presented for Stoddard solvent (SAR).

[d] The hazard ranking for acetic acid should be low because after treatment the chemical will be relased at pH 7. At this pH the chemical is neutral without acid reaction.

[e] Indicates that toxic effects are not expected in a saturated solution during the prescribed exposure period of a standard test.

[f] Algae are particularly sensitive to citric acid. The first value represents predicted toxicity and concern for normal water hardness and the second for moderately hard water.

3.3 HAZARD SUMMARIES BY TECHNOLOGY

3.3.1 Drycleaning Technologies

The review of drycleaning hazards focuses primarily on the use of non-aqueous solvents (PCE and HC solvents), and does not cover spotting chemicals, fabric finishes, water softeners, and detergents that may also be used in the process.

Perchloroethylene

PCE Health Hazard Summary

The majority of information summarized below comes from secondary sources (USEPA, 1985; ATSDR, 1993). Refer to Appendix C for more detailed information.

Studies in laboratory animals have shown that PCE is quickly absorbed by the body after ingestion. In addition, PCE vapor in the air can be rapidly absorbed into the body through the lungs. PCE can be absorbed into the body through the skin; although the absorption via the skin is approximately equal to inhalation at low exposures (410 mg/m^3), it can be as low as 1% of the amount absorbed via inhalation at higher exposures (4,100 mg/m^3). Most of the PCE that is absorbed into the body rapidly leaves, unchanged, in the exhaled air. However, PCE that remains in the body changes into other substances. These other substances are thought to be responsible for many of the adverse health effects attributed to PCE.

People who breathe air that contains PCE for a short time may experience short-term effects on the nervous system that are suggestive of depressed brain activity. The effects range from altered electrical activity in the brain at moderate levels to dizziness, drowsiness, lack of coordination, faintness, headache, and nausea at higher levels and collapse, seizures, coma, and death at still higher levels. The effects on the nervous system gradually fade when the affected person is removed from the contaminated air. Drycleaning personnel who were exposed to low (<350 mg/m^3) concentrations of PCE in the air for three or more years did not perform well on neurobehavioral tests. Studies in laboratory animals have shown that large doses of PCE taken by mouth or inhaled can produce lack of coordination, tremors, narcosis, and death. It is not known if PCE can produce effects on the nervous system by skin contact.

People who breathe air that contains PCE may also have liver and kidney dysfunction. These effects are most strongly associated with short-term exposure to high PCE levels in humans, but mild kidney and liver dysfunction has also been reported from long-term exposure to PCE. In support of findings in humans, studies in laboratory animals have shown that PCE damages both the liver and kidneys. These effects occur regardless of whether PCE is inhaled or taken by mouth and can occur either from short-term exposure to high levels or long-term exposure to lower levels.

The International Agency for Research on Cancer (IARC) recently concluded that PCE is probably carcinogenic to humans based on studies in laboratory animals and human epidemiological studies (IARC, 1995). Male and female mice that breathed air containing PCE or ingested PCE for most of their lifetime developed liver tumors. In addition, rats that breathed air containing PCE for most of their lifetime appeared to have increased rates of leukemia (males and females) and kidney tumors (males only). It is not clear, however, if the tumors that developed in these animals are relevant to humans. Workers exposed to PCE for many years showed increased rates of esophageal cancer. The significance of this finding is limited, however, due to weaknesses in the study. PCE has not been shown to interact strongly with genetic material, but several of the substances produced from PCE in the body have been shown to do so.

It is not known if PCE produces birth defects or interferes with reproduction in humans. Some studies of workers exposed to PCE in the drycleaning industry have reported findings suggesting that such effects occur, but these studies have many limitations that hinder their interpretation. Studies in laboratory animals indicate that PCE produces effects on the developing fetus that include altered growth, birth defects, and death. Exposure of rats to PCE for three consecutive generations resulted in an increased number of stillborn young, decreased litter sizes and survival of the young, and decreased testis weight in males.

The hazard values to be used in the risk assessment (Chapter 5) are a cancer inhalation unit risk value of 7.1×10^{-7} per $\mu g/m^3$ (for use only with exposures below 1.4×10^4 $\mu g/m^3$) and a provisional RfC of 0.17 mg/m^3 (see appendix D for details). The oral values are a cancer slope factor of 0.051 per mg/kg/day (for use only with exposures below 2×10^{-1} mg/kg/day) and an RfD of 0.01 mg/kg/day.

PCE Environmental Hazard Summary

The results of the hazard profile are summarized in Exhibit 3-2. The acute toxicity values for fish obtained from the AQUIRE database range from 13.4 to 21.4 mg/L with a geometric mean of 16.1 mg/L (11 tests) (USEPA, 1994). USEPA did not critically review the studies from the AQUIRE database to determine the validity of the test results reported.

A recent review of PCE toxicity to aquatic species was reported by the United Kingdom (SIAR, 1996). Valid acute toxicity data were reported for rainbow trout (96-hour LC_{50} of 5 mg/L) and daphnids (48-hour LC_{50} of 8.5 mg/L). Valid chronic toxicity data were also reported for fish (28-day no-observed-effect concentration [NOEC] of 2.34 mg/L) and daphnids (28-day NOEC of 0.510 mg/L).

The lowest reported measured NOEC was 0.510 mg/L in a daphnid 28-day study (Richter et al, 1983, as cited in SIAR, 1996). The estimated acute toxicity values for PCE are 5.9, 7.0, and 4.8 mg/L for fish, daphnid and algae, respectively. The estimated acute value for fish of 5.9 mg/L is within a factor of 2.5 of the mean AQUIRE value of 16.1 and is similar to the value of 5 mg/L reported in SIAR (1996). The estimated chronic values for fish, daphnid, and algae are 0.96, 0.66, and 1.07 mg/L, respectively. PCE is of moderate concern for chronic effects to aquatic organisms (equal or greater to 0.1 and less than or equal to 10 mg/L). The overall ranking of PCE based on chronic concerns is included in Exhibit 3-2.

Hydrocarbon Solvents

The hazard summaries for hydrocarbon solvents focus on the solvents used in drycleaning, which are mixtures of linear, branched, and cyclic carbon compounds that have different chemical/physical characteristics. Health data were predominately found for Stoddard solvent (ATSDR, 1995); however, it is believed that the other hydrocarbon solvents, 140°F solvent and DF-2000, would have similar health concerns. This is also true for the description of the environmental hazards of these solvents. Differences are expected, however, in flammability hazards, and these differences are noted.

Hydrocarbon Solvents Health Hazard Summary

It is not known to what extent Stoddard solvent taken by mouth will be absorbed, but comparisons to other petroleum products suggest that at least some of the substances that make up Stoddard solvent can be absorbed into the body through the gut. Stoddard solvent vapor or mist in the air is quickly absorbed into the body through the lungs. Stoddard solvent can also be absorbed into the body through the skin. Stoddard solvent that is absorbed by the body collects in body fat, but over time, it is gradually released from the fat and leaves the body. While in the body, some of the substances that make up the solvent can be changed to other substances by the body's metabolism. It is not known how much of the solvent is changed in this way, nor is much known about the nature of these changes.

Stoddard solvent in the air may be irritating to the eyes, nose, throat, and other moist exposed skin. At moderate levels, comparable to those at which workers are typically exposed, irritation is slight and few people are affected. At higher levels, the irritation becomes stronger and more people are affected. Studies in laboratory animals have shown that liquid Stoddard solvent applied directly to the skin produces moderate skin irritation. In one known case a worker whose skin was in contact with Stoddard solvent developed an allergic skin reaction.

People who breathe air containing Stoddard solvent or whose skin comes into contact with Stoddard solvent may also experience effects on the nervous system. In an experiment, volunteers who breathed air containing high levels of Stoddard solvent for a short period did not perform as well on nervous system tests, which measured reaction time and short-term memory, as people who had not been exposed. Workers exposed to Stoddard solvent have reported headaches, lightheadedness, fatigue, decreased color discrimination, and memory impairment. However, many of these workers were also exposed to other substances at home and work that could have contributed to these effects. Laboratory animals exposed to very high levels of Stoddard solvent in the air showed effects ranging from slowed reactions and incoordination to tremors, convulsions, and death. The levels that produced these effects were more than 10 times the levels to which workers are typically exposed.

It is not known if Stoddard solvent can produce cancer; the available studies in humans and animals were inconclusive. Stoddard solvent has not, however, been shown to interact with genetic material in short-term mutagenicity tests. It is also not known if Stoddard solvent can produce birth defects or interfere with reproduction in humans. Limited studies in laboratory animals have not shown that Stoddard solvent can produce these effects.

The hazard value to be used in the risk assessment (Chapter 5) is a NOAEL (no-observed-adverse-effect level) of 480 mg/m^3 (see Appendix D for details).

Hydrocarbon Solvents Environmental Hazard Summary

A search of the AQUIRE database for aquatic toxicity of Stoddard solvent and 140°F solvents yielded no information (USEPA, 1994). The World Health Organization (WHO) recently published an

Environmental Health Criteria document on Stoddard solvent (WHO, 1996). Limited aquatic toxicity data (acute only) show a range of both daphnid 48-hour LC_{50}s (0.42 to 2.3 mg/L) and fish 96-hour LC_{50} values (2-21 mg/L) under a variety of test conditions.

USEPA assessed the chemicals using SARs to estimate the inherent toxicity of these chemicals to aquatic organisms. The chemicals belong to the chemical class "neutral organics," for which there are predictive equations for estimating three acute and three chronic values. Hydrocarbon solvents are mixtures; the chemical constituents and the percentage of each in the hydrocarbon solvent mixture varies. The standard hazard assessment process using SARs is not appropriate for mixtures such as these, and therefore USEPA evaluated them in a slightly different manner. The constituents in these products include linear hydrocarbons and cyclic hydrocarbons, with the total number of carbons varying between 9 and 12. To measure the toxicity of the solvents, USEPA estimated the toxicity of each individual constituent and then evaluated the potential hazard of the product.

The estimated chronic toxicity values for the individual components (i.e., C_9 to C_{12} linear hydrocarbons and cyclic hydrocarbons) are given in Exhibit 3-3. Acute toxicity data could only be predicted for 9-carbon cyclic compounds (0.14, 0.19, and 0.14 mg /L for fish, daphnid, and algae, respectively); 10- and 11-carbon cyclic compounds (algae only, 0.04 and 0.02 mg/L, respectively); and for 9- and 10-carbon linear/branched compounds (algae only, 0.06 and 0.02 mg/L, respectively). To estimate the toxicity, the geometric mean of the predicted values was calculated. The geometric mean of estimated chronic values for fish, daphnids, and algae range from 0.005 to 0.028 mg/L, which constitutes a high concern for chronic effects.

Measured acute toxicity data for Stoddard solvent suggest chronic values of 0.04 mg/L for daphnids and 0.2 mg/L for fish. These are within a factor of 10 of the predicted acute toxicity values. Using either the measured or predicted values, there is a high concern to aquatic organisms.

Hydrocarbon Solvents Flammability Hazard

The NFPA (19xx) Fire Protection Guide to Hazardous Materials (10th edition) of the National Fire Protection Association (NFPA) ranks chemicals on a scale of 0 through 4 for flammability. Materials ranked 0 will not burn, and those ranked 4 include flammable gases, pyrophoric liquids, and flammable liquids. All of the hydrocarbon solvents covered in the CTSA are ranked 2, meaning that they must be moderately heated before ignition will occur and that they readily give off ignitable vapors.

Stoddard solvent is also considered ignitable based upon the standard outlined in 40 CFR §261.20 (Protection of the Environment, RCRA; Identification and Listing of Hazardous Waste, Characteristic of Ignitability). Under this standard, a chemical is considered ignitable if it "is a liquid, other than an aqueous solution containing less than 24 percent alcohol by volume and has a flash point less than 60°C." DF-2000 and 140°F solvent are considered to have a non-ignitable ranking.

Exhibit 3-3. Estimated Chronic Toxicity Values (mg/L) for Linear, Branched, and Cyclic Hydrocarbon Solvents[a]

Type of Molecule	No. of Carbons	Est. Log K_{ow}[b]	Fish Chronic Value	Daphnid Chronic Value	Algal Chronic Value
Linear or Branched	9	5.4	0.013	0.019	0.045
	10	6.0	0.004	0.008	0.021
	11	6.5	0.002	0.004	0.011
	12	7.0	None[c]	0.002	0.005
Geometric Mean			**0.005**	**0.006**	**0.015**
Cyclic	9	5.0	0.03	0.04	0.08
	10	5.6	0.01	0.02	0.04
	11	6.1	0.004	0.007	0.02
	12	6.7	0.001	0.003	0.009
Geometric Mean			**0.006**	**0.011**	**0.028**

[a] Estimates derived from SAR equation for neutral organics using number of carbons and LogK_{ow}.
[b] Estimated LogK_{ow} (octanol-water partition coefficient) taken from CLOGP Version 3.3 Program (Leo and Weininger, 1985).
[c] No effects expected in a saturated solution during the prescribed exposure period.

Data were not available to assess the potential for the hydrocarbon solvents to ignite and cause a fire incident. A search of the NFPA Fire Incident Database Organization for articles published in the *NFPA Journal* about incidents in drycleaning facilities in which Class II (flammability) combustible liquids were first ignited resulted in no identified incidents (Ahrens, 1998). Fire potential is a commonly recognized hazard of hydrocarbon solvents; however, the significance of that potential or of the differences in potential among the three hydrocarbon solvents is not addressed in this CTSA.

3.3.2 Machine Wetcleaning Technology

Machine wetcleaning detergent formulations are complex mixtures typically containing water and a variety of other different chemicals. Most formulations are trade secrets, and the concentrations of the individual chemicals are unknown to all but the manufacturer. The CTSA bases exposure estimates on two example detergent formulations developed for presentation in the CTSA (see Chapter 4 and Appendix E). Detergent #1 contains 10 constituents (plus water), and Detergent #2 contains 12 constituents (plus water). Seven constituents are common to both formulations, three are unique to Detergent #1, and five are unique to Detergent #2. It is not known how representative these chemicals are of those found in actual detergent formulations.

Health hazard summaries are presented for 10 of the 15 constituents found in the example detergents used in this CTSA. Hazard summaries are not provided for lauryl polyglucose, Aveda's fragrance, cocamphocarboxyproprionate, diazolidinyl urea, and methyl-2-sulfolaurate. Environmental hazard summaries are based upon SAR estimates. The summaries are designed to illustrate the potential range of effects that are associated with surfactant and surfactant aids that are found in machine wetcleaning detergents. The representativeness of these effects for actual formulations in not known. Some environmentally desirable chemical characteristics pertain to a number of different detergent components and may help guide those evaluating detergents.

Typically, the environmental profile of a chemical improves with its rate of biodegradation. However, it is equally important to consider the byproducts formed by the degradation process. These products can be more toxic than the parent compound.

Certain type of polymers have less potential to harm the environment than others. Nonionic (negatively charged) polymers are generally the least aquatically toxic; cationic (positively charged) polymers tend to have higher acute toxicity to aquatic organisms.

Generally, the potential for a molecule to be absorbed and harm an organism is lower the larger the molecule. Also, molecules that have straight carbon chains present less environmental concerns than those that are highly branched and tend to resist biodegradation.

The chemicals in the detergents considered in this hazard summary can be grouped into surfactants and surfactant aids. Surfactants are used to reduce the surface tension of water so that it may more thoroughly wet the surface to be cleaned (Soap and Detergent Association, 1998) and are the primary chemicals found in the example detergent formulation reviewed for this document. Surfactant aids may enhance the functions of the surfactants and can include components such as soil suspenders, pH adjusters, and solubilizers.

The CTSA examines the human health and environmental hazards of surfactants because they are the primary components of most detergents. In general, there are several characteristics of surfactants that may affect the degree to which human health and environmental effects are likely. These chemicals can differ in inherent toxicity, persistence, and bioaccumulation potential, any of which can be a concern. Surfactants that minimize these characteristics are presumed to be more desirable. A desirable property of surfactants is that they can be easily destroyed, either through conventional treatment processes or through biodegradation. Those that are easily destroyed are less likely to be persistent in the environment. For instance, linear alcohol ethoxylates (LAEs) biodegrade to linear alcohols and carboxylic acids, compounds of low environmental concern; alkylphenol ethoxylates, in contrast, may biodegrade under anaerobic conditions to alkylphenols, which persist in the environment and may be highly toxic to aquatic organisms. Also, LAEs are soluble in colder water and so may aid in the development of low temperature, energy-saving detergents.

The following are chemical specific hazard summaries for several surfactants included in the CTSA's example formulations, provided for illustrative purposes.

Surfactants

Cellulose Gum

Cellulose Gum Health Hazard Summary

The information in this summary is taken from CIR (1986a).

Cellulose gum does not appear to be absorbed into the body from the gut or through the lungs or skin and has been shown to be excreted entirely in the feces. The likelihood that exposure to cellulose gum would cause health effects is very low.

Cellulose gum has not been found irritating to the skin, lung, or eyes. Cellulose gum applied to the skin of humans does not appear to be irritating or to produce an allergic reaction. In a few studies, irritation was noted, but it was classified as mild at the worst. Repeated application of cellulose gum to the skin of laboratory animals caused only slight irritation and only in a few animals. Minimal or no eye irritation was noted in laboratory animals given various cosmetic products containing cellulose gum.

No adverse effects were found in people who swallowed cellulose gum regularly over a period of six months to three years. Studies with a variety of laboratory animals have shown that ingestion of large quantities of cellulose gum daily for several months did not cause any changes in behavior or other adverse effects. Similarly, inhalation of cellulose dust has not been shown to cause any toxic effects in exposed workers.

Laboratory animals given cellulose gum by mouth have shown no evidence of birth defects or interference with reproduction. Cellulose gum has been found not to interact with genetic material. There have been no carcinogenicity studies reported for cellulose gum.

Cellulose Gum Environmental Hazard Summary

The environmental hazard summary for cellulose gum is based on the SAR method described above and in Appendix B. Results for cellulose gum (Exhibit 3-2) suggest that it does not warrant concern as a hazard to the aquatic environment.

Cocamidopropyl Betaine (CAPB)

CAPB Health Hazard Summary

The information in this summary is taken from CIR (1991).

It is not known how readily CAPB is absorbed into the body through the gut, lungs, or skin, or how easily the body can change it to other substances or excrete it. Available information suggests that for humans, the most likely route of exposure to CAPB is through the skin.

For humans, CAPB has been found to cause skin irritation. Exposure of human skin to a soap formulation containing CAPB for several consecutive days produced minimal skin irritation, whereas longer exposure produced more severe irritation. In laboratory animals, skin application of CAPB solutions produced a range of irritation reactions, from no reaction to severe irritation, depending on the percentage of CAPB in the solution tested. Allergic reactions were not found in humans whose skin was exposed to several different formulations of CAPB. Several instances of apparent contact dermatitis in humans exposed to consumer products that contain CAPB have been reported, but recent evidence suggests that the major cause of this reaction is a different chemical present in the detergent formulation. Laboratory animals whose skin was exposed to CAPB have shown no or slight allergic responses. CAPB is potentially irritating to the eye. Laboratory animals exposed to varying concentrations of CAPB exhibited swollen eyelids and mild to moderate corneal irritation.

It is not known how long-term exposure to CAPB through ingestion, inhalation, or skin contact affects humans. When ingested by laboratory animals, CAPB does not appear to cause any serious health effects. Animals ingesting a single large dose or several doses of CAPB for one month exhibited only stomach or intestinal irritation. Moreover, when CAPB was applied to the skin of laboratory animals several times a week for 20 months, no serious health effects were observed.

There is no information on whether CAPB can affect the nervous system, interfere with reproduction, or produce birth defects. CAPB has not been found to interact with genetic material in short-term mutagenicity tests. There is no evidence that CAPB can cause cancer. CAPB was not carcinogenic in a mouse skin-painting study.

CAPB Environmental Hazard Summary

The environmental hazard summary for CAPB is based on the SAR method described above and in Appendix B. Results for CAPB (Exhibit 3-2) suggests that it warrants a moderate level of concern as a hazard to the aquatic environment.

Ethoxylated Sorbitan Monodecanoate

Ethoxylated Sorbitan Monodecanoate Health Hazard Summary

The information in this summary is taken from CIR (1984).

It is not known to what extent ethoxylated sorbitan monodecanoate (P-20) is absorbed into the body through the gut, lungs, or skin. If P-20 enters the body, it is broken down by the body. The fatty acid portion of the broken down substance remains in the body, is readily absorbed, and is broken down further to yield energy for important life processes. The remaining portion of the substance is poorly absorbed by body tissues and leaves the body unchanged. The most likely routes of exposure are by mouth and by skin contact. There is very little likelihood of inhalation exposure to P-20.

Skin contact with P-20 may cause little or no irritation in humans or animals. No evidence of allergic skin reactions was found in people whose skin had previously been in contact with P-20. However, skin exposure of laboratory animals to P-20 produced moderate to strong allergic reactions. In laboratory animals, P-20 produced no or mild irritation when it came into contact with the eyes.

Low to moderate amounts of P-20, taken by mouth by humans or animals on one or more occasions, produced no deaths or adverse effects. However, an extremely high dose given over a long period of time produced damage to the kidneys, spleen, and gut in one species of laboratory animal. It is not known if adverse effects occur in people who breathe air containing dusts of P-20.

There is no information on whether P-20 can affect the nervous system, produce birth defects, or interfere with reproduction. Based upon findings for other similar polysorbates, P-20 is not expected to interact with genetic material. Although P-20 is not a cancer-causing substance itself, it has been shown to enhance the activity of known cancer-causing substances and to inhibit tumor growth activity under certain conditions.

Ethoxylated Sorbitan Monodecanoate Environmental Hazard Summary

The environmental hazard summary for ethoxylated sorbitan monodecanoate is based on the SAR method described above and in Appendix B. Results (Exhibit 3-2) suggest that ethoxylated sorbitan monodecanoate warrants a moderate level of concern as a hazard to the aquatic environment.

Lauric Acid Diethanolamide (Lauramide DEA)

Lauramide DEA Health Hazard Summary

The information in this summary is taken from CIR (1986b).

It is not known how readily lauramide DEA is absorbed into the body through the gut, lungs, or skin, or how easily the body can change it to other substances or excrete it.

Contact of human skin with lauramide DEA may cause skin irritation. Exposure of human or animal skin to soaps containing lauramide DEA for several consecutive days produced minimal to moderate skin irritation. The degree of irritation depended on the percentage of lauramide DEA in the soap product. Laboratory animals exposed to skin products containing up to 25% lauramide DEA daily for several months showed only minimal skin irritation. However, very high concentrations of lauramide DEA caused severe skin irritation. Allergic reactions were not found in humans whose skin had been exposed to products containing lauramide DEA.

Lauramide DEA is irritating and potentially damaging to the eyes. Exposure of the eyes of laboratory animals to a low (1%) concentration of lauramide DEA produced only slight, temporary eye irritation. A moderate (5%) concentration of lauramide DEA produced moderate eye irritation, whereas a high (25%) concentration produced severe eye irritation and permanent damage in laboratory animals.

When lauramide DEA is taken by mouth, either in a single large dose or in many smaller doses over a long period of time, it does not appear to cause any serious health effects in laboratory animals. It is not known, however, if the same is true in humans. Laboratory animals fed moderate to high concentrations of lauramide DEA in their diets for three months showed changes in red blood cells, a temporary increase in blood sugar, or a decrease in body weight gain, due to decreased food consumption. A moderate (5%) dose of lauramide DEA in a skin cleanser was repeatedly applied to the skin of laboratory animals for 13 weeks. This dose produced minimal irritation but no evidence of other adverse health effects.

There is no information on whether lauramide DEA can affect the nervous system, produce birth defects, interfere with reproduction, or cause cancer. No interaction of lauramide DEA with genetic material was found in seven studies. One other study suggested that lauramide DEA may interact with genetic material in short-term mutagenicity tests.

Lauramide DEA Environmental Hazard Summary

The environmental hazard summary for lauramide DEA is based on the SAR method described above and in Appendix B. Results (Exhibit 3-2) suggest that lauramide DEA warrants a high level of concern as a hazard to the aquatic environment.

Sodium Laureth Sulfate

Sodium Laureth Sulfate Health Hazard Summary

The information in this summary is taken from CIR (1983).

Sodium laureth sulfate is readily absorbed through the gut after intake by mouth, but is poorly absorbed through the skin. Studies in laboratory animals have shown that most of the sodium laureth sulfate taken by mouth is excreted in the urine, with small amounts appearing in the feces and in exhaled air.

Sodium laureth sulfate has been shown to produce skin and eye irritation at concentrations above 5%. Sodium laureth sulfate applied to the skin of humans or animals produced mild skin irritation. Skin application of consumer products that contained sodium laureth sulfate produced no irritation to severe irritation in humans and animals, depending on the concentration of sodium laureth sulfate in the product. Sodium laureth sulfate did not produce allergic skin reactions when applied to the skin of laboratory animals as a solution in water or when applied to animal or human skin in consumer product formulations. Application of sodium laureth sulfate to the eyes of laboratory animals produced severe eye damage in some animals and no damage in others.

A study of laboratory animals fed diets containing moderate concentrations of sodium laureth sulfate for two years showed no effects except an unexplained weight loss in males. A high concentration of sodium laureth sulfate applied daily to skin with other unspecified substances for 65 days produced severe irritation, hair loss, and death in laboratory animals. At lower concentrations, there were severe skin changes but no deaths.

Studies in laboratory animals suggest that sodium laureth sulfate taken by mouth does not produce birth defects, interfere with reproduction, or cause cancer, and that sodium laureth sulfate applied to the skin does not cause cancer. It is not known if sodium laureth sulfate interacts with genetic material.

Sodium Laureth Sulfate Environmental Hazard Summary

The environmental hazard summary for sodium laureth sulfate is based on the SAR method described above and in Appendix B. Results for sodium laureth sulfate (Exhibit 3-2) suggest that it warrants a moderate level of concern as a hazard to the aquatic environment.

Sodium Lauryl Isethionate (SLI)

SLI Health Hazard Summary

The information in this summary is taken from CCRIS (1995).

Hazard information on SLI is very limited. It is not known how rapidly SLI is absorbed into the body through the gut, lungs, or skin or if SLI is changed into other substances by the body. Available information suggests that SLI may not be a skin irritant and does not interact with genetic material in short-term mutagenicity tests. It is not known if SLI produces birth defects, interferes with reproduction, produces cancer, affects body organs, produces effects on the nervous system, or can produce an allergic response.

SLI Environmental Hazard Summary

The environmental hazard summary for SLI is based on the SAR method described above and in Appendix B. Results for SLI (Exhibit 3-2) suggest that it warrants a moderate level of concern as a hazard to the aquatic environment.

Surfactant Aids

Surfactant aids serve a variety of purposes in the detergent formulation, including builders. These chemicals vary in their potential to cause health and environmental effects. For instance, inorganic phosphates, once commonly used in detergents as builders, are algal nutrients that can cause algal “blooms” (a large increase in algae) in fresh water. The blooms eventually die off, depleting dissolved oxygen in the water; low oxygen levels diminish water’s ability to support many forms of life. Substitution of organic chemicals for inorganic phosphates as detergent builders can avoid this problem and offer a better environmental choice.

Acetic Acid

Acetic Acid Health Hazard Summary

The information in this summary is taken from HSDB (1994).

Acetic acid can be absorbed into the body through the gut after intake by mouth and through the lungs of people exposed to acetic acid vapors or mists in air. It is not known if acetic acid is absorbed into the body from the skin. Once in the body, acetic acid is readily changed by the body into other substances.

The dilute form of acetic acid (under 6%) is commonly known as “vinegar.” Depending on concentrations, exposure to acetic acid results in various levels of irritation when taken by mouth, inhaled, or applied to the skin. Laboratory animals given strong solutions of acetic acid by mouth showed stomach inflammation and damage. Exposure of human skin to acetic acid may cause ulcers, burns, and inflammation of the skin. Exposure of the skin of animals or humans to high concentrations of acetic acid may produce severe irritation. However, when low concentrations of acetic acid came in contact with the skin of animals, they exhibited no potential for causing irritation. Allergic skin reactions to acetic acid, although rare, have been reported in people. Immediate pain and eye injury have resulted from splashing of a dilute solution of acetic acid into the eye. Permanent eye damage occurred in people whose eyes were exposed to undiluted acetic acid.

Workers exposed to high concentrations of acetic acid in the air have exhibited effects such as inflammation of the lungs, throat, and eyes; erosion of the teeth; enlargement of lymph nodes; swelling of the eyelids; digestive disorders; dry or blackened skin; and swelling of the skin. Animal studies (one to four months in length) in which moderate to high levels of acetic acid were used resulted in weight loss (dermal exposure) and stomach lesions (exposure via drinking water).

One study analyzed pregnant laboratory animals given dilute acetic acid by mouth and found no evidence of birth defects. Available information suggests that acetic acid does not interact with genetic material in short-term mutagenicity tests. However, it is not known conclusively if acetic acid interferes with reproduction in humans or animals.

No direct information was found on the ability of acetic acid to cause cancer in humans or animals. A long-term study in which laboratory animals were fed sodium acetate, a salt of acetic acid, found no evidence of tumors.

Acetic Acid Environmental Hazard Summary

The environmental hazard summary for acetic acid is based on the SAR method described above and in Appendix B. Results for acetic acid (Exhibit 3-2) suggest that it warrants a low level of concern as a hazard to the aquatic environment because after treatment the chemical will be released at pH 7. At this pH the chemical is neutral without acid reaction.

Citric Acid and Sodium Citrate

Citric Acid/Sodium Citrate Health Hazard Summary

The information in this summary is taken from HSDB (1994).

Citric acid is normally produced by the human body and occurs naturally in many foods, such as fruits. It is not known to what extent citric acid or sodium citrate is absorbed through the gut or lungs.

Neither citric acid nor sodium citrate, a salt of citric acid, is expected to be absorbed through the skin. Once in the body, sodium citrate is changed to a different substance and is excreted through the urine.

Citric acid is unlikely to cause harmful effects unless large quantities are consumed. Frequent or excessive intake of citric acid by mouth has produced erosion of tooth enamel, local irritation of the mouth, or ulcers in people. People have reported stomach irritation and stomach disturbances after drinking sodas containing citric acid.

Citric acid can be irritating to the nose, throat, or lungs of people who inhale mists or dusts of citric acid from the air. It can also irritate the eyes or skin if direct contact occurs. Strong solutions of citric acid were a mild skin irritant and severe eye irritant to laboratory animals.

Studies in laboratory animals suggest that exposure to citric acid does not produce birth defects or interfere with reproduction. It is not known from experiments if citric acid produces effects on the nervous system, interacts with genetic material, or produces cancer in humans or animals.

Citric Acid/Sodium Citrate Environmental Hazard Summary

The environmental hazard summary for citric acid/sodium citrate is based on the SAR method described above and in Appendix B. Citric acid and its soluble salts, such as sodium (Na) and potassium (K), at pH 7 are expected to be moderately toxic to green algae in freshwater environments (acute toxicity values are greater than 1 ppm but less than 100 ppm).

The average acute toxicity values for freshwater fish and freshwater aquatic invertebrates are expected to be greater than 100 mg/L.

The most sensitive organism is freshwater green algae, especially in soft freshwater. The average toxicity value (i.e., 96-hour EC_{50} for growth) is expected to be between 3 and 10 mg/L. The chronic value (i.e., the concentration that begins to inhibit the growth of algae) is expected to be between 0.3 and 1 mg/L. At concentrations less than the chronic value, citric acid actually is essential for algae growth. Citric acid is indirectly toxic to algae through over-chelation of nutrient elements necessary for the growth of algae (i.e., citric acid chelate calcium, magnesium, and iron ions) and prevents algae from absorbing enough of these nutrients needed for adequate growth.

In hard water (i.e., hardness equal to or greater than 150 mg/L as calcium carbonate) citric acid is not as toxic. When citric acid is chelated with calcium its toxicity has been mitigated; it is then exposed to algae as the calcium salt and can no longer chelate calcium and other nutrient elements that algae need for growth.

Toxicity of citric acid toward marine algae should be lower than it is for freshwater green algae because of the much higher hardness of sea water as compared to freshwater.

Citric acid has a low potential to bioconcentrate because it is negatively charged and very water-soluble. Therefore, food chain transport should be minimal.

Results for citric acid/sodium citrate (Exhibit 3-2) suggest that it warrants a moderate level of concern as a hazard to the aquatic environment.

Sodium Carbonate

Sodium Carbonate Health Hazard Summary

The information in this summary is taken from CIR (1987).

If sodium carbonate is taken by mouth, it reacts with acids in the stomach to produce carbon dioxide, which is released in expired air. Sodium carbonate can be absorbed into the body through the lungs if it is present in air as a mist, but is not expected to be absorbed through the skin.

It is not known if sodium carbonate is irritating to the mouth or stomach if ingested. Sodium carbonate has been found to be irritating if inhaled or applied to the skin. Laboratory animals that were exposed to mists containing high concentrations of sodium carbonate for a short period of time experienced difficulty in breathing, shortness of breath, wheezing, excessive salivation, swelling of the abdomen, and sometimes death, due to changes or damage to the lungs and respiratory tract. Human skin exposures to bar-soap products containing a low concentration of sodium carbonate resulted in weak irritation but not allergic skin reactions. Application of a high concentration of sodium carbonate to intact skin did not produce skin irritation in people or laboratory animals, but application of the same concentration to abraded skin produced moderate skin irritation in people and one animal species, and tissue destruction in some people. When sodium carbonate was placed into the eyes of laboratory animals, it produced redness often accompanied by a discharge.

Workers who were repeatedly exposed to moderate concentrations of sodium carbonate dusts in air experienced severe skin irritation, skin diseases, eye irritation, and upper respiratory irritation. Damage to the lungs was found in laboratory animals that were repeatedly exposed to low concentrations of sodium carbonate mists.

Studies in laboratory animals suggest that sodium carbonate does not produce birth defects. There is no information on whether sodium carbonate interferes with reproduction, produces cancer, produces effects on the nervous system, or interacts with genetic material in humans or animals.

Sodium Carbonate Environmental Hazard Summary

The environmental hazard summary for sodium carbonate is based on the SAR method described above and in Appendix B. Results for sodium carbonate (Exhibit 3-2) suggest that it warrants a moderate level of concern as a hazard to the aquatic environment.

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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.

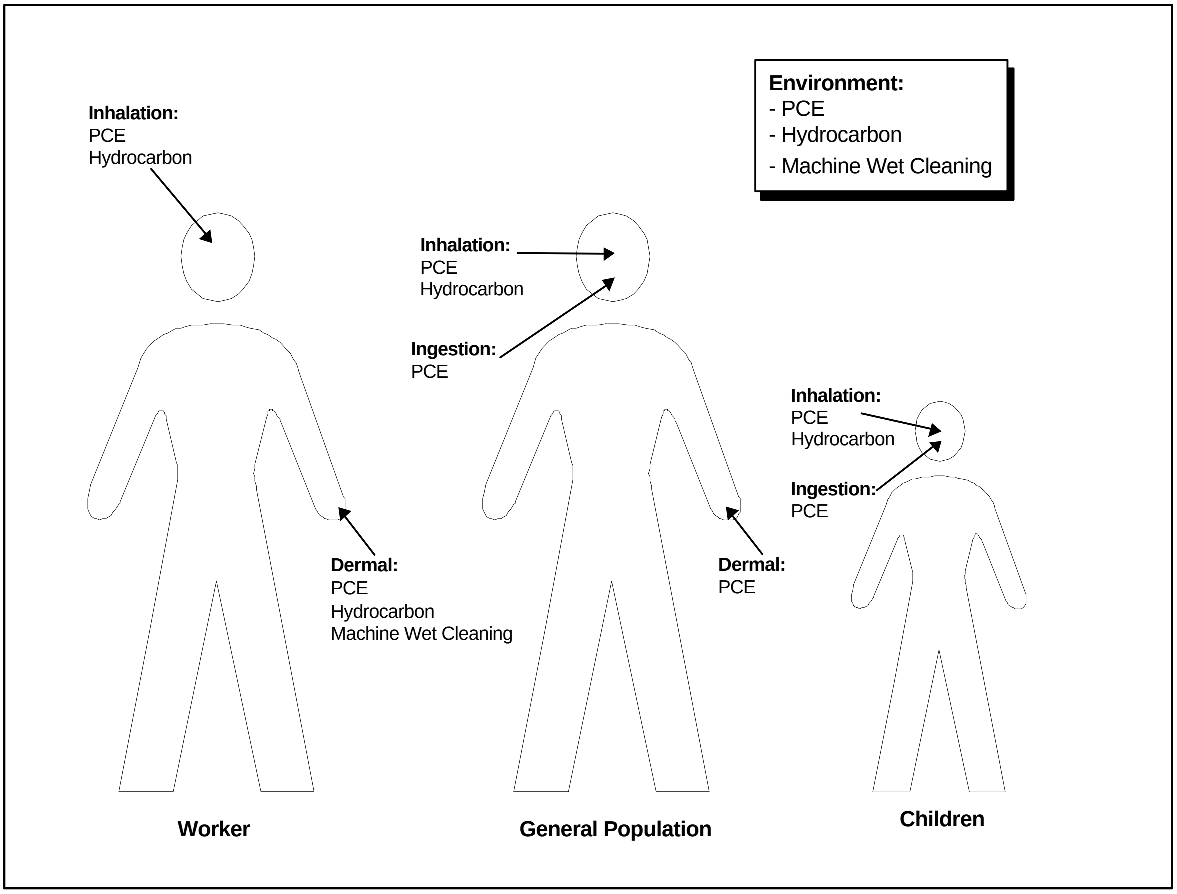
4.3 EXPOSURE OVERVIEW

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 Machines	Worker Job Title (n = number of samples)	TWA PCE Concentration, in ppm [in mg/m^3]		SSD
			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 ($\alpha = 0.05$).

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

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[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^{o}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 x 10^{-8} to 1 x 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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CHAPTER 5
RISK

This chapter integrates the hazard, dose-response, and exposure assessments for several major commercial clothes cleaning processes into a risk assessment for each of the cleaning processes and characterizes the risks as to key issues, major assumptions, and uncertainties. Section 5.1 provides definitions of terms common to risk assessment and descriptions of methodologies. Section 5.2 presents estimates of potential risks to workers, co-located residents (i.e., residents in buildings with drycleaning facilities), and the general population, as well as environmental risks from perchloroethylene (PCE). Section 5.3 estimates potential risks from drycleaning operations using hydrocarbon (HC) technology. Section 5.4 evaluates the risks associated with machine wetcleaning.

CHAPTER CONTENTS

5.1 RISK CHARACTERIZATION—INTRODUCTION

5.1.1 Scope of the CTSA Risk Assessments

This chapter integrates the hazard, dose/response, and exposure assessments for several commercial clothes cleaning technologies into a risk assessment for each of the cleaning processes and characterizes the risks as to key issues, major assumptions, and uncertainties. A summary and characterization of risk are given for each of the following cleaning processes: drycleaning with PCE; drycleaning with HC; and machine wetcleaning. When information is available, risks for exposures to different machinery within processes are also addressed.

The risk assessments were conducted at a “screening level” of review, using readily available information and standard analyses for completion. The risk assessments and characterizations should give an idea of the risks to human health and the environment associated with each of the processes and offer a basis for comparison. However, since the extent and type of hazard and exposure data and uncertainties associated with each process differ widely, the risk comparisons among processes will give only a general, “ballpark” type of comparison. Information is developed with the intent of identifying the types of potential health and environmental risks associated with various clothes cleaning technologies to allow clothes cleaners to better understand the potential implications of technology choices. The information is organized to provide general background on terminology and elements of risk assessment and to present general risk characterizations for individual technologies.

5.1.2 Background Information on Human Risk Assessment Methodology

This section presents general information to increase understanding of the risk assessment process used in this CTSA document. The principles of the risk assessment process are defined, and general methodologies used in classifying potential human health risk are explained. (A description of ecological risk methodology is given in Appendix B.)

Definitions—Risk Assessment

A risk assessment is an interactive process that generally includes the following components of analysis:

> *(1) Hazard Assessment & Characterization*, the process of determining whether or not exposure to a chemical can cause adverse health effects in humans. It includes explanation of the evidence of toxicity and describes major points of interpretation and assumptions. In addition, it explains strengths and weaknesses of the data and analyses, as well as major uncertainties.
>
> *(2) Dose-response Assessment & Characterization*, the process of defining the relationship between the dose of a chemical received and the incidence and severity of adverse health effects in the exposed population. From a quantitative dose-response relationship, toxicity values are derived and used in the risk characterization step to estimate the likelihood of adverse effects occurring in humans at different anticipated exposure levels. It includes explanation of key scientific issues and assumptions, strengths and weaknesses of the data and analyses, and major uncertainties.
>
> *(3) Exposure Assessment & Characterization*, which identifies populations exposed to a chemical, describes their composition and size, and presents the types, magnitudes, frequencies, and durations of exposure to the chemical. It includes discussion of key issues, description of methods used, and strengths and weaknesses of the data and analyses. Major uncertainties are also discussed.
>
> *(4) Risk Characterization*, which integrates hazard, exposure, and dose-response information into qualitative and/or quantitative expressions of risk. A risk characterization includes a description of the major assumptions and key issues, scientific judgments, strengths and weaknesses of data and analyses, and the uncertainties embodied in the assessment.

Methods—Expressions of Human Health Risk

The manner in which estimates of hazard and risk are expressed depends on the human health endpoint of concern and the types of data upon which the assessment is based. Overall, cancer risks are most often expressed as the probability of an individual developing cancer over a lifetime of exposure to the chemical in question. Risk estimates for adverse effects other than cancer are not expressed as probabilities of occurrence; instead, a concentration or dose associated with the presence or absence of a specific toxic endpoint of concern is compared to an estimated dose or exposure level for the population considered. This comparison is expressed as a ratio, which is an indicator of the margin by which the population's exposures differ from (exceed or not) levels where individuals are expected to be free of adverse/deleterious effects. A key distinction between cancer and other toxicologic effects is that *most* carcinogens are generally assumed to have no dose threshold; i.e., no dose or exposure level can be presumed to be without some risk. Other toxicologic effects are generally assumed to have a dose threshold; i.e., a dose or exposure level below which a significant adverse effect is not expected.

Sometimes understanding a process requires characterization of a mixture of chemicals, rather than a single one. Under ideal circumstances, information would be available for the mixture or formulation.

More typically, information is available on at least some ingredients (components). Often, certain components are exchangeable, with selection based on their function in the process, but with exposure and toxicity properties unique to the selection. In Section 5.4, information on examples of these selections will be provided for the machine wetcleaning process. Quantitative assessment of mixtures using their components often relies on the assumption that the components produce their toxicities independently; information on ways one or more components may modify others is incorporated qualitatively. Mixtures with just a few ingredients may be characterized more readily than mixtures with many dissimilar ingredients.

Quantitative Expressions of Risk - Not all substances evaluated for the CTSA have been reviewed previously or have sufficient data available for quantitative expressions of risk. Only PCE has such information for cancer. Only PCE and some hydrocarbon solvents have such information for quantitative expression of other risks.

Cancer Risk Assessment

USEPA employs a “weight-of-evidence” approach to determine the likelihood that a chemical is a human carcinogen. The USEPA’s Cancer Risk Assessment Guidelines (USEPA, 1986) and in particular, its proposed cancer guidelines (USEPA, 1996), emphasize the use of all pertinent information, not just tumor findings in animals or humans, in making a decision about a chemical agent’s carcinogenic potential. This recognizes that information about mode of action of carcinogenic agents at the cellular and sub-cellular levels, as well as toxicokinetic and metabolic process information, should play an important role in evaluating carcinogenic toxicity. According to the 1986 guidelines, EPA describes a chemical’s carcinogenic potential by placing it in one of five weight-of-evidence categories [from Group A (human carcinogen) to Group E (evidence of noncarcinogenicity for humans)] and providing a “basis” statement. The 1996 proposed guidelines recommend major categories (and subcategories) that would be more informative by requiring a brief narrative of information on all the evidence available to be included with each category. In extracting information for this chapter, the CTSA, as a screening level assessment, has aimed to incorporate the spirit of the narrative approach rather than categories per se.

Cancer Risk Indices -Where the available data are sufficient for dose-response assessment, EPA has developed an estimate of the chemical’s carcinogenic potency. An oral “slope factor” expresses carcinogenic potency in terms of the estimated incremental upper bound excess lifetime risk per mg/kg average daily dose ingested. “Unit risk” is a similar measure of potency for air or drinking water concentrations and is expressed as risk per µg/m^3 in air or as risk per µg/L in water for continuous lifetime exposures. Underlying the unit risk concept is the assumption that the relationship between dose and level of excess risk is linear; that is, for a given incremental change in dose, there is a proportional change in estimated risk level. This is referred to as the “linear at low dose” approach throughout this assessment. The unit risk or slope factor is regarded as an upper bound on the incremental lifetime excess cancer risk because it is derived in a way intended to account for experimental variability and extrapolation uncertainties. The lower bound on lifetime excess cancer risk is always recognized to be as low as zero. As described in Appendix D, where possible the experimental data can be used to estimate a magnitude of excess risk, but can only suggest how well the upper bound reflects true excess.

Cancer excess risk is calculated by multiplying the estimated dose or exposure level by the appropriate measure of carcinogenic potency. For example, an individual with a lifetime average daily dose of 0.3 mg/kg of a carcinogen with a slope factor of 0.02 per mg/kg/day would experience a lifetime excess cancer risk of 0.006 [6 X 10^{-3} or a risk of 6 in 1000] from exposure to that chemical. These risks are identified as incremental over background; i.e., beyond those ordinarily sustained by the general population with no particular exposure to the chemical. In general, risks from exposures to more than one carcinogen are assumed to be additive, unless information points toward a different interpretation; that is, when available, component quantitative estimates may be summed to obtain the mixture's estimate.

Risk Assessments for Human Health Toxicities Other Than Cancer

Because adverse effects other than cancer and gene mutations are generally assumed to have a dose or exposure threshold, a different approach is widely used to evaluate potential risk for these non-cancer effects, such as liver toxicity, neurotoxicity, and kidney toxicity. EPA uses the Reference Dose (RfD) or Reference Concentration (RfC) approach to evaluate such chronic effects. The RfD or RfC is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime" and is expressed as a mg/kg/day dose or mg/m^3. The RfD or RfC is usually based on the most sensitive known effect; i.e., the effect that occurs at the lowest dose. The basic approach for deriving an RfD or RfC involves determining a "no-observed-adverse-effect level (NOAEL)" or "lowest-observed-adverse-effect level (LOAEL)" from an appropriate animal study or human epidemiologic study, and applying various uncertainty and modifying factors to arrive at the RfD/RfC. Each factor represents a specific area of uncertainty. For example, an RfD based on a NOAEL from a long-term animal study might incorporate a factor of 10 to account for the uncertainty in extrapolating from the test species to humans, and another factor of 10 to account for the variation in sensitivity within the human population. An RfD based on a LOAEL typically contains yet another factor of 10 to account for the extrapolation from LOAEL to NOAEL. An additional modifying factor (between 1 and 10) is sometimes applied to account for uncertainties in data quality.

To characterize potential risk of adverse health effects other than cancer, a "Hazard Quotient" method is calculated. A "Hazard Quotient" is the ratio of the estimated chronic dose/exposure level to the RfD/C. Hazard Quotient values below unity imply that adverse effects are very unlikely. The more the Hazard Quotient exceeds unity, the greater the level of concern. It is important, however, to remember that the Hazard Quotient is not a probabilistic statement of risk. A quotient of 0.001 does not mean that there is a one-in-a-thousand chance of the effect occurring, it just means that the event is "very unlikely to occur." Furthermore, it is important to remember that the level of concern does not necessarily increase in a linear manner as the quotient approaches or exceeds unity, because the RfD/C does not provide any information about the shape of the dose-response curve.

In general, the index of a mixture is derived by summing the Hazard Quotients for each of its components. Risks from exposures to more than one chemical are considered individually for each type of toxicity and organ affected.

An expression of risk that can be used with non-cancer toxicity evaluations when an RfD/C is not available is a ratio of the expected exposure to a NOAEL or LOAEL from an animal or human study (preferably a chronic study). This alternate approach is meant to determine the proximity of the exposures from the various scenarios for humans to the animal or human experimental range. As with the Hazard

Quotient, it is important to remember that this ratio is not a probabilistic statement of risk. Further, if the ratio is based on a LOAEL, even a ratio of unity may not indicate low concern.

Interpreting the Risk Results: Risk Estimates in the Tables and Text

The tables present Risk Indices for cancer risk and Hazard Quotients for non-cancer risks. The Risk Indices are an estimate of individual cancer risk above background level (and are expressed, for example, as 1×10^{-2} or a 1 in 100 risk). The Hazard Quotients are ratios of the expected human exposure to RfC or RfD values.[1] Hazard Quotients above 1 (which indicate exposure values greater than the RfC or RfD) are considered less likely to be free of deleterious effects.

In general, the index of a mixture is derived by summing the component Hazard Quotients. Risks from exposures to more than one chemical are considered individually for each type of toxicity and organ affected. When the component RfD/Cs reflect different toxicities or target organs, an index analogous to the Hazard Quotient can be formed, using a target organ toxicity dose based on NOAELs or modeled levels (Mumtaz et al., 1997). A sum based solely on all the component RfD/Cs is believed to be high for specific organ toxicities. Thus, there may be several quantitative indices for a particular formulation. When each index is less than 1, and all relevant effects have been considered and are believed to be independent, it may be more appropriate to consider the formulation free of significant toxicity overall than when the indices are less than 1 but important information is missing (such information might indicate that the ingredients interact). Such an analysis is usually not conducted when some components do not have RfD/Cs.

Exhibit 5-1 summarizes the different exposure scenarios evaluated by the CTSA in Chapter 4, which are considered for discussion of risk in this chapter.

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[1] Note: the provisional occupational RfC used in the Hazard Quotients dealing with occupational exposures of PCE differs from the provisional RfC used for all other PCE exposure scenarios, and any RfC in non-PCE exposure scenarios. This is due to the use of an uncertainty factor of 10 only, in the derivation of the provisional RfC for the PCE occupational scenario (see Appendix D).

Exhibit 5-1. Exposure Scenarios Evaluated for Human Health Effects

Exposed Population	Exposure Routes and Pathways					
	Inhalation Exposure		Ingestion Exposure		Dermal Exposure	
	Residence	Workplace	Nursing (Infants)	Drinking Water	Bathing	Workplace
Perchloroethylene						
Workers		✓				✓
Co-located Adults	✓			✓	✓	
Co-located Elderly, Infants and Children	✓		✓			
General Population - Adults	✓			✓	✓	
General Population - Elderly, Infants and Children	✓					
Hydrocarbons						
Workers		✓				✓
General Population - Adults	✓			✓		
General Population - Elderly, Infants and Children	✓			✓		
Machine Wetcleaning Chemicals						
Workers						✓

✓ Indicates that this pathway-population combination is considered in the CTSA

5.2 DRYCLEANING USING PERCHLOROETHYLENE (PCE)

5.2.1 Human Health

Human data indicate that PCE is absorbed into the body via inhalation, from the gastrointestinal tract following ingestion, and through the skin. There is human evidence indicating that PCE can cause neurotoxicity and kidney effects, and animal data show that PCE can cause other effects, including cancer, developmental toxicity, and liver effects. Toxicity comparison values for use in risk assessment are shown in Exhibit 5-2.

Exhibit 5-2. Toxicity Comparison Values for PCE Risk Assessment

Effect	Toxicity Value	Toxicity Value Type	Basis for Toxicity Value: Species/ Duration/Route
Cancer[a]	0.00071 per mg/m^3	Unit risk	Mouse and rat 2 year inhalation bioassay+ inhalation metabolism information[c]
Cancer[a]	270 mg/m^3	ED_{10}	Mouse and rat 2 year inhalation bioassay + inhalation metabolism information[c]
Cancer	.051 per mg/kg/day	Oral Slope factor	Mouse 2 year gavage bioassay + gavage metabolism information[d]
Critical effects (i.e., most sensitive effects)	0.01 mg/kg/day	RfD	Mouse 6 week gavage study (liver)[e]
	0.17 mg/m^3	"RfC_{PCE}"[b]	"RfC": Human cross-sectional occupational study (renal)[f]

[a] Derivation of the unit risk and ED_{10} values are described in Appendix D. Unit risk is 7.1×10^{-7} per µg/m^3, which is converted to mg/m^3 by multiplying as follows:
7.1×10^{-7} per µg/m^3 x 1,000 µg/mg = 7.1×10^{-4} per mg/m^3, or 0.00071 per mg/m^3.

[b] RfC_{PCE} is a provisional RfC developed specifically for use in this document. Unlike the other RfCs and RfDs in this document, it has not undergone formal USEPA review and approval. Details on the derivation of the provisional RfC can be found in Appendix D.

[c] NTP (1986).

[d] NCI (1977).

[e] ATSDR (1993), Buben and O'Flaherty (1985), IRIS (1997).

[f] Franchini et al. (1983).

5.2.2 Human Health Risks

Risk—General

In this section, the hazards and dose-response relationships of PCE are integrated with individual exposure scenarios to address potential risks of PCE to humans and the environment. These risks are presented in tables and discussed with each exposure scenario.

For PCE, in addition to the linear at low dose approach described in Section 5.1.2, a second approach is used. As discussed in Appendix D, questions remain as to the appropriate use of a linear model to represent relative cancer risks at low exposures to PCE. Therefore, a measure of relative risk, suggested by USEPA (1996), is also used in this assessment. This is called the Margin of Exposure (MOE) nonprojection approach (see Appendix D). The intent of the nonprojection approach is to determine the proximity of the exposures from the various scenarios for humans to the animal experimental range, roughly represented by the ED_{10}, the **dose** (in human equivalents) associated with an estimated **excess** tumor response in 10% of an experimental group. [Note: the acronym ED_{10} has no relation to the acronym ED (exposure duration) used extensively in Chapter 4.] The comparison is evaluated by the ratio of the ED_{10} to expected exposure. The ratio is evaluated in this direction because it is hoped that exposures will be far from the range where an excess 10% of the population would show cancer, and a large ratio will be easier to evaluate. Again, the aim of using any approach is to highlight those PCE exposure scenarios that may warrant the most attention for possible risk reduction.

Quantitative Expressions of Risk—Cancer Risk Indices

Relative indices of cancer risk to exposed population groups are presented for various exposure scenarios. These indices are derived as follows:

- For each exposure scenario, an estimated inhalation exposure of PCE in milligrams per cubic meter (mg/m^3) is averaged over a lifetime to generate a Lifetime Average Daily Concentration (LADC). [Footnote “a” in Exhibit 5-3 gives an example of such a calculation.]

- The calculated LADCs are multiplied by the unit risk of 0.00071 per mg/m^3 (unit risk is defined in section 5.1.2) to give linearly-based upper bound lifetime excess risks, called “linear risk indices” hereafter; or divided into the ED_{10} of 270 mg/m^3 to give MOE indices.

In comparing scenarios in these exhibits, one linear risk index value is of greater concern than another if it is **larger,** e.g., 2×10^{-3} (0.002) is of more concern than 5×10^{-4} (0.0005).

When considering oral exposure scenarios, the Lifetime Average Daily Dose (LADD) is used (see footnote “a,” Exhibit 5-7, for sample calculation) instead of the LADC. The LADD is multiplied by 0.051 per mg/kg/day, the slope factor used for oral exposure to PCE (USEPA, 1985), to give a linear risk index value.

The comparison toxicity values and cancer comparison values for use in risk assessment are shown in Exhibit 5-2. These values are compared with predicted (modeled) human exposures to determine whether any of the PCE exposure scenarios poses a concern for cancer or non-cancer effects to the people exposed.

Routes of Exposure

Inhalation

Human exposure to PCE occurs in three ways; inhalation, oral, and dermal. By far, inhalation exposure is the most significant route of exposure. PCE is well absorbed from the lung following inhalation exposure. For purposes of this risk assessment, inhalation and oral doses are assumed to be absorbed 100% into the body.

Oral

Oral exposure to PCE may occur from ingestion of contaminated drinking water or foods (not evaluated here), or from ingestion 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).

Dermal

Dermal absorption is possible from activities that require contact with PCE, as might occur in occupational settings. Dermal absorption can occur not only from direct contact with the liquid, but also from contact with the vapor in the air. Dermal absorption from the liquid state can be modeled. Dermal absorption from vapor may be estimated as approximately equal to the amount absorbed by the inhalation route at low exposure levels (e.g., 58 ppm); or it may be as low as 1% of the amount absorbed by the inhalation route at higher doses (e.g., 600 ppm) [McDougal et al., 1990; Riikimaki and Pfaffli, 1978; as cited in Keifer 1998. Refer to Appendix C.]

5.2.3 Occupational Risks—Drycleaning Workers

Risk from PCE Inhalation

The number of workers exposed to PCE in drycleaning facilities is estimated to be between 119,000 and 278,000 (Chapter 4). The most significant route of exposure for workers is expected to be from inhalation of PCE, although they may also experience dermal exposure. Several data sets provided maximum exposure concentrations (ECs) for PCE inhalation by drycleaning workers. Average ECs were also provided in some of these data sets, and calculated from others. The data are discussed extensively in Chapter 4 and illustrate variations in worker inhalation exposures due to factors such as machine type and controls, number of machines, job category, and date of PCE exposure. In general, increased exposures to PCE would result in an increase in health risk. Therefore, indications (as summarized in Chapter 4) that there are higher PCE exposures for operators/cleaners compared with other job categories; and for workers exposed to transfer machines compared with dry-to-dry machines; and for workers exposed to more than one machine, are also indications for increased health risks to these workers. On the other hand, indications (Chapter 4) that there has been a general decrease in drycleaning exposures to PCE over the past decade, and that new,“fifth generation” machines result in lower worker exposures, indicate health risks can be decreased for workers in those situations. The extent of such trends is variable and is not estimated for this CTSA.

Two studies That include the largest numbers of measurements (OCIS, 1994, 1998; and IFI, 1990) are used for the purpose of assessing workers' risk. The data from these two sources are presented in Exhibits 5-3 and 5-4 and discussed below.

Exhibit 5-3. Occupational Health Risks Via Inhalation to Workers Based on Post-1990 OSHA Monitoring Data for PCE Drycleaning

Job Description #1	Geometric Mean EC[e] (mg/m^3) (±) GSD #2	Maximum EC (mg/m^3) #3	LADC[a] (mg/m^3) #4	Cancer Risk Index[g] (Unit risk[b] x LADC) #5	Non-Cancer Hazard Quotient[f] LADC / Prov. Occ. RfC #6
1990 to1993					
All Jobs [N=386]	69 ± 62	5,000	14	1 x 10^{-2}	8.2
Cleaner [N=157]	80 ± 76	5,000	16	>1 x 10^{-2} [d]	9.5
Spotter [N=37]	53 ± 77	1,100	10	7 x 10^{-3}	5.8
Manager [N=43]	250 ± 31	4,300	49	>1 x 10^{-2} [d]	1.7
Presser [N=41]	37 ± 39	470	7	5 x 10^{-3}	4.1
1997					
All Jobs [N=40]	42 ± 51	2,500	8	6 X 10^{-3}	4.5

[a] LADC = Exp. x $\frac{10\ m^3}{20\ m^3}$ x $\frac{250\ days}{365\ days}$ x $\frac{40\ years}{70\ years}$

where Exp. = Mean exposure concentration (occupational exposure) in mg/m^3

$10\ m^3$ = Volume of air inhaled during an 8 hr workday

$20\ m^3$ = Volume of air inhaled in 24 hours

250 days = Days worked per year for the average worker (this is not the same as the number of days the facility is in operation)

365 days = Days per year

40 years= Years worked in a lifetime

70 years = Average lifetime

[b] The Unit Risk is 0.00000071 per $\mu g/m^3$ x 1,000 µg/mg = 0.00071 per mg/m^3.

[c] ED_{10} = 270 mg/m^3

[d] The LADC exceeds the limit for use of the unit risk

(Note: when LADC exposure levels are >14 mg/m^3, the unit risk should not be used ; therefore, the risk indices are listed as >1 X 10^{-2} , see Appendix D).

[e] The geometric means are used because these have been used historically with occupational data. A geometric mean gives a feel for the median or 50th percentile of values. GSD= Geometric Standard Deviation.

[f] Provisional occupational RfC = 1.7 mg/m^3 TWA (see Appendix D) Sample HQ: "All Jobs" : HQ = 14 mg/m^3/ 1.7 mg/m^3 = 8.2.

[g] Cancer risk index = upper bound lifetime excess cancer risk.

Exhibit 5-3 presents data on PCE inhalation collected by OSHA during compliance inspections or complaint investigations for 1990–93 and for 1997 (OCIS 1994, 1998). Column #1 lists job descriptions and the number of persons sampled from each job category. In 1997, information for "all jobs" is presented. The OSHA data do not give the types nor numbers of drycleaning machines used.

Column #2 presents average PCE exposure concentrations in mg/m^3 presented as geometric means, and Column #3 gives maximum exposure concentrations in mg/m^3. As indicated by the large geometric standard deviations, there is wide variation around the mean exposures. In addition, there are some occasions when exposures can be quite high, as shown in Column #3. Column #4, LADC (Lifetime Average Daily Concentration), assumes that a worker spends 40 years in the drycleaning industry at mean exposure concentrations.

Column #5 gives an indication of upper bound lifetime excess cancer risk for each job type, given average exposures. It can be inferred from the Risk Index that the estimated excess risk for cancer is likely high for workers in all job categories (between 1 in 100 and 6 in 1000). Also, it can be seen from the table that the PCE lifetime average daily concentrations (LADC) for workers in most job categories are only about 20-fold lower than the ED_{10} dose of 270 mg/m^3 [i.e., the dose in human equivalents at which 10% of the animal study population showed excess tumors; see Exhibit 5-2]. Using a margin of exposure (MOE) nonprojection ratio approach as an alternate way of looking at cancer risk shows that there is not much margin between the ED_{10} and the workers' average concentration levels. (When MOEs are calculated for the average exposure levels of the six worker job categories, they range from 6 to 39). MOEs for workers at the maximum range from 0.02 to 0.6, indicating that there is virtually no margin of exposure from the projected 10% effect level to the workers' exposure for each worker job category.

An assessment of non-cancer risk is given in Column #6. This column lists hazard quotients (HQs) for the six worker job categories for lifetime average daily exposures. All the HQs were greater than 1, indicating a concern for non-cancer toxicity risks to these workers. Also, since there is some indication from animal studies that PCE can cause developmental toxicity at high exposures, there would be concern for developmental toxicity at the maximum PCE levels above 2,000 mg/m^3 (see Appendix C for discussion of developmental toxicity).

Exhibit 5-4 (derived from Exhibit 4-5) uses data from a study conducted by the International Fabricare Institute (IFI, 1990). It shows the mean inhalation exposures and subsequent health risks to workers described as "operators" and as "non-operators." It also considers PCE exposures from "dry-to-dry" and "transfer" machines separately. Exposures from transfer machines are greater for both job categories.

Column #1 lists both job descriptions—"operators" and "non-operators"—as well as two types of machines, "transfer" and "dry-to-dry," to which the workers were exposed. Column #2 gives the average exposure concentrations in mg/m^3 as arithmetic means. These data show that "operators" have greater average PCE exposures than "non-operators," regardless of machine type. It also shows that workers in facilities with transfer machines had greater average exposures than workers in facilities with dry-to-dry machines. Column #3, "Risk Index," gives an indication of upper bound lifetime excess cancer risk for operators and non-operators, each group exposed to PCE from transfer machines, or from dry-to-dry machines. It can be inferred that the estimated excess risk for cancer is projected to be high (1 in 100 or greater) for both job categories.

Exhibit 5-4. Occupational Health Risks to Drycleaning Workers From PCE Inhalation - by Job Title and Machine Type

Job Description/ Machine Type #1	Arithmetic Mean Exp.[a] (mg/m^3) #2	LADC[b] (mg/m^3) #3	Cancer Risk Index[c] (Unit risk x LADC) #4	Non- Cancer Hazard Quotient[d] LADC/Prov. Occ. RfC #5
Operators				
Dry-to-dry (N=1,301)	115	23	>1 x 10^{-2}	13.5
Transfer (N=1,027)	328	64	>1 x 10^{-2}	37.6
Non-operators				
Dry-to-dry (N=497)	79	15	1 x 10^{-2}	8.8
Transfer (N=508)	179	35	>1 x 10^{-2}	20.6

[a] Arithmetic means used because only arithmetic means were reported in published study.
[b] LADC calculated as for Exhibit 5-3. (Note: when LADC exposure levels are >14 mg/m^3, the unit risk should not be used; therefore, the risk indices are listed as >1 X 10^{-2}. See Appendix D).
[c] Cancer risk index = upper bound excess lifetime cancer risk.
[d] Provisional occupational RfC = 1.7 mg/m^3 TWA (see Appendix D). Sample HQ: “Operators Dry-to-dry”: HQ = 23 mg/m^3/1. 7 mg/m^3 = 13.5.

In addition, if we use a margin of exposure (MOE) nonprojection ratio approach to compare the lifetime average daily concentrations (LADC) of PCE for workers in both job categories with the ED_{10} of 270 mg/m^3, we find that the workers’ exposures are about 10-fold lower than the ED_{10}. When MOEs are calculated for the four scenarios listed in Exhibit 5-4 they range from 4 to 18.

An assessment of non-cancer risk, using the hazard quotient (HQ) approach, is given in Column #5. All of the HQs are greater than one indicating a potential for non-cancer toxicity to these workers.

Risk From Dermal Exposures

Drycleaning workers are not only exposed to PCE through inhaling the vapor, but also through dermal contact. The two studies cited in Exhibits 5-3 and 5-4 give an indication of exposures and risks due to inhalation. There are no comparable data, however, to assess worker dermal exposures to PCE, and therefore, only a qualitative statement of risk can be made. Dermal exposures can occur through exposures to liquid PCE, such as when handling wet clothes, or when the skin is exposed to PCE vapor present in the workplace. Chapter 4 used a model to estimate possible dermal exposures to liquid PCE. It assumed 1,300 cm^2 as the surface area of two hands, and 24 minutes total duration of contact with the liquid. Using this information, and limited information on absorption rates (Riihimaki et al., 1978; McDougal et al., 1990; Bogen et al., 1992; in Keifer, 1998), a rough estimate can be made of PCE absorbed dermally by workers.[2]

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[2] 0.243 mg/cm^2/hour x 1,300 cm^2 x 24 minutes/60 minutes/day = 126 mg/day divided by 70 kg = 1.8 mg/kg/day PCE absorbed dermally from liquid contact.

Absorption of PCE vapor through the skin is another source of PCE exposure to workers in drycleaning facilities. There are some very limited data indicating that PCE vapor can be absorbed through the skin (Riihimaki et al., 1978; McDougal et al., 1990; Bogen et al., 1992; in Keifer, 1998). These data indicate that absorption of PCE vapor through the skin may be equal to the amount of PCE absorbed via inhalation in situations where the PCE vapor levels are in the range of 58 ppm (400 mg/m^3). In situations where PCE vapor levels are 10-fold higher, (i.e., in the range of 600 ppm [4,000 mg/m^3]), the amount absorbed via the skin would be about 1% of that absorbed via inhalation.

It is assumed that dermal and inhalation exposures of PCE to workers would be additive and dermal exposure could be an important route of entry of PCE into the body.

Combined Risks from Inhalation and Dermal Routes

The health risks to drycleaning workers from PCE depend on PCE entering the body through two major routes—inhalation and through the skin. (Oral, hand-to-mouth exposure is not considered a major route, but would also be added to the total risk). Dermal exposures can be from direct contact with liquid PCE or PCE vapor. The risks from dermal exposures would be added to the risks indicated for inhalation in Exhibits 5-3 and 5-4.

Risk Conclusions—Occupational Exposures

There is a reasonable basis to conclude that there can be a health risk for cancer and non-cancer effects to workers from the relatively high PCE exposures observed on average in the drycleaning industry. This conclusion is based on monitored worker inhalation exposure data from several sources, from information about the circumstances of dermal exposures in the workplace and the absorption potential of PCE through the skin, combined with evidence from animal studies indicating that PCE can cause cancer and non-cancer toxicity in laboratory rodents. The cancer risk analysis used both the unit risk approach and the MOE nonprojection ratio approach. The unit risk approach is tied to an upper bound lifetime excess cancer risk estimate and there is the possibility that the lower bound is as low as zero.

The International Agency for Research on Cancer (IARC) recently reviewed the human and animal cancer data on PCE (IARC, 1995). IARC concluded that PCE is a probable human carcinogen.

Although a provisional RfC was developed for potential non-cancer effects of PCE, to which lifetime exposures would be compared, occupational exposures are properly compared to shorter-term exposures. Because the provisional RfC, based on an occupational level, encompassed evaluation of all types of possible effects, it may be expected that exposures in the workplace at monitored levels offer little or no margin from deleterious effects of some kind. Also, there is an indication that there may be developmental toxicity effects, since one of the studies in the database indicated developmental effects at 300 ppm (2,000 mg/m^3) (Schwetz et al., 1975, as cited in Appendix C). This is an exposure level that some workers exceeded.

It is concluded that workers in the drycleaning industry are potentially at some risk for cancer, and for non-cancer effects. Also, pregnant workers exposed to short-term high PCE levels could be at risk for developmental toxicity.

Uncertainties

The risk conclusions are based on readily available toxicity and exposure data and on models, assumptions, and professional judgements about toxicity and exposure information. These give rise to a variety of uncertainties and assumptions and influence, to a great extent, how close the assessment of risk comes to representing a realistic situation. The factors and uncertainties concerning worker risk conclusions are listed below. Many of these are discussed in more detail in Chapter 4, and Appendices C, D, and E:

- The critical study for the provisional RfC does not permit a quantified dose-response relationship, and does not characterize variability of the exposure concentrations; hence, some lower exposures may still demonstrate the effects.

- It is not clear whether the relationship between PCE dose and human cancer response is best represented by the linear-at-low dose response model used.

- The relevance of animal cancer studies to human carcinogenicity, and whether the mechanism of action of PCE in animals is comparable in humans is under discussion.

- It is not known how representative the occupational exposure studies are of actual exposures to drycleaning workers nationwide. Since the OSHA data are gathered from compliance inspections and compliant investigations, the measurements may not be representative of “average” exposures.

- There are gaps in the human data for developmental and reproductive toxicity, and uncertainties in the animal data, since the study cited included only one dose level.

- The measured Time-Weighted Average samples of PCE may not be representative of the full 8-hour shifts of most workers.

- Variations in the workplace such as machinery maintenance, facility layout, machine controls, work practices, amounts of clothes cleaned daily, and ventilation, may affect an employee’s exposure (and hence risk) from PCE. The extremely wide standard deviations in both worker studies may be explained by some of these workplace factors.

5.2.4 Risks to Residents Co-Located with Drycleaning Establishments

Risks from PCE Inhalation

Co-located residents are persons living in the same building as a drycleaning facility that cleans clothes on the premises. The term encompasses children and the elderly as well as adults. Currently it is not known how many persons living in the U.S. are co-located residents. Monitoring studies indicate that persons living in co-located residences are potentially exposed to elevated levels of PCE . Those exposures, however, are not as high as those shown in Chapter 4 for workers. Studies have measured PCE concentrations in apartments above drycleaners in New York, San Francisco, Germany, and the Netherlands (BAAQMD, 1993; NYSDOH, 1993; Schreiber et al., 1993; Wallace et al., 1995). Preliminary information reported in a recently published abstract (Schreiber et al., 1998) suggests that some body fluid measures of PCE in co-located residents are higher than in control subjects who are not co-located.

Measured concentrations reported in these studies are highly variable, due to a number of factors. These include machine type and condition, machine maintenance, building type, presence of a vapor barrier, small numbers of measurements, and emissions from newly drycleaned clothes stored in the facility (NYSDOH, 1993, 1994). Exposures, and therefore risks from PCE, are expected to vary widely for co-located residents. The wide range of PCE concentrations is shown in Exhibits 4-9 and 4-10. Data are presented by machine type to show their possible significance on measured PCE concentrations.

Monitoring data from four non-overlapping studies of PCE concentrations in U.S. residences co-located with drycleaning establishments were used in assessing exposures and potential for risks to the residents (references listed above). Measurements were taken at different locations, during different seasons, and at different times of the day. (For a detailed discussion of the studies see Chapter 4). Since the studies were conducted under different conditions, they cannot be combined for analysis. However, they can be discussed together qualitatively. Together they give measured PCE concentrations in 62 separate residences co-located with drycleaning establishments.

Exhibit 5-5 illustrates the exposures and relative cancer risk indices for inhabitants of co-located residences. The table lists the average airborne PCE concentrations measured in the four U.S. studies in Column #1. It also indicates which measurements were taken from residences above different machine types. Lifetime Average Daily Concentrations (LADCs) of PCE for adults living in co-located residences are in Column #2. Average LADCs are based on residents' occupying a co-located residence for 2.4 years; high-end exposures are based on an 8-year co-located residency.

Exhibit 5-5. Cancer and Non-Cancer Risks from PCE Associated with Co-located Residences

Study (Number of Residences)	Arithmetic Mean PCE Concentration (mg/m^3) #1	LADC (mg/m^3)[a] #2		Cancer Risk Index[b] (LADC X Unit Risk[c]) #3		Hazard Quotient (LADC / provisional RfC)[d] #4	
		Average 2.4 years	High End 8 years	Average 2.4 years	High End 8 years	Average 2.4 years	High End 8 years
Residences Above Transfer Machines							
Capital District (N=3)	7.72	0.18	0.60	1×10^{-4}	4×10^{-4}	1.1	3.6
New York State (N=1)	15.5	0.36	1.21	3×10^{-4}	9×10^{-4}	2.1	7.1
New York State (N=7)	0.85	0.02	0.07	1×10^{-5}	5×10^{-5}	0.1	0.4
Residences Above Vented Dry-to-Dry Machines							
Capital District (N=1)	0.3	0.007	0.02	5×10^{-6}	1×10^{-5}	0.04	0.12
Capital District (N=1)	45.7	1.05	3.56	3×10^{-3}	$>1 \times 10^{-2}$	6.2	21.0
New York State (N=9)	3.94	0.09	0.31	6×10^{-5}	2×10^{-4}	0.5	1.8
Residences Above Nonvented Dry-to-Dry Machines							
Capital District (N=1)	0.2	0.005	0.02	4×10^{-6}	1×10^{-5}	0.03	0.12
New York State (N=1)	0.75	0.020	0.06	1×10^{-5}	4×10^{-5}	0.12	0.35
Consumers Union (N=29)	1.85	0.040	0.14	3×10^{-5}	1×10^{-4}	0.24	0.82
San Francisco (N=4)	0.25	0.006	0.020	4×10^{-6}	1×10^{-5}	0.04	0.12

[a] LADC (mg/m^3) = Arithmetic Mean PCE Concentration (mg/m^3) x Exposure Duration (ED)/Liftetime (LT)
Expected Duration (ED)
ED = 16.4 hours/day x 365 days/year x 2.35 years (average)
ED = 16.4 hours/day x 365 days/year x eight years (high end)
LT = 24 hours/day x 365 days/year x 70 years
[b] Cancer risk index = upper bound lifetime excess cancer risk
[c] Unit risk = 0.00071 per mg/m^3.
[d] Provisional RfC = 0.17mg/m^3

Upper bound lifetime excess cancer risks, as indicated by the risk indices in Column #3 for both average and high-end exposure situations, range from 1×10^{-6} (risk of 1 in a million) to $>1 \times 10^{-2}$ (>1 in 100). These data show that **in general**, lower exposures were seen in residences above dry-to-dry machines, followed by vented dry-to-dry machines. These are associated with lower risks. The highest exposures (associated with highest risk) were found in residences above transfer machines. However, the one highest exposure level (and highest estimated risk index) indicated in Exhibit 5-5 was measured in the Capital District study in a residence above a vented dry-to-dry machine described as an old unit, "in poor operating condition" (Schreiber et al., 1993). This illustrates that, while both the occupational data and these data for co-located residences indicate higher exposures from transfer machines, machines of any type in poor condition can release high concentrations of PCE.

The data in the table show that all the co-located residences have risk indices greater than 1×10^{-6}. These upper bound risks are projected for adults expected to be at home about 16 hours per day. Sub-populations of persons who would spend approximately 23 hours per day at home (which can include infants, children, and the elderly) are estimated to have exposures about 1.4 times those listed in Exhibit 5-5. Currently, we cannot assess whether these sub-populations are more or less sensitive than the population as a whole to PCE exposure.

As a second method of assessing cancer risk for co-located residents, we can use the margin of exposure (MOE) nonprojection ratio approach by comparing their average and high-end Lifetime Average Daily Concentrations (LADCs) with the ED_{10} dose of 270 mg/m^3 [the level in human equivalents at which 10% of the animal study population showed excess tumors]. All of the average LADCs (except for the one machine known to be in poor condition, cited in Schreiber et al., 1993) are close to, or greater than 1,000-fold lower than the ED_{10} dose. (When MOEs are calculated for these "average" co-located residents' exposures, the MOEs range from 750 to 54,000, indicating a fairly large to very large margin from exposure to effect level.[3] This is also true for the high-end LADC co-located residents (those who spend at least 8 years in the same residence), although the MOEs are lower, especially for residents above transfer machines (MOEs range from 223 to 13,500).

Column #4 in Exhibit 5-5 gives hazard quotients (HQs) for non-cancer effects for average (2.4 years' residence) and high-end (8 years' residence) exposures for the co-located residents. HQ values above 1 indicate a concern for non-cancer effects. The data presented in the table indicate concerns for non-cancer risks to co-located residents living above transfer machines and vented dry-to-dry machines, but not above nonvented dry-to-dry machines, regardless of duration of residence. This concern for risk would also be true for infants, children, and the elderly living in the same residences, whose exposures are estimated at about 1.4 times that of the adults in general. Data are not currently available to evaluate whether these sub-populations are more or less sensitive than the population as a whole to non-cancer effects caused by PCE.

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[3] Sample MOE calculation: $ED_{10}/LADC = 270\ mg/m^3/0.18 = 1,500$.

Risks from Dermal Exposures

As mentioned in the section on occupational risks, dermal absorption can occur from PCE vapor in the air. There are limited data to suggest that the amount absorbed dermally can be equal to the amount absorbed via inhalation at relatively low levels.

Combined Risks

The health risks to co-located residents from PCE are usually considered the sum of all risks due to exposures through all major routes of the body. Data were available to give an indication of PCE exposures through inhalation. No equivalent data were available for dermal exposures. It is possible that an equivalent amount of PCE vapor could also be absorbed into the body through the skin. [This would increase the mean exposure numbers listed in Exhibit 5-5, but the risk indices would still be of the same order of magnitude].

The PCE exposures to the general population through such means as drinking groundwater, showering and bathing, wearing drycleaned clothes, or taking them into the home, would also apply to co-located residents. Risks from these exposure scenarios are discussed in the next section which deals with general population risks. These general population risks would be added to the risk associated with co-residency.

Risk Conclusions—Co-located Populations

There is concern that there can be a cancer risk to residents living in co-location with PCE drycleaning establishments, particularly if they live in such dwellings for several years (indicated by high-end risk indices). The cancer risk indices generally show rates higher than one in a million. The data show that exposures and associated upper bound lifetime excess cancer risks appear to be higher for residents living above transfer machines, although use of poorly maintained dry-to-dry machines also causes high exposures. There is also concern for risk for non-cancer effects. Adults in residences above nonvented dry-to-dry machines appear to have lower exposures. Co-located residents are also at risk through a variety of PCE exposures that the general public experience, in addition to their exposures related to co-location with drycleaning facilities. Risks potentially experienced by the general population, such as drinking PCE-contaminated water, or wearing drycleaned clothes, would be added to the risks due to co-location. Children, infants, and the elderly, who spend most of their day in the residence, may be at slightly greater risk than adults in general for both cancer and non-cancer effects due to increased exposure duration.

As stated previously, the cancer risk analysis approach (unit risk) is tied to an upper bound lifetime excess cancer risk estimate and there is the possibility that the lower bound is as low as zero.

Uncertainties

The risk conclusions are based on readily available toxicity and exposure data and on models, assumptions and professional judgements about toxicity and exposure information. These give rise to many uncertainties and assumptions and influence, to a great extent, how close the assessment of risk comes to realistic representation. In addition to uncertainties regarding the evaluation of PCE’s toxicity, which are enumerated in the section on occupational risks, selected prominent factors and uncertainties concerning conclusions regarding co-located residents' risk are listed below. Many of these are discussed in more detail in Chapter 4, and appendices C, D, and E:

- It is not known whether the exposure data presented can successfully represent co-located residents nationwide, or whether there are major regional or local differences.

- Although conclusions about exposures are based on four U.S. studies, these studies were carried out under different circumstances and may only be regarded individually. Each study in itself is relatively small, and the complaint investigations may not adequately characterize exposure comparisons between machine types.

- Although we discuss risks for residents exposed to estimated arithmetic mean PCE concentrations, there is uncertainty as to what the mean concentration value is, since the individual exposure studies show large variations (standard deviations).

- It is not clear whether the short-term sampling done in some of the studies may have missed major fluctuations in exposures.

- It is not clear whether significant numbers of residents stay in their apartments for more than 8 years, or fewer than 2.4 years.

- In certain studies, the presence of drycleaned clothes in the residences may have added to measured air concentrations.

5.2.5 General Population Risks

Risks from PCE Inhalation

In the mid-1980s, USEPA characterized general population exposures to a selected slate of chemicals in four urban areas. 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 areas. No persons in co-located residences were included in the study.

This study was chosen for use in assessing risk for the CTSA because of its size, coverage of several states, and personal sampling of people's indoor and outdoor exposures over several days. The TEAM study hypothesized that the PCE exposure levels of the persons measured were due not only to ambient air, but also due to PCE exposures from visiting drycleaning shops, wearing and being exposed to others wearing drycleaned clothes, transporting and storing drycleaned clothes, and PCE from non-drycleaning sources.

Exhibit 5-6 illustrates the exposures and risk indices associated with the residents' 24-hour inhalation of combined indoor and outdoor air in a typical home not in proximity to a drycleaning shop. The first entry in Column #1 in the table gives the Lifetime Average Daily Concentration of PCE for the general population based on the 24-hour personal sample average exposures of the persons in the TEAM study (0.017mg/m^3). The CTSA exposure assessment (Chapter 4) assumed this exposure to be constant over a lifetime (to be the Lifetime Average Daily Concentration). Therefore, it is listed as the LADC. Average outdoor ambient air was measured in the TEAM study as 0.003 mg/m^3, and was also assumed to be constant over a lifetime. It is listed in the second entry in Column #1 of the table as the LADC, serving as a background level.

Exhibit 5-6. General Population Cancer and Non-Cancer Risks from Inhalation of PCE

Exposed Population[a] (24 hour exposure)	**LADC (mg/m^3) #1**	**Cancer Risk Index[b] LADC x Unit Risk[c] #2**	**Hazard Quotient LADC/Provisional RfC[d] #3**
General Population-Adults (daily activities indoors & outdoors)	0.017	1. 2 x 10^{-5}	0.1
Ambient Air	0.003	2 x 10^{-6}	0.02

[a] TEAM Study, 1989
[b] Cancer risk index = upper bound lifetime excess cancer risk.
[c] Inhalation Unit Risk = 0.00071 per mg/m^3
[d] "Provisional RfC" = 0.17mg/m^3

Exposures and corresponding cancer risk indices to the general population are lower than those in most co-located residences (Exhibit 5-5), but are higher than PCE levels measured in ambient outdoor air alone from the TEAM study . The calculated risk index of 1.2 x 10^{-5} for the general population seen in Column #2 is above that from exposure to ambient air alone (2 x 10^{-6}).

The LADCs for both the general population and ambient air are more than 1,000 times lower than the ED_{10} of 270 mg/m^3 [the level in human equivalents at which 10% of the animal study population showed excess tumors]. These MOE nonprojection ratios indicate a large margin between expected exposures and the effect level.[4]

Column #3 in Exhibit 5-6 shows the hazard quotients for non-cancer effects. The HQs are below 1, indicating lowered concern that deleterious effects will occur.

Risk from PCE Ingestion

Exhibit 5-7 illustrates potential risks from exposures to PCE-contaminated water. The exposure scenario for drinking water ingestion is based on measurements of PCE in contaminated groundwater from two independent studies, Izzo (1992) and Stasiuk (1993). The California Regional Water Quality Control Board took measurements from more than 215 wells, most of which were large system municipal wells. Many wells contained PCE in excess of 5 ppb (parts contaminant per billion parts of water), California's maximum contaminant level (MCL). The New York State Department of Health has also reported PCE

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[4] LADC compared with ED_{10} : MOE= 270 mg/m^3/0.017 mg/m^3 = 15,882

concentrations in groundwater in public and private wells. They measured PCE in eight public wells at concentrations from 61 to 640 ppb. (See Chapter 4 for further discussion.)

Exhibit 5-7 lists Lifetime Average Daily Doses (LADDs) calculated for individuals assumed to drink 1.4 liters of PCE-contaminated water each day. (See Exhibit 5-7 footnote LADD sample calculation.) It was assumed for this CTSA that PCE contamination of municipal wells would be kept at or below the 5 ppb maximum contaminant level (MCL). The range of the LADDs presented in Exhibit 5-7 would be the lifetime average daily dose expected from drinking water contaminated with PCE at a low of 0.8 ppb to the 5 ppb MCL. The cancer risk indices are also presented as a range from 1×10^{-7} to 5×10^{-7}. Therefore, if PCE contaminant levels are kept below the MCL of 5 ppb, cancer risks would be low. The last column in the table presents hazard quotients (HQs) for non-cancer effects for the high and low end of the exposure range from 0.8 to 5 ppb PCE contamination. The very small HQs suggest low risk for non-cancer toxicity to the public from drinking well water contaminated at these levels.

Exhibit 5-7. Cancer and Non-Cancer Risks from Exposure to PCE-Contaminated Drinking Water

Exposure Scenario	LADD[a] (mg/kg/day) Range	Cancer Risk Index[b] (LADD x Unit Risk[c]) Range	Non-Cancer Oral Hazard Quotients[d] (LADD/RfD)
Potential Risks from PCE-Contaminated Drinking Water - PCE in ground water	0.000002 to 0.00001	1×10^{-7} to 5×10^{-7}	0.0002 to 0.001

[a] LADD = Lifetime Average Daily Dose
LADD = [PCE] x 1.4 liters x 9 years/70 years x 1/72kg
where [PCE] = PCE concentration in drinking water in mg/L
[PCE] = 0.0008 mg/L
1.4 liters = Average adult consumption of drinking water
70 years = Average lifetime
72 kg = Average adult weight

[b] Cancer risk index = upper bound lifetime excess cancer risk

[c] Oral Unit Risk = 0.051 per mg/kg/day. Sample Calculation, Risk Index = 0.0001 mg/kg/day X 0.051 per mg/kg/day = 1×10^{-7}

[d] RfD = 0.01 mg/kg/day.

Risks from Dermal Exposures

Exposures (and consequently risks) could also result from bathing or showering in water contaminated with PCE. Dermal uptake of PCE in bath water has been estimated to equal the dose received from drinking two liters of water a day (Riihimaki et al., 1978; McDougal et al., 1990; Bogen et al., 1992; in Keifer, 1998). Therefore, the estimated risk indices from dermal exposures by daily bathing in PCE-contaminated water would be somewhat similar to those presented in Exhibit 5-7 for drinking 1.4 liters of PCE-contaminated water a day.

The HQs for drinking PCE-contaminated water are well below one; thus, expected risks from dermal exposures from bathing/showering are low for toxicities other than cancer.

Combined Risks from Other Routes

The health risks to the general population from PCE are regarded as the sum of the individual risks due to exposures through all major routes of the body. Therefore, if persons in the general population are also exposed to PCE from contaminated drinking water, shower or bath water, risks from those exposures would be added to the risks from inhalation of PCE.

Risk Conclusions—General Population

If the general population were exposed to PCE via inhalation for its lifetime at the average daily level measured in the TEAM study, there can be a concern for risk of cancer, albeit much lower than either the occupational or co-located resident scenarios described earlier. There would not be a concern for non-cancer health risks. However, it is not possible to generalize from the data that the individuals in the general population of the United States would be exposed at these levels for a lifetime.

If PCE contaminated drinking water is at or below the MCL of 5 ppb, there would not be a concern for health risks to the general public. Although higher PCE levels have been measured in private and municipal wells, it is assumed for this CTSA that PCE levels in excess of the MCL would be remediated so that contamination would not be present in drinking water on a long-term basis.

Uncertainties

The risk conclusions are based on readily available toxicity and exposure data and on models, assumptions and professional judgements about toxicity and exposure information. These give rise to many uncertainties and assumptions and influence to a great extent how closely the assessment of risk represents reality. Prominent specific factors and uncertainties concerning general population risk conclusions are listed below. These and other factors are discussed in more detail in Chapter 4, and Appendices C, D, and E:

- The risk conclusions for the inhalation exposure scenario are based on a single study's exposure estimates. The TEAM study is 10 years old, took measurements over a short time, and focused on persons living in several states across the country. It is uncertain how well this study represents the actual PCE exposures to the general population throughout the United States.

- The TEAM study results included a single, unusually high measured concentration from North Dakota. Since the TEAM study results included this measurement in the calculation of the arithmetic mean concentration, it has been included in the CTSA as well. Wallace (1989) stated that if this measurement were not used, the arithmetic mean concentration would have been 0.012 mg/m^3. The general population's overall LADC then would have been 0.012 mg/m^3, and the associated risk index 2×10^{-6}.

- The two groundwater studies show considerably differing measurements of PCE contamination. It is not known how representative the studies are of groundwater contamination throughout the United States.

- A major uncertainty is whether, in fact, PCE contamination of municipal and private drinking water wells is kept at or below the MCL of 5 ppb.

- The estimates of lifetime average daily dose of PCE from contaminated drinking water used in the CTSA could be conservative since they do not take into account that household water supplies may be drawn from a number of different wells; and they assume there is no PCE removal during treatment.

- The estimates of ingestion exposure assume that there is daily exposure to the PCE contaminated water over a lifetime. It is not known whether this is the case for the general population.

- The inferences regarding potential for dermal exposures are based on very limited data.

5.2.6 Special Sub-populations

General

The data available for this CTSA do not adequately permit addressing the question of whether health risks due to PCE exposures differ significantly between such special sub-populations, as infants, children, the elderly, and adults in general. Therefore, risks to sub-populations from PCE exposures are considered the same as for adults in general unless there is specific information to the contrary. There is a lack of data concerning:

> (1) The toxicity of PCE to different sub-populations compared with adults as a whole (i.e., whether different sub-populations or groups are more susceptible, or less susceptible to the carcinogenic and non-carcinogenic effects of PCE). We currently have no information as to whether PCE is more or less carcinogenic or otherwise toxic to infants, children, or the elderly. The RfD/RfC concept incorporates the idea that a 24-hour exposure over a lifetime at the designated level generally is not expected to be toxic to the general public, including sensitive sub-populations. Therefore, in this CTSA the measures of toxicity (cancer unit risk, RfD/RfCs) used for adults are also used for all sub-populations.
>
> (2) The PCE exposures of different sub-populations compared with adults as a whole. (i.e., whether different sub-populations or groups are exposed to PCE at higher or lower levels than adults in the general population.) There are some indications that certain sub-populations differ from adults in their exposures to PCE. This may be indicative of their different exposure patterns throughout the day. These patterns are mentioned in the discussion of co-located residences. Infants, children, and the elderly on the whole are thought to spend more time in the co-located residence than adults in general, resulting in an estimate of about 1.4 times the exposures of PCE for them than for those adults. Therefore, their risks are derived using the higher exposure level.

Infants

Several models have been developed to estimate the amount of PCE to which an infant is exposed through ingesting breast milk that contains PCE. One model predicted infant exposures would range from

0.0001 to 0.92 mg/kg/day (Schreiber, 1997). Another model (Fisher et al.,1997) estimated infant exposure at 0.34 mg/kg/day. These models and their background information are discussed in more detail in Chapter 4.

One estimate of infant exposure was made for a hypothetical situation in which a woman is exposed at work to PCE at the OSHA Permissible Exposure Level of 25 ppm and then breast feeds her infant. The infant was estimated to ingest 1.36 mg/day of PCE. That author concluded that this would result in a health risk since the infant's exposure would exceed an EPA Health Advisory Intake of 1.0 mg/day. [The Health Advisory is set by the USEPA Office of Water for chronic ingestion of contaminated water by 10 kg children, assuming ingestion of 1 liter of water per day (Fisher et al, 1997)]. Schreiber (1997) concluded that the benefits of breast feeding outweigh the risks; and also estimated that the majority of an infant's PCE exposure results from inhalation rather than ingestion.

It is beyond the scope of this CTSA to properly evaluate these pharmacokinetic models given their complexity in design and assumptions. Further, even with an estimate of PCE delivered by lactation, there is no cancer model or non-cancer comparison value adapted for use with infant exposures. Therefore, no attempt is made to utilize estimated exposures for quantifying potential health risks to infants. Qualitatively, there appears to be a potential for health risks to infants in situations where they are exposed to levels of PCE which are also a concern for the adult population. This could be via inhalation, dermally, or through ingestion. Exposure scenarios which appear to be of most concern for risk for infants are those providing inhalation of PCE-contaminated air in co-located residences, and ingestion of contaminated breast milk.

Children/Families

There have been some studies suggesting that families of drycleaning workers may experience elevated PCE concentrations in their homes, and it has been hypothesized that workers introduce PCE into their homes through their exhaled breath. (Thompson and Evans, 1993; Aggazzotti et al.,1994). The information is of interest (see Chapter 4) and suggests a specific exposure scenario through which children might be at additional health risk from PCE.

Summary

Adult risk does not translate directly to infants, children, and the elderly. In scenarios where high risk indices have been inferred at high exposure levels for adults in general, however, there should be concern for sub-populations exposed by similar routes at similar exposure levels.

5.2.7 Environmental Risk

Risk to Aquatic Organisms

A PCE concern concentration (CC) for aquatic organisms was determined by dividing the lowest chronic toxicity value for PCE, 0.66 mg/l for daphnids (Chapter 3, Exhibit 3- 2), by an assessment factor[5] of ten. The CC of 0.07 mg/l is the concentration of PCE in surface water above which toxic effects may occur to aquatic organisms. The greater the exceedence and the longer the CC is exceeded, the greater the probability of toxicity to aquatic organisms.

If effluent (wastewater) flows from drycleaning facilities are sent to Publicly Owned Treatment Works (POTWs), the estimated PCE concentration in water, 3 ppb (see Section 4.4.1) is expected to be well below the concern concentration of 0.07 mg/L (70 ppb). If effluent flows are not sent to a POTW, it is possible that PCE could be present in surface water in excess of the CC. Anecdotal data suggest, however, that most drycleaners discharge their effluent to a POTW.

Surface water contamination by PCE has been found in many locations throughout the U.S., with PCE concentrations ranging from a fraction of a part per billion to hundreds of thousands of parts per billion. Of course, these levels are due to all sources of PCE and not just from drycleaning establishments. In this assessment, only surface water concentrations in which the contaminating source was identified as a drycleaning facility were used (General Population Exposure Assessment).

Risk Conclusions

The concern concentration (CC) for aquatic organisms for PCE is not exceeded, and therefore, there is low risk to aquatic species for the majority of drycleaners who send their wastewater effluents to a POTW. Drycleaning establishments that do not send their wastewater effluents to a POTW may cause surface waters to exceed the PCE CC, and therefore put aquatic organisms at risk.

Uncertainties

There are uncertainties connected with using the Structure-Activity-Relationship (SAR) methodology (see Appendix B) for calculating the concern concentration. However, the combination of cross-checking the PCE literature and the extent of the PCE database, as well as the history of usage of this technique, increases the belief that this concentration predicts toxicity to aquatic organisms well.

There are uncertainties as to actual surface water levels, since estimated levels are based on estimated wastewater releases from drycleaning establishments, and the assumption that most establishments send effluent wastewaters to a POTW with subsequent further PCE removal.

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[5] Assessment factors incorporate the uncertainty associated with (1) toxicity data--laboratory tests versus field tests and measured versus estimated data; and (2) species sensitivity. Assessment factors range from 1,000 to 1 depending on the amount and quality of available aquatic toxicity data. Because the hazard profile for PCE contained three chronic SAR values (in addition to one measured and two SAR acute values), an assessment factor of 10 was used (for a full explanation, see Appendix B).

Other Environmental Effects

PCE is not a stratospheric (higher atmosphere) ozone depleter, because it is destroyed in the troposphere (lower atmosphere, or a region of the atmosphere extending to between eight and sixteen kilometers above the earth's surface). In the troposphere, PCE undergoes photochemical degradation to the extent that its estimated lifetime is appreciably less than one year (Appendix A).

5.2.8 Human and Environmental Risks—Overall Summary and Conclusions

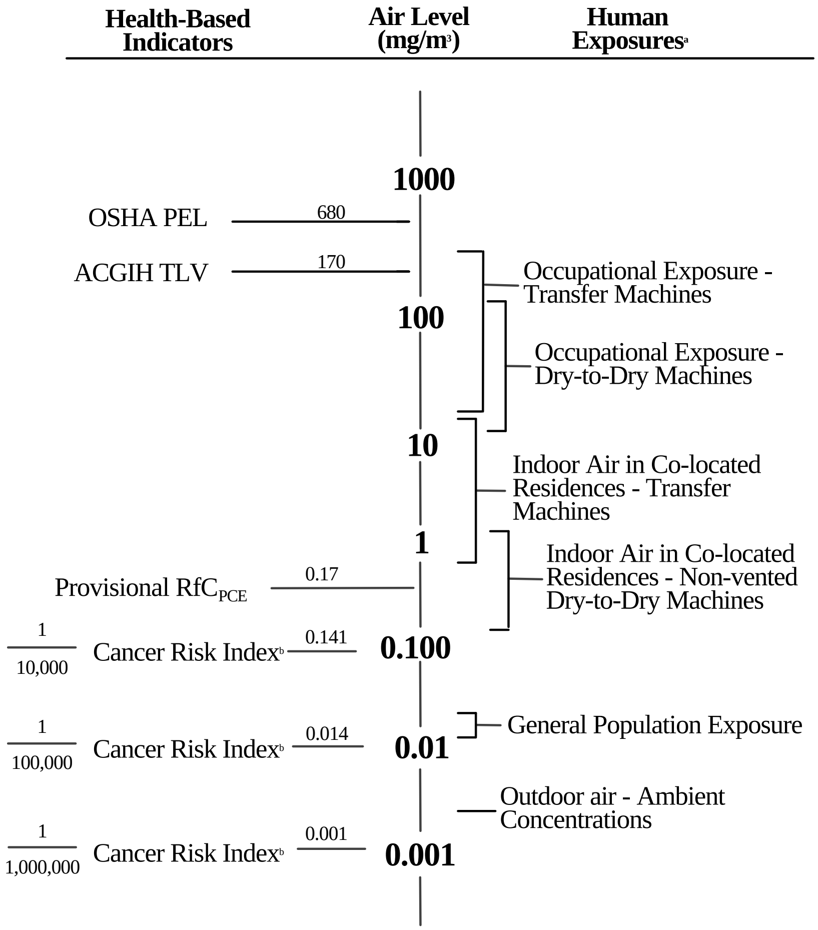
Exhibit 5-8 summarizes in a graphical format the human health hazards of PCE and the inhalation exposures associated with its use as a drycleaning solvent. Two exposure scenarios stand out as the highest levels of concern: occupational exposure to drycleaning workers and exposure to residents (including children) of dwellings located above drycleaning shops. There is a potential concern for cancer and non-cancer toxicity risks to workers exposed to average PCE levels measured in drycleaning facilities. There are also qualitative data supporting a concern for developmental toxicity risk to workers exposed to the high end PCE concentrations measured in the workplace. Exposures and, consequently, risks tend to be higher if transfer machines are used instead of dry-to-dry machines, but there are still health risks associated with PCE exposure levels from dry-to-dry machines. Worker PCE exposures appear highly variable, which may be due to such diverse factors as differences in facility layouts, machine maintenance, machine controls, amount of clothes cleaned, and ventilation. Workers can also be exposed to PCE via dermal exposures, either directly through contact with the liquid, or skin contact with PCE vapor. Risks to workers by this exposure route would be added to risks due to inhalation exposures.

Residences above shops with transfer machines typically have airborne PCE concentrations 10- to 100-fold lower than the occupational scenarios. There is concern for cancer and non-cancer risks to these residents who live co-located with drycleaning facilities. Such residents include infants, children, and the elderly, as well as adults. Residences above non-vented dry-to-dry machines tended to have lower PCE exposures than those above transfer machines and were at the lower end of the exposure range. Some measured levels in such residences are not much higher than ambient indoor air in homes not co-located near drycleaning shops. However, limited data indicate that high exposures can occur even with dry-to-dry machines if they are poorly maintained.

Sufficient data are not available to make quantitative risk conclusions concerning exposures to special sub-populations such as infants, children, and the elderly. As a rule of thumb, however, exposure scenarios where health risks are of concern for adults should be considered to be of concern for health risks to these sub-populations. Models have been developed to predict levels of PCE ingested by infants from contaminated breast milk. This is a possible scenario for a health risk to infants.

Measured ambient air levels of PCE are low, but the general population can be exposed to PCE from a variety of sources in addition to ambient air, such as from visiting drycleaning establishments; bringing home and storing dry-cleaned clothes; wearing dry-cleaned clothes; being exposed to others' dry-cleaned clothes; and drinking and bathing in contaminated well water. Limited data indicate that these exposures can increase average exposures several times over ambient levels. Exposures from inhalation, ingestion, and through the skin would be additive.

Exhibit 5-8. PCE Hazards and Inhalation Exposures



[a] Concentrations are arithmetic means. Therefore, the brackets do not reflect the entire range of concentrations found in any particular study.

[b] Based upon linear-at-low dose approach with a unit risk value of 0.00071 per mg/m^3.

Health risks to aquatic organisms are expected to be low if drycleaning wastewater effluents are sent to (POTWs). This is expected to be the case for most drycleaning establishments. If, wastewater effluent is not sent to a POTW, there could be health risks to aquatic organisms from PCE concentrations in surface waters exceeding the concern concentration. Health risks to terrestrial organisms were not evaluated.

Some yet-unanswered key issues surrounding the assessment of risks due to PCE used during the drycleaning processes are:

- whether PCE causes cancer in humans at low doses, and what its mechanism of action is;
- do the various models used to estimate PCE exposures in nursing infants present realistic estimates of exposures;
- does PCE cause developmental toxicity in humans, and if so, at what concentrations; and
- what is the true range of exposures to PCE experienced by co-located residents throughout the country?

5.3 DRYCLEANING USING HYDROCARBON (HC) SOLVENTS

5.3.1 Human Health

Hydrocarbon (HC) solvents (Stoddard solvent, 140°F solvent, and DF-2000) may be used to dryclean clothes. In this CTSA, hazard information (Chapter 3) on Stoddard solvent is assumed to represent all three solvents. Exposure information (Chapter 4) is available for Stoddard solvent and 140°F solvent. Both Stoddard and 140°F solvents are mixtures that consist of linear and cyclic paraffins with total carbons varying from C9 to C12. The constituents and their percentages vary.

A major hazard identified with the HC solvents considered in the CTSA is their potential flammability (Chapter 3). The National Fire Protection Association (NFPA) gives HC solvents a ranking of “2” for flammability, indicating that they must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. For comparison, perchloroethylene receives a ranking of “0” for flammability, which indicates that it will not burn (Ahrens, 1998).

5.3.2 Human Health Risks

Risk—General

In this section, the hazards and individual exposure scenarios are integrated to address the potential risks of hydrocarbon (HC) solvents. Stoddard solvent will be used, for risk assessment purposes, to represent HC solvents in the drycleaning industry. There is evidence indicating that Stoddard solvent is absorbed into the body via inhalation, the gastrointestinal tract, and through the skin. There are some human data indicating that it can cause neurotoxic effects, and is an irritant to the eyes, mucous membranes, and skin. Kidney toxicity (see Appendix C) has also been reported in animal studies.

There were no data suitable for drawing conclusions concerning the carcinogenic potential of Stoddard solvent, so no expression of risk is made for cancer. No cancer unit risk or slope factor has been established. Also, no oral RfD or inhalation RfC has been established to date for Stoddard solvent or any other HC solvent.

For the purposes of the CTSA, a non-cancer comparison value was derived from an animal study (see Chapter 3 and Appendix C) for a discussion of the spectrum of effects associated with Stoddard solvent. The comparison value was taken directly from a 13-week study in male rats (Carpenter et al., 1975a, 1975b, see Appendix D). A No-Observed-Adverse-Effect Level (NOAEL) was identified as 480 mg/m^3 with recognition that it is not from the usual chronic study. [Note: The American Conference of Government Industrial Hygienists, ACGIH has established a Threshold Limit Value (TLV) guideline for Stoddard solvent exposure in the workplace of 525 mg/m^3 (100ppm) (ACGIH, 1996)].

Routes of Exposure

Inhalation

Inhalation is the likely route of exposure to HC solvents based on their physicochemical characteristics (Appendix A). Stoddard solvent, the HC solvent reviewed in Chapter 3, is readily absorbed from the lung following inhalation exposure.

Oral

There are no data on the oral absorption rate of Stoddard solvent. Based on studies of other petroleum distillates, it is judged that the rate and extent of gastrointestinal absorption of Stoddard solvent is likely to depend on the lipophilicity and size of its various components and the amount of food in the stomach.

Dermal

Dermal absorption is expected to occur, but there is no information on the rate of absorption. Stoddard solvent was found to be dermally absorbed by rats, and by analogy, there should be some absorption through human skin.

5.3.3 Occupational Risks—Drycleaning Workers

Risks from HC Solvent Inhalation

HC solvents are used much less often than PCE in commercial drycleaning, and less information is available for them. The number of workers exposed to hydrocarbon (HC) solvents in facilities that dryclean clothes is estimated to be between 21,000 and 49,000 (Chapter 4) . The most significant route of exposure for workers is expected to be from inhalation, although they may also be exposed through the skin. Only a few studies and data sets are available to characterize inhalation exposures to HC solvents. These are presented and discussed in Chapter 4. Inhalation exposures and consequently, potential risks from HC solvents to workers, are expected to be higher than for any other exposure group.

The two data sets available for exposure estimates are from OSHA air monitoring data for the years 1990-1993 and 1997 (OCIS,1994,1998), and from a pre-1980 NIOSH survey (NIOSH,1980). They are presented in Chapter 4. The OSHA data include a set of 28 inhalation exposure samples listed by worker job category. An additional 11 samples were obtained for 1997, for the category “all jobs.” The NIOSH survey was of 6 drycleaning facilities, ranging from very small to a large industrial facility, and exposures were listed by worker job categories.

As in the case of PCE, there are differences in exposures and risks to workers in different job categories. Limited exposure data give an indication that persons in the job classification “cleaner” (equivalent to “operator”) may be the most exposed to HC solvents via inhalation.

To get a general estimate of non-cancer risks to workers, we can use the exposure levels measured (arithmetic mean as average and maximum as high-end) from the OSHA and NIOSH studies (see Exhibits 4-11 and 4-12) to represent worker exposures in the commercial drycleaning industry, and compare these exposure levels with the toxicity comparison value of 480 mg/m^3 as a NOAEL for non-cancer toxicity. In most cases, (except for job categories “presser” and “customer service”) there was not a large difference between the NOAEL from the animal study and worker lifetime average daily exposures. Worker average exposures ranged from about 5- to 120-fold lower than the animal NOAEL of 480 mg/m^3. Worker high-end lifetime average daily exposures were about 2- to 50- fold lower than the comparison value. These exposures to HC solvents, especially the high-end ones, are indicative of a potential concern for non-cancer risk for workers. (A sample calculation of the LADC and comparisont with the NOAEL is presented using OSHA 1997 data from Exhibit 4-11 for “all jobs”.[6])

Risks from Dermal Exposure

Although there is potential for dermal exposure to HC solvents as with PCE, there are no data to assess the potential magnitude of dermal exposures. Dermal exposures can be modeled, however, and those procedures are discussed in Chapter 4. Dermal exposures can be from direct contact with liquid HC, and also possibly with the HC vapor. The risks from dermal exposures would be added to the risks indicated for inhalation.

Combined Inhalation and Dermal Risks

The health risks to drycleaning workers from HC solvents depend on the solvent entering the body through two major routes of entry—inhalation and through the skin. (Oral, hand-to-mouth exposure is not

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[6] LADC = Exposure x 10 m^3/20m^3 x 250 days/365 days x 40 years/70 years

10 m^3 = Volume of air inhaled during an 8 hr workday
20 m^3 = Volume of air inhaled in 24 hours
250 days = Days worked per year
365 days = Days per year
40 years = Years worked in a lifetime
70 years = Average lifetime

The “All Jobs” arithmetic mean = 150 mg/m^{3,} , therefore using the formula above, the LADC = 29 mg/m$^{3.}$
This LADC is about 17-fold less than the NOAEL of 480 mg/m^3

considered a major route, but if it occurs would also be added to the total risk). Dermal exposures would be added to the overall risks estimated from inhalation exposures, although inhalation is expected to be the dominant route of exposure.

Risk Conclusions

There is a reasonable basis to conclude that there can be a health risk for non-cancer toxicity to workers from the relatively high HC solvent exposures observed in the drycleaning industry. This conclusion is based on monitored worker inhalation exposure data from several sources, from information about circumstances for dermal exposures in the workplace, and the potential for Stoddard solvent to absorb through the skin, combined with evidence from animal studies indicating that Stoddard solvent can be toxic in laboratory rodents. Monitored worker inhalation exposure concentrations, especially at maximum exposure concentrations were close to the toxicity comparison NOAEL.

It was not possible to quantify the risk of fire in this CTSA. However, the risk for fire is an important concern for the HC solvents and would be a greater risk for the HC solvents than for PCE based on their higher flammability rating.

Uncertainties

The risk conclusions are based on readily available toxicity and exposure data and on models, assumptions, and professional judgements about toxicity and exposure information. These give rise to many uncertainties and assumptions and influence, to a great extent, how close the assessment of risk comes to realistic representation. Some central factors and uncertainties concerning worker risk conclusions are listed below. Many of these are discussed in more detail in Chapter 4, and Appendices C, D, and E:

- There is not a sufficient database to indicate whether Stoddard solvent or other HC solvents are carcinogenic in humans or animals. Epidemiologic studies reporting associations of certain cancers with mineral spirits' exposure could not separate this exposure from others sustained by the cases. It is not clear what might be seen if HC solvents were used more widely.

- It was not possible to develop and review a provisional RfC for this CTSA. Therefore, a comparison was made with a NOAEL directly from an animal study. This toxicity comparison value has not had the level of review that the provisional RfC for PCE has had, and therefore there is a greater level of uncertainty as to its validity. The toxicity comparison value may be higher or lower than the one that a USEPA Agency-wide analysis of a more extensive database might select.

- It is not known how representative the occupational exposure studies are of actual exposures to drycleaning workers nationwide. Since the OSHA data are obtained from compliance inspections and complaint investigations, the measurements may not represent "average" exposures. The NIOSH data were collected almost 20 years ago (pre-1980) and may not represent current exposures. Also, they included exposures from industrial drycleaning settings which may not be representative of the commercial drycleaning industry.

- The measured time-weighted average samples of Stoddard solvent may not represent well the full 8-hour shifts of most workers.

- Variations in the workplace, such as machinery maintenance, facility layout, machine controls, work practices, amounts of clothes cleaned daily, and ventilation may affect an employee's exposure (and hence risk) from HC solvents. The extremely wide standard deviations from the mean exposure levels in both worker studies seen in Exhibits 4-11 and 4-12 may be indicative of some of the workplace factors listed here.

5.3.4 General Population Risks—Residents Co-Located with Drycleaning Establishments

It is possible that co-located residents have potential ambient air exposures to HC solvents, and therefore would have health risks. Although no data were available for this exposure scenario, and therefore, no further discussion of risk is considered in the CTSA, the reader may compare the relative magnitudes of worker scenarios between PCE and the HC solvents, and take into account the possibilities for co-located residents exposures to HC solvents.

5.3.5 General Population Risks

Risks from HC Solvent Inhalation

There were no data available for actual ambient air exposure levels for the general population exposed to HC solvents. In this case, therefore, several hypothetical exposure scenarios for potential inhalation exposures were modeled for the general population. Exhibit 4-13 presents a "what-if-exposure scenario," which assumes that HC solvent would be released to air continuously, and expose people at nearby homes to HC vapors throughout the day over a period of 9 years (considered to be the average time spent in any one residence). It gives estimated Lifetime Average Daily Concentrations of HC solvent to such persons. (These would include infants, children, the elderly, and other adults). The exposure scenarios include exposures from facilities 100 meters to 400 meters away, with transfer or dry-to-dry machines.

If the modeled worst case (i.e., a transfer machine releasing HC solvent at a distance of 100 meters from the general population) general population exposure level listed in Exhibit 4-13 is compared to the toxicity comparison value of 480 mg/m^3 for a NOAEL for non-cancer toxicity, it can be seen that the estimated general population lifetime exposure is 240,000 times lower than the NOAEL. This would therefore, suggest low concern for non-cancer health risk.

Risks from HC Solvent Ingestion

There is a lack of information concerning the HC solvents in groundwater; however, it is thought that the migration potential of HC solvents to groundwater is negligible. The estimated drinking water exposure to the general population is very low—much less than one mg per kg per day (Chapter 4), and therefore, risks are estimated to be very low.

Risk Conclusions

Chronic health risks to the general population from estimated inhalation exposures to HC solvents are considered low. Risks from ingesting drinking water contaminated with HC solvents are also considered low, given the very low projected releases of HC solvents to surface waters. These conclusions are based on modeled exposure scenarios combined with evidence from animal studies indicating that Stoddard solvent can cause toxicity in laboratory animals and were hampered by lack of actual exposure data.

Uncertainties

The risk conclusions are based on readily available toxicity and exposure data and on models, assumptions, and professional judgements about toxicity and exposure information. These give rise to many uncertainties and assumptions and influence to a great extent how close the assessment of risk comes to realistic representation. Some central factors and uncertainties concerning general population risk conclusions are listed below. Many of these are discussed in more detail in Chapter 4, and Appendices C, D, and E. The same uncertainties hold as to the limitations of the toxicity database as are indicated in the Uncertainties section on risks from occupational exposures.

- Using models to estimate potential general population airborne exposures and concentrations in drinking water necessitates many assumptions, and therefore introduces uncertainties regarding the closeness of these estimated exposures to reality.

- There are uncertainties as to the actual surface water levels, since estimated levels are based on estimated wastewater releases from drycleaning establishments, and on the assumption that most establishments send effluent wastewater to a POTW with subsequent HC solvent removal.

- Hazard and most of the exposure information are based only on Stoddard solvent. Other HC solvents may differ somewhat.

5.3.6 Special Sub-populations

General

As was the case with PCE, the data available for this CTSA do not provide an answer to the question of whether health risks due to HC solvent exposures differ significantly between special sub-populations, such as infants, children, the elderly, and other adults. Therefore, risks to special sub-populations from HC solvent exposures should be treated the same as for the broad class of other adults unless there is specific information to the contrary. Information regarding items (1) and (2) below may permit future estimations of risk.

(1) The toxicity of HC solvents to infants, children, and the elderly compared with other adults (i.e., whether these different sub-populations or groups are more susceptible, or less susceptible to the toxicity of HC solvents.) We currently have no information on this.

(2) The HC solvent exposures of these different sub-populations compared with adults in general (i.e., whether different sub-populations or groups are exposed to HC solvents at

higher or lower levels than adults in the general population.) Infants, children, and the elderly on the whole may spend as much as 1.4 times longer in their residences than most adults, resulting in higher estimates of HC solvent exposures.

Infants

Since the physicochemical properties of the HC solvents indicate that they would be taken up by fatty tissue, the scenario of prenatal exposure, and hence risk to infants nursing from mothers exposed to HC solvents via inhalation, is reasonable. However, no data on HC solvents nor modeling (as was the case for PCE) are available for this scenario.

Summary

Although adult risk does not translate directly to infants, children, and the elderly, in scenarios where unacceptable risk levels have been determined for adults, there should be concern for similarly exposed (or dosed) sub-populations.

5.3.7 Environmental Risk—Summary and Conclusions

Risk Characterization—Hazard to Aquatic Organisms

The hazard of the HC solvents was assessed using limited toxicity data and structure activity relationships (SAR). Measured acute toxicity values ranged as low as 500 ppb for Stoddard solvent. SAR was used to estimate toxicity values for the individual components of the HC solvents (i.e., C9 to C12 linear paraffins and cyclic paraffins). Since the solvents are very similar chemically and contain approximately equal amounts of linear and cyclic paraffins, they were given the same hazard estimates. The estimated chronic toxicity values for both daphnid and algae are in the range of 80 ppb to 2 ppb which constitutes a high concern for chronic effects. The measured toxicity data for Stoddard solvent are consistent with the SAR predictions (WHO, 1996).

Risk Conclusions

The projected releases of HC solvents to surface water are negligible, on the order of 1×10^{-7} to 1×10^{-8} kg/site/year (Chapter 4). Resulting surface water concentrations are not expected to exceed the aquatic organisms toxicity concern concentrations (CC) of 0.001 mg/L for HC solvents (see Chapter 3 and Appendix B). Thus, there is a low risk of toxicity to aquatic species. Health risks to terrestrial animals were not evaluated.

Uncertainties

The risk conclusions are based on readily available toxicity and exposure data and on models, assumptions and professional judgements about toxicity and exposure information. These give rise to many uncertainties and assumptions and influence to a great extent how close the assessment of risk comes to realistic representation. Some central factors and uncertainties concerning environmental risk conclusions are listed below. Many of these are discussed in more detail in Chapter 4, and Appendices B and E.

- There was no assessment of risks to terrestrial species in this CTSA.

- The hazard assessment for aquatic species is not as certain as that for PCE since the HC solvents are chemical mixtures with uncertainty as to their exact composition, and to the extent that their chemical composition is uncertain, there is uncertainty in the SAR analysis.

- There are uncertainties as to the actual surface water levels, since estimated levels are based on estimated wastewater releases from drycleaning establishments, and an assumption that most establishments send effluent wastewaters to a POTW with subsequent further HC solvent removal.

Other Environmental Effects

None of the CTSA HC solvents have stratospheric ozone-depletion potential, but are volatile organic chemicals (VOCs) and are expected to contribute to lower-level photochemical smog levels. They also have global warming potential.

5.4 MACHINE WETCLEANING PROCESS

Two cleaning formulations were assessed for the machine wetcleaning processes. Water constitutes the majority of each formulation, and weight percentages of the chemical components range from 1% to 10%. Wetcleaning detergent formulations are complex mixtures typically containing water and a variety of different chemicals. Most formulations are trade secrets, and the concentrations of the individual chemicals are unknown to all but the manufacturer. In this CTSA, exposure estimates were based on two example detergent formulations (see Exhibit 2-7). Detergent #1 contains 10 constituents (plus water) and Detergent #2 contains 12 constituents (plus water). Seven constituents are common to both formulations.

5.4.1 Human Health

Very few toxicity data were available in the open literature on the chemical constituents of the two formulations. Some toxicity information, however, was found in reports of the Cosmetic, Toiletry and Fragrance Association (CTFA) (see Chapter 3 and Appendix C). These data do not indicate a potential toxicity for major systemic health effects from the chemicals as low percentage components in an aqueous solution. When hazard data were available, they were generally lacking on key health effects (such as cancer, developmental toxicity, etc.).

5.4.2 Human Health Risks

Risk—General

No oral RfD, inhalation RfC, cancer unit risk, or slope factor has been established to date for any of the sample wetcleaning chemicals reviewed for this CTSA. Unlike for PCE or the HC solvents, toxicity comparison values were not generated for these chemicals.

The example detergents are mixtures. Under ideal circumstances, toxicity information would be available for the mixture or formulation as a whole. More typically, information is available on some or all of the ingredients (components). Often, certain components are exchangeable, with selection based on their function in the process.

Routes of Exposure

Most detergent ingredients, and especially surfactants, are not likely to exist as vapors, mists, or dusts, and inhalation exposure is thus unlikely. Oral exposure to the general population is possible based on potential releases of detergent components to groundwater/surface water resulting in contaminated drinking water.

Since the formulations are expected to be aqueous liquids, the dermal route is the expected route of exposure. Little information is available concerning absorption of the components of the wetcleaning detergent formulations. No data are presented here for dermal absorption rates for the various detergent components.

5.4.3 Occupational Risks—Wetcleaning Workers

Risks from Inhalation and Dermal Exposure

Workers are expected to be the most highly exposed population to machine wetcleaning (MWC) detergent formulations. Dermal exposures are expected, but currently there are no data on actual worker dermal exposures. Inhalation exposure of workers is not expected because of the low volatilities of the component chemicals and because they are in aqueous solution. Dermal exposures to MWC formulations can be modeled, and these models are discussed in Chapter 4, and maximum modeled exposures listed in Exhibit 5-9, along with limited toxicity information. Workers can be exposed to diluted formulation or to full-strength. Maximum modeled exposures assume exposure to full strength formulation.

Operators are the primary workers expected to perform activities which 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. Non-routine activities would more likely expose workers to full-strength formulations.

Risk Conclusions—Occupational Exposures

No quantitative estimate of health risks to workers is possible due to lack of sufficient hazard data. A complete qualitative assessment of risk also requires more extensive hazard data. An illustration of how the available information can be used, however, to indicate whether there can be irritation to workers from dermal exposure to wet process formulations is shown in Exhibit 5-9 using chemicals in the example detergent formulations. Although water is the major constituent of these formulations and the chemical constituents are expected to be found as 1–10% of the mixtures, some studies have suggested some irritant effects at such low concentrations. Sensitization and allergy, however, do not tend to be indicated (Appendix C).

Exhibit 5-9. Summary of Occupational Risk to Example Detergent Constituents via Dermal Exposure

Example Detergent Constituent (amount in formulation)	Example Detergent (taken from Ex. 2-7)	Max. Expected Dermal Exposure[a] (mg/day)	Observed Hazards Following Dermal Exposure in Humans[b]	Qualitative Comparison[c]
Example Surfactants				
Cellulose gum (5%)	1	195	100% soln = no irritation	L
Cocamidopropyl betaine (4.28%)	2	170	3% soln = maximum acceptable cosmetic use	P
Ethoxylated sorbitan monodecanoate (7.5%)	1	290	No irritation observed	L
Lauramide DEA (4.28%)	2	170	≥0.8% soln = mild irritation	L
Sodium laureth sulfate (4.28%)	2	170	≥ 0.5% soln = irritation	P
Sodium lauryl isethionate (3.75%, 2.14%)	1, 2	150, 83	Not enough information	—
Example Surfactant Aids				
Acetic acid (5%)	1	195	5% = vinegar	L
Citric acid (2.5%)	1	98	Not enough information	—
Sodium carbonate (10%)	2	390	50% soln = irritation to abraded skin	L

[a] Level reported in either Exhibit E-13 or E-14 for dermal contact with full-strength detergent formulation.
[b] Taken from Appendix C.
[c] L = low concern; P = potential concern.

Uncertainties

There is a high level of uncertainty as to the health risks to workers from using MWC formulations due to lack of toxicity data for most of the potential chemical constituents of the formulations.

5.4.4 General Population Risks

Dermal exposure of the general population to the component chemicals from wearing newly machine wetcleaned clothing is expected to be negligible. Potential oral exposures to MWC formulations that may be present in drinking water are also expected to be negligible, given the expected levels of less than 1 ppm in surface water for these chemicals (Chapter 4).

5.4.5 Environmental Risk—Summary and Conclusions

Risk Characterization—Hazard to Aquatic Organisms

Acute and chronic toxicity of the chemical constituents to aquatic organisms were estimated using SAR methodology. Almost all of the chemicals in the CTSA example formulation were given a “medium” hazard ranking, and none were considered “high” hazard (see Chapter 3).

All wastes from machine wetcleaning are released to water. The affected population thus is in the aquatic environment. Since these chemicals could be released from many drycleaning sites, site-specific data are not available. Generic assumptions were used to estimate surface water concentrations (USEPA, 1995), and streamflow values for streamflow values for (POTWs). This provides a conservative estimate of surface water concentrations and is appropriate for use when the specific sites are unknown (USEPA, 1995). (See Appendix E for more information.)

Environmental Risk Conclusions

Surface water concentrations were estimated for constituents of the two example wetcleaning formulations. Estimated surface water concentrations for Sample Detergent #1 formulation ranged from 0.04 t0 0.13 ppm. The concern concentrations for aquatic species were not exceeded by any of the chemical constituents. Estimated surface water concentrations for Detergent Sample #2 formulation ranged from 0.04 to 0.43 ppm. The concern concentrations (see Exhibit 3-2) of 0.06 ppm for lauric acid diethanolamide and 0.2 ppm for sodium lauryl isethionate were the only ones exceeded, indicating a hazard for aquatic species from these example constituents.

Uncertainties

There are uncertainties connected with using the structure-activity relationship (SAR) methodology for calculating the concern concentration. However, the combination of confirmation through cross-checking the literature which rests on the available database as well as the general history of usage of this technique lessens the uncertainty.

There are uncertainties as to actual surface water levels, since estimated levels are based on estimated releases of wetcleaning formulations from wetcleaning facilities, and an assumption that most establishments send effluent wastewaters to a POTW with subsequent further removal.

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CHAPTER 6
PERFORMANCE DATA ANALYSIS

CHAPTER CONTENTS

This chapter presents performance data associated with the various fabricare cleaning alternatives. The information and data focus primarily on the factors that affect the ability of a process to clean garments effectively.

Section 6.1 summarizes relevant performance assessment criteria for comparing alternative clothes cleaning processes. Section 6.2 includes a study-by-study presentation of garment and fabricare performance data associated with drycleaning and wetcleaning cleaning technologies. The performance data summarized include the results from clothes cleaning demonstrations and laboratory studies performed in the United States and Canada.

The studies range in scope and complexity, but are generally limited to comparisons of the drycleaning (perchloroethylene [PCE] and hydrocarbon [HC] solvent based) and machine wetcleaning cleaning options. Although improved HC solvents with lower flash points are included in one study in progress, the results were not available at the time of publication. Because the information collected in these studies varies widely, performance results are presented in the format chosen by the study author(s). No further analysis of study data was performed independently to verify results or conclusions. In addition, individual studies may contain specific limitations that are not necessarily identified in this chapter. Due to the wide variability in potential operating conditions, the performance studies summarized in this chapter represent case studies rather than generalizable scenarios.

6.1 PERFORMANCE EVALUATION OF PROFESSIONAL FABRICARE

The Cleaner Technologies Substitutes Assessment (CTSA) has identified various qualitative and quantitative criteria to assist stakeholders in evaluating a fabricare process. This information has been compiled through a review of literature pertaining to performance-based studies of fabricare process options. **When evaluating cleaning performance, it is important to note that variations in technology and the knowledge base of operators will cause a range of results (Blackler et al., 1995).**[1] Although many of the criteria mentioned below are used in the performance-based studies discussed in Section 6.2, they are not universally applied or accepted by the public and private sectors. In addition, other performance considerations may become apparent as clothes cleaning studies expand to include additional alternative technologies.

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[1] In any industry there is a performance learning curve, which is inherent with the use of "cutting-edge" technology. The fabricare industry is no different in this case; the effective cleaning performance and financial viability associated with using innovative fabricare methods, other than drycleaning, will inevitably increase with time. Enhancements in equipment technology, detergents, clothing manufacturing, and care labeling practices are all likely to influence the use, acceptance, and therefore success of innovative cleaning methods by the industry and its customers. Such changes are likely to positively affect traditional drycleaning methods as well (Adamson, 1998; Riggs, 1998).

6.1.1 Performance Assessment Protocol

Consensus protocols for comparing the performance of fabricare options have been under review for several years by a number of public and private organizations. Drycleaning quality control standards have been established by the International Fabricare Institute (IFI). The American Association of Textile Chemists and Colorists (AATCC) also has developed historical criteria for “troubleshooting” drycleaning problems and test methods for standard soil and fabric combinations (Patton, 1994). In addition, the following organizations provide evaluation services for standard soil/fabric combinations: IFI (United States), Krefeld Research Institute for Cleaning Technology (WFK - Germany), Cleaning Techniques Research Institute (TNO - Netherlands), Hohenstein Institute (Germany), and the International Wool Secretariat (England) (Riggs, 1996).

The American Society for Testing and Materials (ASTM) and AATCC have developed performance specifications and test methods, respectively, for acceptable dimensional change (shrinkage and stretching) after laundering and drycleaning (CNT, 1996). These standards assist clothing manufacturers in establishing some consistency in their care labeling instructions. In general, the maximum allowable shrinkage is 2% after three drycleanings and 3% after five launderings (CNT, 1996).

Textile scientists affiliated with AATCC and ASTM have developed performance criteria regarding colorfastness, soil removal, odor, fiber damage, shrinkage, and hand (fabric texture). These standards, listed in volume 7.01 of the *Annual Book of ASTM Standards* (ASTM, 1998) are linked to care labeling guidelines currently under revision by these organizations. Such standards will inevitably affect specifications for soap and detergents, as well as clothes cleaning equipment.

The European Wetcleaning Committee (EWCC), a consortium of research institutes, machine and system manufacturers, detergent suppliers, and organizations with technical expertise, has performed a study to develop a test method for wetcleaning. The EWCC hopes that the combined results of the study and a second series of tests will provide data adequate to establish consensus guidelines for wetcleaning care labels (den Otter, 1996).

6.1.2 Subjective Measures of Cleaning Performance

Numerous studies included in this chapter take advantage of customer mail and telephone surveys to measure customer satisfaction, as a surrogate measure of cleaning process performance. In some instances, researchers have performed parallel surveys to compare customer perceptions of the cleaning performance of two separate process options (e.g., dry versus wetcleaning). Customer surveys are a subjective measure of cleaning performance because they record customers’ perceptions of how “clean” their garments are as a result of using a particular technology. Researchers note that customer perceptions of a clean garment may vary due to regional, socioeconomic, and cultural differences. Variations in acceptable cleaning performance and pricing levels are noted among European, Canadian, and American consumers (Adamson, 1996). Other researchers note that the cultural differences may affect how many times a garment is worn prior to re-cleaning, rather than how “clean” a garment must be for it to be acceptable to a consumer (Riggs, 1998).

6.1.3 Physical and Chemical Characteristics of Clothes Cleaning

All professional clothes cleaning technology should strive to achieve the following goals (Wentz, 1994; Hohenstein, undated):

- Optimize soil removal by overcoming the physical and chemical forces that bind soils to textiles;
- Transport soils away from the textile through the cleaning medium; and
- Preserve and/or restore the original attributes of textiles, including dimensions, dye character, hand, and overall fabric finish.

The cleaning ability of a process depends on the following factors: (1) soil chemistry, (2) textile fiber type, (3) transport medium (aqueous vs. non-aqueous), (4) chemistry of additives (detergents, surfactants), (5) use of spotting agents, and (6) process controls (time, temperature, and mechanical actions). These factors work interactively to provide a range of cleaning abilities for all clothes cleaning processes.

In general, non-aqueous (solvent-based) cleaning processes are effective in dissolving non-polar soils (e.g., oils, fatty stains). Aqueous (water-based) cleaning processes tend to dissolve polar soils (e.g., sugar, salt, perspiration) with greater success. Neither process type removes particulate soils significantly better than the other (Wentz, 1996). However, the cleaning ability of a particular process option may be enhanced with the use of spotting agents, alternative detergents, surfactant additives, and other process modifications such as cleaning time, temperature, or mechanical action.

Non-aqueous cleaning processes are most effectively used with textiles that contain hydrophilic fibers, low-twist yarns, low-count fabrics, and polar colorants. Aqueous cleaning processes are effective with textiles containing hydrophobic fibers, high-twist yarns, high-count fabrics, and non-polar colorants (Wentz, 1996).

Water-based cleaning methods tend to cause expansion of natural and cellulose fibers, leading to a loss of strength, wrinkling, color loss, and dimensional change (shrinkage, stretching). However, such alterations are not necessarily apparent when synthetic fibers are subjected to similar water-based cleaning methods. Textile manufacturers have developed a number of fiber treatments and modifications that may minimize such alterations. For synthetic fibers, non-aqueous cleaning methods may not be appropriate due to potential fiber deterioration (Wentz, 1996).

Other process characteristics that affect cleaning performance include detergent type, mechanical action of equipment, cleaning time, and temperature of cleaning medium. Such characteristics affect not only soil and stain removal, but also potential damage to garments. These individual factors vary in importance according to the cleaning method (Hohenstein, undated).

Pre-treatment and post-treatment spotting is often necessary, regardless of the cleaning method chosen. Spotting agents can be brushed, sprayed, or dripped onto clothing prior to final rinsing and are chosen based on the chemical nature of the target soils. The choice of spotting agent and the application procedure are important considerations because they can cause color changes and dye transfers (Hohenstein, undated).

Another factor in the success of a particular fabricare process is the skill and experience of the clothes cleaning operators. Their ability to properly sort garments and to choose the appropriate process conditions, as well as their knowledge of textiles and cleaning processes, will have a decisive influence on the success of a particular cleaning method. Clothes cleaning operators can also prevent potential damage to garments by being aware of adverse interactions between textiles and cleaning methods (Wentz, 1996). As indicated previously, the ability of cleaning processes to successfully remove soils from a variety of textiles occurs within a range. Because human skill affects that range, textile properties alone cannot be used as a strict guideline for evaluating the ability of a cleaning process (Wentz, 1996; Blackler et al., 1995).

6.1.4 Clothes Cleaning and Textile Damage Potential

Textile damage during cleaning processes includes dimensional change (shrinkage and stretching), appearance change (color loss, dye transfer, damage to decorative trim), tears (mechanical action), and tactile change (garment texture) (Wentz, 1996; Hohenstein, undated). Mechanisms of garment shrinkage include felting (the increase in differential friction between wool fibers caused by swelling in water) and relaxation (the release of microscopic and macroscopic fiber stress via mechanical action, swelling in liquid media, or excessive heat). Relaxation shrinkage, also called progressive shrinkage, is unavoidable in most textiles after multiple cleanings, regardless of the cleaning methodology (Wentz, 1996).

The ability of a fabricare process to maintain the visual (color, finish) and tactile (texture) appearance of a garment is equally important when considering cleaning performance. Restoration of the physical properties of a garment is a function of the cleaning method, textile properties, and the expertise of the operator. In the case of both aqueous and non-aqueous cleaning methods, fabric finishes may be necessary to restore and improve the feel of a garment’s texture (hand). Careful sorting, the use of process additives that protect garment fibers, and careful attention to process conditions and their effect on specific clothing types can mitigate garment damage (Hohenstein, undated).

6.2 REVIEW OF PERFORMANCE STUDIES FOR FABRICARE OPTIONS

6.2.1 Summary of Findings

This chapter has identified laboratory-based and “real world” demonstration studies, both of which are a necessary component of performance evaluation for alternative clothes cleaning processes. Although there are many fabricare technologies under development by manufacturers, the performance assessments identified in this chapter focus entirely on machine wetcleaning as an alternative to non-aqueous based methods. Results of the machine wetcleaning performance studies included here should be considered preliminary due to a lack of uniform performance assessment protocols.

Given the limited number of performance studies available for comparing alternative clothes cleaning options, it is difficult to draw conclusions. The variations associated with clothing fibers and soils result in performance differences for all process options considered. A number of studies mention that the skill of the cleaners follows a distinct learning curve, resulting in greater performance as they adapt to new technology. For example, the *Cleaner by Nature* (UCLA/Occidental/PPERC) study mentioned that their redo rate increased when there was turnover in their cleaner and presser positions

(Gottlieb et al., 1997). Greater use of these cutting-edge technologies in the fabricare industry will inevitably result in advancements in equipment design and operator skills, therefore resulting in increased cleaning performance (Gottlieb et al., 1997; Riggs, 1998; Adamson, 1998).

Most researchers agree that many garments labeled “dryclean only” can be effectively wetcleaned. The results from *The Greener Cleaner, Cleaner by Nature,* and other ongoing demonstration studies indicate that the cleaning performance associated with modern wetcleaning equipment makes this technology an acceptable substitute for a significant fraction of consumer garments. There continues to be debate as to the actual percentage of clothing types traditionally labeled “dryclean only” by manufacturers that can be safely and effectively wetcleaned. Researchers note that the debate should focus not necessarily on percentages of clothing, but on the types of clothing and fabrics that can be successfully wetcleaned (Adamson, 1998; Riggs, 1998).

Based solely on customer claims, one could argue that 99% of all garments can be wetcleaned. However, when an evaluation factor (i.e., a customer satisfaction survey) is introduced, the percentage drops to 93% (CNT - Overall was your clothing clean?), 95% (Environment Canada - Will you use the cleaner again?), and 93% (UCLA/Occidental/PPERC - overall customer rating of excellent or good). If one considers the results of expert panel evaluations of garments wetcleaned multiple times, the percentage is lowered to 83% (UCLA/Occidental/PPERC)[2] and 63% (CNT). In reporting such findings from these studies, it is important to consider that there may be differences between garments that have been wetcleaned, and those that are wetcleaned effectively, to the satisfaction of the customer. Other study variables noted to affect the feasibility of wetcleaning in professional fabricare operations include cleaning costs, garment sample size, garment type, and operator skill.[3]

Additional financial analysis, in conjunction with performance assessment, is necessary to determine the feasibility of using the alternative technologies in the professional clothes cleaning market. Although the clothes cleaning customer is an important arbiter for deciding the effectiveness of a garment care option, fabricare operators must also consider the cost effectiveness of each process option. The competitive nature of the fabricare industry demands that both traditional and innovative technologies be cost-competitive, regardless of their ability to clean garments to the satisfaction of customers. Future work related to performance of cleaning operations should focus on technology cost assessment studies, in addition to the development of consensus testing and evaluation protocols. An ongoing U.S. Environmental Protection Agency (USEPA) laboratory study is expected to aid in the development of the latter information (Riggs, 1998).

Cleaning performance data from several comparative clothes cleaning studies are presented in the following section. Performance assessment techniques include customer satisfaction surveys, evaluation

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[2] The percentage of drycleaned garments whose appearance was deemed acceptable is 87.5%.

[3] Modern wetcleaning is new to the professional fabricare industry, compared to drycleaning with PCE or HC solvents. Several factors may influence the performance of this and other innovative technologies in comparison studies: (1) operator inexperience, (2) relative immaturity of the equipment, (3) fabric and dye incompatibility, and (4) garment labeling biases (Gottlieb et al., 1997). In particular, operator skill is consistently cited as an important factor in improving the success of wetcleaning in the studies included in this chapter (Adamson, 1998). The fabricare industry is currently working with government regulators, garment and fabric manufacturers, and equipment manufacturers to resolve these issues in a manner that is beneficial for all stakeholders (Riggs, 1998).

of cleaned garments and fabric swatches by industry experts, and analysis of repeatedly cleaned and damaged garments. Each study summary includes general project information, results indicated or expected, and additional results provided by researchers.

6.2.2 Alternative Clothes Cleaning Demonstration Shop (*The Greener Cleaner*) - Draft Final Report (September 1996)

Sponsor:	USEPA
Investigating Organization:	Center for Neighborhood Technology (CNT)
Duration of Study:	12 months (May 1995 to May 1996)
Location:	Chicago, Illinois
Source of Information:	Center for Neighborhood Technology, 1996

Summary of Performance Evaluations

- Two customer satisfaction telephone surveys of customers of *The Greener Cleaner*
- Evaluation of a random sample of wetcleaned customer garments by *The Greener Cleaner*
- Evaluation of identical garments before and after wetcleaning and drycleaning
- Comparison of “old” clothing after multiple wet and drycleanings

Wetcleaning Demonstration Site

Between 1995 and 1996, CNT designed, monitored, and evaluated a machine wetcleaning shop, *The Greener Cleaner*. This shop was developed and operated to mimic a “typical” commercial drycleaning shop in terms of size, price, fabric types, and garments cleaned. Exhibit 6-1 is a demonstration profile for *The Greener Cleaner* operation. Using only wetcleaning equipment for this aspect of the study, CNT evaluated the costs and customer satisfaction associated with a range of typically drycleaned garments. Performance results for this part of the CNT study pertain to the 1 year the shop was operated as a demonstration site.

Exhibit 6-1. *The Greener Cleaner* Demonstration Shop Profile

Description	Retail garment cleaning operation, plant on premises, 100% wetcleaning	
Location	5312 North Broadway, Chicago; mini-mall shopping plaza	
Shop Size	1250 sq. ft.	
Personnel	Noam Frankel (owner) Ann Hargrove (plant manager) 1 to 2 pressers (full-time equivalent) 2 to 3 counter personnel (full-time equivalent)	
Cleaning/Drying Equipment	Wascomat/Aqua Clean ACS50G (50 lb. washer and 30 lb. gas-heated dryer) Whirlpool domestic washing machine Drying cabinet	
Pressing/Finishing Equipment	Unipress utility press Unipress hot head press Cissell triple puff Cissell form finisher Veit pants topper Veit form finisher Veit ironing table	
Cleaning Supplies for Wetcleaning Equipment	Bufa Aquasafe Detergent Bufa Aquasafe Pre-Finish	
Sample Price List	Tie	$3.00
	Pants	3.50
	2-piece wool suit	6.50
	Silk dress	7.50
	Full-length down coat	13.00
Number of Garments Wetcleaned	31,734 (60% labeled “dryclean only”)	

Exhibits 6-2 and 6-3 describe the distribution of the fiber and garment types, respectively, cleaned during *The Greener Cleaner* demonstration. Blended fibers are recorded in terms of the dominant fiber or the fiber most difficult to clean. Clothes were cleaned between May 11, 1995, and May 11, 1996. The report recognizes that regional and seasonal variations make it difficult to develop a “typical” sample of garments that includes an industry-wide representation of fiber types, fabrics, and garment types. The shop accepted virtually all garments for cleaning regardless of the instructions on the care label. During the duration of this study, 43 garments (0.14%) were rejected for machine wetcleaning if the shop employees felt they would not be able to clean them successfully. The shop fully guaranteed its work and reimbursed customers for the few damaged garments. Claims were paid on 28 (0.08%) of the total garments cleaned, which included 9 lost garments, 10 garments with shrinkage, 3 garments with color loss or fading, 1 garment with a burn from pressing, 1 garment with unresolved spotting problems, and 4 garments with miscellaneous or unreported problems.

Exhibit 6-2. Fiber Types Machine Wetcleaned at *The Greener Cleaner*

Fiber Type	Number Cleaned	% of Total
Wool	7,341	23%
Rayon	6,468	20%
Cotton	5,117	16%
Silk	3,532	11%
Linen	1,984	6%
Polyester	199	1%
Down	221	1%
Unknown	6,872	22%
Total	**31,734**	**100%**

Exhibit 6-3. Garment Types Machine Wetcleaned at *The Greener Cleaner*

Garment Type	Number Cleaned	% of Total
Suit	2,715	9%
Pants	6,766	21%
Blazer/jacket	2,783	9%
Vest	517	2%
Shirt	2,673	8%
Blouse	4,363	14%
Skirt	1,924	6%
Dress	2,372	7%
Scarf	280	1%
Outerwear	1,416	4%
Sweater	3,403	11%
Home items	589	2%
Tie	355	1%
Misc.	1,578	5%
Total	**31,734**	**100%**

Results of Customer Satisfaction Survey

Two independent surveys were performed by Audits and Surveys Worldwide, Inc. During November 1995, 203 of the 1,800 customers of *The Greener Cleaner* were randomly chosen for telephone interviews. Eighty-five percent of these individuals rated the shop's performance as either "good" or "excellent." In June 1996, 100 of the 2,868 shop customers were randomly chosen for the same survey. Eighty-seven percent of these individuals rated the shop's overall service as "good" or "excellent," and 84% said they would recommend the service to a friend. The second survey indicated that 64% of the customers used *The Greener Cleaner* as a result of their concern for the environment. The questions and the results of both surveys are listed below in Exhibit 6-4.

Exhibit 6-4. Telephone Survey Questions and Results

Survey Question	Response	November 1995	June 1996
1. How would you rate their service overall ?	Excellent	41.0%	48.5%
	Good	45.0%	38.5%
	Acceptable	6.5%	8.0%
	Poor	6.5%	4.0%
	Don't know/refused	1.0%	1.0%
2. How would you rate their counter service overall?	Excellent	49.0%	48.5%
	Good	42.0%	40.5%
	Acceptable	7.0%	9.0%
	Poor	1.5%	2.0%
	Don't know/refused	0.5%	0.0%
3. After being serviced by *The Greener Cleaner*, were your clothes pressed and finished nicely?	Yes	90%	88.0%
	No	9.0%	9.0%
	Don't know/refused	1.0%	3.0%
4. Was there any size difference?	Yes	14.0%	18.0%
	No	82.0%	82.0%
	Don't know/refused	4.0%	0.0%
4a. Would that be.....?	Shrinking	13.0%	15.0%
	Stretching	1.0%	5.0%
	Other	0.0%	1.0%
5. Did the seams pucker or bulge?	Yes	7.0%	5.0%
	No	87.0%	93.0%
	Not applicable	1.0%	1.0%
	Don't know/refused	4.0%	1.0%
6. Was there any odor present in your clothing?	Yes	3.0%	1.0%
	No	96.5%	99.0%
	Don't know/refused	0.5%	0.0%
6a. If odor was present, was this odor acceptable or unacceptable?	Acceptable	1.5%	1.0%
	Unacceptable	1.5%	0.0%
7. Was there any color change to your clothing?	Yes	6.0%	1.0%
	No	92.0%	99.0%
	Don't know/refused	2.0%	0.0%

Exhibit 6-4. Telephone Survey Questions and Results (Cont'd)

7a. With regard to the color change was there....?	Overall change with improvement Overall change, no improvement Some unevenness in color Don't know/refused	0.0% 3.5% 2.0% 0.5%	0.0% 0.0% 1.0% 0.0%
8. Were stains or spots removed?	Yes No Not applicable/no spots or stains Don't know/refused	60.0% 14.0% 23.0% 3.0%	63.0% 15.0% 18.0% 4.0%
9. Were there any rips or tears?	Yes No Don't know/refused	2.0% 96.5% 1.5%	8.0% 91.0% 1.0%
10. If your clothing had any buttons or decorations were any...	Damaged Missing No problems/decorations Not applicable/no buttons or decorations Don't know/refused	3.5% 1.5% 59.0% 34.0% 2.0%	0.0% 3.0% 95.0% 3.0% 0.0%
11. Overall, was your clothing clean?	Yes No Don't know/refused	94.5% 5.5% 0.0%	93.0% 4.0% 3.0%
12. Would you recommend *The Greener Cleaner* to a friend?	Yes No Don't know/refused	85.0% 12.0% 3.0%	84.0% 12.0% 4.0%
13. Why did you first take your clothes to *The Greener Cleaner?*	Convenient location/parking Concern about the environment Reputation for quality and service Curious Other Don't know/refused	Question not used in survey	18.0% 64.0% 11.0% 16.0% 14.0% 0.0%
14. Were you aware that the process used at *The Greener Cleaner* is water based, not the usual solvent-based process that is used to dryclean clothes?	Yes No Don't know/refused	Question not used in survey	87.0% 12.0% 4.0%
14a. How did you first react to hearing of the use of this water-based process?	Very positive Somewhat positive Neither positive or negative Somewhat negative Very negative Don't know/refused	Question not used in survey	61.0% 12.0% 12.0% 1.0% 0.0% 1.0%

Random Evaluation of Machine Wetcleaned Garments

A panel of 19 volunteers (one or two per evaluation) and a CNT engineer randomly selected 460 garments (108 knit, 352 woven) and evaluated them prior to and after washing by *The Greener Cleaner*. The volunteers included 12 drycleaners, two fashion design educators, two fabric specialists working with large retailers, and three consumers. The selected garments were not made apparent to shop personnel in order to minimize cleaning bias. Care labels were found on 355 of the 460 garments (77%). Of those garments, 68% were labeled "dryclean," "dryclean only," or "professionally dryclean." The remainder were labeled "hand or machine wash." Exhibit 6-5 contains the results of these evaluations.

Exhibit 6-5. Results of Panel Evaluation of Wetcleaned Clothes at *The Greener Cleaner*

Evaluation Criteria	Percent of Total
Overall Appearance	
Excellent	28%
Good	39%
Fair	23%
Poor	10%
Presence of Odor	
None detectable	87%
Slight odor	7%
Fresh odor	3%
Objectionable odor	3%
Stain Removal	
No stain detectable prior to cleaning	53%
Stain/soil completely removed	21%
Minor stain/soil remain	7%
Stain/soil remain	19%
Dimensional Change - Woven Garments	
0 to 2% dimensional change	62%
2 to 4% dimensional change	27%
Greater than 4% dimensional change	11%
Dimensional Change - Knit Garments	
0 to 2% dimensional change	20%
2 to 4% dimensional change	22%
Greater than 4% dimensional change	58%

Evaluators commented on the general appearance of the garment before and after cleaning. Evaluators did not note any of the following problems for clothes evaluated: color unevenness, splotchiness, tears, missing buttons, or other problems related to cleaning and finishing.

Dimensional change measurements were noted in test garments in terms of the maximum amount per garment. In one example, a jacket shrinks 1% in length, 0% in the waist, and 2% in the sleeves. Its maximum dimensional change is therefore reported as -2%. The variables reported for this aspect of the evaluation included fiber type, fabric (knit or woven), garment type, color, and care label. The study indicated that dimensional change is best correlated with fabric type (i.e., knit garments). Operators modified their cleaning procedure by placing knit garments in mesh bags prior to washing, thus reducing the effect of mechanical action on dimensional change. After drying to 15% residual moisture, sweaters were placed on flat surfaces to complete the drying process.

Side-by-Side Evaluation of Identical Garments

In this test, 52 sets of identical garments (three per set) were compared throughout six wash-and-wear cycles. One garment per set was wetcleaned at *The Greener Cleaner*, one was drycleaned at one of six different shops, and the third was used as a control for comparison. Volunteers wore garments and noted any unusual wearing conditions such as spills, tears, or rips. An effort was made to make these tests blind; for example, wearers did not know which cleaning method would be used. Evaluation of the garments took place immediately after purchase and again after multiple wash and wear cycles. Exhibit 6-6 summarizes the results of these evaluations, which include general appearance and color change. Although both cleaning methods were evaluated with similar success in terms of color change (87% and 85%, respectively), the general appearance of wetcleaned garments had significantly lower acceptance (63%) than the drycleaned ones (88%).

Exhibit 6-6. Side-by-Side Evaluations of Identical Wet and Drycleaned Garments

	Acceptable	**Not Acceptable**
General Appearance		
Drycleaned	88%	12%
Machine wetcleaned	63%	37%
Color Change		
Drycleaned	85%	15%
Machine wetcleaned	87%	13%

Exhibits 6-7a and 6-7b summarize the evaluations of maximum dimensional change for woven garments and fabrics. Exhibits 6-8a and 6-8b summarize the evaluations of maximum dimensional change for knit garments and fabrics. The wool, rayon, and silk fabrics seemed to exhibit the most dimensional change (greater than 6%) for both knit and woven garments. These results indicate that greater percentages of wetcleaned woven and knit garments (21% and 77%, respectively) exhibit significant dimensional change (greater than 4%) than similar drycleaned garments (5% and 38%, respectively).

Comparison of "Old" Clothing After Multiple Wet and Drycleanings

A small sample (25 garments) of volunteer-owned clothing was selected and assigned by coin toss to either the wet or drycleaning process. Clothing samples were evaluated, cleaned six times, and re-evaluated for evaluator and volunteer approval, as well as maximum dimensional change. Protocols similar to those used in the previous evaluations were followed to maintain accuracy and test validity. A greater number of the wetcleaned garments experienced more dimensional change than the drycleaned ones. Evaluators noted that 7 of 11 wetcleaned garments and 6 of 11 drycleaned garments were judged "good." Researchers note that the small sample size and absence of control garments limits the value of this comparison.

Additional Comments

The CNT project was designed to mirror an average commercial drycleaning operation in terms of volume, rates, and fabric and garment types cleaned (Patton, 1996). Prior to the release of the UCLA wetcleaning study, the CNT study represented one of the most complete wetcleaning studies to date. Researchers concluded that wetcleaning, although not a complete replacement for drycleaning, is a viable substitute for a significant percentage of clothing labeled "dryclean only." They also concluded that the many variables associated with performance assessment make it difficult to establish a generic guide appropriate for commercial cleaning shops (CNT, 1996).

Exhibit 6-7a. Maximum Dimensional Change for Woven Garments[a]

Garment Type	0-2% Dim. Change		2-4% Dim. Change		4-6% Dim. Change		6+% Dim. Change		Total Number
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	
Pants	5	6	6	5					11
Jacket	3	5	2	1	2	1			7
Vest	2	2							2
Shirt				1			1		1
Blouse		1					1		1
Skirt	4	4	1	3	1	1	2		8
Scarf				1			1		1
Coat	1	1	4	4					5
Tie		1	3	2					3
Total **% of Total**	**15** **38%**	**20** **51%**	**16** **41%**	**17** **44%**	**3** **8%**	**2** **5%**	**5** **13%**	**0** **0%**	**39**

[a] Thirty-nine sets of woven garments were analyzed in this comparison.

Exhibit 6-7b. Maximum Dimensional Change for Woven Fabrics[a]

Fabric Type	0-2% Dim. Change		2-4% Dim. Change		4-6% Dim. Change		6+% Dim. Change		Total Number
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	
Cotton	1	1	2	2	1	1			4
Wool	5	8	7	7	2	1	2		16
Rayon	3	4	1	3			3		7
Silk	1	1	3	3					4
Linen	1	2	2	1					3
Acrylic	1	1							1
Polyester	3	3	1	1					4
Total **% of Total**	**15** **38%**	**20** **51%**	**16** **41%**	**17** **44%**	**3** **8%**	**2** **5%**	**5** **13%**	**0** **0%**	**39**

[a] Thirty-nine sets of woven garment fabrics were analyzed in this comparison.

Exhibit 6-8a. Maximum Dimensional Change for Knit Garments[a]

Garment Type	**0-2% Dim. Change**		**2-4% Dim. Change**		**4-6% Dim. Change**		**6+% Dim. Change**		**Total Number**
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	
Pants				1			1		1
Shirt							1	1	1
Sweater		2	3	5	2	3	6	1	11
Total **% of Total**	**0** **0%**	**2** **15%**	**3** **23%**	**6** **46%**	**2** **15%**	**3** **23%**	**8** **62%**	**2** **15%**	**13**

[a] Thirteen sets of knit garments were analyzed in this comparison.

Exhibit 6-8b. Maximum Dimensional Change for Knit Fabrics[a]

Fabric Type	**0-2% Dim. Change**		**2-4% Dim. Change**		**4-6% Dim. Change**		**6+% Dim. Change**		**Total Number**
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	
Cotton					1	1			1
Wool			1	3		1	3		4
Rayon						1	1		1
Silk			1	3			4	2	5
Linen		1			1				1
Acrylic		1	1						1
Total **% of Total**	**0** **0%**	**2** **15%**	**3** **23%**	**6** **46%**	**2** **15%**	**3** **23%**	**8** **62%**	**2** **15%**	**13**

[a] Thirteen sets of knit garment fabrics were analyzed in this comparison.

6.2.3 Final Report for the Green Clean Project (October 1995)

Sponsors: Environment Canada, Korean Dry Cleaners Association, Ontario Fabricare Association, Ontario Ministry of Environment and Energy
Investigating Organization: Environment Canada
Duration of Study: Phase I - June to November 1994; Phase II - December 1994 to February 1995; Phase III - September 1995 to March 1996
Location: Phase I - Toronto and Markham, ONT; Phase II - Toronto, Markham, and Windsor, ONT; Phase III - Hamilton, ONT
Source of Information: Environment Canada, 1995

Summary of Performance Evaluations

- Customer response surveys (Survey I - wet and steam options; Survey II - wet, steam, and dry options; Survey III - dry option) to rate garment appearance, fit, damage, cleaning, and repeat visit potential
- Analysis of customer claims based on first 6 months of Phase I
- Fabric swatch studies (related to shrinkage, color change, soil removal, and effect on fusible interfacing) performed for Environment Canada at the University of Guelph, Textile Science Group
- Comparison of 13 dry and wetcleaned consumer garments in terms of shrinkage, pressing quality and visual appearance, and pressing and finishing time

Project Description

Exhibit 6-9 provides a demonstration shop profile for the wetcleaning operation undertaken for this study. Exhibit 6-10 is a profile of the garment and fabric types wetcleaned during the same period.

Phase I of this study consisted of establishing a “drop-off” site (*Green Clean Depot*) for researching and evaluating customer acceptance of solvent-free cleaning (wetcleaning and steam cleaning with no drycleaning option). Multi-process wetcleaning technology was installed at two existing drycleaning plants.

Exhibit 6-9. Wetcleaning Shop Profile for the Green Clean Project[a]

Description	Multiple garment cleaning plants; wet and drycleaning equipment on premises
Location	Toronto, Ontario, Canada
Shop Size	Varies
Wet Cleaning Equipment[a]	IPSO/Aqua Tex: HFH 145 (18 lb), 324 (50 lb), 304 (70 lb) Milnor 30022F8W (33 pounds) Aqua Clean: 30S (18 pounds), 50S (30 pounds), 80S (80 pounds) Unimac: UA 75, 160 (12 pounds), 230 (20 pounds), 400 (52 pounds) Miele WS 5190 TR
Drying Equipment	Aqua Tex - American W/C (30 pounds) American: ADS 50 (30 pounds) and 75 (45 pounds) Aqua Clean S & G 30 (18 pounds), 50 (30 pounds), 80 (48 pounds) Unimac DTB - 50/75 CSHPMM (18 pounds, 30 pounds, 45 pounds) Miele T6550 TR
Finishing Equipment	Not specified
Cleaning Supplies	Not specified
Sample Price List	Not specified

[a] All machine capacities (pounds) represent 60% of laundry capacity specified by manufacturer.

In Phase II a private operator took over the *Green Clean Depot.* Three additional wetcleaning locations were established. Customers were given the option of multi-process wet or drycleaning.

In Phase III an existing drycleaning plant was converted to a wetcleaning-only facility. During this phase project participants evaluated the financial viability of a wetclean-only plant, as compared to a drycleaning alternative.

The results presented in the October 1995 report study were collected between June 1994 and February 1995. They apply to all of Phase I and the first 3 months of Phase II.

Customer Satisfaction Survey

Up to three survey cards per customer were distributed with each garment cleaned. Postage was pre-paid on cards for return mail, and cards were also accepted at the drop-off points. A breakdown of the survey response is as follows: 412 responses for Survey I on wet and steam options (June 6 to November 30, 1994); 60 responses for Survey II on wet, steam, and dry options (December 1994 to February 1996); and 201 responses for Survey III on drycleaning only (November 1994 to April 1995). Note that the survey schedule does not necessarily correlate with the project schedule. Also, the Survey II results are not differentiated in terms of cleaning method.

Exhibit 6-10. Garment Profile Summary for the *Green Clean Depot*

Garment Type	Number Cleaned June–November 1994	Number Cleaned December 1994–February 1995
Bedding	72	29
Coat	231	102
Drapes	18	2
Dress	217	68
Pants	916	446
Shirt (hand pressed)	547	248
Skirt	443	140
Shorts	53	3
Suit jacket	757	258
Suit vest	71	27
Sweater	258	172
Ties	20	11
T-shirt	26	5
Machine pressed shirts	1,391	385
Other	162	52
Fabric Type		
Cotton, polyester, nylon	905	333
Wool	815	450
Wool polyester mix	308	8
Angora/cashmere	37	48
Linen	195	89
Rayon	439	176
Silk	315	141
Rayon linen/acetate viscose mix	321	90
Rayon, cotton, linen mix	152	11
Rayon, linen, ramie mix	112	15
Down	29	14
Leather and suede	29	0
Unknown	134	188
Total	**5,182**	**1,948**

Exhibit 6-11 is a summary of the results obtained from customer satisfaction surveys. Exhibit 6-12 summarizes the negative responses received for each survey. The results of the second survey do not distinguish which of the three cleaning methods was chosen by customers. In addition, the response rates for Surveys II (9.7%) and III (3.5%) were much lower than the response rate for Survey I (27.4%). The Green Clean report makes the following overall observations regarding these customer response surveys:

- There was little difference in the amount of garment shrinkage reported on the surveys.

- Garment damage was not significant, with the exception of button deterioration associated with drycleaning.

- In evaluating general appearance, 97% of customers who chose wetcleaning (Survey I), 97% of customers who chose wet/steam/drycleaning (Survey II), and 98% of customers who chose drycleaning (Survey III) stated that their clothing was clean overall.

Exhibit 6-11. Summary of Customer Satisfaction Surveys[a]

Survey Question	Response	SI - Wet/Steam Clean Options[a]	SII - Wet, Steam, and Dry Options[b]	SIII - Dry Option Only[c]
Garment Appearance				
- Are clothes pressed/finished nicely?	Yes	93%	90%	97%
	No	7%	10%	3%
- Is the shaping/body OK?	Yes	96%	95%	98%
	No	4%	5%	2%
- Do any seams pucker or bulge?	Yes	4%	1%	2%
	No	96%	99%	98%
- How is the color?	No change	89%	83%	91%
	Some improvement	9%	11%	6%
	Not an improvement	3%	6%	3%
Garment Fit				
- How is the size?	No change	95%	98%	95%
	Some shrinkage	5%	0%	5%
	Some stretching	<1%	2%	0%
Garment Damage				
- Are there any new tears?	Yes	0%	0%	0%
	No	100%	100%	100%
- Are buttons and decorations OK?	Yes	89%	87%	77%
	Not applicable	11%	12%	17%
	Broken or missing	<1%	1%	6%
Garment Cleaning				
- Is the clothing clean overall?	Yes	97%	97%	98%
	No	3%	3%	2%
- Were stains or spots removed?	Not applicable	44%	42%	39%
	Yes	50%	51%	55%
	No	6%	7%	5%
- Is any unpleasant odor present?	Yes	1%	2%	5%
	No	99%	98%	95%
Customer Return				
- Will use Cleaner again	Yes	95%	97%	98%
	No	5%	3%	2
Number of Surveys Returned		**412**	**60**	**201**
Survey Response Rate		**27.4%**	**9.7%**	**3.5%**

[a] Wet and steam cleaning performed at two facilities for Survey I.
[b] Wet, steam, and drycleaning performed at one facility for Survey II.
[c] Drycleaning performed at six facilities for Survey III.

Exhibit 6-12. Summary of Customer Satisfaction Surveys with Negative Responses

Survey Question	Survey I[a]			Survey II[b]	Survey III[c]
	Number of Responses	Wetclean	Steam Clean	Number of Responses	Number of Responses
Garment Appearance					
- *Not pressed and finished nicely*	29	19	10	5	7
- *Shaping or body not OK*	17	12	5	3	4
- *Seams pucker or bulge*	16	11	5	0	4
- *Change in color of garment, no improvement*	13	10	3	4	5
Garment Fit					
- *Some shrinkage/stretching*	24	14	10	1	10
Garment Damage					
- *Tears*	0	0	0	0	0
- *Buttons and decorations not OK*	3	3	0	1	12
Garment Cleaning					
- *Garment is not clean overall*	13	10	3	2	5
- *Odor*	5	5	0	1	10
- *Stains and spots not removed*	25	18	7	5	11
Customer Return					
- *Will not use Cleaner again*	20	16	4	2	3
Number of Surveys Returned	**412**			**60**	**201**
Survey Response Rate	**27.4%**			**9.7%**	**3.5%**

[a] Wet and steam cleaning performed at two facilities for Survey I.
[b] Wet, steam, and drycleaning performed at one facility for Survey II.
[c] Drycleaning performed at six facilities for Survey III.

- Responses regarding stain and spot removal did not vary significantly among the three surveys.
- Customers were most dissatisfied with the color change associated with the wetcleaning-only option.
- Wetclean and dryclean-only customers responded similarly to questions about garment size.

Analysis of Customer Claims

Customer claims about damaged clothing were analyzed using the IFI's Fair Claims Guide. Claims were paid on 14 out of 3,791 garments cleaned during the first 6 months of operation (Survey I) of the *Green Clean Depot* (7 - color/dye run; 5 - shrinkage; 2 - stains and cracking). Out of 1,563 garments washed, 2 claims resulting from wetcleaning silk and specialty wool were paid between December 1994 and February 1995 (Survey II). No claims are mentioned in this study for the Survey III period.

Fabric Swatch Studies

Some data regarding fabric swatch studies performed at the University of Guelph (Section 6.2.7) are presented in this study. Swatches were tested using drycleaning (Lindus Dry-to-Dry Refrigerated System), wetcleaning (Wascomat Aqua Clean Washer and Dryer System; IPSO Washer and American Dryer System), home laundering (Maytag Top-loader Laundry Machine), steam cleaning (steam gun and detergent spray treatment), and pressing only.

The following types of fabric swatches were tested in this experiment: undyed test fabrics (for shrinkage), dyed consumer fabrics (for shrinkage and color change), standard soiled fabrics (for soil removal), and bonded fabrics (for determining effects on fusible interfacing). All fabrics, except bonded fabrics, were prepared and measured by students and faculty in the Textile Science Group at the University of Guelph. Bonded fabrics were prepared and evaluated by Canada Hair Cloth, a Canadian manufacturer. A total of 414 swatches were processed 950 times at two drycleaning facilities in Toronto with regular garment loads. Pressing was completed according to ASTM D-2724-87 (Bonded Apparel Fabrics Method) by Environment Canada staff.

Exhibit 6-13 contains the results for the shrinkage studies on processed undyed fabric swatches. The study identifies both rayon and wool as fabrics with "problem shrinkage." Past experience with drycleaning, however, indicates that shrinkage may have been exaggerated for the undyed test fabrics in this study (Environment Canada, 1995).

Exhibit 6-13. Percent Warp Shrinkage of Undyed Fabrics After One Cleaning[a]

Fabric Swatch	Press Only	Dryclean	Steam Clean	Home Laundry	Wetclean (GC)	Wetclean (WC)
Low Shrinkage (Less than 3%)						
Polyester plain	0.00	0.80	0.67	1.73	1.47	0.80
Cotton/polyester	0.00	0.00	0.47	0.40	0.53	0.40
Silk	0.27	0.00	-0.13	4.67	-0.53	0.40
Moderate Shrinkage (Less than 5%)						
Acetate	1.33	1.87	3.13	3.07	2.80	3.60
Mercerized cotton	0.00	0.40	3.73	5.20	4.27	4.40
Cotton	0.80	3.47	6.73	10.00	7.60	8.40
Worsted wool	2.13	3.07	5.07	10.40	6.40	6.13
Linen	0.53	0.80	2.93	8.13	5.13	4.80
Problem Shrinkage (more than 5%)						
Wool	2.00	2.53	4.40	12.27	7.53	7.33
Rayon	0.93	0.27	4.40	7.87	6.07	7.33

[a] Percent shrinkage is calculated on the basis of original measurements on fabrics.

Exhibit 6-14 contains the results of a shrinkage study performed on dyed consumer fabrics that were donated by garment manufacturers. Problem shrinkage was exhibited in the following fabrics: polyester after one drycleaning, light wools and polyester after five wetcleanings, and laundered light wools and polyesters after one or more cleanings. Steam cleaning produced no problems except for slight bubbling of polyester after the fifth cleaning. There was a wide range of results for bonded fabric interfacing, indicating the difficulty in predicting results for some cleaning methods, especially wetcleaning.

Exhibit 6-15 contains the results of standard soil removal tests for cotton fabric swatches. In addition, a white swatch area was evaluated for soil redeposition. Results for drycleaning indicate that it was deficient in cleaning blood and red wine and had the highest amount of redeposition. Wetcleaning was most effective with blood and red wine and had the lowest amount of redeposition. Home laundry removed the highest amount of carbon black/mineral oil. Steam cleaning seemed to have little or no soil removal capacity.

Exhibit 6-14. Percent Shrinkage Results for Consumer Fabric Swatches[a]

Fabric Swatch	Press Only	Dryclean	Steam Clean	Wetclean (Wascomat)	Wetclean (IPSO)	Home Laundry
Low Shrinkage (Less than 3%)						
100% Polyester plain	0.0%	0.4%	1.1%	1.2%	0.5 %	3.1%
55% Cotton/45% polyester plain	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
100% Polyester twill	1.2%	2.1%	1.5%	2.0%	0.9%	4.9%
100% Mercerized cotton ripstop	0.1%	0.3%	1.6%	2.0%	1.7%	2.7%
100% Silk	0.7%	0.0%	0.0%	- 0.3%	- 0.9%	1.5%
50% Linen/50% polyester	0.4%	0.5%	1.3%	1.2%	1.3%	2.1%
Moderate Shrinkage (Less than 5%)						
70% Wool/20% nylon/10% cashmere	1.6%	1.6%	4.3%	4.7%	4.3%	8.4%
Problem Shrinkage (more than 5%)						
96% Cotton/4% lycra twill	0.8%	4.1%	3.2%	5.7%	5.2%	10.1%
64% Acetate/36% rayon crepe	1.7%	1.6%	4.8%	8.7%	7.3%	9.5%
95% Rayon/5% silk	0.1%	2.0%	5.1%	9.3%	5.9%	14.4%
100% Wool (loose weave)	0.0%	1.1%	2.4%	5.5%	5.3%	8.3%

[a] Results are presented for maximum shrinkage in either warp or weft direction after one cleaning. Results in most cases are for 40 cm (15 inch) square fabric swatches with triplicate measurements. Results were within the 99% confidence interval for 98.5% of measurements. Results were within the 95% confidence interval for 100% of measurements.

Exhibit 6-15. Percent Soil Removal from Standard Soil Test Fabrics

Soil Type	Dryclean	Steam Clean	Home Laundry	Wetclean (IPSO & Lever)	Wetclean (Aqua Clean)
Unsoiled (redeposition)	6	2	3	3	1
Carbon black/mineral oil	30	10	68	24	30
Cocoa	18	0	16	7	7
Blood	8	0	39	58	20
Red wine	4	2	14	10	20

Garment Comparison Study

Thirteen sets (three identical garments per set, including one control) of consumer garments were compared after multiple wet and drycleanings. Garment samples were selected to represent clothing typically drycleaned. They were wet and drycleaned five times with other laundry loads, alternating between the two facilities. Pressing facilities included a medium/large facility (Cleaner A) and a relatively small facility (Cleaner B) in order to assess differences in pressing times.

Results for shrinkage, pressing quality, visual appearance, and pressing and finishing time are presented in Exhibits 6-16, 6-17, and 6-18. In general, results for shrinkage and finishing quality varied, depending on textile type. Finishing problems are noted for the rayon blouse (wet), cotton knit shorts (wet and dry), viscose/linen jacket (wet and dry), wool/viscose dress (wet), and wool/polyester/pinstripe dress (wet and dry).

Pressing and finishing time was reported to be a function of shrinkage; that is, garments with significant shrinkage require more time to return to their pre-cleaning state. Wetcleaned garments required between 5% and 50% more pressing time, compared to drycleaned garments. Exhibit 6-18 presents a range, as a result of differences identified in facility scale, and percent capacity used, of dry and wetcleaning options. It was concluded that some garments should not be wetcleaned based on the amount of pressing time required to adequately restore them.

Exhibit 6-16. Percent Garment Shrinkage Results Before and After Pressing[a]

Color	Material	Garment	Point of Measure	Cleaner A[b]		Cleaner B[c]	
				Dryclean	Wetclean	Dryclean	Wetclean
Garments with Shrinkage Less than 3%							
Red	100% Silk	Shirt (Protocol)	After drying After pressing	0.7% 0.0%	1.3% 1.1%	1.7% 0.5%	1.2% 1.0%
Patterned Multi-color	100% Silk	Tie (Leo Chevalier)	After drying After pressing	0.5% - 0.6%	0.5% - 0.3%	2.2% 0.8%	1.6% 0.1%
Beige	100% Linen	Shirt (Dalia)	After drying After pressing	0.3% 0.0%	1.6% 1.2%	1.2% 0.8%	1.7% 1.1%
Brown	100% Cotton	Pants (Functionals)	After drying After pressing	1.3% 0.5%	1.4% 0.8%	1.8% 0.9%	1.4% 0.8%
Grey	100% Wool	Pants (Protocol)	After drying After pressing	0.5% 0.0%	1.6% 0.8%	1.2% 0.1%	1.8% 1.2%
Patterned Black/White	100% Wool	Pants (Cool Wool)	After drying After pressing	1.3% 0.0%	1.8% 0.7%	0.3% 0.0%	2.2% 0.6%
Patterned Black/White	100% Wool	Suit Jacket (Cool Wool)	After drying After pressing	0.4% 0.1%	0.5% 0.8%	1.3% 0.5%	1.3% 0.4%
Light Green	100% Polyester	Suit Jacket (Tan Jay)	After drying After pressing	0.3% 0.3%	0.9% 0.9%	0.7% 0.4%	1.3% 1.1%
Garments with Shrinkage Greater than 3%							
Patterned Multi-color	100% rayon	Blouse w/pads (Jessie)	After drying After pressing	0.9 0.4	5.4 4.4	2.1 0.5	6.5 3.0
White	100% cotton knit	Shorts (Divine One)	After drying After pressing	1.2 0.8	15.2 15.6	4.6 4.2	16.0 14.5
Light Blue	80% Viscose 20% Linen	Suit Jacket (Sterling)	After drying After pressing	1.4 0.8	5.7 3.7	2.2 1.0	7.6 2.7
Dark Blue	60% Wool 40% Viscose	Dress (Holt Renfrew)	After drying After pressing	1.2 0.9	4.5 1.7	2.0 0.6	4.8 1.5
Brown Pinstripe	99% Wool 1% Polyester	Dress (Holt Renfrew)	After drying After pressing	0.5 0.2	9.9 8.0	1.7 0.5	10.0 4.6

[a] Shrinkage results are calculated from original reference measurements and are cumulative effects. Results are for the same garments after four and five cleanings, respectively, for Cleaner A and Cleaner B.
[b] Cleaner A cleaned and pressed garments for the second and fourth treatments.
[c] Cleaner B cleaned and pressed garments for the first, third, and fifth treatments.

Exhibit 6-17. Garment Pressing Quality

Color	Material	Garment	Cleaner A[a,b]		Cleaner B[a,c]	
			Dryclean	Wetclean	Dryclean	Wetclean
Garments with Low Shrinkage (Less than 3%)						
Red	100% Silk	Shirt (Protocol)	B	B	A	A
Patterned multi-color	100% Silk	Tie (Leo Chevalier)	A	A	A	A
Beige	100% Linen	Shirt (Dalia)	B	B	A	A
Brown	100% Cotton	Pants (Functionals)	A	A	A	A
Grey	100% Wool	Pants (Protocol)	A	A	A	A
Patterned black/white	100% Wool	Pants (Cool Wool)	A	A	A	A
Patterned black/white	100% Wool	Suit jacket (Cool Wool)	A	A	A	A
Light green	100% Polyester	Suit jacket (Tan Jay)	A	A	A	A
Garments with Problem Shrinkage (More than 3%)						
Patterned multi-color	100% Rayon	Blouse w/pads (Jessie)	A	A	A	A
White	100% Cotton knit	Shorts (Divine One)	B	A	B	A
Light blue	80% Viscose 20% Linen	Suit jacket (Sterling)	B	D	B	C
Dark blue	60% Wool 40% Viscose	Dress (Holt Renfrew)	B	B	B	B
Brown pinstripe	99% Wool 1% Polyester	Dress (Holt Renfrew)	B	D	B	C

[a] A - Finished Nicely; B - Some Minor Defects; C - Many Minor Defects; D - Major Defects/Possible Claim/Unwearable.
[b] Cleaner A cleaned and pressed garments for the second and fourth treatments.
[c] Cleaner B cleaned and pressed garments for the first, third, and fifth treatments.

Exhibit 6-18. Garment Pressing Time

Color	Material	Garment	Cleaner A[a] Dryclean (min.)	Cleaner A[a] Wetclean (min.)	Cleaner A[a] % More W/C time[c]	Cleaner B[b] Dryclean (min.)	Cleaner B[b] Wetclean (min.)	Cleaner B[b] % More W/C time[c]
Garments with Low Shrinkage (less than 3%)								
Red	100% Silk	Shirt (Protocol)	2.4	2.5	3%	2.9	3.3	11%
Patterned multi-color	100% Silk	Tie (Leo Chevalier)	0.5	0.5	0%	0.3	0.3	0%
Beige	100% Linen	Shirt (Dalia)	2.9	2.8	- 3%	4.0	4.3	8%
Brown	100% Cotton	Pants (Functionals)	1.9	1.9	0%	1.8	1.8	0%
Grey	100% Wool	Pants (Protocol)	2.4	2.6	7%	1.9	2.3	17%
Patterned black/white	100% Wool	Pants (Cool Wool)	1.8	2.0	9%	2.3	2.7	15%
Patterned black/white	100% Wool	Suit Jacket (Cool Wool)	2.5	2.6	3%	3.3	3.8	15%
Light green	100% Polyester	Suit Jacket (Tan Jay)	1.8	1.5	- 18%	2.5	2.3	- 10%
Garments with Problem Shrinkage (more than 3%)								
Patterned multi-color	100% Rayon	Blouse w/pads (Jessie)	0.9	0.9	0%	1.5	1.7	11%
White	100% Cotton knit	Shorts (Divine One)	1.0	0.9	- 8%	1.2	1.0	- 15%
Light blue	80% Viscose 20% Linen	Suit Jacket (Sterling)	3.1	3.9	27%	3.5	6.7	91%
Dark blue	60% Wool 40% Viscose	Dress (Holt Renfrew)	1.2	2.3	99%	2.7	3.8	43%
Brown pinstripe	99% Wool 1% Polyester	Dress (Holt Renfrew)	3.5	6.3	81%	3.3	7.8	135%

[a] Cleaner A cleaned and pressed garments for the second and fourth treatments.
[b] Cleaner B cleaned and pressed garments for the first, third, and fifth treatments.
[c] W/C denotes wetcleaning.

6.2.4 Pollution Prevention in the Garment Care Industry: Assessing the Viability of Professional Wetcleaning, Final Report (*Cleaner by Nature*) (December 11, 1997)

Sponsors:	South Coast Air Quality Management District, California Air Resources Board, USEPA Office of Research and Development, UCLA Center for Environmental Risk Reduction, University of California Toxic Substances Research and Training Program, Occupational and Environmental Division of the Los Angeles County District Attorney's Office
Investigating Organization:	UCLA /Occidental College, Pollution Prevention Education and Research Center
Principal Investigator:	Robert Gottlieb
Duration of Study:	1 year (February 1996 to January 1997)
Location:	Los Angeles, California
Source of Information:	Gottlieb et al., 1997

Summary of Performance Evaluations

- Profile of customer garments cleaned at *Cleaner by Nature*, including information about the care labels of garments, the garment type, and the fiber type
- Analysis of rejected garments, redos, and customer claims to provide a quantitative measurement of the extent and type of garments that pose a problem for professional wetcleaning
- Repeat clean test to compare professional wetcleaning and drycleaning performance after the repeated wearing and cleaning of "dryclean only" labeled garments
- Survey of volunteers wearing the garments used in the repeat clean test, used to compare the results from the quantitative measurement of test garments in the repeat clean test with the experience of customers wearing these same garments
- Telephone survey of *Cleaner by Nature* and drycleaning customers, used to measure their experience and level of satisfaction with the professional wetcleaning process compared to the drycleaning process

Cleaner by Nature *Wetcleaning Demonstration Site*

The *Cleaner by Nature* demonstration site opened on February 6, 1996, as a wetcleaning-only facility, located in Los Angeles, California. A drop-off store was located in Santa Monica. The combined operation was set up as a small drycleaning shop, with the exception of the cleaning equipment. Exhibit 6-19 contains a demonstration profile for this wetcleaning operation.

A total of 34,950 garments were processed by *Cleaner by Nature* during the first year of operation (February 1, 1996, and January 31, 1997). However, a computer register failure during the months of October, November, and December 1996 corrupted some of the data set for this study. Additional data were lost for the month of August 1996; however, data are included from March 11 to April 11, 1997. Therefore, in some instances data analyzed in the final report are from variable time periods, as specified in the following summaries.

Exhibit 6-19. Demonstration Shop Profile for *Cleaner by Nature*

Description	100% wetcleaning operation with a Santa Monica agency and a Los Angeles plant
Location	2407 Wilshire Blvd., Santa Monica, CA 904023 (agency) 3317 La Cienega Place, Los Angeles, CA 90016 (plant)
Size	~ 850 sq. ft. (agency) ~ 2,000 sq. ft. (plant)
Personnel	1 full-time clerk, 1 to 2 part-time clerks, 1 part-time delivery person (agency) 1 full-time cleaner, 1 part-time presser, 1 part-time assembly person (plant)
Cleaning/Drying Equipment	Aquatex 30/50 lb. microprocessor washer Aquatex 50 lb. microprocessor dryer Maytag domestic washer Maytag domestic dryer
Pressing/Finishing Equipment	Forenta hot head press Forenta utility press Cissell steam iron (2) Forenta upright pant topper (reconditioned) Cissell form finisher (reconditioned) Forenta 3-way puff (reconditioned) High-steam JAM 500 tensioning form fitter (reconditioned)[a] High-steam PAM 200 tensioning pant topper (reconditioned)[a]
Other Equipment	Spotting Board Lattner 9.5 HP gas boiler Rol-Aire 5 HP vertical compressor Vertical dryset vacuum 800 slot conveyor (Iowa Tech) Rayne water conditioning unit
Cleaning Supplies	Aquatex detergent Aquatex finish Aquatex leather detergent Aquatex leather finish
Cycle Length	Wash cycle 18 to 20 minutes Dry cycle 15 to 30 minutes
Sample Price List	Pants/skirt $ 4.15 2-Piece suit 8.75 Dress 7.75 Shirt/blouse 4.35

[a] Purchased in September 1996; tensioning equipment has replaced the function of the Forenta pant topper and Cissell form finisher originally purchased by *Cleaner by Nature.*

Profile of Customer Garments

Exhibit 6-20 shows a profile of the garment types cleaned by *Cleaner by Nature* from February to September 1996 and for January 1997. During this time period a total of 23,094 identifiable garments and 559 unidentifiable garments were wetcleaned at the facility. The study notes that jackets may be under-represented because of the missing data for the colder months of October, November, and December. However, garment profile data collected by a drycleaner during January 1997 are comparable to the data collected by *Cleaner by Nature* for the duration of the study.

Exhibit 6-20. Garment Types Cleaned at *Cleaner by Nature*
(February 1 to September 30, 1996, January 1997)

Garment Type	Total	Percentage
Pants	5,675	24.0
Shirts/blouses	5,456	23.1
Suit jackets/outer jackets	2,267	9.6
Sweaters	2,142	9.1
Dresses	1,726	7.3
Skirts	1,311	5.5
2-piece suit, 2-piece tuxedo[a]	794	3.4
Bedding[b]	442	1.9
Household items[c]	686	2.9
Vests	334	1.4
Shorts	427	1.8
Ties	198	0.8
Miscellaneous[d]	1,077	4.6
Unknown	559	2.4
Total	**23,653**	**100.0 %**

[a] Two- and three-piece suits are counted as one item.
[b] Includes sheet, pillow case, sham, and comforter.
[c] Includes tablecloth, curtain, napkin, drape, and sofa cover.
[d] Includes coat, raincoat, hat, gloves, robe, three-piece suit, jumpsuit, nightwear, shawl, culottes, shoes, and sleeping bag.

Exhibit 6-21 provides a profile of fiber types for the garments cleaned during the demonstration period. This data set includes 60% (20,808/34,950) of those garments cleaned for which fibers could be properly identified. The percentage of wool garments cleaned during the demonstration period may be under-represented because of the corrupted data for October, November, and December. Wool, linen, mohair, silk, cashmere, rayon, and acetate fibers, which are all typically drycleaned, account for 70% of all garments cleaned by *Cleaner by Nature*. Cotton was the fiber cleaned most frequently by *Cleaner by Nature* (24%).

Exhibit 6-21. Fiber Types Cleaned at *Cleaner by Nature* (February 1, 1996 to January 1997)[a]

Fiber	Wool	Down[b]	Misc.[c]	Linen	Silk	Cashmere	Rayon	Acetate	Polyester[b]	Cotton[b]
% of Total	18.8%	0.6%	1.1%	10.9%	15.5%	0.9%	21.9%	2.3%	4.3%	23.8%

[a] This profile of fiber types represents 60% of the garments cleaned by *Cleaner by Nature,* for which fiber information was available (20,808/34,950).
[b] Cotton, polyester, and down are not fibers normally labeled "dryclean only."
[c] Miscellaneous (Misc.) includes acrylic, leather, and ramie.

Profile of Problem Garments

During the demonstration period, *Cleaner by Nature* kept records on four types of problem garments:

- *Rejects* - garments turned away by the cleaner because they could not be safely cleaned;
- *Customer claims* - damaged or lost garments that needed to be replaced;
- *Store credits* - store credit awarded for damaged or lost garments; and
- *Redos* - garments brought back by customers who felt their clothing required additional attention.

The number of rejects was tracked at *Cleaner by Nature* from February 1996 to August 1996 and from September 1996 through January 1997. A total of 33 items (0.09% of total) were rejected by *Cleaner by Nature*, the majority because of potential problems with colorfastness (90%). There was no comparative information on rejects available for drycleaning.

The number of claims (cash payments for lost or damaged garments) paid to *Cleaner by Nature* customers was tracked from February 1996 to August 1996, September 1996 to January 1997, and March 11, 1997, to April 11, 1997. There were a total of 14 customer claims on the 44,860 garments cleaned during these periods. Over half of the claims (eight) were related to shrinkage problems. The study notes that there was a decline in the claim rate as a result of the increased experience of the cleaner at the facility.

In addition to cash payments made for claims on lost or damaged garments, *Cleaner by Nature* issued store credit when problems occurred with garments. Data for store credit issued were collected from November 1996 through April 11, 1997. During this 5-month period, the store manager reported issuing store credit for 8 garments out of 21,937 cleaned (0.037%). Researchers combined the claims rate for the post-start-up period (0.010%) and the store credit rate for this 5-month period (0.037%) for a total rate of 0.047% (11 out of 21,937 garments).

The study also compared the claims and store credit rate for *Cleaner by Nature* with those of a local drycleaning facility. Researchers note that the drycleaner had a policy of awarding store credit as rarely as possible, which is the reason for combining the store credit and claims data in this comparison. Even though lost garments are not necessarily a direct measure of cleaning performance, they are included in the analysis because the owner of the drycleaner suspected that spotters who ruin garments may be tempted to "lose" garments in order to avoid responsibility for the damage. *Cleaner by Nature's* combined claims/store credit rate (0.047%, or 11 of 21,937 garments cleaned) was about three times greater than the figure for the drycleaner (0.015%, or 16 of 107,692 items cleaned).

The total redo rate for *Cleaner by Nature* was 0.52% (163 redos out of 31,524 garments cleaned) for data collected between February 1996 and January 1997, but excluding August 1996. This redo rate is comparable to that of a local drycleaner, whose overall redo rate was 0.45% (59 redos out of 13,256 garments cleaned). Spotting (i.e., stain removal) was reported as the most common reason for a redo (40%), followed by pressing (25%), shrinkage (25%), colorfastness problems (4%), odor (3%), and other miscellaneous damage (3%). The study reports that the redo rate was related to the level of expertise of the facility's cleaners, noting that the redo rate increased in months when a new cleaner was hired. The following related observations were reported, including:

- There was a general decline in the percentage of garments returned for problems related to spotting and shrinkage during the study period.
- Pressing problems did not appear to decline over the study period, which is potentially related to the high turnover rate for pressers.
- Customers returned silk garments for additional work at a higher than expected rate (25% of all redos were silk).
- Thirty-nine percent of all spotting problems were related to silk garments.
- Thirty-six percent of all pressing problems were related to wool garments, and 18% were related to linen garments.
- Fifty-four percent of garments redone for shrinkage were rayon.

Repeat Clean Test

A blind repeat clean test was used to compare the performance of wet and drycleaning on garments labeled "dryclean only" after repeated cleaning and wear. Three identical sets of 40 "dryclean only" garments were obtained for the test. One of the sets was wetcleaned six times, another drycleaned six times, and a third stored for comparison. Volunteers were recruited to wear two garments from the wet and drycleaned sets between cleanings. Trained evaluators were used to determine changes in garment dimensions, general appearance, color, color migration, and odor.[4] Evaluators and wearers were not informed as to which garments were being dry or wetcleaned. Garment types included shirts/blouses, pants, skirts, dresses, jackets, sweaters, vests, and ties. Fiber types included acetate, acrylic, cashmere, linen, polyester, rayon, silk, and wool. In addition, a representative sample of woven versus knit; tailored versus unstructured; and light, medium, and dark colors was chosen.

Exhibit 6-22 shows the results of the dimensional change experiments for measurements of length and width, as compared to drycleaned garments. For each garment, dimensional change was calculated as the difference between the initial measurement and the final measurement, divided by the initial measurement. AATCC test method 158-1990 was used for guidance on dimensional change calculations. The average dimensional change in length was 2.65% for wetcleaning and 2.35% for drycleaning. The average dimensional changes in width for wetcleaning (2.96%) and drycleaning (2.97%) were virtually identical. Therefore, the study notes that there were no statistically significant differences in measurements between dry and wetcleaning. The study also states that while dimensional change varied substantially depending on a garment's construction, fiber, and fabric, the cleaning method did not alter the results significantly.

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[4] Although not reported in this study, the evaluators also tested for garment resiliency, stain and soil removal, and hand. Researchers noted that both cleaning methods performed similarly for these tests.

Exhibit 6-22. Dimensional Change for Identical "Dry Clean Only" Garments Repeatedly Wet Cleaned and Dry Cleaned[a]

Grouping	Length - Dimensional Change			Width - Dimensional Change		
	(n)[b]	Wetclean	Dryclean	(n)[b]	Wetclean	Dryclean
All Garments	36	2.65%	2.35%	35	2.96%	2.97%
Fabrication						
Woven	29	2.20%	2.05%	28	2.18%	2.14%
Knit	7	4.48%	3.58%	7	6.08%	6.31%
Construction						
Tailored	22	2.37%	1.75%	21	2.24%	1.87%
Unstructured	14	3.07%	3.30%	14	4.03%	4.71%
Fiber						
100% & blends						
Rayon	12	3.26%	3.28%	12	3.09%	3.52%
Silk	10	2.31%	1.92%	8	2.18%	1.84%
Wool	7	2.60%	2.38%	7	3.59%	4.14%
Linen	5	2.64%	1.30%	6	2.51%	2.57%
Origin						
Natural[c]	21	2.51%	1.95%	19	2.98%	3.03%
Manf.[d]	11	2.60%	3.29%	11	3.90%	3.96%

[a] Percentage measurements noted are averages.
[b] (n) refers to the number of pairs of garments, with one wetcleaned and one drycleaned.
[c] Natural fibers include wool, silk, linen, or blends of natural fibers (including cotton).
[d] Manufactured fibers include rayon, polyester, acetate, or blends of manufactured fibers (including acrylic).

Exhibit 6-23 contains the results of the expert panel's general appearance evaluations, including cleaning performance quality, and the acceptability of appearance and pressing. The exhibit identifies cases where a problem was identified with one garment in the pair but not with the other (discordant pairs) and cases where the evaluator was either satisfied or dissatisfied with both garments (concordant pairs). The study notes that most garment pairs were judged acceptable in terms of pressing (35 of 39) and general appearance (32 of 40).

Exhibit 6-23. Performance Quality and Acceptability of General Appearance Evaluations

Performance Quality and Acceptability Ratings[a]	Discordant Pairs		Concordant Pairs	
	Yes - WC[b] No - DC[c]	No - WC Yes - DC	Yes - WC Yes - DC	No - WC No - DC
Color consistency problems	5	2	2	30
Tears, rips, split seams[d]	6	8	15	10
Button problems	1	4	3	31
Trim problems	1	0	0	38
Shoulder pad problems	1	1	1	36
Stains or soil evaluation	3	5	10	21
Pressing acceptable	0	2	35	2
General appearance acceptable	1	3	32	4

[a] These questions are not covered by an AATCC protocol.
[b] WC - wetcleaned garment in pair.
[c] DC - drycleaned garment in pair.
[d] Category includes loose seams, fabric damage, and hanging or pulling threads.

Exhibit 6-24 contains data pertaining to the color change evaluation performed by the panel of evaluators. Color change was visible in both the wet and drycleaned garments (21 of 39). There was color change in 69% of all wetcleaned garments (27 of 39) and 62% of all drycleaned garments (24 of 39), indicating color change problems with both cleaning processes. Although color migration was not a large problem overall, the study notes that there seems to be a disproportionate amount associated with wetcleaning (four discordant pairs) when compared to drycleaning (one discordant pair).

Exhibit 6-24. Color Change Evaluation

Performance Quality	Discordant Pairs		Concordant Pairs	
	Yes - WC[a] No - DC[b]	No - WC Yes - DC	Yes - WC Yes - DC	No - WC No - DC
Visible color change	6	3	21	9
Visible color migration	4	1	2	32

[a] WC - wetcleaned garment in pair.
[b] DC - drycleaned garment in pair.

If color change or color migration was observed in garment pairs, the intensity of change and/or migration was quantified using the AATCC Gray Scale for Color Change rating and the AATCC Chromatic Transference Scale. Data for these tests are shown in Exhibit 6-25. Color change and migration were rated from 1 (maximum change) to 5 (no change). Color consistency and migration problems for wet and drycleaning were noted as comparable, although slightly higher (i.e., better) for wetcleaning. The average degree of color change for wetcleaned garments was 4.42 versus 4.55 for drycleaned garments; the average degree of color migration for wetcleaned garments was 3.63 versus 4.17 for drycleaned garments.

Exhibit 6-25. Gray Scale for Color Change and Chromatic Transference Scale for Color Migration

Cleaning Method	Number of Garments	Minimum	Maximum	Mean
Gray Scale for Color Change[a]				
Wetcleaning	38	2.75	5.0	4.42
Drycleaning	38	1.75	5.0	4.55
Chromatic Transference Scale[a]				
Wetcleaning	6	3.0	4.5	3.63
Drycleaning	3	4.0	4.5	4.17

[a] Color change and chromatic transference scales range from 5 (no change) to 1 (maximum change).

Exhibit 6-26 contains the data from the odor evaluation. Evaluators made a slit in the plastic bag near the center of the front of the garment and inhaled through the hole. Odors were reported and described in detail. Overall, all odors were considered acceptable, although evaluators were able to detect some odor in practically all of the garments—81% of wetcleaned garments (32 of 39) and 95% of drycleaned garments (37 of 39). The study notes that more of the drycleaned garments had a chemical or “drycleaning” smell, and more of the wetcleaned garments smelled clean than those drycleaned.

Wearer Survey

A survey of 28 volunteer wearers who participated in the repeat clean test was used to assess whether the experience of wearing a wetcleaned garment differed from wearing an identical, drycleaned garment. Questions included reference to both positive qualities (e.g., cleanliness, satisfaction with pressing) and negative performance (e.g., shrinkage, discoloration). The results of this survey are found in Exhibit 6-27. Responses are divided into cases where the wearer was satisfied with one garment in the pair but not with the other (discordant pairs) and cases where the wearer was either satisfied or dissatisfied with both garments in the pair (concordant pairs).

The study notes that while not statistically significant, the results in Exhibit 6-27 indicate slightly more dissatisfaction with the pressing and shrinkage of wetcleaned garments. In addition, problems with discoloration, rips or tears, buttons, and garment feel were virtually the same for both wet and drycleaned garments.

Exhibit 6-26. Odor Evaluation

Performance Quality	Discordant Pairs		Concordant Pairs	
	Yes - WC[a] No - DC[b]	No - WC Yes - DC	Yes - WC Yes - DC	No - WC No - DC
Has odor	1	6	31	1
Smells clean	9	1	1	28
Smells like chemical	1	12	2	24
Smells like drycleaning	4	18	3	14
Odor unacceptable	0	0	39	0

[a] WC = wetcleaned garment in pair.
[b] DC - drycleaned garment in pair.

Exhibit 6-27. Positive and Negative Performance Qualities: Distribution of Wearer Responses

Performance Quality	Discordant Pairs		Concordant Pairs	
	Yes - WC[a] No - DC [b]	No - WC Yes - DC	Yes - WC Yes - DC	No - WC No - DC
Satisfied with pressing	1	3	33	2
Satisfied with stain removal	0	0	3	2
Satisfied with appearance	4	5	25	6
Shrinkage	3	1	1	35
Stretching	0	2	0	38
Discoloration	0	0	4	35
Feels worse	1	0	0	38
Rips or tears	2	2	1	35
Damaged buttons	2	1	0	37

[a] WC - wetcleaned garment in pair.
[b] DC - drycleaned garment in pair.

Exhibit 6-28 includes the survey results for overall satisfaction with the wet and drycleaned garments worn by volunteers. The study notes that for most of the garments (60.6%), wearers responded that they had no preference. Exhibit 6-29 contains survey results for preference of wearing wet and drycleaned garments. For those who did have a preference, twice as many seemed to prefer wetcleaned garments (69.2%) over drycleaned garments (30.8%).

Exhibit 6-28. Percent with Preference for Wearing One Garment Pair

Response	**Frequency**	**Percent**
Yes	13	33.3%
No	23	60.6%
Don’t know	3	7.7%

Exhibit 6-29. Preference for Wearing Wetcleaned or Drycleaned Garments[a]

Preference	Frequency	Percent
Wetcleaned garment	9	69.2%
Drycleaned garment	4	30.8%

[a] Wearers did not know which garment was being wetcleaned and which drycleaned. The survey asked the wearer to write down the number associated with the specific garment for which they had a preference.

In summary, the study notes that wearers did not notice any significant difference between wet and drycleaned garments in shrinkage, stretching, pressing, color change, spot removal, odor, damage, or appearance. More wearers identified shrinkage and pressing problems associated with wetcleaned garments, while stretching problems were associated with drycleaned garments. In addition, twice as many wearers preferred wearing the garment that was wetcleaned over the garment that was drycleaned.

Customer Satisfaction Survey

Two telephone surveys were conducted to measure customer satisfaction, a key indicator of performance viability. The first telephone survey, directed toward customers who used *Cleaner by Nature* at least once, was used to measure satisfaction with and attitudes toward this professional cleaner. The second telephone survey was directed toward drycleaning customers who live in or near *Cleaner by Nature’s* market area. The purpose of this second survey was to assist in evaluating the results of the *Cleaner by Nature* survey by comparing it with customers’ satisfaction with drycleaning.

Cleaner by Nature Customers

Exhibit 6-30 summarizes the questions related to positive performance attributes that professional cleaners seek to maximize. The customer response rate to the *Cleaner by Nature* survey was 78% (180 surveys out of a total of 231 contacts). Exhibit 6-31 summarizes the responses to questions related to negative performance attributes that professional cleaners seek to minimize. The study notes that more than three quarters of the customers reported that their garments were always clean and that they were always satisfied with how the garments were pressed. Fewer than half the customers who brought garments to *Cleaner by Nature* with spots or stains said they were always removed to their satisfaction. However, 78.6% of all customers were always or frequently satisfied with stain removal. Over 80% of *Cleaner by Nature* customers interviewed reported never experiencing any shrinkage, stretching, change in color, change in feel, bad odors, rips or tears, or damage to buttons or decorations. Shrinkage was the most common problem reported, with more than 15% of customers interviewed having shrinkage in the garment cleaned by *Cleaner by Nature.*

Exhibit 6-30. Positive Performance Qualities Experienced by *Cleaner by Nature* Customers

Performance Quality	Always	Frequently	Sometimes	Never
Clean	88.4%	8.1%	2.3%	1.2%
Satisfied with pressing	75.8%	15.2%	6.1%	3.0%
Satisfied with stain removal	47.5%	31.1%	13.9%	7.4%

Exhibit 6-31. Negative Performance Qualities Experienced by *Cleaner by Nature* Customers

Performance Quality	Never	Sometimes	Frequently	Always
Shrinkage	84.1%	12.9%	1.8%	1.2%
Stretching	92.9%	6.0%	0.6%	0.6%
Change in color	92.3%	4.7%	2.4%	0.6%
Change in feel	88.7%	9.4%	1.3%	0.7%
Odor	94.1%	3.6%	0.0%	2.4%
Rips or tears	95.9%	4.1%	0.0%	0.0%
Damage to buttons or decorations	95.7%	3.6%	0.7%	0.0%

The study notes that if each of the 10 performance measures in Exhibits 6-30 and 6-31 is treated individually, there appears to be a high level of satisfaction with how customers' garments were treated. Stain removal was noted as the largest problem: over half of surveyed customers with spotted or stained garments noted that the spots or stains were not always removed to their satisfaction. Other problems noted included shrinkage (15% of customers) and pressing (25% of customers). Collectively, half of all customers (91 of 180) reported having at least one of the performance problems noted in Exhibit 6-31, yet only half of these customers reported that they had experienced a "problem" with the garment as a result of sending it to *Cleaner by Nature*.

Exhibit 6-32 contains the results of customer rating of *Cleaner by Nature.* More than 60% of the 180 customers surveyed reported *Cleaner by Nature* as an excellent professional cleaner, 32.4% rated it as good, 4.6% rated it as fair, and 2.3% rated it as poor. These data are highly correlated with whether or not customers would recommend *Cleaner by Nature* to friend: all but 4 of the 161 customers interviewed who rated *Cleaner by Nature* as excellent or good also would recommend it to a friend, while 3 of the 12 customers rating it as fair to poor would recommend it to a friend. In addition, 77.8% of the customers surveyed said they were still customers of *Cleaner by Nature.*

Exhibit 6-32. Customer Rating of *Cleaner by Nature* as a Professional Cleaner

Rating	Frequency	Percent
Excellent	105	60.7%
Good	56	32.4%
Fair	8	4.6%
Poor	4	2.3%

Of the 39 customers who stopped using *Cleaner by Nature*, 41% noted that location was the reason why they stopped. Other reasons for not using *Cleaner by Nature* included dissatisfaction with cleaning quality (23.1%), price (20.5%), and service or convenience (15.4%). The study notes that nearly 65% of *Cleaner by Nature* customers use it exclusively, while the remaining 35% still use a drycleaner also. Three quarters of these customers take fewer than 25% of their garments to the drycleaner. The reasons for continuing to use a drycleaner, in addition to *Cleaner by Nature*, include location/convenience (43.9%), cleaning quality (29.3%), price (14.6%), and turnaround time (12.2%).

A customer comparison of *Cleaner by Nature* customers who still used a local drycleaner was also performed for this survey. All customers interviewed mentioned that they had used drycleaning in the past. When asked to state which operation was better for the environment, all customers stated that *Cleaner by Nature* was better. In terms of cost, 37% of customers said drycleaning was lower, 22% said *Cleaner by Nature* was lower, 28% said prices were equivalent, and 13% said it depended on the individual cleaner. *Cleaner by Nature* customers rated the quality of cleaning for that operation to be higher than drycleaning 73% of the time (compared to 5.8% for drycleaning) and rated the quality as the same 20.6% of the time. In addition, nearly 86% of customers were more satisfied, overall, with *Cleaner by Nature*, compared to 10.3% of customers being more satisfied with drycleaning. The remaining 4% of customers were equally satisfied with dry and wetcleaning results.

Drycleaning Customers

A survey of customers of drycleaners, conducted in May 1997, was performed to provide a baseline for analysis of the *Cleaner by Nature* customer satisfaction survey. The customer response rate to the dryclean survey was 36% (100 surveys out of a total of 250 contacts). Exhibit 6-33 summarizes how experienced *Cleaner by Nature* customers and drycleaning customers responded to questions relating to three positive performance qualities that professional cleaners seek to maximize. The study notes that while over 96% of *Cleaner by Nature* customers reported their garments as clean, only 79% of drycleaning customers reported the same. While satisfaction with garment pressing was similar (89.6% for *Cleaner by Nature*; 83.8% for drycleaning), fewer than 50% of the drycleaning customers expressed satisfaction with stain removal, versus nearly 80% for *Cleaner by Nature* customers.

Exhibit 6-33. Positive Performance Qualities Experienced by *Cleaner by Nature* Customers and DryCleaner Customers[a]

Performance Quality	Professional Cleaner	Frequently or Always	Never, Rarely,[b] or Sometimes
Clean	*Cleaner by Nature* Drycleaning	96.2% 79.0%	3.80% 19.0%
Pressing	*Cleaner by Nature* Drycleaning	89.6% 83.8%	10.4% 16.2%
Stain removal	*Cleaner by Nature* Drycleaning	79.7% 49.0%	20.3% 51.0%

[a] *Cleaner by Nature* customers with six or more transactions.
[b] Only drycleaning customers were asked whether these performance attributes occurred rarely.

Exhibit 6-34 summarizes how repeat *Cleaner by Nature* customers and drycleaning customers responded on seven negative performance qualities that professional cleaners seek to minimize. Based on the data from this table, shrinkage, stretching, and rips and tears in garments are reported similarly for both cleaning methods. The study notes that drycleaning customers reported significantly more problems with changes in the color or feel of garments, damage to buttons or decorations, and odor, compared with wetcleaning customers.

In terms of overall customer satisfaction with the cleaning process, 91.1% of *Cleaner by Nature* customers provided an excellent or good rating, versus 86.6% for drycleaning. In addition, 93.2% of *Cleaner by Nature* customers said they would recommend the cleaner to a friend, versus 87.7% of drycleaning customers. The study also reports that 54.0% of drycleaning customers have stopped using a professional cleaner in the last year, while only 22.7% of all *Cleaner by Nature* customers reported that they were no longer using *Cleaner by Nature.*

Exhibit 6-34. Negative Performance Qualities Experienced by *Cleaner by Nature* Customers and DryCleaning Customers[a]

Performance Quality	Professional Cleaner	Rarely or Never[b]	Sometimes, Frequently, or Always
Shrinkage	*Cleaner by Nature*	74.0%	26.0%
	Drycleaning	81.0%	19.0%
Stretching	*Cleaner by Nature*	86.8%	13.2%
	Drycleaning	86.0%	14.0%
Rips or tears	*Cleaner by Nature*	91.0%	9.0%
	Drycleaning	89.0%	11.0%
Color change	*Cleaner by Nature*	90.4%	9.6%
	Drycleaning	79.0%	21.0%
Change in feel	*Cleaner by Nature*	83.1%	12.9%
	Drycleaning	66.3%	33.7%
Damage to buttons[c]	*Cleaner by Nature*	96.1%	3.9%
	Drycleaning	63.0%	37.0%
Unpleasant odor	*Cleaner by Nature*	100.0%	0.0%
	Drycleaning	72.7%	28.3%

[a] *Cleaner by Nature* customers with six or more transactions.
[b] Only drycleaning customers were asked whether performance attributes occurred rarely.
[c] This category also includes damage to decorations.

Exhibit 6-35 shows the distribution of reasons why customers stopped using a professional cleaner. The proportion of *Cleaner by Nature* customers citing quality of cleaning or price as the primary reason they stopped using this wetcleaner is similar to the proportion of drycleaning customers who also listed these as their primary reason. The study also notes that twice as many *Cleaner by Nature* customers mentioned location as the primary reason for discontinuing use of the wetcleaner, while almost twice as many drycleaning customers mentioned service and convenience.

Exhibit 6-35. Primary Reason Customers Stopped Using Professional Cleaner: A Comparison of *Cleaner by Nature* and Drycleaning Customers[a]

Professional Cleaner	Location	Quality of Cleaning	Price	Service/Convenience
Cleaner by Nature[a]	42.9%	28.6%	14.3%	14.3%
Drycleaning	23.5%	35.3%	15.7%	25.5%

[a] Includes all *Cleaner by Nature* customers.

Performance Assessment Conclusions

The *Cleaner by Nature* study concludes that it is possible for all garments brought in by customers, including those labeled "dryclean only," to be wetcleaned. The researchers note that, overall, *Cleaner by Nature* was comparable to a drycleaner in terms of the magnitude of problems identified through the cleaning performance evaluation. Problems areas that were identified for wetcleaning included color change, shrinkage, and pressing, while problem areas associated with drycleaning operations included stain removal, garment damage, and stretching. The study also mentions a high level of satisfaction with *Cleaner by Nature* overall, continual growth of its customer base, and a high retention rate of customers.

6.2.5 Alternative Textile Care Technologies: Part I

Sponsor:	USEPA, Office of Research and Development
Investigating Organization:	Texas Woman's University, Department of Fashion and Textiles
Principal Investigator:	Dr. Charles Riggs
Duration:	3 years (currently funded for 1 year)
Location:	Houston, Texas
Source of Information:	Riggs, 1996

Summary of Performance Evaluations

This study is assessing the performance of alternative technologies. Researchers hope to gather data using machine wetcleaning, PCE drycleaning, HC solvent drycleaning (Exxon's DF-2000), and potentially liquid CO_2 technology. The scope of this study is limited to soil and fabric combinations that are problem areas for the cleaning industry.

Performance Evaluations

- Identification of "problem" soil and fabric combinations for alternative clothes cleaning technologies
- Development of a methodology to evaluate the cleaning performance of alternative technologies
- Work with North Carolina State University to develop consensus procedures for evaluating clothes cleaning technology

Experimental Technology

- Unimac wetcleaning machine (Model UA230) with Seitz chemicals
- Aquatex drying cabinet
- Boewe-Passat, Permac PCE drycleaning machine (P546 - 46 lb)
- Boewe-Passat, Permac DF-2000 HC drycleaning machine
- Liquid CO_2 cleaning technology (may not be available for test)

6.2.6 Alternative Textile Care Technologies: Part II

Sponsor:	USEPA, Office of Research and Development
Investigating Organization:	North Carolina State University, College of Textiles
Principal Investigator:	Dr. Perry Grady
Duration of Study:	3 years (currently funded for 1 year)
Location:	Raleigh, North Carolina
Source of Information:	Grady, 1996

Summary of Performance Evaluations

This study focuses on testing and developing alternative cleaning technologies to reduce indoor air emissions from PCE drycleaning and drycleaned fabrics. Currently, the project is studying the effectiveness of “piggy backing” ultrasonic cleaning technology with current wet and drycleaning methods. Additional work is planned with a bench scale apparatus for liquid CO_2 cleaning technology. Fabric and soil samples will be used in cooperation with the investigation in Part I (Section 6.2.5). The goal of this exploratory study is to develop a cleaning system that removes complex soils and eliminates the use of non-aqueous solvents.

Performance Evaluations

Ultrasound and, possibly, liquid CO_2 technologies will be used in tandem with machine wetcleaning, traditional PCE drycleaning, and HC solvent drycleaning systems.

Preliminary Test Results

Ultrasound assists solvent soil removal with compatible soils (i.e., oil-based). In terms of water-based cleaning, ultrasound technology reduces the need for mechanical agitation, decreasing the amount of shrinkage in garments. It may also reduce the temperature and mechanical agitation necessary for non-aqueous-based clothes cleaning methods.

6.2.7 University of Guelph Fabric Swatch Study

Sponsor: Environment Canada
Investigating Organization: University of Guelph, Textile Sciences Group
Principal Investigator: Anne Wilcock
Location: Guelph, ONT, Canada
Duration: Unknown
Source of Information: Wilcock, 1996

Summary of Performance Evaluations

The data obtained from this study have not been analyzed in total due to a lack of research funding. Environment Canada has used selective parts of the data to support the previously mentioned Green Clean study (Section 6.2.3). Most of the data generated by the principal investigator remain unpublished and unanalyzed at this time.

Performance Evaluations

Six cleaning processes (pressing only, steam cleaning, drycleaning in PCE, “green cleaning,” machine wetcleaning, and home laundering) were used for comparison in this study. Textile swatches included undyed/unfinished fabrics, dyed/finished fabrics, fused fabrics, and whole garments. Within each category, 4 to 13 different fabrics were cleaned, representing an array of weights, fiber mixtures, and constructions likely to be encountered in day-to-day business. The data obtained from these cleaning trials have not yet been completely analyzed.

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CHAPTER 7
PROCESS COST ESTIMATES

CHAPTER CONTENTS

The costs of running a professional clothes cleaning business include rent, basic operating expenses, equipment, and labor. The equipment capacity, equipment type, and the location of the facility will affect the costs and economic viability of a professional cleaning operation. While some fabricare technologies have been in use for many years, others are still prototypes and have not yet been commercially marketed. As manufacturers gain expertise with new machines, and their production quantities increase, it is expected that there will be a decrease in the cost of production of new machines relative to established technologies and therefore a decrease in the cost of these options to fabricare operators (Pindyck and Rubinfeld, 1989).

This chapter focuses on the evaluation of a subset of costs associated with using fabricare technologies. Section 7.1 provides an introduction to the technologies and cost elements that have been included in the cost estimations that follow. Section 7.2 describes the methodology and assumptions used to estimate the cost components in this chapter. In Sections 7.3, 7.4, and 7.5, operational cost estimates are provided for the various fabricare process options. The analyses presented in this chapter should be regarded as a general guide for cost comparisons.

7.1 SUMMARY OF TECHNOLOGIES AND COST ELEMENTS MODELED

The technologies analyzed in this chapter include eight configurations of perchloroethylene (PCE) equipment, three configurations of hydrocarbon solvent (HC) equipment, and one configuration of machine wetcleaning technology.

The cost categories considered in this analysis are capital equipment cost, annualized cost of that equipment, annual solvent cost, energy cost, hazardous waste disposal cost, regulatory compliance costs, cost of filters and other supplies, and maintenance cost. These cost elements were chosen for evaluation because of their importance to facility operation, their potential for highlighting differences among technologies, and the availability of data. Exhibit 7-1 presents additional operating factors that are associated with fabricare operations, many of which are outside the scope of this analysis.

Exhibit 7-1. Potential Operating Factors Associated with Fabricare Facilities

Revenues
- Sale of product
- Marketing of by-product
- Change in process throughput
- Change in sales from improved corporate image and market share

Utilities
- Electricity
- Cooling and process water
- Refrigeration
- Fuel (gas or oil)
- Plant air and inert gas
- Sewerage

Direct Labor
- Operating labor and supervision
- Clerical labor
- Inspection (QA & QC)
- Worker productivity changes

Materials
- Direct product materials
- Solvents
- Wasted raw materials
- Transport and storage

Waste Management (Materials and Labor)
- Pre-treatment and on-site handling
- Storage, hauling, and disposal
- Insurance

Future Liability
- Fines and penalties
- Personal injury

Regulatory Compliance
- Equipment monitoring and lab fees
- Personal protective gear
- Reporting, notification, inspections, and manifesting
- Training (right-to-know, safety) and training materials
- Workplace signage and container labeling
- Penalties, fines, and solvent-use fees
- Insurance, closure and post-closure site maintenance

Indirect Labor
- Maintenance (materials and labor)
- Miscellaneous (housekeeping)
- Medical surveillance

Source: USEPA (1997).

Exhibit 7-2 provides a summary comparison of the various costs associated with a number of the fabricare technology options. This table is presented for illustrative purposes and provides comparisons among the technology types. Detailed explanations of how cost estimates were derived, as well as varying configurations of individual technologies, are provided in Sections 7.3, 7.4, and 7.5.

Wherever possible, the cost information reported is based on current prices of equipment and supplies offered by domestic manufacturers or distributors. If current prices are not available (e.g., equipment is no longer sold), then historic prices provided by a vendor are used if they are available. Costs or cost ranges may also be derived from secondary sources (materials published by the U.S. Environmental Protection Agency [USEPA], state and local governments, and industry). If prices are obtained from both current sources and published materials, the current prices are used, and the information from published sources is noted in the text. Where applicable, sample calculations are included for each cost element.

Exhibit 7-2. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technologies[a]

Fabricare Technology[b]	Capital Cost of Base Equipment[c]	Capital Cost Total[d]	Annualized cost of Equipment[e]	Annual Cost Solvent[f]	Annual Energy Cost[g]	Regulatory Compliance Costs[h]	Annual Cost Hazardous Waste[i]
PCE	$38,511	$38,511	$4,228	$1,434	$136	$3,680	$4,594
HC	$37,432	$37,432	$4,110	$2,236	NA	NA	$9,820
Machine Wetcleaning	$11,102	$11,102	$1,219	$763	$788	NA	NA

Exhibit 7-2. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technologies[a] (Cont'd)

Fabricare Technology[b]	Annual Cost Filters and Detergent[j]	Annual Cost Maintenance[k]	Total Annual Operating Cost[l]	Total Annual Cost[m]	Total Annual Cost/Pound
PCE	$1,913	$6,000	$14,077	$18,305	$0.34
HC	$1,551	$6,000	$19,607	$23,717	$0.44
Machine Wetcleaning	$3,162	$376	$5,089	$6,308	$0.12

NA means cost category not applicable for technology or that data are not available at this time.

[a] The values include the price of equipment and services directly related to the various drycleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333-pound (24,191-kg) annual volume of clothes cleaned per facility.

[b] Configurations for fabricare technology include PCE dry-to-dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (PCE-C), as required by the PCE NESHAP regulation; HC transfer with recover dryer and condenser (HC-A2); and Unimac UW30 washer and DTB50 dryer.

[c] List price of 35 pound PCE drycleaning system includes control equipment, distillation unit, and filters; List price of 35- to 40-pound HC drycleaning system includes control equipment, filters, and an explosion kit.

[d] Base machine costs (actual or implied) are added to cost of control capital.

[e] Annual cost of drycleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[f] PCE solvent cost based on $6.83 per gallon for PCE in 1997 dollars (BLS, 1997; USEPA, 1993) and "mileage" from EPA engineering estimates; HC solvent cost based on $2.24 per gallon for hydrocarbon solvent and "mileage" based on engineering estimates; wetcleaning solvents cost based on $3.06/100 feet^3 for water (BLS, 1997; USEPA, 1993).

[g] All technology energy costs are based (USEPA, 1991a) on $0.0764/kWh national average electricity cost (BLS, 1997).

[h] Regulatory compliance costs for PCE are based on 1.84% of total annual revenues of $200,000 (Gottlieb et al., 1997; NCAI, 1998).

[i] Hazardous waste disposal costs for PCE and HC based on $6.94 per gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates, excluding disposal cost for potentially hazardous spotting chemicals. Hazardous waste associated with PCE-based machines includes filters, distillation residues, and spent carbon. Hazardous waste associated with HC-based machines includes spent cartridge filters and vacuum still bottoms.

[j] Cost includes of cleaning detergents, spotting chemicals, and replacement filters (Hill, Jr., 1994b; USEPA, 1993).

[k] Annual maintenance cost for PCE and HC based on 3.0% of total revenues of $200,000 annually; costs for machine wetcleaning based on 3.39% of total capital costs (Murphy, 1994).

[l] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[m] Includes all operating costs and annual capital costs.

7.2 ASSUMPTIONS AND COST ESTIMATION METHODOLOGY

Only those process-dependent cost components (i.e., equipment and chemicals) that are directly related to the various cleaning processes are included in these cost analyses. Operating costs that do not vary with the process used, such as storefront operations and rent, are excluded from these analyses. Note that rounding and unit conversions associated with cost components may result in slight differences between numbers reported in the text and the actual data.

Some of the costs are based on the average of prices offered by several vendors, while others are based on reported prices from a single vendor. Solvent and detergent cost estimates are adjusted to 1997 dollars using the Producer Price Index for Chemicals and Allied Products (PPI-Chem). All other cost estimates are adjusted to 1997 dollars using the Producer Price Index for Capital Equipment (PPI-CE) (BLS, 1997). Exhibit 7-3 shows the values from the PPI-CE and PPI-Chem indices. Cost figures are presented in constant 1997 dollars in order to allow direct comparison among the process options. A sample calculation of conversion to constant dollars based on PPI-CE is given below Exhibit 7-3.

Exhibit 7-3. Producer Price Index for Machines and Equipment (PPI-CE) and Chemicals and Allied Products (PPI-Chem)

Year	1982	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997[a]
PPI-CE	100	109.7	111.7	114.3	118.8	122.9	126.7	129.1	131.4	134.1	136.7	138.3	138.3
PPI-Chem	100	102.6	106.4	116.3	123.0	123.6	125.6	125.9	128.2	132.1	142.5	142.1	143.6

Source: BLS (1997)
[a] PPI-CE and PPI-Chem estimates based on 10-month average for 1997 (January to October).

Sample Calculation of Conversion to Constant Dollars - Data from Section 7.3.3:

Capital Cost for Retrofit of Equipment in 1994 dollars = $8,556
PPI-CE 1994 (base year) = 134.1
PPI-CE 1997 (current year) = 138.3

$$\$8{,}556\ \ (1994\ \ dollars)\ \ x\ \left[\frac{138.3}{134.1}\right] = \$8{,}824\ \ (1997\ \ dollars)$$

7.2.1 Clothes Cleaning Plant Capacity

In this chapter, the model clothes cleaning plant for each technology is assumed to process an annual average clothing volume of 53,333 pounds.[1] This annual clothing volume for the average facility is derived by dividing the total volume of clothes cleaned using PCE and HC solvents in the commercial sector (1.92 billion pounds) by the number of firms using PCE and HC solvents in the commercial sector (36,000) (Wolf, 1998; Wong, 1998). Facilities are assumed to operate 312 days annually (6 days a week and 52 weeks a year [Shaffer, 1995]) and to have an average daily throughput of approximately 171 pounds of clothing.

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[1] The total throughput of the model plant is 66,666 pounds, of which 80% is drycleaning or an alternative and 20% is washing (Faig, 1998). It is assumed that the revenue per pound is constant at $3, generating a revenue per facility of $200,000.

7.2.2 Equipment Capacity

The cost estimates for PCE assume a 35-pound (15.9 kg) nominal capacity machine with a distillation unit and filtration system, unless otherwise noted. This is the machine size most commonly used in the commercial sector (USEPA, 1991b). The price of retrofitting machines with emission control equipment is estimated for the same cleaning capacity. It is assumed that the PCE machines operate at 90% capacity (USEPA, 1993), and that 6 loads per day are needed to process the throughput.

The cost estimates for the HC machines assume a 40-pound (18.1 kg) nominal capacity machine that includes a washer/extractor (with filter and explosion kit) and a basic dryer. The HC solvent machines are assumed to operate at 80% capacity (Jenkins, 1994), resulting in a daily throughput of six loads per day.

The cost estimates for wetcleaning machines assume a 30-pound (13.6 kg) nominal capacity. Manufacturer estimates indicate that wetcleaning equipment is designed to be operated at 100% capacity, resulting in a daily throughput of six loads per day.

7.2.3 Capital Equipment Costs

Capital costs for equipment and the costs of retrofitting machines with control technologies are converted to annual cost equivalents using a 7% real cost of capital and a 15-year lifespan[2] (equivalent to using a capital recovery factor of 0.1098), to be consistent with previous clothes cleaning analyses (USEPA, 1993).[3] The example below demonstrates the annualization of capital costs and the calculation of capital equipment costs using constant dollars.

Sample Annualization Cost Calculation[4] - Data from Section 7.3.3:

Where:
A_c = Annualized cost
T_c = Total cost
i = Interest rate (7%)
n = Number of years (15)
[ ] = Note that bracketed term is the capital recovery factor of 0.1098

$$A_c = T_c \ x \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right]$$
$$A_c = T_c \ x \ 0.1098$$
$$A_c = \$27{,}801 \ x \ 0.1098$$
$$A_c = \$3{,}053$$

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[2] According to Ken Faig of the International Fabricare Institute (1996) the average life of wetcleaning washers and dryers is 15 to 18 years, comparable to that of drycleaning equipment. Fifteen years was assumed, to be consistent with prior analyses.

[3] The cost of capital used to analyze public investments and private investments is different. The real cost of capital of 7% is a typical value used in evaluating public investments. For the private firm deciding to purchase equipment, the appropriate value is the interest rate charged on the loan modified by the inflation over the course of the payments. The authors investigated the typical loans for clothes cleaning equipment and discovered that they varied considerably. In addition, the tax savings from depreciation must be included for an individual making a financial decision. The public financing rate has been used in this analysis.

[4] The annualization of capital equipment expenses allows recovery of the original investment over the course of the lifetime of the equipment (15 years in this case), accounting for the time value of currency. The discounted annualized costs (where the discount rate equals the interest rate) summed over the lifetime of the equipment is equal to the total immediate cost of purchasing the equipment (Perry and Chilton, 1973).

7.2.4 Equipment Maintenance Costs

The Neighborhood Cleaners Association International (NCAI) estimates the annual maintenance costs for PCE-based fabricare operations to be between 1.25% and 3% of total annual revenues, based on a range of standard garment pricing[5] (NCAI, 1998). The International Fabricare Institute (IFI) estimates annual equipment maintenance costs for PCE-based operations to be 2.27% to 3.26% of total annual revenue, based on an annual sales volume of $100,000 to $300,000 (IFI, 1992). The Pollution Prevention Environmental Research Center (University of California at Los Angeles/Occidental College) study averages the low-end IFI and NCAI estimates (2.27% and 1.25%, respectively) and applies a 50% preventive maintenance factor to yield 1.765% of total sales revenue. For the purpose of the CTSA, PCE and HC annual equipment maintenance costs are calculated as 3% of total annual revenues. The equipment maintenance costs for other technologies are noted directly in the corresponding text of this chapter.

7.2.5 Energy Costs

Energy costs are based on the national average commercial electricity price of $0.0764 per kilowatt-hour (EIA, 1997). Energy use estimates for each technology include only actual cleaning and drying equipment and do not include non-cleaning processes such as pressing. In cases where data are available, energy costs are provided for machines and emissions control technologies, based on estimates by equipment manufacturers and suppliers. Estimates for energy use of PCE emissions control technologies are derived from information in the PCE National Emission Standard for Hazardous Air Pollutants (NESHAP) (USEPA, 1991a). More recent energy use data for PCE transfer machines are not available because these machines are not currently in production.

Sample Calculation for Energy Consumption Costs - Data from Section 7.3.4:

Assumption: Energy use estimate of 725 kilowatt-hours/year is based on capacity of 105,240 pounds of clothes cleaned per year (USEPA, 1993).

53,333 pounds per year/105,240 pounds per year = 0.507 (adjustment for facility capacity)
Cost of Energy = $0.0764/kilowatt-hour x 725 kilowatt-hour/year x 0.507
Cost of Energy = $28/year

7.2.6 Installation Costs

Installation costs are included in the cost of retrofitting machines with emissions control technologies, as these costs are a necessary and unavoidable part of the retrofitting process. For the purpose of this analysis, installation costs are not included for new equipment because the installation costs of a new machine vary significantly. Replacing an existing machine requires relatively little installation cost, while an entirely new installation requires significantly higher costs to provide water, steam, and electricity supplies.

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[5] The NCAI estimate of annual maintenance costs is based on a survey of 854 fabricare stores with between $130,000 and $334,000 in annual sales revenue (NCAI, 1998).

7.2.7 Solvent and Other Material Costs

Solvent costs may vary based on per-gallon and bulk prices.[6] PCE solvent costs range from \$5.50/gallon to \$8.01/gallon, based on estimates provided by manufacturers and distributors. A median PCE solvent price of \$6.83/gallon is used for the purposes of this analysis.

HC solvent costs range as follows: (1) Stoddard solvent costs \$1.50/gallon to \$4.00/gallon, with a median price of \$2.24/gallon; (2) DF-2000 costs \$3.49/gallon to \$5.01/gallon, for a median price of \$3.79/gallon; and (3) Drylene solvent costs \$7.50/gallon. For the purpose of this analysis, the median price of Stoddard solvent (\$2.24/gallon) will be used to calculate total HC solvent costs, although it should be recognized that costs will vary depending upon which HC solvent is used.

Water for wetcleaning costs \$2.73/100 cubic feet in 1993 dollars or \$3.06/100 cubic feet in 1997 dollars (USEPA, 1993; BLS, 1997). This price includes the average cost of water and sewerage fees.

Sample Calculation for Solvent/Material Consumption Costs - Data from Section 7.3.3:

Assumed usage = 417 gallons PCE/year
Total Solvent Cost = 417 gallons PCE/year x \$6.83/gallon PCE (1997 dollars)
= \$2,848/year

7.2.8 Filters/Cleaning Supplies

PCE filters are estimated to cost \$606 annually, and detergents and spotting chemicals for PCE machine configurations are calculated to cost \$1,307 annually, for a total of \$1,913 (BLS, 1997; USEPA, 1993). For the HC configurations, the filters cost \$244 annually, while the detergents and spotting agent costs are estimated at \$1,307 annually, for a total of \$1,551 (BLS, 1997; Hill, Jr., 1994a). Annual costs for machine wetcleaning detergent, fabric softener, and spotting chemicals are calculated to be \$2,877, \$40, and \$245, respectively, for a total of \$3,162 (BLS, 1997).

7.2.9 Hazardous Waste Disposal Costs

Because PCE is a hazardous waste, the CTSA compares the costs of hazardous waste disposed. For the purposes of this analysis, all hazardous waste cost estimates provided in this chapter include only the cost of disposal and do not include the cost of associated paperwork and other regulatory compliance activities noted in Exhibit 7-2. The cost of disposing of potentially hazardous spotting chemicals is not included in this analysis. Hazardous waste disposal costs for PCE and HC-based equipment are calculated using a cost of \$6.94 per gallon[7] and engineering estimates of volume. Hazardous waste cost estimates included in the HC estimates assume that all the waste products require hazardous waste disposal procedures. Wastes derived from HC drycleaning processes are not necessarily classified as hazardous wastes under environmental regulations. Wastes composed solely of HC products, such as well-drained filter cartridges and drained filter muck, are not likely to meet the criteria for classification as ignitable solids (USEPA, 1990). However, other cleaning process by-products (such as dissolved fats, dyes, and

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[6] Several states have instituted annual usage fees (\$100 to \$2,500) and/or per-gallon taxes on PCE solvent, which can increase the purchase price of this product from \$3.75 to \$10.00 per gallon. Additional information regarding solvent use taxes is presented in Chapter 8 of this document.

[7] Hazardous waste costs are estimated at \$111/16 gallons (\$6.94/gallon) (Beedle, 1998).

cleaning products), in combination with the HC solvent, may create wastes that fail the Toxicity Characteristic Leaching Procedure (TCLP) and qualify as hazardous waste under the Resource Conservation and Recovery Act (RCRA) definition. Water is not a hazardous waste under environmental regulations. However, as with HC cleaning, wastes derived from using these solvents in clothes cleaning applications could generate some hazardous waste.

Sample Calculation for Annual Hazardous Waste Disposal Costs - Data from Section 7.3.2:

Assumed production of hazardous waste = 658 gallons/year
Hazardous Waste Disposal Cost = 658 gallons of hazardous waste/year x $6.94/gallon
= $4,567/year

7.2.10 Regulatory Compliance

Compliance with government regulations imposes industry-specific costs upon the private sector. Exhibit 7-1 lists many of the regulatory compliance cost categories pertinent to the fabricare industry, including expenditures for waste management. The range of equipment ages and types currently in use will result in variations in regulatory compliance costs within and across process categories. In addition, regulatory compliance costs will vary regionally due to differing local and state fees, taxes, and permitting procedures.[8] For the purpose of this analysis, the use of spotting agents is not factored into the regulatory cost estimates provided in this chapter.[9]

NCAI estimates that regulatory compliance costs associated with PCE technology are between 2.25% and 4.5% of total revenues[10] (NCAI, 1998). These costs include registration and permit fees for pollution abatement; hazardous waste disposal charges; USEPA and Occupational Safety and Health Administration (OSHA) compliance; local water pollution discharge fees; and other local, state, and federal fees. The Pollution Prevention Environmental Research Center (University of California at Los Angeles/Occidental College) study calculates regulatory compliance costs for drycleaning based on the NCAI estimate of 2.25% of annual revenue ($5,483) but subtracts out hazardous waste disposal costs ($1,010) and the cost of regulatory fees[11] ($851), for a final annual estimate of $3,622. Because hazardous waste costs have already been considered separately, regulatory compliance costs associated with PCE-

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[8] Regulatory fees tend to vary, based on local and state requirements (Gottlieb et al., 1997).

[9] Spotting agents that contain regulated chemical ingredients are used by fabricare operators, regardless of the cleaning technology they employ. It is important for a user to consider the additional regulatory impact, and therefore additional cost, these chemicals might have upon a fabricare business.

[10] The NCAI estimates for regulatory compliance costs are based on a survey of 854 stores with annual sales revenue ranging from $130,000 to $364,000. The base price of cleaning a two piece suit ranges from $6.50 (4.5% estimate) to $8.50 (2.25% estimate) (NCAI, 1998).

[11] The PPERC/UCLA study includes the following annual regulatory fees in their cost of compliance for PCE drycleaning: hazardous waste control license ($412) and hazardous materials control license ($110) from the Los Angeles County Fire Department, South Cost Air Quality Management District annual operating fee ($168) and emissions fee (exempt; $0.21/pound of PCE emitted for businesses that emit more than 4,000 pounds annually), Los Angeles County Public Health licence fee ($111), and California Air Resources Board employee training course taken every three years by employees ($150) (Gottlieb et al., 1997).

based drycleaning are estimated to be 1.84% of total annual revenues, the percentage resulting from the Pollution Prevention Environmental Research Center (University of California at Los Angeles/Occidental College) study when the hazardous waste costs are subtracted from the regulatory compliance costs (Gottlieb et al., 1997).

No data are currently available for estimating the regulatory compliance costs associated with HC drycleaning. USEPA is currently in the process of writing a NESHAP regulation for HC solvents used in the fabricare industry. The proposed NESHAP is expected to be released by November 15, 1999, and then formally promulgated by November 15, 2000. Currently, HC drycleaners are regulated under the Clean Air Act by New Source Performance Standards, which include required record keeping, leak detection, and maintenance procedures. The NESHAP is expected to require HC solvent drycleaners to use maximum available control technology to reduce emissions from their fabricare operations (KSBEAP, 1997; Szykman, 1998). Therefore, this NESHAP could result in an increase in regulatory costs associated with Clean Air Act compliance over current levels. At this time, there are insufficient data to determine regulatory compliance costs for HC-based drycleaning operations. For the purpose of this analysis, regulatory compliance costs are excluded from the total cost calculation of this technology.

No data are currently available for estimating the regulatory compliance costs associated with wetcleaning. However, fabricare operators may be subject to permitting fees and record keeping costs associated with their local sewerage authority. At this time, there are insufficient data to determine total regulatory compliance costs for wetcleaning operations. For the purpose of this analysis, regulatory compliance costs are excluded from the total cost calculation of this technology.

7.2.11 Labor Costs

Labor costs associated with professional clothes cleaning operations vary based on the mix of employee job functions, qualifications and experience of workers, productivity of workers, equipment type and configuration, facility size, and geographic location of the facility. For example, rough pressers tend to earn a lower wage than specialized pressers, who are trained to work on intricate garments such as wedding dresses and expensive fabrics such as silks (Seitz, 1996). It is also noted that one employee may perform several job functions within a fabricare shop, each of which requires different skill levels. For example, an employee may work at the drop-off counter during part of his shift, in addition to sorting and washing clothing in the back of the facility. Because of this variability and the lack of available quantitative data, the labor costs associated with fabricare operations are not included in this cost model.

7.3 COST ESTIMATES FOR PCE MACHINE CONFIGURATIONS

The cost components of the eight PCE drycleaning machine configurations are summarized in Exhibit 7-4. The discussion that follows explains the cost estimates of each technological configuration of PCE equipment.

7.3.1 PCE Transfer with No Carbon Adsorption or Refrigerated Condenser (PCE-A1)

Capital Cost: New transfer machines are no longer available, so historic data must be used. The estimate of the price of an uncontrolled transfer drycleaning machine is based on responses to the Clean Air Act Section 114 Questionnaires, which was a survey conducted for the Chemical and Petroleum Products

Division, Office of Pesticides and Toxic Substances (USEPA, 1988). The price of a 35-pound transfer machine was estimated at $15,895 (1987 dollars), or $19,680 in 1997 dollars (BLS, 1997).

Solvent Cost: Assuming a solvent use of 627 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon, the solvent cost is $4,282. The mileage is 85 pounds per gallon.

Energy Cost: Data are not available for this technology.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000), for a total of $3,680.

Hazardous Waste Disposal Costs: The estimate of hazardous waste disposal cost is based on engineering estimates of 658 gallons of waste generated per year and a disposal cost of $6.94 per gallon (Beedle, 1998), for a total of $4,567.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $576, or $606 in 1997 dollars (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (BLS, 1997; USEPA, 1993), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (BLS, 1997; USEPA, 1993).

Maintenance Cost: Maintenance costs are based on 3.0% of annual revenue ($200,000), for a total of $6,000.

7.3.2 PCE Transfer with Carbon Adsorber (PCE-A2)

Capital Cost: Current price quotes are not available for this configuration. The price for a retrofit carbon adsorber (CA) unit is based on information from the 1991 NESHAP document (USEPA, 1991a). The estimated cost of retrofitting an uncontrolled transfer machine with a CA is $6,976 (1989 dollars), or $8,121 in 1997 dollars (BLS, 1997). An alternative source of price information (not used but included for comparison) is a report from the Division of Air, Office of Policy and Program Analysis, New York State Department of Environmental Conservation, *Regulating PCE Emissions from Dry Cleaning Machines: An Economic and Public Health Impact Analysis* (NYSDEC, 1993). It estimates that the addition of a total vapor containment system, including a CA, to an existing transfer machine would cost from $10,000 to $12,000 including installation (1991 dollars, or between $10,916 and $13,099 in 1997 dollars) (BLS, 1997). The implied cost of an uncontrolled transfer equipment combination ($19,680 from Option PCE-A1) is added to the retrofit cost of $8,121 to give a total effective capital cost of $27,801.

Solvent Cost: Assuming a solvent use of 469 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon, the solvent cost is $3,203 (USEPA, 1993). The mileage is 114 pounds per gallon.

Energy Cost: Data are not available at this time.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000) for a total of $3,680.

Exhibit 7-4. Estimated Process-dependent Cost Components of Selected PCE Machine Configurations[a]

Machine Configuration[b]	Capital Cost of Base Equipment[c] (Implied Cost)	Capitol Cost of Retrofit Control Technology[d]	Capital Cost Total[e]	Annualized Cost of Equipment[f]	Annual Cost Solvent[g]	Annual Energy Cost[h]	Regulatory Compliance Costs[i]
Transfer							
Transfer with no CA or RC (PCE-A1)	$19,680	$0	$19,680	$2,161	$4,282	NA	$3,680
Transfer with CA (PCE-A2)	$19,680	$8,121	$27,801	$3,052	$3,203	NA	$3,680
Transfer with RC (PCE-A3)	$19,680	$8,823	$28,503	$3,129	$2,848	NA	$3,680
Dry-to-Dry							
Dry-to-dry with no CA or RC (PCE-B1)	$31,781	$0	$31,781	$3,489	$3,832	$78	$3,680
Dry-to-dry with CA (PCE-B2)	$31,781	$7,477	$39,258	$4,310	$2,425	$94	$3,680
Dry-to-dry converted to closed-loop (PCE-B3)	$31,781	$7,607	$39,388	$4,325	$2,069	$106	$3,680
Dry-to-dry closed-loop with no CA or with door fan and small CA (PCE-C)	$38,511	$0	$38,511	$4,228	$1,434	$136	$3,680
Dry-to-dry closed-loop with unvented integral secondary CA (PCE-D)	$47,475	$0	$47,475	$5,213	$1,216	$186	$3,680

See notes at end of table.

Exhibit 7-4. Estimated Process-Dependent Cost Components of Selected PCE Machine Configurations[a] (Cont'd)

Machine Configuration[b]	Annual Cost Hazardous Waste[j]	Annual Cost Filters and Detergent[k]	Annual Cost Maintenance[l]	Total Annual Operating Cost[m]	Total Annual Cost[n]	Total Annual Cost/pound
Transfer						
Transfer with no CA or RC (PCE-A1)	$4,567	$1,913	$6,000	$16,762	$18,923	$0.35
Transfer with CA (PCE-A2)	$4,629	$1,913	$6,000	$15,745	$18,797	$0.35
Transfer with RC (PCE-A3)	$4,567	$1,913	$6,000	$15,328	$18,457	$0.35
Dry-to-Dry						
Dry-to-dry with no CA or RC (PCE-B1)	$4,567	$1,913	$6,000	$16,390	$19,879	$0.37
Dry-to-dry with CA (PCE-B2)	$4,629	$1,913	$6,000	$15,061	$19,371	$0.36
Dry-to-dry converted to closed-loop (PCE-B3)	$4,567	$1,913	$6,000	$14,655	$18,980	$0.36
Dry-to-dry closed-loop with no CA or with door fan and small CA (PCE-C)	$4,594	$1,913	$6,000	$14,077	$18,305	$0.34
Dry-to-dry closed-loop with unvented integral secondary CA (PCE-D)	$4,594	$1,913	$6,000	$13,909	$19,122	$0.36

NA means Not Available.

[a] The values include the price of equipment, labor, and services directly related to the various drycleaning processes but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333 pound (24,191 kilogram) annual volume of clothes cleaned per facility.

[b] CA - carbon adsorber; RC - refrigerated condenser

[c] Average of list prices of 35 pound drycleaning machine or system with control equipment as shown. Price includes distillation unit and filters where applicable. Base technology prices are shown for the relevant, less controlled drycleaning equipment system on which the retrofit control equipment is mounted.

[d] Average of list prices for retrofitting control technology.

[e] Base machine costs (actual or implied) are added to cost of control capital.

[f] Annual cost of drycleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[g] Based on $6.83 per gallon for PCE in 1997 dollars (BLS, 1997; USEPA, 1993) and "mileage" from USEPA engineering estimates.

[h] Based on (USEPA, 1991a) and $0.0764/kWh national average electricity cost (BLS, 1997).

[i] Based on 1.84% of total annual revenues of $200,000 (Gottlieb, 1997; NCAI, 1998).

[j] Based on $6.94 per -gallon PCE hazardous waste disposal cost (Beedle, 1998) and volume calculations from USEPA engineering estimates, excluding disposal costs for potentially hazardous spotting chemicals. Hazardous waste associated with PCE-based machines includes filters, distillation residues, and spent carbon.

[k] Cost of drycleaning detergents, spotting chemicals, and replacement filters (USEPA, 1993).

[l] Based on 3.0% of total revenues of $200,000 annually.

[m] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[n] Includes all operating costs and annual capital costs.

Hazardous Waste Disposal Costs: Hazardous waste costs are based on engineering estimates of 667 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,629.

Cost of Filters/Cleaning Supplies: Each 35 -pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $576, or $606 in 1997 dollars (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (USEPA, 1993;BLS, 1997), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (USEPA, 1993; BLS, 1997).

Maintenance Cost: Maintenance costs are based on 3.0% of annual revenue ($200,000), for a total of $6,000.

7.3.3 PCE Transfer with Refrigerated Condenser (PCE-A3)

Capital Cost: The cost shown is based on quotes from two vendors. Kleen Rite will retrofit a transfer machine with a refrigerated condenser (RC) for a list price of $8,611, which includes a $300 installation fee (Becknell, 1994). ArtiChill will retrofit a transfer machine with an RC for a list price of $8,500, which includes a $500 installation fee (Stork, 1994). Indexing the average price of $8,556 to 1997 dollars brings the total to $8,823 (BLS, 1997). An alternative source of price information (not used in the table, but included for comparison) is the Source Reduction Research Partnership (SRRP, 1992). The SRRP estimates that retrofitting an uncontrolled transfer machine with an RC costs $9,366 in 1997 dollars (BLS, 1997). To calculate the annualized cost of equipment on a comparable basis with new equipment, the implied cost of an uncontrolled transfer equipment combination ($19,680 from Option PCE-A1) is added to the retrofit cost of $8,823 to give a total effective capital cost of $28,503 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 417 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon (USEPA, 1993;BLS, 1997), the solvent cost is $2,848. The mileage is 128 pounds per gallon.

Energy Cost: Data are not available at this time.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000) for a total of $3,680.

Hazardous Waste Disposal Costs: Hazardous waste costs are based on engineering estimates of 658 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,567.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $576, or $606 in 1997 dollars (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (USEPA, 1993;BLS, 1997), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (USEPA, 1993;BLS, 1997).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000) for a total of $6,000.

7.3.4 PCE Dry-to-Dry with No Carbon Adsorber or Refrigerated Condenser (PCE-B1)

Capital Cost: Uncontrolled dry-to-dry machines are no longer available, so historical information must be used. The price for an uncontrolled dry-to-dry machine is based on a 1989 price sheet from Marvel Manufacturing Company (Villareal, 1994). The 1989 list price with a filter and still was $27,300. Adjusting to 1997 dollars brings the price to $31,781 (BLS, 1997). An alternative source of price information (not used but included for comparison) is the Clean Air Act Section 114 Questionnaires, which was a survey conducted for the Chemical and Petroleum Products Division, Office of Air Quality, Planning, and Standards. The median reported price of a 35-pound dry-to-dry machine was $24,000 in 1987 dollars (USEPA, 1988). Adjusting to 1997 dollars brings the total to $29,715 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 561 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon, the solvent cost is $3,832. The mileage is 95 pounds per gallon.

Energy Cost: A Model M-30 Böwe Permac dry-to-dry machine with no CA or RC draws approximately 1.1 kilowatt-hours (kWh) of electricity (Morgal, 1998). Six loads per day (30 minutes per load) are needed to process the annual throughput of 53,333 pounds. Therefore, at a cost of $0.0764/kWh, annual energy costs are calculated to be $78.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000), for a total of $3,680.

Hazardous Waste Disposal Costs: Hazardous waste costs are based on engineering estimates of 658 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,567.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $606 (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (BLS, 1997; USEPA, 1993), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (BLS, 1997; USEPA, 1993).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.3.5 PCE Dry-to-Dry with Carbon Adsorber (PCE-B2)

Capital Cost: The cost is based on quotes from two vendors. District Cleaners Equipment retrofits a 35-pound capacity vented dry-to-dry machine to a closed-loop machine with a CA unit for $7,000 to $8,000 (the median price of $7,500 is used to calculate the average price) (Immanuel, 1994). Ilsa Multi-Solver produces a free-standing CA unit for dry-to-dry vented machines for $7,000 (including $500 installation) (Lage, 1994). The average price of these two units is $7,250. Indexing for inflation brings the total price to $7,477 (BLS, 1997). An alternative source of price information (not used but included for comparison) is the New York State Department of Environmental Conservation report previously cited (NYSDEC, 1993), which estimates that the addition of a CA to an existing dry-to-dry machine would cost $6,000 including installation (1991 dollars, equivalent to $6,549 in 1997 dollars) (BLS, 1997). The implied cost of an uncontrolled dry-to-dry machine ($31,781 from Option PCE-B1) is added to the retrofit cost of $7,477 to give a total effective capital cost of $39,258 in 1997 dollars (BLS, 1997).

Solvent Cost: Assuming a solvent use of 355 gallons/year (USEPA estimate) and a solvent price of $6.83 per gallon, the solvent cost is $2,425. The mileage is 150 pounds per gallon.

Energy Cost: A Model M-30 Böwe Permac dry-to-dry machine draws approximately 1.1 kWh of electricity (Morgal, 1998). Six loads per day (30 minutes per load) are needed to process the annual throughput of 53,333 pounds. The total energy use of a CA unit on a dry-to-dry machine is 344 kWh/year reported in USEPA (1991a) for an annual throughput of 87,524 pounds per year. In this analysis, the throughput is 60.9% (53,333 pounds/87,524 pounds) of that used in USEPA (1991a). The adjusted annual energy use for the CA unit is therefore 210 kWh/year. Therefore, at a cost of $0.0764/kWh, annual energy costs are calculated to be $94.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000) for a total of $3,680.

Hazardous Waste Disposal Costs: Hazardous waste costs are based on engineering estimates of 667 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,629.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $606 (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (BLS, 1997; USEPA, 1993), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (BLS, 1997; USEPA, 1993).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.3.6 PCE Dry-to-Dry Converted to Closed-Loop (PCE-B3)

Capital Cost: The price to retrofit a vented dry-to-dry machine with an RC unit is based on a survey of equipment offered by four drycleaning manufacturers and distributors. Pros Equipment (Hope, 1994) retrofits a 35-pound vented dry-to-dry machine to a closed-loop machine with an RC unit using a water-cooled condensing unit for $6,000, and an RC unit using an air-cooled condensing unit for $5,400. Although the air cooled unit is less expensive, 80% of Pros' current customers select the water cooled system because it tends to be both easier for them to understand and easier to install. Therefore, the $6,000 price is used to calculate the average. District Cleaners Equipment retrofits a 35-pound vented dry-to-dry machine to a closed-loop machine with an RC unit for $6,000 to $8,000 (the $7,000 midpoint is used to calculate the average) (Immanuel, 1994). ArtiChill sells the Arctic Dry 75, a closed-loop conversion system that retrofits a 35-pound capacity vented dry-to-dry machine to a closed-loop machine with an RC unit for $9,995 (Stork, 1994). The Vapor Condensing System by Kleen-Rite, a closed-loop conversion system that retrofits a 35-pound capacity vented dry-to-dry machine to a closed-loop machine with an RC unit, costs $6,507 (including $300 installation) (Becknell, 1994). The average price of these four units is $7,376 (1994 dollars). Indexing to 1997 dollars brings the average price to $7,607 (BLS, 1997). In order to calculate the annualized cost of equipment on a comparable basis with new equipment, the implied cost of an uncontrolled dry-to-dry machine ($31,781 from Option PCE-2A) is added to the retrofit cost of $7,607 to give a total effective capital cost of $39,388 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 303 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon, the solvent cost is $2,069. The mileage is 176 pounds per gallon.

Energy Cost: A Model M-30 Böwe Permac dry-to-dry machine draws approximately 1.1 kWh of electricity (Morgal, 1998). Six loads per day (30 minutes per load) are needed to process the annual throughput of 53,333 pounds. The total energy use of an RC unit on a dry-to-dry machine is 604 kWh/year, for an annual throughput of 87,524 pounds per year (USEPA, 1991a). In this analysis the throughput is 60.9% (53,333 pounds/87,524 pounds) of that used in USEPA (1991a). The adjusted energy use for the RC unit is therefore 368 kWh/year. Using the price of $0.0764/kWh, the total annual energy cost is calculated to be $106.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000) for a total of $3,680.

Hazardous Waste Disposal Costs: Hazardous waste costs are based on engineering estimates of 658 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,567.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $606 (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (BLS, 1997; USEPA, 1993), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (BLS, 1997; USEPA, 1993).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.3.7 PCE Dry-to-Dry Closed-Loop with no Carbon Adsorber or with Door Fan and Small Carbon Adsorber (PCE-C)

Capital Cost: The price of a closed-loop dry-to-dry machine with an RC unit is based on a survey of equipment offered by six major drycleaning manufacturers. The six machines are Fibrimatic's Ecodry, with a purchase price of $24,500 (Du Bach, 1994); Fluormatic's Blue Tiger Model 37, with a list price of $39,500 (Moser, 1994); Marvel's Ranger 35, with a list price of $36,875 (Villareal, 1994); VIC's Model 1235FS, with a list price of $41,400 (Giesen, 1994); Boewe Passat's Model P535 (36-pound capacity), with a list price of $47,105 (Cannon, 1994); and Multimatic Shop Star 300, with an estimated list price of $34,667 (list price estimated based on purchase price of $26,000) (Immanuel, 1994). The average price of these six machines is $37,341. Indexing to 1997 dollars brings the total average price to $38,511 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 210 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon, the solvent cost is $1,434. The mileage is 254 pounds per gallon.

Energy Cost: Model P-536 Böwe Permac dry-to-dry machine draws approximately 1.9 kWh of electricity (Morgal, 1998). Six loads per day (30 minutes per load) are needed to process the annual throughput of 53,333 pounds. Therefore, at a cost of $0.0764/kWh, annual energy costs are calculated to be $136.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000) for a total of $3,680.

Hazardous Waste Disposal Costs: Hazardous waste estimates are based on engineering estimates of 662 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,594.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $606 (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (BLS, 1997; USEPA, 1993), for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (BLS, 1997; USEPA, 1993).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.3.8 PCE Dry-to-Dry Closed-Loop with Unvented Integral Secondary Carbon Adsorber (PCE-D)

Capital Cost: The price for new “fourth generation” drycleaning equipment includes filters and a distillation unit and is based on a survey of three distributors and manufacturers: Fibrimatic’s Ecostar 4th Plus, with a list price of $29,995 (Du Bach, 1994); Fluormatic’s Blue Tiger 37 Next Generation, with a list price of $45,000 (Moser, 1994); and Boewe Passat’s Model P535 (36-pound capacity), with a list price of $63,105 (Cannon, 1994). The average price for these three machines is $46,033. Indexing to 1997 dollars brings the average total price to $47,475 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 178 gallons/year (USEPA estimates) and a solvent price of $6.83 per gallon, the solvent cost is $1,216. The mileage is 300 pounds per gallon.

Energy Cost: P-536 Böwe Permac dry-to-dry machine with CA unit (consorber) draws approximately 2.6 kWh of electricity (Morgal, 1998). Six loads per day (30 minutes per load) are needed to process the annual throughput of 53,333 pounds. Therefore, at a cost of $0.0764/kWh, annual energy costs are calculated to be $186.

Regulatory Compliance Cost: Regulatory compliance costs are estimated at 1.84% of annual revenue ($200,000) for a total of $3,680.

Hazardous Waste Disposal Costs: Hazardous waste estimates are based on engineering estimates of 662 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $4,594.

Cost of Filters/Cleaning Supplies: Each 35-pound capacity machine needs 20.24 replacement standard carbon core filters at $17.57 per filter and 7.59 double all carbon filters at $29.03 per filter (USEPA, 1993), for an annual cost of $606 (BLS, 1997). All costs presented for filters and cleaning supplies are average costs. (Individuals will not buy 7.59 filters but are likely to buy packages of 8 or 10. This is also true of cleaning supplies.) The annual cost of detergents and spotting chemicals is estimated at $1,307/year (BLS, 1997; USEPA, 1993) for a total supplies cost of $1,913 per year. The annual cost of supplies without spotting chemicals is $1,527 (BLS, 1997; USEPA, 1993).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.4 COST ESTIMATES FOR HYDROCARBON SOLVENT MACHINE CONFIGURATIONS

Exhibit 7-5 summarizes the three HC solvent machine configurations analyzed. The discussion that follows details the cost estimates of each technology configuration for HC solvents.

7.4.1 HC Transfer Machine with Standard Dryer and No Condenser (HC-A1)

Capital Cost: A transfer machine has two components, a washer/extractor machine and a dryer (or reclaimer). The solvent removed during the extractor process (i.e., spin drying) in the washer/extractor equipment is captured, filtered, and reused. The two components are available for sale separately. The price of an uncontrolled HC solvent transfer machine is based on a J&T Model 40 (40-pound capacity) washer/extractor (with filter and explosion kit), which sells for $23,900 (Jenkins, 1994) plus the average cost of a basic Cissell Dryer, $3,085 (Stanley, 1994). The combined price for the two components is $26,985 (1994 dollars). Indexing to 1997 dollars brings the total to $27,830 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 2,159 gallons/year (USEPA estimates) and a Stoddard solvent price of $2.24 per gallon, the solvent cost is $4,836. The solvent mileage is 25 pounds per gallon.

Energy Cost: Data are not available at this time.

Regulatory Compliance Cost: Regulatory compliance costs are excluded from this analysis due to a lack of information.

Hazardous Waste Disposal Costs: Hazardous waste estimates are based on engineering estimates of 1,415 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $9,820. Note that HC solvent waste may not be considered hazardous waste under RCRA if their flashpoint is greater than 140°F. This is the case for DF-2000. Therefore, this value represents an upper bound estimate. If wastes are considered non-hazardous, operating expenses may be significantly reduced.

Cost of Filters/Cleaning Supplies: Each machine needs 4.92 replacement standard carbon core filters at $34 per filter and 1.64 double all carbon filters at $42 per filter (Hill, 1994a), for an annual cost of $244 in 1997 dollars (BLS, 1997). Adding the cost of detergents and spotting chemicals, $1,307 (BLS, 1997; USEPA, 1993), yields a total of $1,551 (BLS, 1997). The annual cost of supplies without spotting chemicals is $1,169 (BLS, 1997).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

Exhibit 7-5. Estimated Process-dependent Cost Components of Selected HC Solvent Machine Configurations[a]

HC Machine Configuration[b]	Capital Cost of Base Equipment[c] (Implied Cost)	Capital Cost of Retrofit Control Technology[d]	Capital Cost Total[e]	Annualized Cost of Equipment[f]	Annual Cost Solvent[g]	Annual Energy Cost[h]	Annual Cost Hazardous Waste[i]
Transfer - standard dryer (HC-A1)	$27,830	$0	$27,830	$3,056	$4,836	NA	$9,820
Transfer - recovery dryer with RC (HC-A2)	$37,432	$0	$37,432	$4,110	$2,236	NA	$9,820
Dry-to-dry closed-loop with RC (HC-B)	$52,082	$0	$52,082	$5,718	$1,151	$149	$9,820

Exhibit 7-5. Estimated Process-dependent Cost Components of Selected HC Solvent Machine Configurations[a] (Cont'd)

	Annual Regulatory Compliance Cost	Annual Cost Filters and Detergent[j]	Annual Cost Maintenance[k]	Total Annual Operating Cost[l]	Total Annual Cost[m]	Total Annual Cost/pound
Transfer - standard dryer (HC-A1)	NA	$1,551	$6,000	$22,207	$25,263	$0.47
Transfer - recovery dryer with RC (HC-A2)	NA	$1,551	$6,000	$19,607	$23,717	$0.44
Dry-to-dry closed-loop with RC (HC-B)	NA	$1,551	$6,000	$18,671	$24,389	$0.46

NA means Not Available.

[a] The value includes the price of equipment, labor, and services directly related to the various drycleaning processes but excludes costs for expenses such as pressing, storefront operations, and rent. All values are reported in 1997 dollars and all calculations assume a 53,333-pound (24,191 kilogram) annual volume of clothes cleaned per facility.

[b] CA - carbon adsorber; RC - refrigerated condenser.

[c] The list price of a 35- to 40 -pound drycleaning machine (or system) with control equipment as shown. The price includes filters and an explosion kit where applicable.

[d] Average of list prices for retrofitting control technology.

[e] Base machine costs (actual or implied) are added to cost of control capital.

[f] Annual cost of drycleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[g] Based on $2.24 per gallon for HC solvent and "mileage" based on engineering estimates.

[h] Based on $0.0764/kWh national average electricity cost (BLS, 1997). Energy costs estimated to be 10% higher than those for comparable PCE machines (Hill, 1994a). The authors used the energy costs for PCE-C ($136) to calculate this value for HC-B.

[i] Based on $6.94 per gallon hazardous waste disposal cost (Beedle, 1998) and volume calculations from USEPA engineering estimates, excluding disposal cost for potentially hazardous spotting chemicals. Hazardous waste associated with HC-based machines includes spent cartridge filters and vacuum still bottoms. Note that HC solvent wastes may not be considered hazardous waste under RCRA if its flashpoint is less than 140°F.

[j] Cost of drycleaning detergents, spotting chemicals, and replacement filters (USEPA, 1993; Hill, 1994b).

[k] Maintenance costs based on 3.0% of annual revenues of $200,000.

[l] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[m] The estimate includes all operating costs and annual capital costs.

7.4.2 HC Transfer Machine with Recovery Dryer (HC-A2)

Capital Cost: The price of a transfer machine system, including a reclaimer dryer, is the sum of the washer/extractor in the transfer system in Option HC-A1 ($23,900), plus the price of the Hoyt Petro-Miser solvent reclaimer ($12,395) (King, 1994), or $36,295. Indexing the cost from 1994 dollars to 1997 dollars brings the combined total to $37,432 (BLS, 1997).

Solvent Cost: Assuming a solvent use of 998 gallons per year (USEPA estimates) and a Stoddard solvent price of $2.24 per gallon, the solvent cost is $2,236. The mileage is 53 pounds per gallon. The manufacturer claims the Petro-Miser reclaims from 3.5 to 5 gallons of solvent for every 100 pounds of clothes washed.

Energy Cost: Data are not available at this time.

Regulatory Compliance Cost: Regulatory compliance costs are excluded from this analysis, due to a lack of information.

Hazardous Waste Disposal Costs: Hazardous waste estimates are based on engineering estimates of 1,415 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $9,820. Note that HC solvent waste may not be considered hazardous waste under RCRA if its flashpoint is greater than 140°F. Therefore, this value represents an upper bound estimate. If wastes are considered non-hazardous, operating expenses may be significantly reduced.

Cost of Filters/Cleaning Supplies: Each machine needs 4.92 replacement standard carbon core filters at $34 per filter and 1.64 double all carbon filters at $42 per filter (Hill, 1994a), for an annual cost of $244 in 1997 dollars (BLS, 1997). Adding the cost of detergents and spotting chemicals, $1,307 (BLS, 1997; USEPA, 1993), yields a total of $1,551 (BLS, 1997). The annual cost of supplies without spotting chemicals is $1,169 (BLS, 1997).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.4.3 HC Dry-to-Dry Closed-Loop with Refrigerated Condenser (HC-B)

Capital Cost: The price of an HC dry-to-dry closed-loop machine with filter and RC that uses an azeotropic process during the final aeration is based on the $50,500 price for a Midwest 35 pound capacity machine ($41,000 for machine, $5,000 for filter, and $4,500 for RC) (Hill, 1994b). Indexing the cost to 1997 dollars brings the total price to $52,082 (BLS, 1997). A distillation unit can be added for $10,000 but would not be necessary for good performance, according to the machine's supplier (Hill, 1994b).

Solvent Cost: Assuming a solvent use of 514 gallons per year (USEPA estimates) and a Stoddard solvent price of $2.24 per gallon, the solvent cost is $1,151. The solvent mileage is 104 pounds of clothes cleaned per gallon of solvent.

Energy Cost: Energy costs, based on Hill's assumption that HC process energy costs are 10% higher than those for a comparable PCE drycleaning machine (PCE-C), are estimated to be $149.

Regulatory Compliance Cost: Regulatory compliance costs are excluded from this analysis due to a lack of information.

Hazardous Waste Disposal Costs: Hazardous waste estimates are based on engineering estimates of 1,415 gallons per year. Assuming a hazardous waste disposal cost of $6.94 per gallon (Beedle, 1998), the total cost is $9,820. Note that HC solvent waste may not be considered hazardous waste under RCRA if its flashpoint is greater than 140°F. Therefore, this value represents an upper bound estimate. If wastes are considered non-hazardous, operating expenses may be significantly reduced.

Cost of Filters/Cleaning Supplies: Each machine needs 4.92 replacement standard carbon core filters at $34 per filter and 1.64 double all carbon filters at $42 per filter (Hill, 1994a) for an annual cost of $244 in 1997 dollars (BLS, 1997). Adding the cost of detergents and spotting chemicals, $1,307 (BLS, 1997; USEPA, 1993), yields a total of $1,551 (BLS, 1997). The annual cost of supplies without spotting chemicals is $1,169 (BLS, 1997).

Maintenance Cost: Maintenance costs are based on 3.0% of total revenue ($200,000), for a total of $6,000.

7.5 COST ESTIMATES FOR MACHINE WETCLEANING

Exhibit 7-6 details the cost components for machine wetcleaning. The discussion below provides information on the cost estimates of for this technology configuration. Capital costs include both washing and drying.

Capital Cost: Wetcleaning equipment ranges in price considerably based on the size and sophistication of the equipment. Six suppliers and their list prices are the Aqua Clean 80S ($36,380) and 80G ($33,475); the Böwe Permac Wash 200 with a 35-pound capacity including single reuse tank, circulation pump, and door pump with spray ($37,605); the Unimac UW30 with a 30-pound capacity ($8,373) and the DTB50 dryer with a 75-pound capacity ($2,729); the Marvel ADS 60# with a 60-pound capacity including thermometer, alarm, steam injection, extra supply, and two thermal fills ($25,585); the Milnor 30022 F8W with a 55-pound capacity ($17,245 without dryer; $25,061 with dryer); and the Daewoo DWF-1088PA with a 24-pound capacity ($1,099)[12] (Fleck, 1998; Schmelik, 1998; Star and Vasquez, 1997). The configuration of the Unimac UW30 washer and DTB50 dryer will be used in this analysis. The total capital cost for this equipment is $11,102. Based on Unimac specifications, this equipment is expected to run at 100% capacity, resulting in 6 loads per day for an annual throughput of 53,333 pounds of clothes (Fleck, 1998; Schmelik, 1998).

Solvent Cost: The solvent used in machine wetcleaning is water. Based on Unimac's specifications, an average of 3.5 gallons of water is used per pound of clothes cleaned. The price of water is $3.06/100 ft^3 (USEPA, 1993; BLS, 1997). Based on an annual throughput of 53,333 pounds, the total cost is $763 in 1997 dollars (BLS, 1997; Fleck, 1998; Schmelik, 1998).

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[12] The large price difference between Daewoo brand wetcleaning machines and the other commercial brands is associated with the following factors: (1) Daewoo machines have pre-programmed cycles, while a fully programmable microprocessor control is available for many of the other brands; and (2) the capacity of the Daewoo machines is considerably less than many of the other manufacturer's models (Star, 1998).

Exhibit 7-6. Estimated Process-dependent Cost Components for Machine Wetcleaning[a]

Technology	Total Capital Cost of Equipment	Annualized Cost of Equipment[b]	Annual Cost Solvent[c]	Annual Energy Cost[d]	Annual Cost Hazardous Waste[e]	Annual Cost Filters and Supplies[f]
Machine Wetcleaning	$11,102	$1,219	$763	$788	NA	$3,162

Exhibit 7-6. Estimated Process-dependent Cost Components for Machine Wetcleaning[a] (Cont'd)

Technology	Annual Cost Regulatory Compliance[g]	Annual Cost Maintenance[h]	Total Annual Operating Cost[i]	Total Annual Cost[j]	Total Annual Cost/Pound
Machine Wetcleaning	NA	$376	$5,089	$6,308	$0.12

NA means data are unavailable at this time.

[a] The values include the price of equipment and services directly related to machine wetcleaning but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars, and all calculations assume a 53,333 pound annual volume of clothes cleaned per facility.

[b] Annual cost of equipment, annualized using 7% interest; assuming equipment life of 15 years.

[c] Solvent costs based on $3.06/100 cubic feet for water (BLS, 1997; USEPA, 1993).

[d] Assumes $0.0764/kWh national average electricity cost (BLS, 1997).

[e] No hazardous waste disposal costs are estimated for machine wetcleaning. However, some spotting agents and wetcleaning detergents may contain chemical constituents that are considered RCRA hazardous wastes.

[f] Assumes detergent costs ($2,878), fabric softener costs ($40), and spotting chemical costs ($245).

[g] Regulatory costs could not be estimated at this time.

[h] Machine wetcleaning maintenance costs are based on 3.39% of total capital costs (Murphy, 1994).

[i] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[j] Includes all operating costs and annual capital costs.

Energy Cost: The total energy draw of the washer is 2.2 kWh with an average cycle time of 25 minutes. The dryer uses 9.18 kWh of energy with an average cycle time of 30 minutes. Using the price of $0.0764 per kWh, the total energy cost is calculated to be $788 (Fleck, 1998; Schmelik, 1998).

Hazardous Waste Disposal Cost: This analysis assumes that no hazardous waste disposal costs are associated with the wetcleaning process. However, some spotting agents (e.g., PCE and trichloroethylene) and wetcleaning detergents may contain chemical constituents that are considered RCRA hazardous wastes when they are present in a waste water stream.

Regulatory Compliance Cost: Machine wetcleaning technology is too new to the fabricare industry for regulatory compliance costs to be estimated at this time.

Cost of Filters/Cleaning Supplies: Unimac estimated detergent costs of $1.19 (1993 dollars) to clean 30-pounds of lightly soiled clothes and $1.72 (1993 dollars) to clean 30-pounds of heavily soiled clothes. An average price of $1.46 (1993 dollars) per 30-pounds of clothes cleaned is used, assuming that 50% of loads are lightly soiled and 50% are heavily soiled (BLS, 1997). Chemicals used include Seitz Chemicals Company's Frankolan S and Frankopal W. The ingredients of these detergents are proprietary information and therefore confidential. For an annual throughput of 53,333 pounds of clothes cleaned, detergent costs are $2,877 in 1997 dollars (BLS, 1997). The total cost of $3,162 includes fabric softener ($40) and spotting chemicals ($245) in 1997 dollars (BLS, 1997).

Maintenance Cost: For the purpose of this analysis, the wetcleaning equipment maintenance cost is estimated as 2% per year of the purchase price with a major overhaul, costing 8% of the purchase price, every 5 years for the life of the machine (Murphy, 1994). These investments are annualized using 7% over the 15-year life span of the equipment, for an annual maintenance cost of 3.39% of the capital cost. The total annual maintenance cost is $376. This estimate is consistent with the UCLA/PPERC study wetcleaning maintenance estimate of $379 annually for 15 years, which includes replacing the door lock, water drain valve, water extractor bearings, circulation pumps, and computer control unit (Gottlieb et al., 1997).

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CHAPTER 8
SELECTED FEDERAL REGULATIONS

CHAPTER CONTENTS

This chapter describes some federal regulations that may affect the various fabricare alternatives analyzed in this document. Regulatory requirements are an important aspect of comparing alternative fabricare processes because of their effect on daily and long-term costs, equipment requirements, cleaning processes, overhead, owner/operator liability, and business compliance time (Blackler et al., 1995).

Professional clothes cleaners may be affected by the requirements of the following federal air, water, waste management, and occupational health and safety regulations: (1) Clean Air Act (CAA); (2) Clean Water Act (CWA); (3) Safe Drinking Water Act - Underground Injection Control Regulations (SDWA-UIC); (4) Resource Conservation and Recovery Act (RCRA); (5) Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); (6) Occupational Safety and Health (OSH) Act; and (7) the Federal Trade Commission's Care Labeling Rule.

Following a summary of each of these federal regulations, individual sections discuss how each statute applies to the individual fabricare processes. The final section of the chapter provides examples of state and local regulations, as well as consensus standards of the National Fire Protection Association (NFPA) that apply to the fabricare industry. Exhibit 8-1 summarizes the federal regulations that apply to the various fabricare technologies covered in this Cleaner Technologies Substitutes Assessment (CTSA).

In some cases implementation of federal mandates may be delegated to a state agency. Such programs must be at least as stringent as the applicable federal regulation. However, state and local authorities may impose requirements that are more stringent than those addressed by federal law. There may also be additional state or local requirements that have no federal counterpart.

Owners and operators of drycleaning facilities are encouraged to consult USEPA's *Plain English Guide for Perc Drycleaners: A Step by Step Approach to Understanding Federal Environmental Regulations* [EPA 305-B-96-002 (USEPA, 1996a)] and *Multimedia Inspection Guidance for Drycleaning Facilities* [EPA 305-B-96-001(USEPA, 1996c)] for more detailed discussions of perchloroethylene (PCE) drycleaning regulations.

The discussion in this document is intended for informational purposes only. Stakeholders are encouraged to examine all potentially applicable federal, state, and local regulatory requirements that apply to professional fabricare operations in their jurisdiction. Although spotting agents, fabric finishes, and water softeners are not covered in this regulatory assessment, they should not necessarily be overlooked for their impact on a fabricare operation's regulatory compliance activities.

Exhibit 8-1. Summary of Regulations Related to Fabricare Technologies[a]

Fabricare Option	CAA	CWA	RCRA	CERCLA	OSH	Care Labeling Rule	Other
PCE cleaning	✓	✓	✓	✓	✓	✓	NFPA-32
HC cleaning	✓	✓	✓	✓	✓	✓	NFPA-32
Machine Wetcleaning	NA	✓	NA	NA	NA	✓	NA

✓ Indicates that a technology is regulated specifically in statute.
NA Indicates that although the statutes apply to the technology there are no specific regulatory requirements.
[a] The list of regulations covered in this chapter should not be considered exhaustive and may not cover all regulated aspects of the fabricare industry.

8.1 CLEAN AIR ACT

The Clean Air Act (CAA) and subsequent amendments are a regulatory framework established to protect and improve ambient air quality in the United States. The CAA was passed in 1970 and amended with significant provisions in 1977 and 1990.

Section 111 established new source performance standards and best achievable technology standards for sources of specific volatile organic chemical compounds (e.g., fabricare establishments). These standards require establishments that emit volatile chemicals to establish and maintain records, make reports, install/use/maintain monitoring equipment, sample locations, and provide this information to applicable regulatory agencies.

Section 112 of the CAA establishes requirements that directly restrict the emission of 189 hazardous air pollutants. USEPA has listed 174 categories of emitters of hazardous air pollutants and developed a schedule for establishing national emissions standards for hazardous air pollutants (NESHAP). These standards require emitters to establish and maintain records, make reports, install/use/maintain emissions controls and monitoring equipment, sample locations, and provide this information to applicable regulatory agencies.

Under Title V, “major sources” of air pollutants may be required to apply for operating permits. Section 112 of the CAA defines major sources as having the potential to emit more than 10 tons per year of any one hazardous air pollutant (e.g., PCE), or more than 25 tons per year of any combination of hazardous air pollutants. Generally, these permits are issued by state programs approved by USEPA. Fabricare operators should contact their appropriate state agency to help them in determining the applicability of “major source” requirements under Title V.

Title VI of the CAA, included in amendments passed in 1990, calls for a phase-out in the production and importation of chlorofluorocarbons (CFCs)in the year 2000 and trichloroethane in 2002 due to their ozone-depleting potential. USEPA originally set up a program to control production and importation of these chemicals through allowances or permits that would be expended in the production and importation of these chemicals. In response to new scientific evidence, USEPA accelerated the phase-out dates to December 31, 1995. This ban has affected drycleaners using CFCs as their primary solvent and also the type of spotting agents used in all fabricare processes.

8.1.1 Perchloroethylene Cleaning

On September 23, 1993, USEPA promulgated a NESHAP to control PCE emissions from drycleaning facilities (National Perchloroethylene Air Emissions Standards for Dry Cleaning Facilities - 40 CFR Part 63, Subpart M). Compliance with this NESHAP was required by September 1996 for cleaners operating prior to December 9, 1991. Cleaners that began operating on or after December 9, 1991 were required to immediately comply with this regulation. The NESHAP regulations for drycleaners are technology-based, rather than emissions-based. USEPA felt that it would have been prohibitively burdensome to require owners to continuously monitor emissions concentrations and solvent mileage. Therefore, USEPA, as authorized under Section 112(h) of the CAA, passed standards that require installation of certain levels of emissions control equipment combined with mandatory performance testing to ensure that the equipment is functioning properly. NESHAP standards for drycleaners are intended to control emissions of major sources to a level that is represented by maximum achievable control technology. Some area sources (non-major sources) are required in the framework of these regulations to control their emissions to a level that is represented by generally available control technology.

The applicability of NESHAP requirements is dependent on the facility's size category. Exhibit 8-2 presents the air control requirements for drycleaners with new and existing machines based on the volume of PCE purchased and the type of drycleaning machine (USEPA, 1996a). Facilities with coin-operated drycleaning equipment, although mentioned in the NESHAP, are specifically exempted from all NESHAP regulations (40 CFR§63.320(j)). With regard to the three remaining size categories, requirements involving installation of equipment are generally more stringent for larger facilities. The intent is to avoid unduly burdening small businesses with requirements they cannot afford to meet. On the other hand, requirements involving little or no capital investment (e.g., monitoring and recordkeeping) have been standardized for all drycleaners regardless of size.

Requirements for the PCE NESHAP, summarized in Exhibit 8-3, are divided into the following four categories:

- Emissions control equipment requirements (intended to reduce PCE emissions);
- Emissions equipment monitoring (tests to ensure that the control devices are operating properly);
- Fugitive emissions control (prevention of miscellaneous PCE emissions resulting from leaks, improper operation of drycleaning machines, or improper handling of PCE and PCE wastes); and
- Recordkeeping and reporting (demonstration of compliance).

Aside from these requirements, the provisions of this NESHAP prohibit the sale of new transfer machines and require all new machines to be sold with vapor control technology. New transfer machines installed between December 9, 1991, and September 22, 1993, are considered "existing" transfer machines. Existing machines installed before December 9, 1991, are excluded from the equipment requirements in the NESHAP. However, such machines require specific equipment and facility retrofitting if they fall under "large area" and "major source" classifications (40 CFR§63.320). For more specific information, individuals are encouraged to consult the PCE NESHAP directly, or USEPA's *Multimedia Inspection Guidance for Drycleaning Facilities* (USEPA, 1996c).

Exhibit 8-2. Air Control Requirements for Drycleaners with New and Existing Machines Based on PCE Purchase Volume[a]

Small Area Source Dry Cleaner	Large Area Source Dry Cleaner	Major Source Drycleaner
Dry-to-dry machines only; PCE use less than 140 gallons/year **-or-** Transfer machines only; PCE use less than 200 gallons/year **-or-** Transfer and dry-to-dry machines; PCE use less than 140 gallons/year	Dry-to-dry machines only; PCE use 140 to 2,100 gallons/year **-or-** Transfer machines only; PCE use 200 to 1,800 gallons/year **-or-** Transfer and dry-to-dry machines; PCE use 140 to 1,800 gallons/year	Dry-to-dry machines only; PCE use more than 2,100 gallons/year **-or-** Transfer machines only; PCE use more than 1,800 gallons/year **-or-** Transfer and dry-to-dry machines; PCE use more than 1,800 gallons/year
Install main PCE vapor recovery system (refrigerated condenser or carbon adsorber) for new machines upon start-up No control equipment required for existing machines Meet good housekeeping, monitoring, recordkeeping, reporting, and leak detection/repair requirements	Install main PCE vapor recovery system (refrigerated condenser or carbon adsorber) for new machines upon start-up Install main PCE vapor recovery system (refrigerated condenser or carbon adsorber)[b] for existing machines by September 23, 1996 Meet good housekeeping, monitoring, recordkeeping, reporting, and leak detection/repair requirements	Same requirements as large area source, plus install additional carbon adsorber for new machines upon start-up and for existing machines by September 23, 1996 Surround all existing transfer machines with room enclosure vented by carbon adsorber by September 23, 1996 Meet good housekeeping, monitoring, recordkeeping, reporting, and leak detection/repair requirements

Source: USEPA, 1996a

[a] Usage is based upon the total amount of PCE purchased at facility location for all PCE machines for the previous 12 months.

[b] PCE vapor recovery system should be refrigerated condensers or existing carbon adsorbers installed before September 22, 1993.

PCE drycleaners characterized as a major source are required to obtain a Title V operating permit, in addition to meeting the requirements of the PCE NESHAP. USEPA or a designated state agency may be the entity that issues a Title V operating permit in a particular state. Note that any drycleaner defined as a major source is required to obtain a Title V permit. Owner/operators of major source drycleaning facilities are encouraged to contact the applicable state agency to obtain additional information regarding the permit process under Title V.[1] If a drycleaner is not considered a major source (i.e., it is a small or large area source), USEPA recommends that the owner check with the appropriate state air authority to determine if Title V or other air permits are required in the drycleaner's jurisdiction.

Many of the newer PCE drycleaning systems use R-22 (HCFC-22) as a refrigerant in their refrigerated condensers. Although R-22 is a replacement for CFCs, this refrigerant still has ozone-depleting potential. USEPA has established a ban on all production and consumption of R-22 for the year 2020. In the year 2010, production and consumption of R-22 will be banned for all uses except as a chemical feedstock and as a refrigerant in appliances manufactured prior to January 1, 2010. Older machines may still contain the now banned CFC-11 or CFC-12 refrigerants, which have an even higher

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[1] Under Section 507 of the CAA, USEPA set up a Small Business Assistance Program (SBAP) to assist industries in complying with regulations in every state. Drycleaning operators can contact the SBAP program office in their state to assist them in making a determination of their potential status as a major source under the PCE NESHAP. The SBAP Web site contains a list of state-level contacts for this program (http://www.epa.gov/ttn/sbap).

Exhibit 8-3. PCE NESHAP Compliance Requirements for Drycleaners

Requirement	Size Category of Drycleaning Facility		
	Small Area Source	**Large Area Source**	**Major Area Source**
Equipment Requirements			
Elimination of all transfer machines classified as new	Required		
Existing transfer machines surrounded with room enclosure vented by carbon adsorber	Not required	Not required	Required
Installation of main PCE vapor recovery system (refrigerated condenser or carbon adsorber)[a]	Required	Required	Required
Installation of additional carbon adsorber for residual PCE recovery system	Not required	Not required	Required
Emissions Equipment Monitoring			
Monitoring of refrigerated condensers	Weekly monitoring required		
Monitoring of carbon adsorbers	Weekly monitoring required		
Fugitive Emissions Control			
Leak detection program	Biweekly inspections	Weekly inspections	Weekly inspections
Simple leak repair	Repair within 24 hours		
Leak repairs requiring ordering parts	Order parts within 2 working days and install parts within 5 days of receipt		
Disposal of cartridge filters	Drain for at least 24 hours		
General operation of drycleaning machines	As per manufacturer specifications and recommendations		
Machine doors kept closed when transferring clothes	Required		
PCE and PCE waste stored in tightly sealed containers	Required		
Reporting			
Initial compliance report	Required upon start-up		
Additional compliance report	Required 30 days after start-up and after any change in facility status[b]		
Recordkeeping			
Facility log book	Maintain on-site for 5 years		

Source: USEPA, 1996c

[a] PCE vapor recovery systems should be refrigerated condensers or existing carbon adsorbers installed before September 23, 1996.

[b] Change in facility status includes changes in ownership or address of the facility, purchase of new equipment, or a change in size category.

ozone-depleting potential and contribute to global warming. As mentioned previously, these chemicals were banned from production and importation on December 31, 1995. If equipment using such chemicals is in need of a recharge, the refrigerant technology must be retrofitted or replaced to accommodate an allowable alternative (Gottlieb et al., 1997).

8.1.2 Hydrocarbon Solvent Cleaning

New source performance standards (NSPSs) for hydrocarbon-based (HC) drycleaners[2] (40 CFR Part 60 - Subpart JJJ) were promulgated on September 24, 1984. They are applicable in CAA *non-attainment areas*[3] for ozone and related photochemical oxidants and may also have been adopted by individual states. The NSPSs set limits on solvent loss from drying, outline standards on the use of filters, and require leaks to be repaired in a timely manner. Drycleaners must add control devices to reduce solvent loss from the washer, dryer, and filters. In addition, they must monitor their machines more closely for leaks (USEPA, 1995).

The following equipment is regulated if it is installed at a facility having a total manufacturer's rated dryer capacity equal to or greater than 84 pounds (38 kg) and constructed after December 14, 1982: (1) HC solvent drycleaners, (2) washers and filters, and (3) stills and settling tanks. The total manufacturer's rated dryer capacity is the sum of the rated capacity for each HC solvent dryer that is in operation or is proposed for operation after a facility modification is finished. A dryer is exempt from these regulations if it was constructed between December 14, 1982, and September 21, 1984, and uses less than 4,700 gallons (17,800 L) of solvent per year.

The following are requirements under the current USEPA NSPS for HC solvent drycleaning operators (KSBEAP, 1997):

- Installation of solvent recovery dryer only.
- Conversion to cartridge-type solvent filters.
- Draining of cartridge-type solvent filters for 8 hours in their sealed housing before removal from equipment.
- Posting of leak inspection and repair notices on all dryers with a clearly visible label. Leak inspection and repair notices also must be recorded in a manual (see 40 CFR§60.622 for recommended label warnings).
- Performance of an initial test to verify that the flow rate of recovered solvent from the solvent recovery dryer at the end of the recovery cycle is no greater than 0.05 L per minute (50 mL/minute).
- Recording of all performance testing as specified in the regulation.

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[2] These new source performance standards specifically regulate drycleaners that use petroleum-based solvents and do not mention the term "hydrocarbon." For the purpose of this analysis, the phrase "hydrocarbon solvent" encompasses three different types of petroleum solvents, two of which were not available to the drycleaning industry when the standards were promulgated in 1984. USEPA encourages stakeholders to refer to the specific regulations (40 CFR Part 60 Subpart JJJ) for a more detailed definition.

[3] *Non-attainment areas* are geographic areas that do not meet the national ambient air quality standards for one or more of the six criteria air pollutants outlined in the CAA (i.e., sulfur dioxide, nitrogen oxides, particulate matter, lead, carbon monoxide, ozone). Non-attainment areas are designated as such if monitored ambient concentrations of criteria pollutants have exceeded the standard more than the acceptable number of times over a specified period. The time period and number of acceptable exceedences varies among criteria pollutants. Typically, a non-attainment area includes the county(ies) that make up a metropolitan statistical area plus one ring of surrounding counties or communities (USEPA, 1995).

Fabricare operators should note that USEPA is considering the proposal of a NESHAP for HC solvents. Should a proposal proceed, the NESHAP would be expected to require HC solvent drycleaners to use maximum available control technology to reduce emissions from their fabricare operations (KSBEAP, 1997; Szykman, 1998).

8.1.3 Machine Wetcleaning

The chemical detergents and additives analyzed by USEPA for the purposes of this document do not contain ingredients that are regulated under the CAA. However, other wetcleaning products may contain such chemicals. Fabricare operators should always check the ingredient list and material safety data sheet of wetcleaning detergents, additives, and spotting agents to determine the potential applicability of the CAA and other regulations.

8.2 CLEAN WATER ACT

The Clean Water Act (CWA) is the federal law designed to protect the chemical, physical, and biological quality of surface waters in the United States. The original statute of the CWA and subsequent amendments evolved from the Federal Water Pollution Control Act of 1972 (PL 92-500). The CWA regulates both wastewater discharges directly into surface waters via the National Pollutant Discharge Elimination System (NPDES) and discharges into municipal sewer systems. The CWA designates and regulates pollutants in waste water effluent according to the following three categories:

- *Priority Pollutants* - 126 toxic chemicals;
- *Conventional Pollutants* - include biological oxygen demand, total suspended solids, fecal coliform, fats/oils/greases, and pH; and
- *Non-conventional Pollutants* - any pollutant not identified as conventional or priority.

8.2.1 National Pollutant Discharge Elimination System Program

Direct, or point source, discharges of discrete sources of wastewater into a navigable waterbody are regulated under USEPA's NPDES program (CWA§402). This program applies to commercial and industrial facilities, as well as municipal wastewater treatment plants (also known as publicly-owned treatment works, or POTWs). This program requires regulated facilities to apply for an NPDES permit that is issued either by USEPA or an authorized state agency. There are currently 42 USEPA-approved state NPDES programs.

The permits issued under the NPDES program contain industry-specific, technology-based, and water quality-based standards for wastewater effluent. Generally, the standards vary according to the classification of receiving waters. For example, state- and locally-mandated water quality criteria may be designated to protect surface waters for aquatic life and recreation. Such standards may not necessarily account for technological feasibility and/or cost of effluent treatment, more typical of other federal technology-based emissions standards. In addition, NPDES permits specify the pollutant monitoring and reporting requirements for each regulated source of waste water effluent.

There is a small business exemption [40 CFR§122.21 (g)(8)] for all NPDES permit applicants with gross total annual sales averaging less than $100,000 per year in 1980 dollars (approximately $146,000 in 1997 dollars).[4] This exempts small businesses from submitting quantitative data on certain organic toxic pollutants (see 40 CFR 122.21 Table II). However, small businesses must still provide quantitative data for other toxic pollutants (metals and cyanides) and total phenols, as listed in 40 CFR 122.21 Table III. Other small business exemptions may apply to clothes cleaning operations, depending on state and/or regional variances in water quality standards. Regulations concerning other hazardous and non-conventional pollutants are similar for both small and larger facilities.

8.2.2 Wastewater Discharges to Publicly-owned Treatment Works

A facility that diverts its wastewater to a publicly-owned treatment works (POTWs) is not required to obtain an NPDES permit. A national pretreatment program [CWA§307(b)] was established to regulate the indirect discharge of pollutants to POTWs by users. Commercial and industrial customers may be required to comply with regional and local discharge requirements and pretreatment standards. Pretreatment standards include both “categorical” industry standards, implemented on a nationwide basis, and “local limits.” These requirements, which include both narrative and numeric pretreatment standards, are established by the local and regional sewerage authorities to prevent significant interference with the POTW[5] and to allow POTWs to meet the effluent standards set by their NPDES permits.

Narrative pretreatment standards consist of general and specific prohibitions (40 CFR§403.5), which apply to all discharges made to a POTW. General prohibitions specify that pollutants introduced into POTWs by a non-domestic source (e.g., fabricare operations) shall not pass through the POTW or interfere with the operation or performance of treatment works, create problems with sludge disposal, or cause health and safety problems for plant workers from exposure to chemicals.

The specific prohibitions prevent the discharge of pollutants that cause the following conditions (USEPA, 1996c):

- Fire or explosion hazard (including discharges with a closed-cup flashpoint below 140°F);
- Corrosive structural damage (no $pH<5.0$);
- Solid or viscous pollutants in amounts that will cause obstruction of flow in the POTW, resulting in interference;
- Any pollutant released in a discharge at a flow rate and/or pollutant concentration causing interference;
- Heat causing inhibition of biological activity and temperature at the treatment plant exceeding 40°C (104°F);
- Petroleum oil, non-biodegradable cutting oil, or products of mineral oil origin in quantities that will cause pass through and interference;

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[4] This estimate is based on conversion using the Apparel and Upkeep Consumer Price Index for urban consumers.

[5] Many POTWs are required, through their NPDES permits, to implement a pretreatment program that provides for control of toxics and compliance with narrative numeric pretreatment standards by its users. A POTW’s authority to implement this program is contained in its local Sewer Use Ordinance (USEPA, 1996c).

- Pollutants that result in the presence of toxic gases, vapors, or fumes in the POTW that may cause acute worker health and safety problems; and
- Trucked or hauled wastes, except at locations designated by the POTW.

Numeric standards consist of categorical standards and local limits. Categorical standards apply to many types of specific industries (e.g., metal finishers), but do not apply specifically to fabricare operators. POTWs required to develop pretreatment programs must develop local limits to implement the general prohibitions listed above. Local limits are site-specific numeric standards, enforceable by the POTW that ensure protection of the treatment works and the receiving water body. Local limits apply to all discharges to the POTW, including those from drycleaners.

One of the reporting requirements that may be applied to a drycleaning facility through a permit is the submission of a report at least once every 6 months regarding the nature, concentration, and flow of pollutants in the wastewater, based on a sampling study and analysis (40 CFR§403.12). Additional reporting requirements that apply to all users of a POTW include (40 CFR§125) (USEPA, 1996c):

- Notification of the POTW, USEPA, and appropriate state agency of any discharge to the POTW that would be considered hazardous if discharged in a different manner. A discharge of more than 15 kg per month of a hazardous waste (e.g., 2.4 gallons of pure PCE) into the sewer would require this type of notification;
- Notification of the POTW in advance of any substantial change in volume or character of pollutants in their discharge, including hazardous wastes; and
- Requirement to submit a notice of discharges, including slug loadings, immediately upon identification of such discharges that could cause problems for the POTW.

Users subject to monitoring requirements must also comply with specific recordkeeping requirements and maintain the records for a minimum of 3 years. Such records include date/place/method/time of sampling and person(s) taking samples, date(s) sample analysis was performed, person performing analysis, analytical technique/method used in analysis, and the results of the analysis (USEPA, 1996c).

As a part of the national pretreatment program, POTWs are required to identify significant industrial users (SIUs), as defined in 40 CFR 403.3. Fabricare operators may be considered significant based on their reasonable potential to adversely affect the POTW or to violate any pretreatment requirements (e.g., through spills or sludge discharges). The regulations further require that POTWs use a control mechanism (i.e., permit) to ensure that all applicable standards and requirements are met by the SIUs (40 CFR§403.8(f)(2)(iii)). Typically, fabricare facilities are not issued permits. However, operators should be aware of the requirements and contact the local POTW to determine the status of their facility. Permits issued by POTWs include effluent limitations, monitoring and reporting requirements, and standard and special conditions.

All professional cleaners, regardless of process option, use several different spot removal products for clothing. Although many biodegradable spotting agents have been developed, a number of the more popular ones (i.e., trichloroethylene, acetone, 2-[2-butoxyethoxy] ethanol) should be disposed of as hazardous wastes, rather than washed down the drain. Wastewater testing performed for the Center for Neighborhood Technology's wetcleaning demonstration project indicates that use of the spotting agent

Picrin™ (100% trichloroethylene) could result in concentrations that exceed USEPA drinking water standards (5 parts per billion, or ppb) (CNT, 1996). Therefore, potentially hazardous spotting agents should be identified and treated appropriately, or eliminated from use.

8.2.3 Perchloroethylene Cleaning

Fabricare facilities using PCE drycleaning technology produce wastewater contaminated with PCE. Possible sources of the wastewater are the use and maintenance of emission control and filtration devices (carbon adsorbers, cartridge stripping cabinets, stills, muck cookers, and refrigerated condensers). PCE-contaminated wastewater is typically called separator water and includes (WEF, 1995):

- Water added to PCE and detergent at the start of the drycleaning cycle;
- Steam used in the desorption step when a carbon adsorber is the primary air pollution control device;
- Water vapor from air that is condensed when a refrigerated condenser is the primary air pollution control device;
- Water used in steam-stripping the cartridge filters;
- Water used in the distillation process; and
- Water used in the vacuum press.

Wastewater is typically gravity-separated prior to discharge. Concentrations of PCE in wastewater vary depending on removal technology (25 to 150 ppm in separator water depending on temperature). Refrigerated condensers produce about 50 gallons of PCE-contaminated wastewater per year, while carbon adsorbers produce up to 1,500 gallons per year depending on the size and type of equipment (Blackler et al., 1995).

If more than 15 kg per month (2.4 gallons) of PCE is discharged into the sewer, operators must notify their local municipal authority, the USEPA Regional Waste Management Division Director, and the state hazardous waste authority in writing. In this case, the notification must include the name of the hazardous waste (PCE), the USEPA hazardous waste number (F002 - still bottom, U210 - unused PCE from machine or storage tanks), and the type of discharge (i.e., batch event or continuous/ongoing spill). If more than 100 kg per month (approximately 16 gallons) is discharged into the sewer, the following must be included in the written notification: hazardous constituents (i.e., additional solvents), an estimate of how much was discharged (in terms of mass and concentration), and an estimate of how much will be discharged during the next 12 months.

To meet the 15 kg threshold, a drycleaner would have to discharge approximately 28,000 gallons of wastewater based on a PCE concentration of 150 ppm. However, if a spill of pure PCE occurred, a release of only 2.4 gallons into the sewer would be needed to meet this threshold level (USEPA, 1996a).

Under section 307(b) of the CWA, a national pretreatment program controls the indirect discharge of pollutants to POTWs by “industrial users.” Therefore, large-scale clothes cleaning facilities may need to meet pretreatment standards for wastewater containing PCE residuals. Technically, PCE-contaminated wastewater at levels greater than 0.7 ppm is considered a hazardous waste under RCRA. However, USEPA has excluded such wastewater from regulation under RCRA if it is discharged directly to a POTW. Unless local POTWs require discharge permits, it is not illegal to dispose of wastewater in this manner. PCE-contaminated wastewater may not be discharged into a septic system according to regulations specified under the SDWA.

8.2.4 Hydrocarbon Solvent Cleaning

Discharge of HC solvents to a POTW may be prohibited under the CWA if their closed-cup flashpoint is less than 140°F and therefore may cause a significant fire or explosion hazard. HC solvents may be classified as "oils" under the CWA (40 CFR§311.1) and the Oil Pollution Act of 1990. Discharge or spills of oils that produce a visible sheen on either surface water, or in waterways and sewers that lead to surface waters, must be reported to the National Response Center at 1-800-424-8802 if they meet reportable quantity criteria. Fabricare operators are encouraged to check the material safety data sheet of a particular HC solvent to determine the applicability of the CWA and other regulations.

8.2.5 Machine Wetcleaning

Machine wetcleaning can result in the discharge of significant amounts of wastewater. The amount of wastewater discharged depends on the fabricare technology used. The content of the wastewater is determined by the soils and the chemical additives used during the cleaning process (i.e., detergents, finishing additives, spotting agents). The contaminants that must be monitored in the evaluation of wastewater will depend on state regulations and local POTW restrictions. The following is a sample of contaminants of concern identified by the Illinois Environmental Protection Agency Bureau of Water and the Illinois Department of Public Health (Tchobanoglous and Burton, 1991; CNT, 1996):

- *Biological Oxygen Demand* - The rate at which organisms use oxygen in the water while stabilizing decomposable organic matter under aerobic conditions. Biological oxygen demand is a measure of the organic strength of wastes in water and the environmental impact of chemical pollution.
- *Suspended Solids* - The nonfilterable residue present upon evaporation of wastewater at 103° to 105°C.
- *Fats, oils, and greases*.
- *Ammonia Nitrogen, Nitrogen, and Phosphorus* - Depending on the receiving stream these components may or may not be desirable.
- *Metals* - The type and level of metals allowed for discharge to municipal treatment systems depends on the treatment systems available to remove them. Standards may be process-specific or applied across an industry.
- *Total Toxic Organics* - There are 126 priority pollutants found in Appendix D of Section 307 of the Clean Water Act (40 CFR 423, Appendix A) for which water quality levels have been developed under the NPDES program.

Analysis of facility wastewater performed in conjunction with two recent wetcleaning studies (Center for Neighborhood Technology; Pollution Prevention Environmental Research Center - University of California at Los Angeles/Occidental College) indicate that such facilities are within POTW wastewater discharge standards (CNT, 1996; Gottlieb et al., 1997). The chemical detergents and additives analyzed by USEPA for the purposes of this document do not contain ingredients that are regulated under the CWA. However, other wetcleaning products may contain constituent chemicals that are regulated under the provisions of the CWA. Fabricare operators should always check the ingredient list and material safety data sheet of wetcleaning detergents, additives, and spotting agents to determine the potential applicability of this and other regulations.

8.3 SAFE DRINKING WATER ACT - UNDERGROUND INJECTION CONTROL REGULATIONS

The Safe Drinking Water Act (SDWA) prohibits the injection of contaminants through wells that will cause a public water supply system to violate a national drinking water standard or otherwise endanger public health or the environment. This statute requires USEPA to set maximum levels for contaminants in water delivered to users of public water systems. Such standards are health-based for drinking water and require water supply system operators to come as close as possible to meeting these standards by using the best available technology that is economically and technologically “feasible.” Primary enforcement responsibility may be delegated to states that request it, if they adopt drinking water regulations no less stringent than the national standards and implement adequate monitoring and enforcement procedures (USEPA, 1996c).

Of special concern are toxic contaminants in water from underground sources. Fabricare operations that use cesspools or septic systems capable of handling the sole sanitary waste of more than 20 people per day, or that use on-site disposal systems for the disposal of industrial waste (different types of Class V injection wells), are subject to federal or state underground injection control regulations (UIC) established under SDWA (USEPA, 1996c).

A Class V injection well is a sub-surface apparatus that meets the definition of an injection well and is used to emplace fluids above or into underground sources of drinking water. USEPA regulates all large household, commercial, and industrial cesspools and septic systems capable of serving more than 20 people no matter what they inject; excluded from USEPA regulation are individual household cesspools and septic systems serving less than 20 people that inject solely sanitary waste. USEPA regulations applicable to Class V injection wells are found in 40 CFR 144 and 146 (Underground Injection Control Program). USEPA Class V guidance documents are currently under development (USEPA, 1996c).

An on-site disposal system typically includes a septic tank and fluid distribution system, or leachfield, which relies on biological organisms and gravity flow to treat and disseminate solely sanitary wastewater. Disposal of even small quantities of industrial wastewater into a septic system is dangerous to the environment in two important ways: (1) industrial waste contains harmful chemicals that undergo minimal change in a septic tank before entering the sub-surface environment and ground water resources; and (2) the industrial waste may also destroy biological organisms in the septic system necessary for sanitary wastewater treatment.

The SDWA prohibits any activity that would “endanger” underground sources of drinking water by contamination. Septic systems discharge wastewater directly underground without any treatment. Industrial waste fluids washed down floor drains into dry wells or cesspools undergo even less change before entering the ground. Chemicals that are denser than water (e.g., PCE) will “sink” below the water table and migrate down through sandy aquifers and fractures in bedrock when released to the ground (USEPA, 1996c).

Violation of the “endangerment” criteria for underground sources of drinking water can result in fines, remediation costs for clean-up, and possible closure of operations and can require permitting procedures. Fabricare operators found in non-compliance may be responsible for penalties up to $25,000 for each day of non-compliance (USEPA, 1996a).

USEPA directly regulates Class V wells in 15 states,[6] American Samoa, the Virgin Islands, and the District of Columbia, and for all Indian Tribes. In the other 35 states, Guam, Puerto Rico, and the Commonwealth of the Northern Marianas, drycleaners are subject to applicable state UIC regulations (USEPA, 1996c).

8.3.1 Perchloroethylene Cleaning

In USEPA jurisdictions, all drycleaners who dispose of industrial waste in on-site disposal systems must, at a minimum, submit inventory information to be in compliance with UIC regulations. In addition, drycleaners are required to submit inventory information for cesspools and septic systems that are capable of handling the sole sanitary waste of more than 20 people per day, even if PCE waste or other hazardous chemicals are not disposed of in the system. In all state jurisdictions, drycleaners should contact their applicable state agency to determine minimum compliance requirements (USEPA, 1996c).

A drycleaning facility that disposes of PCE waste and other hazardous chemicals into a Class V injection well is in violation of the SDWA and should close its on-site disposal system immediately. On-site disposal systems that receive PCE waste and hazardous chemicals are associated with many documented cases of groundwater contamination. USEPA considers them high-risk and advises closing all of them. The highest priorities for closure include (USEPA, 1996c):

- Dry wells;
- Cesspools and septic systems that discharge PCE waste and hazardous chemicals into aquifers in Wellhead and Source Water Protection Areas;
- Aquifers that are hydrologically connected to drinking water aquifers;
- Aquifers designated as Sole Source Aquifers; and
- Aquifers that support sensitive ecosystems in estuaries, coastal zones, and watersheds.

USEPA Class V regulations and guidance applicable to drycleaners focus on (USEPA, 1996c):

- Employing pollution prevention methods such as recycling, proper hook-ups to sewers, good housekeeping methods and best management practices, holding tanks and removal off-site, and waste minimization;
- Reporting the location of all on-site disposal systems that receive industrial waste to the applicable state UIC program director;
- Inspecting on-site disposal systems to determine if they are being properly operated and maintained, and if they are being used to dispose of PCE waste or other hazardous chemicals;
- Evaluating the public health and environmental risk of the injection fluid or on-site system based on the site hydrogeological setting of the system;
- Requiring analysis of injected fluids, ambient monitoring, and additional soil or groundwater sampling, as warranted;
- Closing on-site disposal systems that receive PCE waste and other hazardous chemicals or otherwise endanger public health, underground sources of drinking water, or the environment;
- Requiring groundwater remediation, as warranted; and

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[6] These states are Alaska, Arizona, California, Colorado, Hawaii, Indiana, Iowa, Kentucky, Michigan, Minnesota, Montana, New York, Pennsylvania, South Dakota, Tennessee, and Virginia (USEPA, 1996c).

- Closing all cesspools.

Cesspools receive and discharge untreated solely sanitary water. All states except Hawaii have recognized the high risk posed by cesspools by, at a minimum, banning the construction of new cesspools (USEPA, 1996c).

8.3.2 Hydrocarbon Solvent Cleaning

The UIC regulations mentioned above for PCE cleaning apply similarly to HC solvents.

8.3.3 Machine Wetcleaning

If an on-site disposal system of a machine wetcleaning operation receives hazardous chemicals (e.g., detergents, spotting agents, and additives), it may be regulated under the provisions of the SDWA-UIC regulations. Local municipalities and states regulate the discharge of wetcleaning waste from a professional cleaner into a septic system. In many states, waste from professional clothes cleaners is considered industrial, and its disposal into a septic system is therefore prohibited (TURI, 1996). The wetcleaning detergent and additive formulations analyzed by USEPA for the purpose of this document are not regulated by the SDWA-UIC regulations. However, other chemical detergents and additives used in wetcleaning equipment may contain ingredients that are regulated by this and other provisions of the SDWA. Fabricare operators are encouraged to check the ingredient list and material safety data sheet of wetcleaning products to determine the applicability of this and other regulations.

8.4 RESOURCE CONSERVATION AND RECOVERY ACT

Passed in 1976, the Resource Conservation and Recovery Act (RCRA) is the primary waste management statute in the United States. RCRA regulates the management and disposal of hazardous (Subtitle C) and solid (Subtitle D) wastes. It establishes a “cradle to grave” system for tracking the production, management, and disposal of hazardous waste. Detailed definitions are provided for both hazardous and solid wastes, as well as specific requirements related to waste generation, management, storage, and disposal. The Hazardous and Solid Waste Amendments of 1984 strengthened RCRA’s waste management provisions and added Subtitle I, governing the management of underground storage tanks.

USEPA has issued regulations implementing the federal RCRA statute (40 CFR Parts 260-299). As of March 1994, 46 states were authorized to implement their own RCRA programs. Non-RCRA-authorized states (Alaska, Hawaii, Iowa, and Wyoming) may have additional or more stringent state laws pertaining to hazardous waste management. Facility operators should always check with their state regulator when determining which requirements apply to their waste management activities.

RCRA sets forth the following requirements for companies that generate sources of hazardous waste:

- Procedures for generators to identify solid and hazardous wastes or wastes exempted from regulation (40 CFR Part 261);
- Standards for obtaining a generator identification number, performing manifesting and other recordkeeping and reporting requirements, ensuring proper labeling and packaging, and waste accumulation units (40 CFR Part 262);
- Land disposal restrictions and treatment standards (40 CFR 268);
- Used oil storage and disposal requirements (40 CFR Part 279);
- Emission standards for volatile organic compounds stored in tanks and containers (40 CFR§264-265, Subpart C); and
- Requirements regarding design and release detection for underground storage tanks, as well as financial responsibility and corrective action standards.

8.4.1 Classification of Hazardous Wastes

USEPA classifies wastes as “hazardous” through regulations (40 CFR Part 261) and lists many wastes according to industrial processes. A waste can be classified as hazardous if it is either listed as a waste or is a characteristic waste. Listed wastes are specifically named in the regulations (e.g., discarded commercial toluene, spent non-halogenated solvents). The different lists of hazardous wastes found in Appendix VII of 40 CFR§261 are as follows:

- F List - wastes from non-specific sources, including wastes generated by industrial processes that may occur in several different industries;
- K List - wastes from specific industry sources;
- P List - acutely hazardous commercial chemical products that have been or are intended to be discarded;
- U List - hazardous commercial chemical products that have been or are intended to be discarded; and
- D List - materials exhibiting a hazardous waste characteristic (ignitability, corrosivity, reactivity, or toxicity).

Characteristic wastes, a subset of listed wastes, are defined as hazardous if they meet the defined criteria for one of four hazardous characteristics (as defined in 40 CFR 261.21-24), which are:

- *Ignitability* - ability to start burning easily; liquids with a flashpoint below 140°F; solids that spontaneously ignite; or oxidizing;
- *Corrosivity* - ability to dissolve metal or burn skin; pH less than or equal to 2.0 or greater than or equal to 12.5;
- *Toxicity* - materials that are poisonous to humans and other living organisms, as determined by the toxicity characteristic leachate procedure[7]; and

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[7] The toxicity characteristic leachate procedure is an analytical test that simulates the acidic conditions found in a landfill and determines the amount of a certain regulated substance that would leach from the waste if placed in a landfill. Regulatory levels in parts per million (ppm) are set for 39 hazardous constituents. Any waste exceeding these levels is considered a *toxic hazardous waste.*

- *Reactivity* - ability to undergo rapid or violent chemical reactions, which necessitates special handling requirements.

The waste generator has the responsibility for determining whether a waste is hazardous and what classification, if any, may apply to a waste stream. In addition to laboratory testing, waste generators may use their own knowledge and familiarity with a waste stream to characterize its status under RCRA. They are subject to enforcement penalties for improperly determining that a waste is not hazardous.

8.4.2 Classification of Hazardous Waste Generators

Generator requirements under RCRA are found in 40 CFR Parts 261.5 and 262. A hazardous waste generator is defined as any person, by site, who creates a hazardous waste or a waste subject to RCRA Subtitle C (USEPA, 1995). Generators are divided into the following three categories (USEPA, 1996b):

- *Large Quantity Generators (LQGs)* generate more than 1,000 kg (approximately 2,200 pounds) of hazardous waste per month, or more than 1 kg (2.2 pounds) of acutely hazardous waste per month;
- *Small Quantity Generators (SQGs)* generate between 100 and 1,000 kg (approximately 220 to 2,200 pounds) of hazardous waste per month, or less than 1 kg (2.2 lbs) per month of acutely hazardous waste; and
- *Conditionally Exempt Small Quantity Generators (CESQGs)* generate no more than 100 kg (approximately 220 pounds) of hazardous waste per month or less than 1 kg (2.2 pounds) of acutely hazardous waste per month.

Exhibit 8-4 contains the RCRA requirements for LQGs, SQGs, and CESQGs. CESQGs are required to evaluate the hazardous waste produced by their facility, considering all objects that come in contact with potential waste. In addition, CESQGs must ensure delivery of the hazardous waste to an off-site permitted hazardous waste facility and limit the quantities accumulated on-site to less than 1,000 kg (2,200 pounds). Hazardous waste generators who do not meet the conditions for CESQGs must comply with the recordkeeping and reporting requirements and meet the following requirements (USEPA, 1996b):

- Obtain a generator identification number;
- Store and ship hazardous waste in suitable containers or tanks (for storage only);
- Conduct weekly inspections of hazardous waste storage area(s);
- Properly manifest waste and label containers;
- Maintain copies of the manifest, a shipment log covering all hazardous waste shipments, and testing records;
- Comply with employee training requirements;
- Use only licensed treatment, storage, and disposal facilities;
- Comply with applicable land disposal restriction requirements; and
- Report releases, or threats of releases, of hazardous wastes that may exceed the reportable quantity.

The provisions of 40 CFR§262 provide that SQGs may accumulate up to 6,000 kg of hazardous waste on-site at any one time for up to 180 days without being regulated as a treatment, storage, or disposal facility (TSDF). The provisions of 40 CFR§262.34 (f) allow SQGs to store waste on-site for 270 days without having to apply for TSDF status, provided the waste must be transported over 200 miles.

Exhibit 8-4. RCRA Requirements for Hazardous Waste Generators

Requirement	**Category of Hazardous Waste Generator**		
	Conditionally Exempt Small Quantity Generator (CESQG)	Small Quantity Generator (SQG)	Large Quantity Generator (LQG)
General Requirements			
Determination of whether waste Is hazardous	Required	Required	Required
USEPA I.D. Number	Not federally required	Required	
Personnel training	Not federally required	Employees must be familiar with proper waste handling and emergency procedures	Hazardous waste handling training required for all employees
Contingency planning and emergency procedures	Not federally required	Basic plan required	Full plan required [40 CFR§262.34(a)(4)]
Waste Storage Requirements			
On-site storage quantity limit	≤2,200 lbs (1,000 kg)	≤13,200 lbs (6,000 kg)	No limit
On-site storage time limit[a]	No limit	180 days or ≤200 days if TSDF is over 200 miles away[b]	≤90 days[b]
Satellite accumulation of waste	Not applicable	≤55 gallons	≤55 gallons
Storage maintenance requirements	Not federally required	Basic requirements with technical standards under Part 265 for storage tanks and containers	Full compliance with management tanks, containers, and drip pads
Transporting Requirements			
Packaging, labeling, marking, and placarding requirements	Not federally required	In accordance with applicable DOT regulations	In accordance with applicable DOT regulations
Uniform hazardous waste manifest	Not federally required	Required	Required
Exception reports	Not federally required	Report missing manifest return copy within 60 days of transporter accepting	Contact transporter and TSDF within 35 days of transporter accepting waste to determine status; submit report within 45 days
Type of facility required for off-site management of waste	State-approved solid waste facility or RCRA permitted/interim status hazardous waste facility; check state-specific requirements	RCRA permitted/interim status hazardous waste facility	RCRA permitted/interim status hazardous waste facility
Land disposal notification requirement	Not federally required	Required	Required

Requirement	Category of Hazardous Waste Generator		
	Conditionally Exempt Small Quantity Generator (CESQG)	Small Quantity Generator (SQG)	Large Quantity Generator (LQG)
Recordkeeping Requirements			
Copy of manifests	Not federally required	Maintain copies for 3 years	Maintain copies for 3 years
Copies of biennial report	Not federally required	Not federally required	Maintain copies for 3 years (40 CFR 262.41)
Records of waste analyses	Not federally required	Maintain for 3 years after last shipment of waste	Maintain for 3 years after last shipment of waste

Source: USEPA, 1996c

[a] This period precludes a generator from being regulated as a hazardous waste treatment, storage, and disposal facility (TSDF), which is required to adhere to a separate, more stringent set of federal and state regulations (USEPA, 1996c).

[b] Storage must occur in tanks or containers only.

LQGs have only a 90-day window to ship wastes off-site without needing a RCRA TSDF permit. Most provisions of 40 CFR 264 and 265 (for hazardous waste TSDFs) do not apply to generators who send their wastes off-site within the applicable window (USEPA, 1996b).

In the case where a fabricare facility produces varying amounts of hazardous waste each month, USEPA has established *episodic generator* status. For example, a facility may be considered an SQG (non-exempt waste) one month and a CESQG (exempt waste) the next month, based on varying levels of hazardous waste production. If an episodic generator mixes waste produced from varying months (e.g., exempt and non-exempt waste), the waste and the facility are held to the most stringent standards of the regulated non-exempt waste (SQG or LQG). However, if the waste is stored and managed separately at the facility, the generator may manage the waste streams separately, according to the applicable standards under which they were produced (56 FR 10153; March 24, 1986).

8.4.3 Underground Storage Tanks

In addition to the provisions regarding hazardous waste management and disposal, RCRA contains requirements regarding the management of underground storage tanks (USTs). A regulated underground storage tank is defined as a tank or combination of tanks and underground connected piping that have at least 10% of their volume underground and which are, were, or may have been used to contain petroleum, hazardous, or other regulated substances (MDEQ, 1996). Facilities that store clothes cleaning chemicals in USTs may be required to protect the tanks from corrosion and equip them with devices to prevent spills and overfills, as well as corrosion protection. The USTs must also have leak detection equipment that provides monitoring data every 30 days (40 CFR§265.190-196) (USEPA, 1995, 1996a).

8.4.4 Perchloroethylene Cleaning

Drycleaners using PCE commonly produce up to seven types of listed hazardous wastes (F002), including (USEPA, 1996a, 1996b, 1996c):

- Spent solvent;
- Still residues from solvent distillation (still bottoms);
- Spent filters and filter media from recovery of used PCE from washers (e.g., cartridge, disk, powder, regenerative, non-regenerative);
- Cooked powder residue or filter muck (associated with powder filters only);[8]
- Button and lint trap wastes, rags and solvent storage containers; and
- Process water (e.g., from a separator).

Occasionally, drycleaners may dispose of unused PCE (including spill residue or materials used to clean spills), which is listed as a hazardous waste (U210). Amounts of these wastes produced depend on the cleaning capacity of the facility and the type of equipment used. Therefore, RCRA management, reporting, and employee training requirements for drycleaning owners/operators will vary, potentially resulting in episodic generator status. Owners/operators of PCE drycleaning facilities are encouraged to consult USEPA's *Plain English Guide for Perc Drycleaners: A Step by Step Approach to Understanding Federal Environmental Regulations* (USEPA, 1996a), USEPA's *Multimedia Inspection Guidance for Drycleaning Facilities* (USEPA, 1996c), or the state regulatory office for additional RCRA-specific requirements and classifications.

The slightly-contaminated wastewater generated from PCE cleaning is considered hazardous waste under RCRA because it was "derived from" an F002 waste. The previously mentioned variance under the CWA precludes regulation of PCE-contaminated wastewater under RCRA as a listed hazardous waste (spent halogenated solvent). Drycleaners are reminded that such discharges to a POTW must comply with the CWA and any local regulations. In addition, typical separator water contains 150 ppm of PCE, which is much higher than the toxicity threshold for PCE-contaminated waste. Separator water may therefore be considered a "toxic" hazardous waste as a result of failing the toxicity characteristic leachate procedure test for this waste stream.[9]

There are two additional disposal options for hazardous separator water produced by a drycleaning operation. USEPA and the drycleaning industry encourage individual businesses to have a licensed waste management company haul and dispose of their PCE-contaminated wastewater for treatment at a properly permitted facility (USEPA, 1995; Ohio EPA, 1996b). It is also acceptable in some states to use an evaporator unit to treat separator water on-site. Although the PCE vapors that result from this treatment method are not considered a hazardous waste, individual states may have specific emissions control

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[8] Cooked powder residues are a by-product of PCE cleaning processes that use diatomaceous earth (clay) powder filters to remove oil and grease from the solvent. This potentially hazardous waste product is not associated with PCE cleaning processes that use carbon cartridge and fabric disk filters.

[9] In some instances, a material is considered hazardous based on two or more criteria in RCRA. For example, PCE separator water is considered a hazardous waste by default under RCRA's "Derived From" rule, because it is derived from an F002 waste. In addition, separator water typically contains about 150 ppm of PCE. Since this level exceeds the TCLP level of 0.7 ppm for PCE contaminated waste, the separator water meets the RCRA toxicity criteria for a characteristic hazardous waste (Blackler et al., 1995; USEPA, 1995).

standards for evaporator equipment used in this manner (IDEM, 1995; Ohio EPA, 1996a). Drycleaners are encouraged to contact their applicable state regulatory agency to determine the most appropriate disposal method for their jurisdiction.

Land disposal restrictions have been established for chemicals regulated under RCRA, prohibiting the disposal of waste containing more than 1% (10,000 ppm) of halogenated solvents (40 CFR Part 268). Since wastewater typically contains 150 ppm of PCE, the federal land disposal restrictions provision is not likely to apply to this waste source (USEPA, 1995). However, there may be state regulations affecting drycleaning operators that supersede this federal exemption.

Drycleaning facilities that store PCE in USTs are subject to USEPA and state UST regulations. These require that a tank be protected from corrosion, equipped with devices that prevent spills and overfills, and monitored for leaks every 30 days (40 CFR§265.190-196) (USEPA, 1995, 1996a).

8.4.5 Hydrocarbon Solvent Cleaning

Waste materials contaminated with HC solvents may be considered characteristic hazardous waste under RCRA if the flashpoint is less than 140°F (ignitable). Fabricare operators who use these types of HC solvents will have to comply with hazardous waste generator requirements under RCRA. Many of the newer HC solvents and associated cleaning technologies have been developed with a flashpoint equal to or greater than 140°F specifically to avoid classification as ignitable.

Sources of waste contaminated with HC solvents are similar to those found in PCE drycleaning operations and may include (USEPA, 1996a, 1996b, 1996c):

- Spent HC solvent;
- Still residues from solvent distillation (still bottoms);
- Process water (e.g., from a separator);
- Spent filters and filter media from recovery of used HC from washers (e.g., carbon cartridge, fabric disk, diatomaceous earth powder-coated, regenerative, non-regenerative);
- Cooked powder residue (associated with powder filters only);
- Button and lint trap wastes; and
- Rags and solvent storage containers.

Drycleaning facilities that store HC solvent in underground storage tanks are subject to USEPA and state UST regulations. These require that a tank be protected from corrosion, equipped with devices that prevent spills and overfills, and monitored for leaks every 30 days (40 CFR§265.190-196) (USEPA, 1995, 1996a).

8.4.6 Machine Wetcleaning

The chemical detergents and additives analyzed by USEPA for the purposes of this document do not contain chemicals regulated under RCRA. However, other wetcleaning product formulations may contain ingredients that are regulated under RCRA. Fabricare operators are encouraged to check the ingredient list and/or material safety data sheet of wetcleaning detergents and additives to be sure that this and other regulations do not apply.

8.5 COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), known more commonly as Superfund, is the federal statute that establishes a variety of mechanisms to clean up sites contaminated with improperly disposed chemical wastes. This 1980 statute authorizes USEPA to respond to releases, or threatened releases, of hazardous substances that may endanger public health, welfare, or the environment. CERCLA also enables USEPA to force responsible parties to clean up environmental contamination or reimburse USEPA's Superfund for emergency response costs. The Superfund Amendments and Reauthorization Act (SARA) of 1986 revised various sections of CERCLA, extending the taxing authority for the Superfund and creating an additional free-standing federal law (SARA Title III - Emergency Planning and Community Right to Know Act).

Under CERCLA, potentially responsible parties (PRPs) that contribute to chemical contamination on a particular site, regardless of the extent or intent of their involvement, are held strictly liable. Such liability is retroactive; that is, PRPs can be identified for a contaminated site many years after the actual event has occurred, regardless of the legality of the management and disposal practices at the time of disposal. Current and past land owners, as well as fabricare shop owners, may be held liable if any type of contamination is found on a site. Even if concentrations of chemicals in wastewater are within limits set by a POTW, there is a possibility that individual shops can be held liable in the future if a sewer line leaks contaminated wastewater.

CERCLA regulations apply to any release of a *hazardous substance* on a site, as defined in the following manner:

- Substances designated pursuant to Section 311(b)(2)(A) of the Federal Water Pollution Control Act;
- Elements, compounds, mixtures, solutions, or substances designated pursuant to Section 102 of CERCLA;
- Hazardous wastes having the characteristics identified under or listed pursuant to Section 3001 of the Solid Waste Disposal Act (excludes any waste whose regulation under the SWDA has been suspended by Act of Congress);
- Toxic pollutants listed under Section 307(a) of the Federal Water Pollution Control Act;
- Hazardous air pollutants listed under Section 112 of the CAA; and
- Imminently hazardous chemical substance or mixture with respect to which the USEPA Administrator has taken action pursuant to Section 7 of the Toxic Substances Control Act.

Petroleum, including crude oil or any fraction thereof, which is not otherwise specifically listed or designated as a *hazardous substance*, is exempted from regulation under CERCLA. This exemption includes natural gas, natural gas liquids, liquefied natural gas, synthetic gas usable for fuel, and mixtures of natural and synthetic gases.

Hazardous substance release reporting regulations under CERCLA (40 CFR Part 302) direct the person in charge of a facility to report to the National Response Center any environmental release of a hazardous substance that exceeds a “reportable quantity.” Reportable quantities are defined and listed in 40 CFR 302.4. Generally, a release report triggers a response by USEPA or by one or more federal or state emergency response authorities (USEPA, 1995).

USEPA implements hazardous substance responses according to procedures outlined in the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) (40 CFR Part 300). The NCP includes provisions for permanent clean-ups, known as “remedial actions,” and other clean-ups, referred to as “removals.” USEPA generally takes remedial actions only at sites on the National Priorities List, which currently includes 1,300 sites. Both USEPA and states can act at other sites; however, USEPA provides responsible parties the opportunity to conduct removal and remedial actions and encourages community involvement throughout the Superfund response process (USEPA, 1996a).

8.5.1 Perchloroethylene Cleaning

The presence of PCE in the separator water of drycleaning operations is a potential liability concern for professional clothes cleaning operations. The traditional discharge of this water directly into municipal sewer systems, a practice that the drycleaning industry now discourages, may be responsible for contamination of groundwater in some areas. Accidental spills and leaks of PCE on cement floors are reported to have caused some soil and groundwater contamination at these sites (Blackler et al., 1995). Leakage of underground storage tanks containing PCE is another potential source of contamination at these sites (USEPA, 1995).

Many sites with past and present PCE drycleaning operations are already contaminated to levels that will limit future uses of the property. Indeed, many property owners will not lease space to clothes cleaners who use PCE and other solvents in their operations. CERCLA allows USEPA to hold land owners and drycleaning operators jointly and severally liable for PCE contamination. The industry is working with Congress to incorporate provisions in the reauthorization legislation for CERCLA that address the clean-up of PCE-contaminated drycleaning operations (Blackler et al., 1995).

The effluent water of drycleaning operations can contain as much as 150 ppm of PCE and can contribute 0.3 to 6 pounds per year of PCE loss depending on the equipment (WEF, 1995). Although this dilute waste stream is discharged directly to a municipal sewer system, pipe leakage of wastewater from this potentially persistent source can result in contamination of soils and ground water (Blackler et al., 1995). Installation of a refrigerated condenser, in addition to a carbon adsorber, can reduce the amount of wastewater by 30 times. Even so, the industry now recommends that all wastewater be disposed of through properly licensed RCRA waste hauling and disposal companies (USEPA, 1995, 1996a).

Since passage of CERCLA, court rulings have repeatedly established the liability of property owners in Superfund actions. Therefore, financial lending institutions and realtors have developed specific procedures to reduce their liability if they are associated with drycleaning facilities. These procedures include requirements for site inspections, soil and groundwater monitoring, and survey and sampling work, all often at the cost of the drycleaner. Leasing restrictions and loan withdrawal mechanisms have become a part of real estate and lending transactions to drycleaners (Gottlieb et al., 1997).

The potential financial liability that CERCLA places on drycleaners and their property owners has promoted protective legislation in eight states. This legislation may include funding mechanisms to assist drycleaners in reducing their liability exposure, drycleaner registration fees, per-gallon surcharges on PCE purchases, mandatory liability insurance, and/or a gross receipts tax.[10] Additional information regarding this topic is presented in Section 8.8 (Other Applicable Regulations) (Gottlieb et al., 1997).

8.5.2 Hydrocarbon Solvent Cleaning

Fabricare operations that result in the contamination of a site with HC solvents may result in CERCLA liability, in a manner similar to sites contaminated with PCE solvent. Many HC solvents can be characterized as a hazardous substance under CERCLA, because they are considered ignitable (listed) hazardous wastes under RCRA (flashpoint less than 140°F). However, the petroleum exemption and the nature of HC solvent mixtures necessitates making the following determination:

- Mixtures of petroleum distillate fractions that are modified beyond the refining process (i.e., chemicals considered hazardous substances are added to the mixture) are considered hazardous substances.
- Mixtures of petroleum distillate fractions that contain hazardous substances, but are not modified beyond the refining process, are not considered hazardous substances under CERCLA's petroleum product exemption.

Therefore, the chemical composition and the manner in which HC solvent products are produced will determine if CERCLA liability applies to specific substances. Also, some of the newer solvents, such as 140°F solvent and DF-2000, may not be considered ignitable (hazardous) due to their higher flashpoints. Fabricare operators are encouraged to carefully read the ingredient list and material safety data sheet of petroleum solvent products to assist them in making a determination in this regard (USEPA, 1987). Even if CERCLA does not apply to a particular HC solvent product, fabricare operators should check with an appropriate state agency to determine if future liability can result under a state statute.

8.5.3 Machine Wetcleaning

Contamination of a wetcleaning site may occur as a result of leaky wastewater pipes and accidental spills. Analyses performed in conjunction with two recent studies (Center for Neighborhood Technology; Pollution Prevention Environmental Research Center - University of California at Los Angeles/Occidental College) indicate that a site contaminated with wetcleaning wastewater has the potential to result in CERCLA liability. Constituents of concern identified in the wastewater effluent of

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[10] Legislation has been enacted in Connecticut, Florida, Kansas, Minnesota, Oregon, South Carolina, and Tennessee, with legislation pending in Illinois, New Jersey, North Carolina, and Pennsylvania (Gottlieb et al., 1997).

wetcleaning operations include heavy metals, phthalate, acids, acetone, diethylene monobutyl ether, and various organic spotting chemicals (PCE and trichloroethylene) (CNT, 1996; Gottlieb et al., 1997).

The wetcleaning detergent and additive formulations analyzed by USEPA for the purposes of this document did not contain chemicals that are regulated under CERCLA. However, fabricare operators are encouraged to check the ingredient list and material safety data sheet of all wetcleaning products to determine the potential applicability of this and other regulations.

8.6 OCCUPATIONAL SAFETY AND HEALTH ACT

The Occupational Safety and Health Administration (OSHA) was established in 1970 under the U.S. Department of Labor to reduce occupational fatalities, injuries, and illnesses and to develop health and safety standards and training programs for the protection of workers in the United States.

Section 6 (a) of the Occupational Safety and Health (OSH) Act enabled OSHA to promulgate existing federal and national consensus standards as OSHA standards. Under authority of this provision, the Health Standards program of OSHA established the following exposure limits for general industry air contaminants (29 CFR 1910.1000 Subpart Z):

- *Permissible Exposure Limit-Time-Weighted Average (PEL-TWA)* - an 8-hour average exposure that workers should not exceed. A PEL-TWA assumes a 40-hour work week, 50-week work year, and 45 years of work.
- *Short Term Exposure Limit (STEL)* - a 15-minute, TWA exposure that shall not be exceeded at any time during a workday unless another time limit is specified for the contaminant.
- *Ceiling Limits* - exposure levels that shall not be exceeded during any part of the workday. If instantaneous monitoring is not feasible, the ceiling limit shall be assessed as a 15-minute average exposure that shall not be exceeded during any part of the workday.

Most PELs were adopted from the Walsh-Healey Public Contracts Act, which adopted standards from the 1968 Threshold Limit Values of the American Conference of Governmental Industrial Hygienists. On June 7, 1988, OSHA proposed to revise the PELs by adding 164 substances to the list and lowering the PEL for 212 of the 600 substances listed. OSHA also wanted to establish skin designations, STELs, and ceiling limits for some of these substances. In 1994 the 11th Circuit Court of Appeals vacated the standard. OSHA currently only enforces the earlier PELs for the substances in the original Z tables. OSHA can rely on the "general duty clause," Section 5(a)(1) of the OSH Act, if it considers exposure to any air-borne substance to be too high. Under Section 5(a)(1) citations, the burden is on OSHA to show what is technologically and economically feasible for the cited employer. The 1994 court ruling prompted OSHA to begin developing individual PELs, STELs, and ceiling limits for the substances included in the Health Standards program (USEPA, 1996b).

In addition to chemical exposure standards, OSHA has established exposure standards for a number of relevant physical hazards found in occupational environments (e.g., non-ionizing radiation - 29 CFR 1910.97, occupational noise exposure - 29 CFR 1910.95). OSHA standards also cover the following workplace health and safety issues:

- Employee hazard communication (employee-right-to-know) and required signage;
- Recordkeeping associated with workplace injuries and illness;
- Employee personal protective equipment;
- First aid, blood-borne infectious diseases, workplace sanitation, and emergency response guidelines;
- Machine guarding, fire safety, electrical safety, and lockout/tagout standards; and
- Employee training.

These and other occupational health and safety issues are discussed in detail in the State of Michigan’s *Regulatory Guide for the Michigan Fabricare Industry* (MDEQ, 1996). Fabricare operators are also encouraged to contact OSHA and their state occupational health and safety department to determine which regulations pertain to their operation and jurisdiction.

8.6.1 Perchloroethylene Cleaning

The PEL for PCE is 100 ppm; however, when OSHA promulgated its PELs in 1989, the state-plan states also adopted them. Since these standards were not vacated by court decision, some states may still enforce the 25 ppm 8-hour TWA. Many drycleaners voluntarily have taken measures to meet the 25 ppm PEL in their facilities by installing control devices, such as carbon adsorbers or refrigerated condensers, and implementing work practice controls (Blackler et al., 1995). Today, OSHA recommends that drycleaners limit occupational exposures of PCE to 25 ppm, but can only enforce 100 ppm. In addition to the PEL-TWAs, there is a ceiling limit of 200 ppm (5-minute average in any 3 hours) and a 300 ppm maximum peak never to be exceeded during the workday. OSHA is currently undertaking a review of the PEL for PCE in the drycleaning industry (Gottlieb et al., 1997).

8.6.2 Hydrocarbon Solvent Cleaning

Some regulatory and recommended limits have been determined for Stoddard solvent, a specific type of HC solvent. In January 1989, OSHA adopted a 100 ppm PEL-TWA to replace the pre-1989 PEL. However, the pre-1989 PEL for Stoddard solvent of 580 ppm TWA is in effect because all new 1989 PELs were vacated via court decision. Some states may still maintain the 1989 PEL, however.

8.6.3 Machine Wetcleaning

Acetic acid, which is an additive to the water used in wetcleaning, has a 10 ppm PEL-TWA established by OSHA. A dilute mixture of acetic acid and water forms the equivalent of household vinegar.

8.7 CARE LABELING RULE

The Care Labeling Rule (16 CFR 423) was promulgated by the Federal Trade Commission (FTC) in order to establish uniform care instructions for textile garments and accessories. This rule requires clothing manufacturers to label garments with an acceptable cleaning method, supported by a “reasonable basis.” The reasonable basis for labeling a garment with a particular cleaning method can be based either upon the historical success with a particular cleaning technology or actual test results that consider fiber, fabric, and garment construction variables (Riggs, 1998).

There is some controversy over the effectiveness and usefulness of this rule in promoting drycleaning versus alternative cleaning methods. A garment often can be cleaned effectively by either dry, wet, or other cleaning methods. In order to avoid confusion and ambiguity, as well as potential liability associated with damaged clothing, clothing manufacturers may label a garment with a "dryclean only" label (Blackler et al., 1995). Researchers call this practice "low labeling," in which manufacturers tend to indicate very cautious care instructions, in an effort to avoid liability for damaged merchandise (Riggs, 1998).

Professional clothes cleaners are not legally bound to clean garments in the manner specified by the manufacturer. However, they are legally responsible for any damage to a customer's garment if it is not cleaned in the manner specified by the manufacturer. Otherwise, it is the manufacturer's legal responsibility to reimburse a customer if damage occurs when the garment is cleaned according to its instructions. Low labeling therefore discourages customers and professional cleaners from using alternative process options (Blackler et al., 1995).

In 1994 and 1995 the FTC requested public comment on the Care Labeling Rule in an effort to begin revisions that would remove barriers to the use of alternative clothes cleaning process options. The FTC is now in the process of collecting additional information for revision of this rule (Vecellio, 1996). USEPA is also working with fabricare stakeholders, including clothing and textile manufacturers, to develop a more accurate care labeling system that does not discriminate among cleaning methods.

8.8 OTHER APPLICABLE REGULATIONS

There are numerous regional, state, and local health, safety, and environmental regulations that may affect the fabricare industry in the U.S. As mentioned previously, many federal regulations are enforced more strictly by designated state agencies.

As an example, the State of Oregon established a waste minimization and hazardous waste management program designed to eliminate future drycleaning solvent releases to the environment. This program was established in response to the following concerns:

- The drycleaning industry feared that individual drycleaners would go out of business as a result of the liability associated with Oregon's cleanup law. This law would have required business and property owners to pay for the cleanup of contamination on or around their premises.
- Property owners faced considerable difficulty in obtaining loans from lending institutions if a fabricare operation was co-located or adjacent to their property.
- Drycleaners were finding it increasingly difficult to obtain and renew leases.

The law established an exemption for drycleaners from paying environmental clean-up costs and damages as a result of solvent contamination, set up a program in which all drycleaners paid annual fees to be used to clean up contaminated sites, and required individual operations to establish equipment and waste management practices to prevent future contamination of the environment. Faced with uncertainties and potentially damaging liabilities, drycleaning organizations have successfully promoted the passage of similar legislation in seven other states, with legislation pending in four states[11] (Gottlieb et al., 1997; ODEQ, 1997). Exhibits 8-5 and 8-6 contain information regarding state fees and other provisions for reduced liability exposures, respectively.

In addition, cities and municipalities have enacted numerous zoning restrictions that may affect all types of fabricare operations. For example, the City of Beverly Hills, California, has passed restrictions on drycleaning operations that specify noise and odor requirements, allowable cleaning capacities, numbers of machines per operation, location of equipment in buildings, and required approval of building inspectors and the fire department prior to equipment installation and/or modification. In addition, many localities have adopted some or all of the National Fire Protection Association's standards for drycleaning equipment and operations (NFPA-32), as noted below (CBH, 1997).

The National Fire Protection Association (NFPA) is a national consensus-building organization that has established fire protection safety standards. Although all NFPA standards are considered voluntary, many localities and state agencies have adopted them into law. Owners of drycleaning operations should consult with their local fire marshal about the applicability of NFPA-32 standards. In 1996 the NFPA passed safety standards (NFPA-32) for drycleaning plants classified in the following solvent categories:

- Type I - systems employing solvents with a flashpoint of less than 100°F (37.8°C);
- Type II - systems employing solvents with a flashpoint between 100°F and 140°F (38°C and 60°C), such as Stoddard solvent;
- Type IIIA - systems employing solvents with a flashpoint of 140°F (60°C) and above, such as 140°F solvent and DF-2000;
- Type IIIB - systems employing liquids with a flashpoint at or above 200°F (93.4°C) and complying with building requirements (ventilation, fireproofing, and electrical equipment) of Chapter 3 of the regulation;
- Type IV - systems employing nonflammable liquids (PCE) and complying with building requirements (ventilation and electrical equipment) of Chapter 4 of the regulation;
- Type V - systems employing nonflammable solvents (PCE) and complying with building requirements (ventilation and electrical equipment) of Chapter 5 of the regulation.

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[11] States with current liability-limiting legislation pertaining to drycleaners include Connecticut, Florida, Kansas, Minnesota, Oregon, South Carolina, and Tennessee. Legislation is pending in Illinois, New Jersey, North Carolina,and Pennsylvania. Arizona does have cleanup and reduced liability legislation, but there is no specific reference to the drycleaning industry. Similar legislation was introduced to the California legislature in 1995 (Assembly Bill 1096), but was subsequently withdrawn with no current plans of reintroduction (Gottlieb et al., 1997).

Exhibit 8-5. State Fees for Reduced Liability Exposures

State	Annual Fee[a]	PCE Tax	Gross Receipt Tax	Equivalent Cost Per Garment
Connecticut	**NA**	**NA**	**1%**	**$0.054**
Florida	**$100**	**$5.00/gallon**	**2%**	**$0.124**
Kansas	**NA**	**$3.75/gallon[b]**	**2%**	**$0.116**
Minnesota	**$1,000**	**$3.50/gallon**	**NA**	**$0.028**
North Carolina	**$2,500[c]**	**$4.25/gallon**	**NA**	**$0.061**
Oregon	**$1,500[d]**	**103% of sale**	**NA**	**NA**
South Carolina	**$1,500**	**$10.00/gallon**	**NA**	**$0.052**
Tennessee	**$1,000**	**$10.00/gallon**	**NA**	**$0.041**

Source: Gottlieb et al., 1997
NA Category not applicable to individual state.
[a] For facilities with approximately nine employees (or no cost difference for size was indicated).
[b] This tax will be raised by $0.25 each year until the fee reaches $5.50/gallon.
[c] Cost can be lowered to $500 if financial responsibility is demonstrated by obtaining pollution and remediation legal liability insurance with coverage of not less than $1 million or deposit with the Commission securities or a third-party bond for securing for pollution and liability for $1 million.
[d] Fee is lowered to $1,000 if annual sales are less than $50,000.

The NFPA is currently in the process of revising this standard in order to reflect updated equipment, alternative HC solvents, and the newer fabricare technologies that are currently being developed. The NFPA expects the revised standards to be performance-based, rather than focusing on specific technology. This revision is slated for completion by mid-1999 (Spencer, 1998).

Exhibit 8-6. State Legislative Provisions for Reduced Liability

State	Deductible[a]	Maximum Paid/Year	Site Investigation	Remediation and/or Treatment	Monitoring
Connecticut	$10,000 if reported prior to 1990; $20,000 if after 1990	$50,000	X		
Florida	Up to 6/30/97 - $1,000 7/1/97 to 6/30/01 - $5,000 7/1/01 to 12/31/05 - $10,000 After 2005 - fund pays $0		X	X	X
Kansas	$2,500	Up to 7/1/95 - $100,000; After 7/1/95 - 10% of fund's income for previous fiscal year	X	X	X
Minnesota	$10,000	20% of account balance at beginning of fiscal year	X		
North Carolina	$10,000	$200,000; or $400,000 if substantial threat to human health or the environment	X	X	X
Oregon	$10,000			X	
South Carolina	Prior to 10/1/97 - $1,000 10/1/98 - $5,000 10/1/99 - $10,000 10/1/00 - $15,000 10/1/01 - $20,000 After 2001 - $25,000		X	X	X
Tennessee	10% with a max. of $10,000	$200,000	X	X	

Source: Gottlieb et al., 1997

[a] For facilities with approximately nine employees.

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CHAPTER 9
ADDITIONAL ENVIRONMENTAL IMPROVEMENT APPROACHES

CHAPTER CONTENTS

This chapter focuses on techniques that may be employed by fabricare operations to prevent pollution, reduce chemical consumption, and minimize waste, with significant emphasis on perchloroethylene (PCE) and hydrocarbon (HC) solvent technologies. Section 9.1 examines the pollution prevention options with the potential to achieve environmental improvements for facilities using PCE and HC solvent technologies. The most common operating and maintenance procedures, control devices, and their effects are presented, including options for recycling. Methods for extracting solvents are addressed, as are methods for treating spent solvents so that they may be reused. In addition, this section discusses the impact of facility conditions and remedial actions on PCE concentrations in co-located residences (i.e., residences located in the same building as a fabricare operation). Section 9.2 suggests practices and improvements that may help cleaners using machine wetcleaning reduce chemical releases and exposure. Section 9.3 provides a summary of the several major clothes cleaning trade and research associations, their contact numbers, and some of their initiatives and publications involving environmental improvement practices.

9.1 PCE AND HC DRYCLEANING FACILITIES

9.1.1 Recommended Operating and Maintenance Procedures

On September 22, 1993, USEPA finalized the National Emission Standard for Hazardous Air Pollutants (NESHAP) for PCE drycleaners (58 FR 49354). This regulation set standards for the reduction of PCE emissions from drycleaning operations. Included in the NESHAP were requirements that owners or operators of drycleaning machines and control devices follow their manufacturers' instructions for the proper operation and maintenance of machines and control devices. Owners or operators are required to keep a copy of any manufacturers' specifications or operating and maintenance recommendations at the drycleaning facility.

USEPA realizes that some drycleaners may no longer have equipment manuals for older drycleaning machines and control devices. However, owners or operators of older machines and control devices should make every reasonable effort to obtain these manuals. These efforts include contacting manufacturers, if the manufacturers are still in business, and contacting local, state, and national trade associations.

In case efforts to obtain manufacturers' manuals are unsuccessful, USEPA's Office of Air Quality Planning and Standards (OAQPS) has developed many of the following recommendations for operating and maintenance practices for owners or operators of PCE drycleaning machines and emission control devices. The Office of Pollution Prevention and Toxics (OPPT) has supplemented the 1994

OAQPS recommendations, primarily based on some more recent information. These recommendations serve only as a last resort when manufacturers' information is not available. They should never supersede available manufacturers' information.

This section includes various practices and improvements that may help drycleaners reduce releases, exposures, and usage of PCE or HC solvents. This section primarily provides recommendations on the operation and maintenance of PCE drycleaning equipment but also contains suggestions for HC drycleaning equipment. In 1992, the International Fabricare Institute (IFI) published an "Industry Focus" (IFI, 1992) documenting general information on the operation and maintenance of petroleum drycleaning equipment. For drycleaners using HC equipment, this IFI publication is likely more informative and relevant than the information provided in this chapter of the Cleaner Technologies Substitutes Assessment (CTSA). It should also be noted that some of the changes identified in this section may not be appropriate when site-specific factors are taken into account. Emphasis is placed on the importance of operating and maintaining the drycleaning equipment according to manufacturers' specifications. Training workers on proper maintenance and operating procedures may serve to further reduce releases, exposures (including their own exposures), and usage of solvents.

Maintenance and Operation of Drycleaning Machine Components

Exhibit 9-1 provides a summary of recommended maintenance practices for drycleaning machine components when manufacturers' information is not available. These recommendations should never supersede available manufacturers' information. The remainder of this section discusses those practices in more detail. Exhibit 8-3, "Summary of PCE NESHAP Compliance Requirements for Drycleaners," identifies the items required by the NESHAP and references other USEPA documents that contain details for complying with NESHAP requirements.

Dry-to-Dry Machine Cylinder

Although dry-to-dry machines wash and dry garments in one cylinder, PCE emissions can come from many sources, which include the cylinder, a leaking door gasket or other gaskets, and the unloading of garments that have not been adequately dried (reclaimed). Drycleaning operators should detect and repair liquid and vapor PCE leaks during a weekly inspection program. If a liquid leak is detected, the operator should replace the seal immediately because significant PCE loss can occur. Vapor leaks can sometimes be detected by running a finger along the entire perimeter of the door seal while the machine is operating or by placing a liquid bubble solution around the door seating and looking for bubbles. An electronic halogen leak detector is capable of locating vapor leaks that other methods might miss.

Vented dry-to-dry machines and dryers with add-on refrigerated condensers or carbon adsorbers have exhaust dampers to control the flow of hot air. Because the exhaust damper can be a major source of PCE losses, operators should check it monthly to ensure that it is functioning properly. Even though the exhaust damper is usually difficult to access, every effort must be made to check and repair it. Operators may check for leaks by placing and sealing a collapsed, inflatable plastic bag over the ductwork used to vent the dry-to-dry machine. Operators should ensure that the bag is placed at a point downstream from the direction of flow past the exhaust damper. If the exhaust vent outlet cannot be used, operators may need to make some minor modifications to the ductwork, such as drilling a small test hole, which can be

Exhibit 9-1. Maintenance Schedule for Drycleaning Equipment

Component	Frequency	Maintenance Procedure
Machine Component		
Dry-to-dry machine cylinder	Weekly Monthly	Check door seatings and gaskets for leaks. Check exhaust damper (vented machines) for leaks.
Transfer washer/extractor cylinder	Weekly	Check door seatings and gaskets for leaks.
Transfer dryer (reclaimer)	Weekly Monthly	Check door seatings and gaskets for leaks. Check exhaust damper for leaks.
Heating and condensing coils	Monthly Annually	Check for lint build-up. Clean coils.
Button trap	Daily Weekly	Clean strainer. Check lid for leaks.
Fans	Annually	Inspect and lubricate.
Lint trap	Daily Weekly	Clean lint bag, check lint build-up on temperature probe, and check ductwork for lint build-up. Dryclean or launder lint bag.
Auxiliary Equipment		
Filters	[a]	Clean and change filters (filters drained and muck stored in sealed containers).
Distillation unit	Bi-weekly Monthly Semi-annually	Check seals and gaskets for leaks. Check steam and condensation coils. Clean steam and condensation coils.
Muck cooker	Monthly Semi-annually Annually	Check steam and condensation coils. Clean steam and condensation coils. Lubricate motor and gear box.
Water separator	Weekly Monthly	Clean separator tank. Check vent.
Pumps	[a]	Check for vapor and liquid leaks.
Tanks	[a]	Check for vapor and liquid leaks.
Control Device		
External refrigerated condenser	Daily Weekly Weekly Monthly Annually	Clean any lint filters in air stream. Measure temperature on exhaust for dry-to-dry machines/transfer dryer reclaimer. Measure temperature on inlet and exhaust for transfer washer. Check seals, gaskets, and diverter valve for leaks. Check refrigerant coils for lint build-up. Clean refrigerant coils.
Carbon adsorber	Daily or before saturation Weekly	Desorb. Measure concentration of PCE in exhaust air stream or in machine drum, clean all lint filters, and check gaskets and ductwork.

Source: USEPA, 1994b.

[a] Maintain according to manufacturer or media supplier's specifications or recommendations.

resealed with a leak proof plug or tape. New ductwork or a manual damper can also be added for the testing. Operators should place and seal the plastic bag over the test hole during the beginning portion of the drying cycle. At that point, the vent to the control device should not be in use, but should be shut off with the exhaust damper. Operators should check to see if the plastic bag (placed over the exhaust outlet vent or test hole) inflates. If it inflates, then there is a leak and the exhaust damper will need to be repaired. It is also common for these dampers to stick in a position that does not allow them to close all the way, and thus they leak. As a result, it is very important to check the operation of the damper and its closed position very closely to ensure that the damper swings freely and closes completely when not in use. Dampers are also known to wear and will need parts repaired so that they will seal properly again.

Transfer Washer/Extractor Cylinder

Potential emissions from the washer cylinder result from leaking door gaskets. Operators should detect and repair liquid PCE leaks from door seatings and gaskets during a weekly inspection program. Operators should check for these leaks in the same manner as discussed above for leaks from the dry-to-dry machine cylinder.

Transfer Dryer (Reclaimer)

As with the washer cylinder, one source of potential PCE emissions from a dryer, or reclaimer, is through the door. Operators should check for leaking door gaskets in the same manner as discussed above for leaks from the dry-to-dry machine cylinder. Operators should not open the door before the end of the drying cycle. When the machine door is open, operators should vent the dryer air to a carbon bed. If the carbon bed is small (approximately 1- to 2-pound carbon capacity), the carbon should be changed or desorbed daily to ensure its effectiveness (NIOSH, 1997). Another main source of potential PCE emissions from dryers is through intake and exhaust dampers on exhaust systems. The machine damper gaskets should be checked monthly to ensure proper operation. It is quite common for these dampers to stick in a partially open position. As a result, it is very important to check the operation of the damper and its closed position very closely to ensure that the damper swings freely and closes completely when not in use.

Heating and Condensing Coils

Operators should check heating and condensing coils of dryers for lint build-up every month and thoroughly clean them on an annual basis. Operators should place special emphasis on the fins surrounding the heating and condensing coils. Only heating and condensing coils on older tilt back dryers for transfer systems need daily cleaning.

As mentioned above, operators should clean the coils annually at a minimum. However, if the coils are covered with lint that is difficult to remove when cleaned annually, operators should clean the coils on a semi-annual basis. Heating coils can be cleaned by blowing compressed air or steam over the coils. Condensing coils can be cleaned by brushing the coils with a stiff brush to loosen lint, then picking up the residue with an industrial vacuum.

Button Trap

The button trap lid and strainer need regular servicing. Operators should open button traps only long enough for cleaning. Operators should clean the strainer daily and check the lid for a vapor leak proof seal during the weekly leak inspection program. Operators should replace the door gasket on the button trap when needed. Operators should ensure that the lid is seated properly to prevent vapor loss and allow for proper operation of the pump (IFI, 1994).

Fans

Operators need to inspect and lubricate fans annually to ensure that they are functioning properly. According to the International Fabricare Institute (IFI, 1994), to properly control emissions the local fans for PCE drycleaning machines should be capable of maintaining a 300 to 500 cubic feet per minute air velocity.

Lint Trap

The lint trap located in the air flow system usually contains a removable lint bag or filter. Operators should clean this bag or filter daily and wash or dryclean it weekly. Operators should open lint baskets only long enough for cleaning. Operators should never run a dry-to-dry machine or dryer without a lint bag or filter and should use a second lint bag or filter while the first is being cleaned. Once a day, operators should check the ductwork in front of and behind the lint bag or filter for lint build-up. Also, operators should also make a daily check for lint build-up on machines with heat sensor probes located under or behind the lint bag or filter.

Maintenance and Operation of Auxiliary Drycleaning Equipment

In addition to the components of drycleaning machine systems, all drycleaning facilities use auxiliary equipment in the drycleaning process. This equipment is also covered by the NESHAP and includes filters, distillation units, muck cookers, and water separators. Spotting and pressing activities are not covered under the NESHAP or the CTSA; therefore, the equipment used for these activities is not discussed. Exhibit 9-1 provides a summary of recommended maintenance practices for drycleaning machine auxiliary equipment when manufacturers' information is not available. These recommendations should never supersede available manufacturers' information. The remainder of this section discusses those practices in more detail. Exhibit 8-3, "Summary of PCE NESHAP Compliance Requirements for Drycleaners," identifies the items required by the NESHAP. Section 8.1.1 summarizes the NESHAP and references other USEPA documents that contain details for complying with NESHAP requirements.

Filters

Filters are used to remove suspended particles and dyes from PCE. Several types of filters are currently used at drycleaning facilities, including spin disk (powder and powderless), constant pressure powder, regenerative powder, and cartridge filter systems. Most drycleaning facilities currently use some type of cartridge or disk filter system. Proper maintenance includes solvent recovery from filter media and muck.

Spin Disk Filters

Using spin disk filters instead of cartridge filters may lower PCE releases and increase solvent mileage (CEPA, 1993). Spin disk filters allow the operator to backwash filtered material directly into the still, which results in lower worker exposure to PCE vapors than changing cartridge filters. Spin disk filters are manufactured either to use filter powder or to be powderless. A motor drives a shaft, which spins the disks. The spin disk filters often contain 36 double-walled disks with 15-inch diameters. The disks are made of a polyester fine-mesh material and are mounted on a center support. Solvent enters the filter housing through the center mounting and flows through both walls of the disks and out through perforations on the shaft.

Soils and filter powder (if used) collect on the disks, which are stationary during filtration. Spin disk filters have a pressure gauge to measure the pressure drop across the filter. Once the pressure reaches 22 pounds per square inch (psi), the filter needs to be regenerated (NIOSH, 1997). Regeneration of the filter involves spinning the disks to wash off the soil and powder (CEPA, 1993). A drain valve opens, and the solvent, soil, and sludge flow into the still. The operator then precoats the filter with powder (if used) after each regeneration of the filter. To ensure proper performance of the PCE solvent, a powderless spin filter system may require finishing or polishing to catch and trap residual dyes.

Constant Pressure Filters

Constant pressure filters are only used in powder filtration systems. The pump must run continually to keep the powder adhered to the filter. The type of constant pressure filters presently in use uses a rigid tube. Rigid tube filters need at least 4.5 pounds of powder per 1,000 gallons per hour rated flow, or 30 square feet of filtering area, for a good precoat.

The diatomite filter powder is lightweight, organic, and composed of fossil shells. The powder forms clusters, which remain porous and allow PCE to flow through while trapping soil particles. Operators should clean off the powder built up on the tube and reapply fresh powder to the tube when the PCE flow rate decreases to 1 gallon per minute for each pound of rated load capacity that enters the wheel. The rate of build-up will vary depending on the amount of clothing cleaned, the size of the filter, and the size of the pump.

Excessive filter pressure is a common problem. The causes of excessive pressure include the accumulation of muck in the filter to a point above the manifold, which reduces the filtering area; PCE in poor condition; and nonvolatile residue, which causes slime to deposit on the filter plate if the filter is drained and not refilled. Damp filter powder and improper or insufficient precoating can also cause excessive pressure.

Operators should store all powder in a dry place to keep it from absorbing moisture. Operators should determine the correct amount of filtering powder for the filter according to the filtering area. For example, operators should use 1.5 pounds of powder per 10 square feet of filtering area for precoat and should use at least 0.5 pound per 100 pounds of clothes to maintain the filter coating. Some common causes for loss of precoat are back pressure, air in the filters, and obstructions or air leaks in the inlet line to the pump that result in uneven settling of the filter powder. Slipping pump belts or badly worn tubes could also cause a loss of precoat.

Regenerative Filters

Regenerative filters are one of the most widely used powder filters. They consist of flexible tubes that are constructed of braided metal wire, metal helical springs, or braided knit fibers. Unlike constant pressure filters, regenerative filters do not require body feed, since the precoat is bumped off after each load and is reapplied to the tube before the next load. Since no body feed is needed, operators should use 2.5 pounds of powder per 10 square feet of area to precoat regenerative filters.

The chief advantage of regenerative filters is that they do not require as much filter area as constant pressure filters. A 100-pound washer using a regenerative filter requires only 60 square feet, compared to 150 square feet for a constant pressure filter.

The braided wire tubes in regenerative filters can become crimped during the bumping operation, leaving holes in the tubes that result in leakage. Damaged tubes also allow powder and carbon to pass through the filter and muddy the PCE. Operators should correct this by repairing or replacing damaged tubes. If carbon or powder appears in the load, or the filter is not working well, operators should inspect the filter for holes and replace it if necessary.

Tubes can also become clogged. There must not be any interruption of PCE flow after precoating and while PCE is flowing into the washer. Operators should ensure that the tubes are seated properly. Backwashing may eliminate the clogging. If this is not successful, operators should remove the tubes and clean them with trisodium phosphate.

Cartridge Filters

Cartridge filters require less maintenance than regenerative or constant pressure filters because neither precoating nor body feed is necessary. The filters come in a range of sizes and use various filtering media. Because cartridges are changed routinely, manufacturers’ information for cartridges is always readily available and should always be used. Operators should determine and maintain the ideal amount of clothing cleaned for each filter cartridge before stripping. To dispose of the carbon filters, operators should drain used filters for 24 hours and should steam strip drained filters at a proper steam pressure in a still, if available. There are two types of commonly used cartridges:

- *Standard Cartridges.* Standard cartridges are 7¾ inches in diameter and 14¼ inches high and use various filtering media. Carbon-core cartridges remove both insoluble soil and color from PCE. They have a normal life span of approximately 1,000 pounds per cartridge, depending on the type of work being processed and the amount of soil, moisture, and lint it contains. All-carbon cartridges primarily remove color.

- *Adsorptive Cartridges.* Adsorptive cartridges are 13½ inches in diameter and 18 inches high and contain more activated clay and carbon than standard cartridges. Half-sized cartridges, or “splits,” which are 9 inches high, are also available and are easier to handle. Adsorptive cartridges are designed to remove insoluble soil and non-volatile residue along with the color. Most full-sized adsorptive cartridges are built to process 2,000 pounds before being replaced. Half-sized cartridges are made to process 1,000 pounds before being replaced. Operators should not exceed the poundage recommendations on the cartridges.

Operators should determine when to change cartridges either by the number of pounds cleaned or by a measurement pressure increase according to the manufacturers' instructions. Operators should change cartridges at a specific pressure, or at a pressure increase over the original, according to instructions and should never let the pressure exceed 40 psi. The ability to remove nonvolatile residue may be exhausted before a pressure rise indicates that the cartridge's capacity for insoluble soil has been reached. Exceeding this pressure may force soil through the filter and rupture it. If PCE starts to become too dark or streaks and swales appear, operators should change cartridges or increase the distillation rate.

Operators should ensure that gaskets or felt washers used between the cartridges are seated properly. Gaskets that are damaged or used too long can allow soil to leak out. Some all-carbon cartridges take a different size gasket than other cartridges made by the same manufacturer. Operators should read the manufacturers' instructions carefully and replace gaskets frequently.

Excess moisture or poorly dispersed moisture in the filter will cause a rapid increase in pressure. The same result may occur when some water repellents or fabric finishes are removed from fabric by the PCE and carried over into the filter.

Operators should inspect new cartridges for physical damage before installing them. Also, a new set of cartridges will often leak insoluble soil and carbon until several loads have been cleaned. Operators should run only dark loads until this leakage stops.

Distillation Unit

The purpose of a distillation unit is to purify and recover used PCE to recycle it back into the drycleaning system. Distillation units typically consist of steam and condensation coils. Water and PCE retrieved from the distillation process are channeled to a water separator. Potential PCE loss from these units can be due to leaks in seals and gaskets, build-up of still bottoms on the heating coil, and improper water or steam temperatures.

Seals and gaskets in the distillation unit should be checked for leaks and repaired at least every 2 weeks. The steam and condensation coils for the distillation unit should be checked monthly and cleaned semi-annually to avoid lint build-up. They may be cleaned in the same way as the coils used in the drycleaning machine. Some stills do not require coil removal for cleaning.

The following practices are recommended to achieve optimum still performance and minimize PCE in the still residue:

- Operators should never exceed 75% of the still kettle capacity, or the level recommended by the manufacturer.
- Operators should set up condenser water flow countercurrent to PCE flow.

- Operators should keep the PCE return temperature at a maximum of 32°C (90°F) to minimize evaporative loss through the PCE storage tanks.
- Operators may redistill still bottoms used solvent at a rate of 6 to 8 gallons per 100 pounds of clothes cleaned (IFI, 1994).
- Operators may redistill still bottoms with more water following boil down to recover more solvent. However, this may create more hazardous wastewater and maintenance problems (USEPA, 1997).

Muck Cooker

Older drycleaning systems with tubular powder filtration systems (constant pressure and regenerative) use muck cookers to distill the residue from these systems. Maintenance procedures for muck cookers are the same as for distillation units, except that annual or more frequent lubrication of the motor and gear box is needed.

Water Separator and Water Evaporator

Water separators separate water and PCE from the PCE-water mixture that comes from various condensates, including carbon desorption, distillation, machine condenser, and pressing. To function properly, water separators must be vented to the atmosphere. The vent can become clogged and should be checked each month. The maintenance schedule for water separators should also include vapor and liquid leak detection procedures. In addition, operators should clean the separator tank weekly. It should be noted that separator water usually contains minor amounts of PCE. Operators should treat separator water as a hazardous waste and should not pour it down a drain or flush it down a toilet.

A proper way to control PCE from separator water is through double-activated carbon treatment of separator water and evaporation (provided the separator water does not contain a layer of separated PCE). Operators should send the spent carbon cartridges and other hazardous wastes to a USEPA-licensed hazardous waste hauler. Vapor from the evaporator contains PCE and should be vented outside the facility. Venting this vapor inside the facility may increase PCE concentrations in the facility and may increase workers' exposure to PCE.

Maintenance and Operation of Emission Control Devices

USEPA's NESHAP for PCE drycleaning was intended to reduce emissions primarily by introducing requirements for emission control devices. Under the NESHAP, drycleaning machines installed before December 9, 1991, are considered "existing" machines, while machines installed on or after December 9, 1991, are considered "new" machines (USEPA, 1994a). All "new" drycleaning machines must be equipped with at least a refrigerated condenser used as a PCE vapor recovery system.

"Large"[1] drycleaners with "existing" drycleaning machines must be equipped with a refrigerated condenser (or a carbon adsorber if it was in place before September 22, 1993). "Small"[2] drycleaners do not need to install PCE vapor recovery systems on "existing" machines. In addition, existing major source drycleaning facilities must keep their transfer machine systems inside a room enclosure, and new major source drycleaning facilities must install both a refrigerated condenser and a secondary carbon adsorber.

Exhibit 9-1 provides a summary of recommended maintenance practices for refrigerated condensers and carbon adsorbers. These recommendations should never supersede available manufacturers' information. The remainder of this section discusses those practices in more detail.

Refrigerated Condensers

Drycleaning operators should route the refrigerated condenser's one-pass outlet ducts to exhaust outside the plant. The ducting is recommended in the rare configurations where the refrigerated condenser exhausts to the atmosphere. The NESHAP requires temperature monitoring and checking of all gaskets and seals during a weekly leak detection and repair program. Operators should clean all lint filters in the ductwork associated with refrigerated condensers on a daily basis.

Carbon Adsorbers

Operators should route carbon adsorber (CA) one-pass outlet ducts to exhaust outside the plant. The exhaust stack should be monitored during the exhaust process with a detector tube, an ionization detector, or an equivalent sensor (NIOSH, 1997). Integral CAs in fourth and fifth generation machines (see Chapter 2 for equipment details) are not included since these CAs do not exhaust to the atmosphere. It is also recommended that operators determine the maximum quantity of PCE that the CA can hold. The CA must be desorbed (i.e., steam stripped) daily, unless the daily return of PCE from the CA is less than 50% of that capacity. One way to determine the maximum capacity a CA can hold is to check the CA exhaust with a colorimetric detector tube. Once the exhaust reads over 100 ppm (parts per million) of PCE, the CA is considered saturated. Operators should then completely desorb the saturated CA by steam desorption for 1 hour. The amount of PCE returned from this desorption will be the maximum quantity of PCE that the CA can hold.

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[1] "Large" drycleaners are defined as facilities (1) with transfer machines only and that purchase 200 or more gallons of PCE per year; (2) with dry-to-dry machines only and that purchase 140 or more gallons of PCE per year; or (3) with a combination of dry-to-dry and transfer machines and that purchase 140 or more gallons of PCE per year.

[2] "Small" drycleaners are defined as facilities (1) with transfer machines only and that purchase less than 200 gallons of PCE per year; (2) with dry-to-dry machines only and that purchase less than 140 gallons of PCE per year; or (3) with a combination of dry-to-dry and transfer machines and that purchase less than 140 gallons of PCE per year.

Operator maintenance is crucial with carbon adsorption. The NESHAP recommends the following operating and maintenance practices:

- Operators should clean the lint screen regularly.
- Operators should check for leaks in the damper that restricts steam from entering the adsorber.
- Operators should determine and maintain the maximum or ideal ratio of clothes cleaned per activated carbon used (USEPA, 1997).
- Operators should determine and maintain ideal stream pressure passed through the bed to strip solvents from the carbon beds (USEPA, 1997).
- Operators should restrict desorption to a maximum of 60 minutes, whether or not PCE is still returning. It is extremely important to dry out the adsorber for at least 15 minutes after desorbing.
- If, after an undetermined period, the carbon bed becomes contaminated, then operators should try an extended, all day steam stripping at the highest possible steam pressure. If that does not burn off the contamination, the carbon bed may have to be replaced.
- Operators should determine how often to desorb and maintain that schedule. An adsorber's capacity is determined by the pounds of carbon it contains. Typical adsorber capacities are 2 gallons, 4 gallons, or 6 gallons.
- To establish a desorption schedule, operators should begin by desorbing every day. If the capacity is 4 gallons and every day produces less than 2 gallons but at least 0.5 gallon, operators should strip every second day. If the stripout produces more than 2 gallons, operators should strip every day. If the stripout produces 4 gallons every day, operators must strip twice daily, or preferably, determine why so much PCE is getting to the adsorber and remedy the problem. If the stripout produces no more than 1 gallon daily, operators should strip the carbon adsorber every third day.

In addition to the monitoring requirements of the NESHAP, operators should clean all lint filters and screens associated with carbon adsorbers on a weekly basis. Operators should include all gaskets and ductwork associated with the carbon adsorber in a weekly detection and repair program.

Operators should always maintain the proper air filter type specified by the manufacturer. Some older "lint filters" (e.g., furnace filters) may be improper. Improper filters can allow fine particles to slowly clog the pores of the activated carbon. This clogging reduces the ability of the carbon to adsorb PCE.

A CA's maximum holding capacity can diminish substantially over time depending on how heavily the carbon is used. Operators can use a cumulative flow meter to monitor the solvent recovery process. It is recommended that operators consider replacing or reactivating the activated carbon every 5 years, or more or less frequently depending on how heavily the adsorber is used.

Facility Design and General Operating Procedures

Additional practices to improve environmental performance involve the design of exhaust and ventilation systems and proper operating procedures. This section discusses those issues in more detail. Recommendations in this section should never supersede available manufacturers' information for the systems discussed.

Exhaust Systems

Proper design and maintenance of exhaust systems is essential for controlling emissions. Local exhaust systems consist of an exhaust fan, ductwork, and a hood. Local exhaust systems are designed to collect contaminants at the source to prevent their escape into the work environment, thus reducing PCE exposure (NIOSH, 1997). Operators should use elevated hoods between the washer and dryer for transfer operations rather than less effective floor ducts to collect vapors into local exhaust systems. Operators should avoid abrupt changes in duct size in local exhaust systems. Operators can also install permanent pressure gauges on local exhaust systems to allow identification of system performance changes. Operators should practice regular maintenance procedures and promptly repair holes in air and exhaust ducts upon detection. Operators should use exhaust ventilation through doors of washers and dryers.

The National Fire Protection Association (NFPA) guidelines recommend that drycleaning machines have an integral exhaust system and a door face velocity of at least 100 feet per minute (NIOSH, 1997). This face velocity provides a draft of clean air over the items removed from the machine, thus reducing solvent vapors escaping into the shop. Also, the Michigan Department of Public Health Rules state that the blower must be ducted to a point 5 feet above the roof. This prevents vapors from re-entering the work environment. Another option is to place a ventilation hood outside the machine door and maintain an airflow capacity in cubic feet per minute, not less than 100 times the door opening area in square feet (NIOSH, 1997).

Ventilation Systems

Proper design and maintenance of ventilation systems is also essential for controlling emissions. Local ventilation involves removing the contaminant at or near the source to prevent emissions from reaching the breathing zone or diffusing through the plants (NIOSH, 1997). Subsequently, general ventilation involves diluting the concentration of the contaminant before it reaches the worker's breathing zone. Drycleaning systems should pull air from other areas into the drycleaning area to avoid solvent dispersion into peripheral plant areas (i.e., operators should keep the drycleaning and pressing rooms under negative pressure). Operators should design ventilation systems in temperate climate areas for winter conditions when natural ventilation is at a minimum. Also, operators should adequately ventilate areas where garments are hung after removal from the dryer. According to NFPA codes and Michigan Department of Public Health Rules, there should be an air change in the workroom every 5 minutes to decrease background PCE concentrations (NIOSH, 1997).

Liquid Leakage and Vapor Control

To find liquid leakage, operators should look for the brown residue of PCE-soluble nonvolatile compounds on the underside of fittings. This can be a sign of leakage in pipe fittings, welds, elastomers, and plastic hose connections. Loose pipe connections are generally caused by wear, normal expansion and contraction created by temperature, and vibration of equipment. Operators should check connections, unions, and couplings as soon as they start to leak. When required, operators should replace the packing on the valves.

PCE loss from pipe fittings can be considerable. For example, PCE dripping at the rate of one drop per second means that a gallon of PCE is lost in an 8-hour work day. Routine checkups with a portable halogenated hydrocarbon leak detector around the pumps, seals, flanges, door openings, and other components of the machine can detect vapor losses before they become leaks (CEPA, 1993).

The proper storage and use of chemicals can also prevent liquid leaks. Operators should properly label all chemicals and should not store chemicals in extreme heat or cold, which may diminish the chemicals' shelf-life or make them unusable (USEPA, 1997). New solvent, saturated lint from lint baskets, dirty filters or filter powder, and recovered solvent from condensers, adsorbers, and water separators should all be collected and stored in closed containers (NIOSH, 1997). Operators should provide secondary containment around storage areas and should keep dip tanks for water repellent covered, even during the drainage of clothing (USEPA, 1997). Operators should drain filter cartridges in a closed container or consider drying filters in housings vented to carbon adsorbers. Operators should not allow hazardous materials to mix with non-hazardous materials, as this will result in all of the waste requiring hazardous waste treatment. Finally, it is important to inspect all chemical and waste storage containers for leaks.

Transfer Operations

To prevent PCE releases and exposure during transfer operations, the washer and dryer should be near each other in PCE systems (NIOSH, 1997). HC transfer machines, however, should be separated to reduce the fire hazard. Operators should transfer clothing from washer to dryer quickly after drainage and close machine doors immediately after loading and unloading. Enclosed, automated transfer from washer to dryer may be an additional prevention measure.

Exhibit 8-3, "Summary of PCE NESHAP Compliance Requirements for Drycleaners," includes requirements for certain transfer operations. In some cases, operators may implement these requirements using room enclosures. Room enclosures without adequate ventilation may contain high PCE concentrations. Therefore, operators must ensure that PCE concentrations in room enclosures do not exceed regulatory limits such as the OSHA PELs. Operators should design room enclosures to avoid increasing their workers' exposures to PCE.

Cooling Water or Drying Temperature

If the temperature of the cooling water or refrigerant is not kept low enough, the condenser coils cannot cool the air stream enough, and less PCE condenses out of the stream. When the air is recycled to the dryer, it cannot pick up as much PCE, and drying takes longer. One indication of this problem is if clothes have a PCE odor after the end of the typical drying cycle. In summer months in warmer climates, this can be a problem at drycleaning facilities using water-cooled condenser coils and water cooling towers. The water-cooled condenser temperature should be no higher than 90°F (NIOSH, 1997). Some potential solutions are to increase drying time, use a water chiller, or use a city water supply. The exhaust air stream from a refrigerated condenser must not be above 45°F (USEPA, 1994a).

Drying temperature is important for the same reasons as proper cooling temperature. If the temperature is not hot enough, clothes will not be dry when the cycle is completed. The operator should maintain adequate steam pressure to keep the drying temperature between 135°F and 145°F for a regular cycle and about 120°F for a fragile load (IFI, 1994; NIOSH, 1997).

Drying Time

The drying cycle should be long enough to ensure that garments are completely dry when they are finished. The operator should not open the machine door until the drying cycle is complete. In addition, the proper cycle length may vary according to the amount of air flow through the machine. To ensure the maximum amount of air flow in the machine, operators should keep the steam and condenser coils and lint bags clean.

Loading of Machine

To ensure that clothes are completely dry and that machines recover the maximum amount of PCE, it is recommended that machines be under-loaded by at least 5 pounds, but not by more than 25% of the machine's capacity. Otherwise, the normal PCE losses that occur when running the machine will outweigh the PCE savings gained by slight under-loading.

When feasible, operators should clean clothes of similar types together. If mixtures of fabric types are cleaned, some clothes removed from the machine may not be dry or may be damaged by excess drying (USEPA, 1997).

Handling of Other Wastes

Waste reduction applies to all wastes generated, not just hazardous waste. Operators should try to replace disposable items with reusable ones (USEPA, 1997). For example, operators should ask suppliers to provide solvents in returnable containers. Operators should recycle materials such as plastics, glass, cardboard, and paper and should encourage customers to use reusable garment bags or to return unused hangers (Department of Natural Resources and Environmental Control, 1998). Operators should maintain a consistent waste reduction policy and should try to identify other possibilities. A successful waste reduction program continually searches for additional ways to eliminate wastes.

9.1.2 Impact of Facility Conditions and Remedial Actions on PCE Concentrations in Co-located Residences

There is empirical evidence to demonstrate that remedial actions and proper maintenance can lower PCE emissions in co-located residences. However, results of such studies vary because successful remediation must encompass all PCE transmission pathways.

Overall facility conditions affect PCE concentrations in co-located residences in many ways (BAAQMD, 1993; MHS, 1993; NYSDOH, 1993a, 1994). It is important for drycleaning owners and operators to understand the prospective benefits of proper maintenance procedures, remedial actions, and state-of-the-art equipment. USEPA has reviewed the available information and has drawn the following conclusions:

- Buying a state-of-the-art machine will not eliminate PCE concentrations in co-located residences, but it can reduce them, perhaps substantially (depending upon the condition of the old machine).

- Vapor barriers and room enclosures are marginally effective in reducing PCE concentrations in co-located residences, and their effectiveness increases when they enclose both the drycleaning and pressing areas.

- Proper machine maintenance is very important. For example, saturated carbon adsorbers can elevate PCE concentrations.

- Building condition is also important. Cracks and holes in the ceiling facilitate PCE transmission.

- Venting above the roof at a high velocity may substantially alleviate PCE concentrations.

- Alleviation of the problem is not guaranteed even after substantial remedial efforts, particularly if pathways of PCE transmission remain intact.

- Remedial efforts must address the whole problem if they are to succeed. For example, substantive machine modifications and the construction of vapor barriers will not compensate for holes in the ceiling.

These conclusions are based on a review of several studies conducted in the U.S. and abroad. The most informative of these studies was an in-depth look at remediation for two drycleaners in New York City (NYSDOH, 1994). For one of these drycleaners (Facility 21), three sets of remedial actions were inadequate to alleviate concentrations of PCE in a co-located residence. These remedial actions included building a room enclosure and installing a vapor barrier. Indoor air sampling in a second floor apartment showed a PCE concentration of 12.7 mg/m^3 (NYSDOH, 1994).

The above-mentioned remediations to Facility 21 did not include repairing large holes in the ceiling above the pressing area. These holes provided an ideal route of PCE transmission from the facility on the ground floor to the apartments on the second floor (NYSDOH, 1994). This highlights the importance of addressing all PCE transmission pathways before undertaking remedial efforts. To be successful, remediations in co-located facilities must include operator training, improved machine maintenance, repairs to the building, and blockage of other obvious routes of PCE transmission such as venting to a courtyard. Again, successful remediation requires more than upgrading machines and building vapor barriers.

For the other drycleaner (Facility 41), a facility with apartments next door, remediation resulted in improvements but did not eliminate PCE concentrations. As part of the remediation efforts, the owner of the drycleaner facility built a room enclosure around the machines, installed a vapor barrier, improved ventilation, tried to reduce the available pathways of PCE transmission through the building, and improved the PCE reclamation process. However, PCE concentrations ranged from ambient levels (0.026 mg/m^3) to nearly 5 mg/m^3 after these remedial efforts (NYSDOH, 1994).

New York State officials have performed and supervised remedial efforts on a number of other drycleaners, mainly to reduce PCE concentrations in the facility itself. The results show that reductions in PCE concentrations inside the facility do not necessarily lead to the elimination of PCE concentrations in the co-located residence (NYSDOH, 1993b).

In San Francisco, PCE concentrations were measured above facilities with state-of-the-art equipment and controls. PCE concentrations measured by the Bay Area Air Quality Management District (BAAQMD) above four non-vented dry-to-dry machines with refrigerated condensers ranged from 0.002 to 0.67 mg/m^3. These concentrations are lower than most of the reported samples taken in New York (BAAQMD, 1993). The BAAQMD's recommendation is that a "combination of state-of-the-art equipment, good diffusion proofing (barriers/taping), and high ventilation rate (10,000 cubic feet per minute) may be the optimal solution for preventing exposure of PCE to people residing above drycleaning facilities" (BAAQMD, 1993).

The effects of remediation have also been examined in Amsterdam, the Netherlands, as part of a study of PCE concentrations in co-located residences. Here again, the results indicate that remedial actions do not necessarily remove the concern. PCE concentrations were relatively high after remedial actions took place (MHS, 1993).

Machine type also affects PCE concentrations in co-located residences. A study of PCE concentrations above three transfer machines, two well-functioning dry-to-dry machines, and one dry-to-dry machine in poor condition was performed in Capital District, New York. The results showed that PCE concentrations above the transfer machines were higher than concentrations above the two well-functioning dry-to-dry machines. The maximum PCE concentration at the pressing station was found to correlate well with the measured concentrations in co-located residences. However, no correlation was found with the residential concentrations and the type of ceiling and location of exhaust vents (NYSDOH, 1993a).

Other New York State data collected in response to residential complaints show that PCE concentrations above non-vented dry-to-dry machines are significantly lower than concentrations above vented dry-to-dry and transfer machines.

9.2 MACHINE WETCLEANING FACILITIES

Information on best management practices and environmental and exposure control options for this technology is very limited. Several of the following may be considered but should not supersede available manufacturers' information:

- Automated addition of water and chemicals to washing machines, particularly decreasing the amount of human error due to spillage or addition of excessive detergent amounts.

- Good housekeeping practices, such as keeping detergent storage containers tightly closed to reduce chance of spillage.

- Recycling/recovery of rinse water/steam condensate.

9.3 TRADE ASSOCIATION CONTACTS FOR FURTHER INFORMATION

This section provides a summary of the major clothes cleaning trade and research associations, their contact numbers, and their initiatives and publications involving environmental improvement practices. This listing does not constitute endorsement of these institutions, their initiatives, and publications, nor is the listing intended to be a complete listing of sources that may have beneficial information. Rather, this list is intended as a source of some information that may prove useful to drycleaners and others interested in drycleaning issues.

Neighborhood Cleaners Association International (NCAI)
252 West 29th Street
New York, NY 10001-5201
Tel: (212) 967-3002

NCAI initiatives and publications include a training manual and a publication entitled "Keep It Clean: Guidelines To Reduce or Eliminate PCE Releases to Air, Soil, and Water." These offer useful maintenance and operation guidelines. NCAI also offers a self-test on the Internet that covers such topics as hazardous waste laws; laws on discharges to ground (soil), air, and water; Occupational Safety and Health laws; general requirements; tanks; and the federal NESHAP.

Federation of Korean Drycleaners Association (FKDA)
25606 Alicia Parkway
Lagona Hills, CA 92653
Tel: (714) 770-8613

FKDA provides educational opportunities through newsletters as well as educational seminars on subjects such as pollution prevention and other critical issues. State FKDA chapters may provide additional resources to their members.

International Fabricare Institute (IFI)
12251 Tech Road
Silver Spring, MD 20904
Tel: (301) 622-1900

IFI initiatives and publications include a training manual that describes compliance issues, pollution prevention practices, proper waste handling procedures, waste reduction methods, and occupational safety methods. IFI also implements the Certified Environmental Drycleaner (CED) program, which promotes the environmentally improved operation of drycleaning establishments. To become a CED, a drycleaner must pass a standard examination that tests drycleaners on various environmental topics, including environmental regulations, proper waste handling, occupational safety and health, safe operation of drycleaning equipment, and other federal regulatory requirements. IFI also offers a self-study drycleaning course that focuses on drycleaning and the environment. This course includes USEPA regulations, OSHA regulations, recent federal regulations, state regulations, and operating practices and procedures. IFI also published an article that focuses on maintenance guidelines and offers a checklist for minimizing pollution:

International Fabricare Institute. 1993. Pollution prevention in the drycleaning industry. Industry Focus. No. 5. November.

Hohenstein Institutes (Forschungsinstitut Hohenstein)
Boenningheim, Germany
Tel: 011-49-7143-2710
Fax: 011-49-7143-2717

The Hohenstein Institutes are an independent, internationally recognized research and service center. The Hohenstein Institutes have published research reports that focus on fugitive emission control technologies, analytical measurements, and the effectiveness of diffusional barriers in 114 German drycleaning plants. Relevant reports include:

1. Hohenstein Institutes. 1991. The feasibility of lowering solvent vapor load in the vicinity of drycleaning machines. Research sponsored by the German Environmental Protection Agency. September.

2. Hohenstein Institutes. 1994. Reduction of solvent vapor concentration in the vicinity of drycleaning plants. Research sponsored by the six German State Agencies. November.

Additional information can be retrieved from the Hohenstein Institutes' Web site at <http://www.hohenstein.de/englisch/kurzcon1.htm>.

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CHAPTER 10
TRADE-OFF ISSUES

CHAPTER CONTENTS

The Cleaner Technologies Substitutes Assessment's goal is to offer as comprehensive a picture as possible of the relevant factors associated with each of the available clothes cleaning alternatives—the possible environmental and health risks, the costs of mitigating these risks, operating costs, and the level of cleaning performance associated with each alternative. With this information, fabricare professionals can make more informed decisions regarding pollution prevention and the possible advantages and disadvantages associated with alternative approaches for reducing exposures to chemicals used in fabricare processes.

This chapter summarizes much of the information presented throughout the CTSA. Section 10.1 presents a summary of the factors influencing choices in cleaning technology or the type of equipment used within a cleaning technology category. The factors associated with each cleaning process include the following: (1) potential risks, (2) costs, (3) performance characteristics, and (4) other characteristics. Section 10.2 introduces a benefit/cost analysis as a method of assessing alternative options. This section reformulates the summary discussion in Section 10.1 by demonstrating how the factors discussed there can be assessed using a benefit/cost approach. Section 10.2 also presents an assessment of the costs and benefits of alternative cleaning options using a cost-effectiveness approach.

10.1 SUMMARY OF TRADE-OFF FACTORS

In order to implement pollution prevention and possibly reduce exposures and/or risks from the chemicals used in clothes cleaning, clothes cleaners may consider either controlling releases of chemicals from their current technology or switching to an alternative technology. Such decisions involve numerous trade-offs among costs, performance, health and environmental risks related to a particular process, and other factors. These trade-offs are summarized in the following sections.

10.1.1 Potential Health and Environmental Risks

This section summarizes the available information about the potential health, environmental, and other risks associated with the cleaning alternatives discussed in this document. It is important to acknowledge that several components are relevant to an understanding of the risks associated with the chemicals and/or processes used in clothes cleaning. These components are the hazards or effects that may be caused by chemicals and/or processes, and the exposure to those chemicals and/or processes.

Previous chapters of the CTSA on hazard, exposure, and risk describes the risk considerations associated with the covered technologies. It is clear that there is a disparity in the amount of risk-related information available on the various chemicals and processes. In addition, circumstances affecting hazards (e.g., actual detergent formulations) and exposure (e.g., machine type and operating procedures) will vary for specific operations, thus affecting actual risks. Therefore, the consideration of risk factors is best presented by highlighting the most relevant hazard and exposure components. Those populations that are most likely to be highly exposed, and therefore more likely to experience effects of the chemicals and processes, are identified as populations of concern. It is these populations for which exposure reduction is expected to be most relevant. The information on risk considerations should be reviewed with the appropriate regard to the surrounding uncertainties. It is important to understand that a lack of information does not necessarily mean that a chemical with limited information is better or worse than another.

Exhibit 10-1 summarizes the risk considerations for the clothes cleaning technologies covered in the CTSA. These considerations were primarily identified as those resulting in potential health and environmental risks, given the scenarios and assumptions of the hazard, exposure, and risk characterizations in earlier chapters. Therefore, it is likely that not every identified effect associated with a chemical or process is included. Additionally, the reader should understand that these considerations may be less important or may be heightened by the specific characteristics of individual operations.

The risk assessments for the CTSA were conducted at a “screening level” of review, using readily available information and standard analyses for completion. The risk assessments and characterizations should give a rough idea of the array of potential risks to human health and the environment associated with each of the cleaning processes, and should offer a basis for comparison. However, careful interpretation is necessary, given that the extent of uncertainties associated with the type of hazard and exposure data, and the uncertainties associated with each process, differ widely. It is important to recognize that tabular displays, while convenient for organizing information, cannot extract all the details that may be important for each individual’s decision.

Drycleaning - PCE

There is a reasonable basis to conclude that there can be a health risk of cancer and some non-cancer effects to workers from the relatively high perchloroethylene (PCE) exposures observed on average in the drycleaning industry. Cancer concerns also extend to residents living in co-location with drycleaning establishments, particularly if they live in such dwellings for several years. The risk indices calculated for this CTSA generally show upper bound excess cancer risks to be high. As expected, cancer risks appear to be higher for residents living above transfer machines due to higher levels of exposure (higher levels of solvent release), although poorly maintained dry-to-dry machines have been documented to potentially cause high exposures.

There can also be a risk of non-cancer effects from PCE to co-located residents. Adults in residences above non-vented dry-to-dry machines appear to have lower exposures. Children, infants, and the elderly, who spend most of their days within the residence, may be at slightly greater risk for both cancer and non-cancer effects due to increased exposure duration. Co-located residents are additionally at risk through a variety of PCE exposures experienced by the general public. Risks experienced by the general population, such as drinking or showering with PCE-contaminated water, would be added to the risks due to co-location.

Given the release estimates developed in the CTSA, it does not appear that there is concern for risk to aquatic species from the majority of drycleaners who send their wastewater effluents to a publicly owned treatment works (POTW).

Exhibit 10-1. Risk Considerations

Chemical Name	Human Health			Aquatic Toxicity	Other Hazardous Properties[b]
	Population	Expected Exposure Route	Effect[a]		
Perchloroethylene	Workers	Inhalation, dermal	Cancer, variety of non-cancer effects including neurotoxicity, kidney and liver damage, and reproductive toxicity.	Medium concern	None identified
	Co-located adults	Inhalation, dermal, ingestion			
	Co-located special populations	Inhalation, ingestion			
	General Population	Inhalation, ingestion			
Hydrocarbon Technologies					
Stoddard solvent (petroleum)	Workers	Inhalation, Dermal	Neurotoxicity, irritation.	High concern	flammable, ignitable
140°F solvent	Workers	Inhalation, Dermal	Assumed to be similar to Stoddard solvent.	High concern	flammable, not ignitable
DF-2000	Workers	Inhalation, Dermal	Assumed to be similar to Stoddard solvent.	High concern	flammable, not ignitable

Exhibit 10-1. Risk Considerations (Cont'd)

Machine Wetcleaning Technology - Example Detergent Component					
Surfactants					
Cellulose gum	Workers	Inhalation, dermal	No significant adverse effects in animal and human studies.	Not predicted	None identified
Cocamidopropyl betaine	Workers	Inhalation, dermal	Potential irritation.	Medium concern	None identified
Ethoxylated sorbitan monodecanoate	Workers	Inhalation, dermal	Little or no skin irritation; may enhance tumor activity of carcinogenic compounds.	Medium concern	None identified
Lauric acid diethanolamide	Workers	Inhalation, dermal	Mild eye irritation.	High concern	None identified
Methyl 2-sulfolaurate, sodium salt	Workers	Inhalation, dermal	No health data found.	Medium concern	None identified
Sodium laureth sulfate	Workers	Inhalation, dermal	Eye, skin irritation.	Medium concern	None identified
Sodium lauryl isethionate	Workers	Inhalation, dermal	Very limited health data, apparently no irritation.	Medium concern	None identified
Surfactant Aids					
Acetic acid	Workers	Inhalation, dermal	Eye injury.	Low concern	None identified
Citric acid and sodium citrate	Workers	Inhalation, dermal	Eye, skin irritation.	Medium concern	None identified
Sodium carbonate	Workers	Inhalation, dermal	Eye and skin irritation; respiratory effects.	Medium concern	None identified

[a] Absence of a specific health effect does not mean that effect may not happen where information is limited on a particular substance.

[b] Flammability based upon National Fire Protection Association ranking of 2 meaning that the chemical must be moderately heated before ignition will occur and that it readily gives off ignitable vapors. Ignitability based upon the Resource Conservation and Recovery Act whereby a chemical is considered ignitable if it is a liquid, other than an aqueous solution, containing less than 24% alcohol by volume and has a flashpoint less than 60° C.

Drycleaning - HC

A major hazard identified for the HC solvents considered in the CTSA is their potential flammability. The National Fire Protection Association (NFPA) gives them a grading of “2” for flammability, indicating that the HC solvents must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. For comparison, perchloroethylene receives a grade of “0” for flammability, which indicates that it will not burn. Data are not available to evaluate the risks of fire in drycleaning facilities due to use of these HC solvents. However, the risk of fire from their use can be considered greater than the risk of fire due to PCE-based solvents, based on the NFPA’s low flammability ranking for PCE. In addition, the varying flashpoints of the three HC solvents examined suggest that the fire potential is lessened as one employs a higher flashpoint HC solvent. Of the HC chemicals examined in the CTSA, DF-2000 generally has the highest flashpoint, followed by 140°F solvent, and Stoddard solvent.

The health risk conclusions for the HC solvents in the CTSA are based on findings for Stoddard solvent; however, there are no data suitable for drawing conclusions concerning carcinogenic potential. Worker exposures to HC solvents, especially the high-end exposures, are indicative of a concern for non-cancer risk for workers. No data were available on exposures of co-located residents, and therefore, no risk estimates were made. Based on expected releases, there is a low risk of toxicity to aquatic species from the HC solvents.

Machine Wetcleaning

There may be a risk to aquatic organisms from some of the constituents of the machine wetcleaning formulations, dependent on the local stream flow and water treatment conditions. There is no expected health risk to the general public based on low expected exposures to detergents; however, there could be a possible risk to workers of eye and skin irritation from wet process formulations, based upon findings associated with the example detergents.

10.1.2 Federal Regulatory Environment

Professional clothes cleaners are subject to the requirements of many federal air, water, waste management, and occupational health and safety regulations, including the Clean Air Act (CAA); the Clean Water Act (CWA); the Safe Drinking Water Act - Underground Injection Control Regulations (SDWA-UIC); the Resource Conservation and Recovery Act (RCRA); the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); the Occupational Safety and Health Act (OSH); and the Federal Trade Commission’s Care Labeling Rule. In addition, cities and municipalities have enacted numerous zoning restrictions that may affect all types of fabricare operations. Many localities have adopted some, or all, of the National Fire Protection Association’s standards for drycleaning equipment and operations (NFPA-32). These regulations and requirements can affect the choice of cleaning technology by restricting the use of or adding requirements to the use of certain processes. These restrictions and requirements have the potential to affect costs and liabilities.

Exhibit 10-2 summarizes some federal regulations that relate to fabricare technologies covered in the CTSA. State and other requirements are not included; however, they may have a significant effect on technology choice. Requirements that pertain to the use of spotting chemicals are not covered, but they should not be overlooked because they may affect regulatory compliance activities for fabricare operations.

PCE and HC cleaning are most affected by provisions of federal regulations. Machine wetcleaning currently has fewer requirements that are directly applicable. It is unclear how requirements may change as industry use of these technologies changes. The Care Labeling Rule relates to all cleaning methods, although it does not contain specific requirements for cleaning garments. The rule requires manufacturers to label garments identifying acceptable cleaning methods. Garments that are cleaned in a manner other than that specified by the manufacturer and are subsequently damaged are the responsibility of the cleaner. Manufacturers may cautiously label garments as “dryclean only” (Wentz, 1996; Riggs, 1998). In effect, this may constrain the cleaner interested in avoiding liability from utilizing wetcleaning processes.

Exhibit 10-2. Summary of Federal Regulations Applicable to Fabricare Technologies[a]

Fabricare Option	CAA	CWA	RCRA	CERCLA	OSH	Care Labeling Rule	Other
PCE cleaning	✓	✓	✓	✓	✓	✓	NFPA 32
HC cleaning	✓	✓	✓	✓	✓	✓	NFPA 32
Machine wetcleaning	NA	✓	NA	NA	NA	✓	NA

✓ Indicates that a technology is regulated specifically in statute.

NA Indicates that although the statutes apply to the technology there are no specific regulatory requirements.

[a] The list of regulations covered in this chapter should not be considered exhaustive and may not cover all regulated aspects of the fabricare industry.

10.1.3 Costs

The costs of running a professional clothes cleaning business include rent, basic operating expenses, and equipment. The equipment capacity, equipment type, and location of the facility will also affect the costs and economic viability of a professional cleaning operation. This document has focused on a subset of the costs associated with operating clothes cleaning facilities and a subset of the possible technologies, for which information is available.

The cost components of each of the cleaning options summarized in the CTSA include capital (equipment) cost and the annualized cost of that equipment. In addition, estimates of total annual operating cost, total annual cost (the sum of total annual operating cost and annualized capital cost), and total annual cost per pound of clothes cleaned are provided. Exhibit 10-3 summarizes the process-dependent cost components estimated for selected cleaning technologies covered in the CTSA. Cost figures are presented in constant 1997 dollars in order to allow direct comparisons among the process options. More detailed cost estimates and explanations of how estimates were derived are given in Chapter 7.

In order to reduce exposure to chemicals used or to prevent pollution, cleaners may consider either controlling emissions from the technology they currently use or switching to a different technology. For this reason, the CTSA assesses the costs of PCE and HC process modifications that can reduce exposure. This is intended to provide examples for reducing solvent exposure without changing technologies for cleaners who are unable to change their entire process.

Exhibit 10-3. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technologies[a]

Fabricare Technology[b]	Capital Cost of Base Equipment[c]	Capital Cost Total[d]	Annualized Cost of Equipment[e]	Annual Cost Solvent[f]	Annual Energy Cost[g]	Regulatory Compliance Costs[h]	Annual Cost Hazardous Waste[i]
PCE	$38,511	$38,511	$4,228	$1,434	$136	$3,680	$4,594
HC	$37,432	$37,432	$4,110	$2,236	NA	NA	$9,820
Machine Wetcleaning	$11,102	$11,102	$1,219	$763	$788	NA	NA

Exhibit 10-3. Summary of Estimated Process-Dependent Cost Components for Selected Fabricare Technologies (Cont'd)

Fabricare Technology	Annual Cost Filters and Detergent[j]	Annual Cost Maintenance[k]	Total Annual Operating Cost[l]	Total Annual Cost[m]	Total Annual Cost/Pound
PCE	$1,913	$6,000	$14,077	$18,305	$0.34
HC	$1,551	$6,000	$19,607	$23,717	$0.44
Machine Wetcleaning	$3,162	$376	$5,089	$6,308	$0.12

NA means cost category not applicable for technology or that data are not available at this time.

[a] The values include the price of equipment, labor and services directly related to the various drycleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333 pound (24,191) annual volume of clothes cleaned per facility. Costs are meant to provide relative comparisons and may differ for specific fabricare operations.

[b] Configurations for fabricare technology include: PCE dry-to-dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (PCE-C), as required by the PCE NESHAP regulation; HC Transfer with Recover dryer and condenser (HC-A2); and Unimac UW30 washer and DTB50 dryer.

[c] List price of 35 pound PCE drycleaning system includes control equipment, distillation unit, and filters; List price 35 to 40 pound HC drycleaning system includes control equipment, filters, and an explosion kit.

[d] Base machine costs (actual or implied) are added to cost of control capital.

[e] Annual cost of drycleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[f] PCE solvent cost based on $6.83 per gallon for PCE in 1997 dollars (BLS, 1997; USEPA, 1993) and "mileage" from EPA engineering estimates; HC solvent cost based on $2.24 per gallon for hydrocarbon solvent and "mileage" based on engineering estimates; wetcleaning solvents cost based on $3.06/100 feet^3 for water (BLS, 1997; USEPA, 1993).

[g] All technology energy costs are based (USEPA, 1991) on $0.0764/kWh national average electricity cost (BLS, 1997).

[h] Regulatory compliance costs for PCE are based on 1.84% of total annual revenues of $200,000 (Gottlieb et al., 1997; NCAI, 1998).

[i] Hazardous waste disposal costs for PCE and HC based on $6.94 per gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates, excluding disposal cost for potentially hazardous spotting chemicals. Hazardous waste associated with PCE-based machines includes filters, distillation residues, and spent carbon. Hazardous waste associated with HC-based machines includes spent cartridge filters and vacuum still bottoms.

[j] Cost includes of cleaning detergents, spotting chemicals, and replacement filters (Hill, Jr., 1994b; USEPA, 1993).

[k] Annual maintenance cost for PCE and HC based on 3.0% of total revenues of $200,000 annually; costs for machine wetcleaning based on 3.39% of total capital costs (Murphy, 1994).

[l] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[m] Includes all operating costs and annual capital costs.

The CTSA considers the estimated process-dependent costs of eight PCE machine configurations and three hydrocarbon machine configurations. These alternatives are developed to provide information useful in making comparisons of the relative costs of the alternatives within a single technology (e.g., PCE). Some alternatives are no longer available (e.g., new PCE transfer machines); however, they are still provided so that individual cleaners using these configurations can compare the costs of changing to another configuration. Exhibit 10-4 presents a summary of estimated process-dependent costs for the PCE machine configurations; Exhibit 10-5 presents a summary of estimated process-dependent costs for the HC machine configurations.

10.1.4 Performance Characteristics

The basic performance goals of all professional clothes cleaning technologies are the same. Any cleaning technology applied to a textile should strive to (1) optimize soil removal by overcoming the physical and chemical forces that bind soils to the textile; (2) transport soils away from the textile through the cleaning medium; (3) preserve and/or restore the original attributes of the textile, including its dimensions, dye character, and overall fabric finish; and (4) be cost-effective to the cleaner. Chapter 6 summarizes the performance tests that have been conducted on alternative cleaning technologies. For several reasons (discussed below), however, it is difficult to rank alternative technologies on cleaning performance, and there is no single industry measure that could be used for such a ranking.

Several factors may affect the performance of a cleaning process, including soil chemistry, textile fiber type, transport medium (aqueous vs. non-aqueous), chemistry of additives (detergents, surfactants), use of spotting agents, and process controls (time, temperature, and mechanical actions). These factors work interactively to provide a range of cleaning abilities for all clothes cleaning processes. In addition, customer perceptions of a “clean” garment will vary due to regional, socioeconomic, and cultural differences. Finally, variations in technology and the knowledge base of operators may also affect the performance of the clothes cleaning process.

Although there is insufficient information to characterize the cleaning performance of each of the cleaning technologies considered in this document, some general comparisons are possible between drycleaning (solvent-based) cleaning processes and wetcleaning (water-based) processes. Drycleaning processes are more effective at dissolving oils and fatty stains (non-polar soils), while wetcleaning processes tend to dissolve sugar, salt, and perspiration (polar stains) with greater success. It is unclear whether particulate soils are better handled by one process type or the other. The cleaning ability of both wet and drycleaning processes may be enhanced with the use of spotting agents, alternative detergents, surfactant additives, and other process modifications (e.g., time, temperature, mechanical action).

These two types of cleaning processes also excel at cleaning different kinds of materials. Drycleaning processes are most effectively used with textiles that contain water-loving (hydrophilic) fibers (such as wool), low-twist yarns, low-count fabrics, and polar colorants. Wetcleaning processes are effective with textiles containing water-hating (hydrophobic) fibers (such as polyester and nylon), high-twist yarns, high-count fabrics, and non-polar colorants.

Exhibit 10-4. Estimated Process-dependent Cost Components of Selected PCE Machine Configurations[a]

Machine Configuration[b]	Capital Cost of Base Equipment[c] (Implied Cost)	Capitol Cost of Retrofit Control Technology[d]	Capital Cost Total[e]	Annualized Cost of Equipment[f]	Annual Cost Solvent[g]	Annual Energy Cost[h]	Regulatory Compliance Costs[i]
Transfer							
Transfer with no CA or RC (PCE-A1)	$19,680	$0	$19,680	$2,161	$4,282	NA	$3,680
Transfer with CA (PCE-A2)	$19,680	$8,121	$27,801	$3,052	$3,203	NA	$3,680
Transfer with RC (PCE-A3)	$19,680	$8,823	$28,503	$3,129	$2,848	NA	$3,680
Dry-to-Dry							
Dry-to-dry with no CA or RC (PCE-B1)	$31,781	$0	$31,781	$3,489	$3,832	$78	$3,680
Dry-to-dry with CA (PCE-B2)	$31,781	$7,477	$39,258	$4,310	$2,425	$94	$3,680
Dry-to-dry converted to closed-loop (PCE-B3)	$31,781	$7,607	$39,388	$4,325	$2,069	$106	$3,680
Dry-to-dry closed-loop with no CA or with door fan and small CA (PCE-C)	$38,511	$0	$38,511	$4,228	$1,434	$136	$3,680
Dry-to-dry closed-loop with unvented integral secondary CA (PCE-D)	$47,475	$0	$47,475	$5,213	$1,216	$186	$3,680

See notes at end of table.

Exhibit 10-4. Estimated Process-Dependent Cost Components of Selected PCE Machine Configurations[a] (Cont'd)

Machine Configuration[b]	Annual Cost Hazardous Waste[j]	Annual Cost Filters and Detergent[k]	Annual Cost Maintenance[l]	Total Annual Operating Cost[m]	Total Annual Cost[n]	Total Annual Cost/pound
Transfer						
Transfer with no CA or RC (PCE-A1)	$4,567	$1,913	$6,000	$16,762	$18,923	$0.35
Transfer with CA (PCE-A2)	$4,629	$1,913	$6,000	$15,745	$18,797	$0.35
Transfer with RC (PCE-A3)	$4,567	$1,913	$6,000	$15,328	$18,457	$0.35
Dry-to-Dry						
Dry-to-dry with no CA or RC (PCE-B1)	$4,567	$1,913	$6,000	$16,390	$19,879	$0.37
Dry-to-dry with CA (PCE-B2)	$4,629	$1,913	$6,000	$15,061	$19,371	$0.36
Dry-to-dry converted to closed-loop (PCE-B3)	$4,567	$1,913	$6,000	$14,655	$18,980	$0.36
Dry-to-dry closed-loop with no CA or with door fan and small CA (PCE-C)	$4,594	$1,913	$6,000	$14,077	$18,305	$0.34
Dry-to-dry closed-loop with unvented integral secondary CA (PCE-D)	$4,594	$1,913	$6,000	$13,909	$19,122	$0.36

NA means Not Available.

[a] The values include the price of equipment, labor, and services directly related to the various dry cleaning processes but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333 pound (24,191 kilogram) annual volume of clothes cleaned per facility.

[b] CA - carbon adsorber; RC - refrigerated condenser

[c] Average of list prices of 35 pound drycleaning machine or system with control equipment as shown. Price includes distillation unit and filters where applicable. Base technology prices are shown for the relevant, less controlled dry cleaning equipment system on which the retrofit control equipment is mounted.

[d] Average of list prices for retrofitting control technology.

[e] Base machine costs (actual or implied) are added to cost of control capital.

[f] Annual cost of dry cleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[g] Based on $6.83 per gallon for PCE in 1997 dollars (BLS, 1997; USEPA, 1993) and "mileage" from USEPA engineering estimates.

[h] Based on (USEPA, 1991) and $0.0764/kWh national average electricity cost (BLS, 1997).

[i] Based on 1.84% of total annual revenues of $200,000 (Gottlieb, 1997; NCAI, 1998).

[j] Based on $6.94 per -gallon PCE hazardous waste disposal cost (Beedle, 1998) and volume calculations from USEPA engineering estimates, excluding disposal

costs for potentially hazardous spotting chemicals. Hazardous waste associated with PCE-based machines includes filters, distillation residues, and spent carbon.

[k] Cost of dry cleaning detergents, spotting chemicals, and replacement filters (USEPA, 1993).

[l] Based on 3.0% of total revenues of $200,000 annually.

[m] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[n] Includes all operating costs and annual capital costs.

Exhibit 10-5. Estimated Process-Dependent Cost Components of Selected Hydrocarbon Solvent Machine Configurations[a]

HC Machine Configuration[b]	Capital Cost of Base Equipment[c] (Implied Cost)	Capital Cost of Retrofit Control Technology[d]	Capital Cost Total[e]	Annualized Cost of Equipment[f]	Annual Cost Solvent[g]	Annual Energy Cost[h]	Annual Cost Hazardous Waste[i]
Transfer - standard dryer (HC-A1)	$27,830	$0	$27,830	$3,056	$4,836	NA	$9,820
Transfer - recovery dryer with RC (HC-A2)	$37,432	$0	$37,432	$4,110	$2,236	NA	$9,820
Dry-to-dry closed-loop with RC (HC-B)	$52,082	$0	$52,082	$5,718	$1,151	$149	$9,820

Exhibit 10-5. Estimated Process-dependent Cost Components of Selected HC Solvent Machine Configurations[a] (Cont'd)

	Annual Regulatory Compliance Cost	Annual Cost Filters and Detergent[j]	Annual Cost Maintenance[k]	Total Annual Operating Cost[l]	Total Annual Cost[m]	Total Annual Cost/pound
Transfer - standard dryer (HC-A1)	NA	$1,551	$6,000	$22,207	$25,263	$0.47
Transfer - recovery dryer with RC (HC-A2)	NA	$1,551	$6,000	$19,607	$23,717	$0.44
Dry-to-dry closed-loop with RC (HC-B)	NA	$1,551	$6,000	$18,671	$24,389	$0.46

NA means Not Available.

[a] The value includes the price of equipment, labor, and services directly related to the various dry cleaning processes but excludes costs for expenses such as pressing, storefront operations, and rent. All values are reported in 1997 dollars and all calculations assume a 53,333 -pound (24,191 kilogram) annual volume of clothes cleaned per facility.

[b] CA - carbon adsorber; RC - refrigerated condenser.

[c] The list price of a 35- to 40 -pound dry cleaning machine (or system) with control equipment as shown. The price includes filters and an explosion kit where applicable.

[d] Average of list prices for retrofitting control technology.

[e] Base machine costs (actual or implied) are added to cost of control capital.

[f] Annual cost of dry cleaning equipment, annualized using 7% interest and assuming equipment life of 15 years.

[g] Based on $2.24 per gallon for HC solvent and "mileage" based on engineering estimates.

[h] Based on $0.0764/kWh national average electricity cost (BLS, 1997). Energy costs estimated to be 10% higher than those for comparable PCE machines (Hill, 1994a). The authors used the energy costs for PCE-C ($136) to calculate this value for HC-B.

[i] Based on $6.94 per gallon hazardous waste disposal cost (Beedle, 1998) and volume calculations from USEPA engineering estimates, excluding disposal cost for potentially hazardous spotting chemicals. Hazardous waste associated with HC-based machines includes spent cartridge filters and vacuum still bottoms. Note that HC solvent wastes may not be considered hazardous waste under RCRA if its flash point is less than 140°F.

[j] Cost of dry cleaning detergents, spotting chemicals, and replacement filters (USEPA, 1993; Hill, 1994b).

[k] Maintenance costs based on 3.0% of annual revenues of $200,000.

[l] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[m] The estimate includes all operating costs and annual capital costs.

The preservation of the original attributes of the textile (the third performance goal) may itself depend on the combination of cleaning process and type of textile being cleaned. Wetcleaning methods tend to cause expansion of natural and cellulose fibers, leading to a loss of strength, wrinkling, color loss, and dimensional change (i.e., shrinkage or stretching). However, textile manufacturers have developed a number of fiber treatments and modifications (resin preparation, shrink prevention preparation, wool felt prevention) that may minimize such cleaning impacts on clothing. Such alterations are not necessarily apparent when synthetic fibers are subjected to similar water-based cleaning methods. Drycleaning methods, however, may not be appropriate for synthetic fibers due to potential for fiber deterioration.

Because different cleaning processes are more effective with certain types of materials and/or certain types of soils, and because the effectiveness of all cleaning processes may be enhanced by certain process modifications, it is difficult to draw any general conclusions concerning the relative performance of the cleaning technologies considered in this document.

10.1.5 Other Factors

There are several other factors that may affect a clothes cleaner's decision in selecting alternative technologies. These may include consumer issues beyond performance, such as odor in clothing, liability concerns, and the current state and availability of alternatives. These factors can affect the costs faced by the cleaner, customer satisfaction, or ability to select alternatives.

Clothing cleaned with PCE and some HC solvents can have characteristic odors, although the odors are generally expected to be less for HC. The manufacturer of DF-2000 claims that the solvent is odorless (Exxon, 1998). Odor is not a consideration for machine wetcleaning. This factor may affect consumer satisfaction with cleaning technologies and may affect a clothes cleaner's selection of cleaning solvents.

CERCLA addresses the cleanup of sites contaminated with improperly disposed chemical wastes. Under CERCLA, potentially responsible parties that contribute to chemical contamination of a particular site, regardless of the intent or involvement of that party, are held strictly liable. Many sites with past and present PCE drycleaning operations are already contaminated to levels that will limit future uses of the property. Groundwater contamination is also possible. These liability considerations may affect decisions regarding technology choices.

Other liability concerns could result from worker claims for health effects resulting from chemicals used in clothes cleaning processes or from garment damage resulting from the various cleaning processes. Of particular note is potential liability for garments damaged in wetcleaning processes that are labeled "dryclean only."

PCE and HC technologies are well established; PCE currently dominates the market. Wetcleaning has been available in the U.S. since 1994 and is not as well known as the drycleaning technologies.

10.1.6 Summary of Trade-Off Considerations

Each of the factors summarized above may affect the technology choices made by clothes cleaners. Cleaners must consider the costs of running an operation, the service they can provide to consumers, and at what cost. Choices may also be limited by regulatory requirements and levels of necessary capital investment. The potential effects of technology choice on the health and well-being of the environment and individuals exposed to the chemicals used in the cleaning process are also important factors. The choice of cleaning technology involves a complex array of decision factors. Those identified and summarized in the CTSA are organized and presented in Exhibit 10-6.

10.2 APPROACHES FOR CONSIDERING TRADE-OFFS

Given the number of trade-off considerations identified in the CTSA and summarized in Exhibit 10-6, choosing a technology that best suits the needs of a clothes cleaner, while balancing cost and performance considerations, along with trying to meet the goals of solvent reduction, pollution prevention, and profit, can be daunting. This section of the CTSA presents approaches that can be used to structure these considerations and assist the business decision maker.

10.2.1 Benefit/Cost Analysis

Social benefit/cost analysis is used by decision makers to systematically evaluate the impacts to society resulting from individual decisions. A social benefit/cost analysis seeks to compare *all* the benefits and *all* the costs of a given action, considering both private and external costs and benefits. Private costs include those affecting the cleaner, and are typically reflected in the firm’s balance sheet. In contrast, external costs[1] are those resulting from the business decision and that are imposed on people (or the environment) who are not a party to the decision. Exhibit 10-7 defines a set of terms typically used in benefit/cost analysis.

Benefit/cost criteria could be used by individual cleaners to evaluate their choice of clothes cleaning technologies. A cleaner might ask what effect the choice of a cleaning technology or machine configuration will have on operating costs, compliance costs, liability costs, and insurance premiums (private costs), as well as on cleaning performance and attractiveness to customers (private benefits). It is less likely, however, that the cleaner would be as familiar with the social costs and benefits of decision making. Costs such as the health and environmental risks discussed in the CTSA may not add to the cost of producing clothes cleaning services (other than, perhaps, an increased liability or insurance costs); however, they represent real costs to society.

Therefore, to develop a social benefit/cost analysis of a choice among fabricare processes, the cleaner would consider not only private costs, such as operating costs and regulatory costs, of the different technologies, but also the *external* costs, such as environmental and health effects associated with cleaning services. The considerations summarized in the earlier parts of this chapter (and assessed throughout the CTSA) are the key components of a social benefit/cost analysis. They are presented together in Exhibit 10-8 and are organized as private costs and benefits and known external costs.

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[1] A common example of external costs is provided by the electric utility whose emissions are reducing crop yields for the farmer operating downwind. The external costs incurred by the farmer in the form of reduced crop yields are not considered by the utility when deciding how much electricity to produce. The farmer's losses do not appear on the utility’s balance sheet.

Exhibit 10-6. An Overview of Alternative Cleaning Technologies' Trade-Off Factors[a]

Characteristic	PCE	HC	Machine Wetcleaning
Health and Environmental Risks	**Health:** Risk of cancer to workers, co-located residents. Risks of non-cancer effects, including potential for developmental and reproductive effects for workers. May be cancer and non-cancer risks to co-located children. **Environmental:** Potential risk to aquatic organisms for effluent not treated by a POTW	**Health:** Risk of neurotoxic effects and skin and eye irritation for workers. **Fire:** Highest for Stoddard solvent, less for 140°F and DF-2000, based on flashpoint. **Environmental:** Potential to contribute to smog and global warming.	**Health:** Risk not evaluated quantitatively. Potential risks of skin and eye irritation for workers. **Environmental:** Potential risk to aquatic organisms from specific detergent component releases.
Costs[b]			
Potential liability costs	Groundwater contamination and worker illness.	Fire damage.	Damaged clothing labeled "Dryclean Only."
Capital costs[c]	$38,511	$37,432	$11,102
Hazardous waste disposal[d]	$4,594	$9,820	NA
Annual operating costs[e]	$14,077	$19,607	$5,089
Total annual costs[f]	$18,305	$23,717	$6,308
Market Considerations			
State of technology	Dominant in market.	Well-established in market; use of some HCs may be limited by local fire codes.	Commercial use since 1994 in U.S.; numerous detergent suppliers.
Consumer Issues			
Odor	Yes	Yes, maybe less for particular HCs	No
Cleaning Performance	Wide range of clothes.	Wide range of clothes.	Wide range of clothes.

NA means cost category not applicable for technology or that data are not available at this time.

[a] Configurations for fabricare technology include: PCE dry-to-dry closed-loop with no carbon adsorber or with door fan and small carbon adsorber (PCE-C), as required by the PCE NESHAP regulation; HC Transfer with Recover dryer and condenser (HC-A2); and Unimac UW30 washer and DTB50 dryer.

[b] The values include the price of equipment and services directly related to the various fabricare cleaning processes, but exclude costs for pressing, storefront operations, and rent. All values are in 1997 dollars and all calculations assume a 53,333 pound (24,191) annual volume of clothes cleaned per facility.

[c] List price of 35-pound PCE drycleaning system includes control equipment, distillation unit, and filters; list price of 35- to 40-pound HC drycleaning system includes control equipment, filters, and an explosion kit.

[d] Hazardous waste disposal costs for PCE and HC based on $6.94-per-gallon disposal cost (Beedle, 1998) and volume calculations from EPA engineering estimates; HC solvent waste may not be considered hazardous waste under the Resource Conservation and Recovery Act. Therefore, this is a high-end estimate. Hazardous waste costs associated with spotting chemicals or certain detergent components are not included.

[e] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[f] Includes all operating costs and annual capital costs.

Exhibit 10-7. Glossary of Benefit/Cost Analysis Terms

Term	Definition
Exposed Population	The number of people in the general public or a specific population group exposed to a substance through dispersion of that substance in the environment. A specific population group could be exposed because of its physical proximity to a manufacturing facility that uses or produces the substance (e.g., residents who live near a facility using a chemical), because it uses the substance or a product containing the substance, or through other means.
Exposed Worker Population	The number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be estimated by market share data, as well as by estimates of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration.
Externality	"The effects of production and consumption activities not directly reflected in the market" (Pindyck and Rubinfeld, 1989)--i.e., not affecting market prices. For example, a cost or benefit experienced by a third party not a part of a market transaction; or an adverse health effect experienced by a consumer unaware of the adverse effects associated with the product he is using or consuming. The term "externality" is a general term which can refer to either *external benefits* or *external costs.*
External Benefits	Benefits of production and consumption of private goods not directly reflected in the market; i.e., not affecting market prices. For example, the market price of landscaping materials does not reflect the benefits enjoyed by the neighbors of homeowners who improve the aesthetic view by landscaping.
External Costs	Costs of production and consumption of private goods not directly reflected in the market—i.e., not affecting market prices. For example, if a steel mill emits waste into a river and the waste poisons the fish in a nearby fishery, the fishery experiences an external cost as a consequence of the steel production. Another example is an adverse health effect experienced by a consumer who is unaware of the adverse effects associated with the product he is using or consuming.
Human Health Benefits	Reduced health risks to workers in an industry or business and/or to the general public; such benefits may, for example, result from an industry switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile organic compound, thereby lessening worker inhalation exposures.

Exhibit 10-7. Glossary of Benefit/Cost Analysis Terms (Cont'd)

Term	Definition
Human Health Costs	Increased health risks to workers in an industry or business and/or to the general public; such costs may, for example, result from the production, consumption, and disposal of a firm's product. An example is respiratory effects from stack emissions. These costs can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work.
Cost of Illness	The total cost of an illness to society, including (1) total medical costs and (2) the cost of lost productivity resulting from the illness.
Private (Internalized) Costs	The direct costs incurred by industry or consumers in the marketplace. Examples include a firm's cost of raw materials and labor, and a firm's costs of complying with environmental regulations. The private costs associated with a good or service are reflected in market prices.
Social Cost	The total cost to society of an activity. Social costs are the sum of private costs and external costs. In the example of a steel mill that emits waste into a river and the waste poisons fish in a nearby fishery, the social cost of steel production is the sum of all private costs (e.g., raw material and labor costs) and all external costs (e.g., the costs associated with the poisoned fish).
Social Benefit	The total benefit to society of an activity; i.e., the sum of the private benefits and the external benefits associated with that activity. For example, if a new product yields pollution prevention opportunities (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the external benefit (benefit society receives from reduced waste).
Willingness-to-pay	Willingness-to-pay (WTP) is the measure used for the value an individual places on something, whether it can be purchased in a market or not. If available, estimates of WTP are used in benefits valuation because they encompass the full value of avoiding an adverse health (or environmental) effect, including, for example, the value of avoiding the pain and suffering associated with the health effect. The total cost of an individual's illness, then, is the cost of illness as defined above, plus the individual's WTP to avoid the pain and suffering associated with the illness.

Exhibit 10-8. An Overview of Benefits and Costs of Alternative Cleaning Technologies

Cleaning Technology	Private Benefits	Private Costs		Known External Costs
		Total Annual Cost/Pound Clothes Cleaned	Other Private Costs[a]	
PCE-Based Drycleaning PCE-C dry-to-dry closed loop with no carbon adsorber or with door fan and small carbon adsorber	Cleans a wide range of clothes. Good cleaning performance. Established technology.	$0.34 [Includes: Capital cost; operating cost (solvent, energy, hazardous waste, filters detergent, and maintenance cost)]	Liability for groundwater contamination Costs of worker illnesses Worker liability claims Odor (within work place)	Potential cancer risks to highly exposed individuals that may include workers, co-located residents, and special populations. Potential health risks such as neurotoxicity and kidney effects to highly-exposed individuals that may include workers and co-located residents. Odor.
Hydrocarbon Solvent-Based Drycleaning HC-A2 Transfer with recovery dryer	Cleans a wide range of clothes. Established technology. Good cleaning performance.	$0.44 [Includes: Capital cost; operating cost (solvent, energy, hazardous waste, filters detergent, and maintenance cost)]	Potentially ignitable, which constrains the possible locations and also may require additional safety equipment. Costs of worker illnesses. Odor.	Potentially ignitable and could cause fire injury and damage to person and property. Varies according to particular solvent with lowest ignitability potential expected for DF-2000. Potential health effects to highly exposed individuals that include neurotoxicity, and irritation of the skin and eyes. Odor, less expected for DF-2000.
Machine Wetcleaning Unimac UW30 washer and DTB50 dryer	Cleans a wide range of clothes. No hazardous waste.	$0.12 [Includes: Capital cost; operating cost (solvent, energy, filters, detergent, and maintenance cost)]	Emerging technology (less complete knowledge of operating parameters, producing greater variability in cleaning results, which may disappoint customers). Greater possibility of shrinkage and thus an increased liability for damaged goods. Appropriate for smaller portion of the clothing stream than PCE and HC. Increased liability for damaged goods because wetcleaning a “Dryclean Only“ label makes the cleaner liable for damage.	Potential health effects to workers including dermal and eye irritation from contact with the detergent. Potential risk to aquatic organisms from release of detergents.

[a] These private costs were not included in the calculation of total annual cost per pound of clothes cleaned because of the difficulty in monetizing them.

Because of limited information, the private costs and benefits and external costs associated with the various alternative cleaning options are, for the most part, presented qualitatively. They are intended to give only a broad overview of what may be the important benefits and costs of each of these different options. In actual practice, a business decision maker would evaluate the specifics of the operation under consideration (e.g., particular concerns associated with a machine wetcleaning detergent) and attempt to assign monetary value to the trade-off factors to determine the best choice of cleaning processes.

Where quantitative measures are presented, such as in the area of cost, they are most reflective of the comparison of alternatives relative to each other, rather than a measure of actual value. This is because of the assumptions and uncertainties found when developing general characterizations of the technologies, as done in the CTSA. The effect of such a presentation is to show how the social benefit/cost framework can support the decision-making process, and highlight significant factors and considerations for each technology choice. By understanding which factors are significant, and how they are interpreted as costs and benefits, the individual cleaner could use such information as a starting point for developing technology comparisons for a specific operation.

Comparisons of the costs and benefits associated with different process options within the PCE-based drycleaning category and within the petroleum solvent-based drycleaning category are presented later in this section using an alternative decision-making process.

10.2.2 Cost-Effectiveness Analysis

Given the investment required to switch among technologies, it is also useful to examine the trade-offs faced when attempting to reduce exposure to solvents. Therefore, more detailed comparisons of the costs and benefits associated with different release reduction options are presented. It is recognized that solvent release is not necessarily the best measure of exposures and/or risk, particularly for populations such as co-located residents and the general population. However, the uncertainties involved in assessing exposures and risks associated with specific machine configurations preclude the quantitative estimation of risk trade-offs among those configurations.

As an alternative, the cost-effectiveness of the different options (alternative machine configurations) may be used as a means of comparison. Cost-effectiveness is a measure of the efficiency of an option in achieving a desired goal. In this analysis, the desired goal is the reduction of PCE or HC solvent emissions as a surrogate for reducing exposures to solvents and, therefore, the risks associated with those exposures.

10.2.3 Comparison of Alternative PCE-Based Machine Configurations

PCE is the dominant drycleaning solvent used by industry today. It is used in approximately 82% of all commercial drycleaning facilities. Although there are identified health and environmental concerns with PCE, cleaners currently using PCE may not be inclined to change cleaning technologies for a variety of reasons. They might, however, be willing to make changes to their current PCE technologies that may serve to prevent pollution by reducing releases, thereby potentially reducing exposures. Various modifications of the basic technology are expected to achieve different degrees of reduction in the release of PCE. The CTSA recognizes that release reduction may not be the best surrogate for exposure reduction. However, release reduction is used as a proxy for exposure reduction for illustrative purposes. The costs associated with these variants on the basic PCE-based drycleaning technology are also expected to differ across technologies. This subsection presents a comparison of some of the costs and benefits of eight different variants on the basic PCE-based drycleaning technology.

Exhibit 10-9 summarizes the solvent releases, performance characteristics, and cost characteristics, including capital and operating costs, of several PCE drycleaning machine configurations, and presents qualitative information on potential health and ecological risks using the solvent release volume as an indicator for exposure and risk. The estimated solvent use per year and a relative ranking of solvent mileage is provided for each of the eight PCE drycleaning machine configurations. Estimated solvent releases are also detailed along with information regarding maintenance, capital, operating, and total annual costs. Other issues, such as garment cleanliness and damage, may be considered performance issues in the drycleaning industry, but are not evaluated and are not expected to vary significantly across machine configurations.

Based on the model facility[2] (see Chapters 4 and 7), the PCE closed-loop dry-to-dry machine with unvented integral secondary controls (Option PCE-D) uses the least solvent and has the lowest emissions of the PCE options considered. Solvent usage can be measured in terms of mileage, the number of pounds of clothes cleaned per volume of unrecovered solvent. Exhibit 10-9 ranks mileage, with one being the best and eight the worst. Option PCE-D has the best solvent mileage and Option PCE-A1, a transfer machine with no vent control, has the worst. Therefore, replacing a PCE transfer machine with Option PCE-D, a PCE dry-to-dry closed-loop machine with integrated unvented secondary controls, decreases both PCE use and releases to air by 449 gallons per year while increasing the total wastewater and total hazardous waste volumes (the latter only slightly).

Along with all other dry-to-dry options, Option PCE-D is expected to result in less exposure to PCE to the extent that releases are indicative of exposure. This implies that risks to human health are probably lessened with dry-to-dry technologies when compared with the uncontrolled transfer machine option (PCE-A1). Option PCE-D is also expected to result in lower risks to aquatic life relative to those posed by Option PCE-A1. Overall costs do increase somewhat in going from Option PCE-A1 ($18,923) to PCE-D ($19,122). A more important comparison of costs is the difference between PCE-B1 ($19,879) and PCE-D ($19,122). The slight cost difference indicates a financially positive incentive for fabricare

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[2] The model facility processes 53,333 pounds of clothes per year and operates six days a week for 52 weeks a year.

Exhibit 10-9. Estimated Release Reduction Performance and Cost Characteristics of PCE Drycleaning Machine Configurations

Release Reduction Performance and Cost Characteristics	PCE-A1 Transfer No Control	PCE-A2 Transfer with CA Vent Control	PCE-A3 Transfer with RC Vent Control	PCE-B1 Dry-to-Dry with no Control	PCE-B2 Dry-to-Dry with CA Vent Control
Total PCE Solvent Use (gallon/year)	627	469	417	561	355
Solvent Mileage Rank Best = 1 Worst = 8	8	6	5	7	4
Solvent Releases (gallon/year)	627	469	417	561	355
PCE to air	501	342	290	434	228
PCE to water (total wastewater)	0.007 (75)	0.1 (1500)	0.014 (150)	0.007 (75)	0.1 (1,500)
PCE in hazardous waste (total hazardous waste)	127 (658)	127 (667)	127 (658)	127 (658)	127 (667)
Relative Health Risks	High	High	High	High	Medium
Relative Risks to Aquatic Life	Low	Low	Low	Low	Low
Required Control Device Maintenance	NA	Low	High	Low	High
Impact of Poor Control Device Maintenance	NA	Increased PCE Use	Increased PCE Use	NA	Increased PCE Use
Capital Costs[b]	$19,680	$27,801	$28,503	$31,781	$39,258
Annual Operating Costs[c]	$16,762	$15,745	$15,328	$16,390	$15,061
Total Annual Costs[d]	$18,923	$18,797	$18,457	$19,879	$19,371

See Notes at End of Exhibit.

Exhibit 10-9. Estimated Release Reduction Performance and Cost Characteristics of PCE Drycleaning Machine Configurations (Cont'd)

Release Reduction Performance and Cost Characteristics	PCE-B3 D-t-D Converted to Closed Loop	PCE-C D-t-D C-L with No CA or With Small CA and Door Fan	PCE-D D-t-D C-L with Unvented Integral Secondary CA
Total PCE Solvent Use (gallon/year)	303	210	178
Solvent Mileage Rank Best = 1 Worst = 8	3	2	1
Solvent Releases (gallon/year)	303	210	178
PCE to air	176	83	51
PCE to water (total wastewater)	0.014 (150)	0.0014 (150)	0.0014 (150)
PCE in hazardous waste (total hazardous waste)	127 (658)	127 (662)	127 (662)
Relative Health Risks	Medium	Low	Low
Relative Risks to Aquatic Life	Low	Low	Low
Required Control Device Maintenance	Low	Low	Medium
Impact of Poor Control Device Maintenance	Increased PCE Use	Machine Failure	Machine Failure; Increased PCE Use
Capital Costs[b]	$39,388	$38,511	$47,475
Annual Operating Costs[c]	$14,655	$14,077	$13,909
Total Annual Costs[d]	$18,980	$18,305	$19,122

NA means cost category not applicable for technology or that data are not available at this time.

[a] Based on New York State Monitoring Data.
[b] List price of 35-pound PCE drycleaning system includes control equipment, distillation unit, and filters.
[c] Includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.
[d] Includes all operating costs and annual capital costs.

professionals to use the maximum available control technology when converting transfer equipment. More detailed information on the risks of the options and the types of costs associated with each is described in Chapters 5 and 7.

Since benefit/cost analysis is not entirely possible in the CTSA because of the lack of quantified benefits, cost effectiveness can be used as an approach for comparing the eight PCE options. The cost-effectiveness of an option is a measure of its efficiency in achieving a desired goal. In this analysis, the options are the 8 PCE machine configurations, and the desired goal is the reduction of PCE emissions as a surrogate for reducing exposures to solvents and, quite likely, the risks associated with those exposures.

Exhibit 10-10 compares the cost effectiveness of the three PCE transfer machine options in controlling PCE releases. Compared to the baseline technology option, a transfer machine with no vent control (PCE-A1), the transfer control options (PCE-A2 and PCE-A3) both have lower total annual costs, as well as lower solvent releases per year. Each of these alternatives therefore results in a *cost-savings* per gallon of solvent emissions controlled. Therefore, instead of the cost per gallon of emissions reduced, the number of gallons of emissions reduced per dollar saved is used as the measure of cost effectiveness. Each bar in Exhibit 10-10 represents the gallons of solvent emissions reduced per dollar saved when a technology option is compared with the baseline option (PCE-A1). For example, there is a 0.45 gallon reduction in PCE emissions for every dollar saved by switching from a transfer machine with no vent control (PCE-A1) to one with carbon adsorber vent control (Option PCE-A3). This figure is derived by taking the difference in the total annual number of gallons of solvent released, 210, and dividing by the savings in total annual cost resulting from moving from Option PCE-A1 to Option PCE-A3, $466. Compared to a baseline transfer machine with no vent control (Option PCE-A1), all additional transfer control options have less initial capital cost. These options reduce solvent usage on an annual basis, as well as having a lower initial capital cost for retrofitting existing transfer equipment. It is also clear from Exhibit 10-10 that retrofitting a transfer machine with a carbon adsorber (PCE-A2) is the most cost-effective option, using the above definition of cost-effectiveness, within this PCE technology category.

Similarly, Exhibit 10-11 compares the cost-effectiveness of the five PCE dry-to-dry machine options in controlling PCE releases. As with the comparison of transfer options, the alternative dry-to-dry options (PCE-B2, PCE-B3, PCE-C, and PCE-D) all have both lower total annual cost and lower solvent releases (in gallons/year) than the baseline technology option (dry-to-dry with no control, option PCE-B1) with which they are being compared. Each bar in Exhibit 10-11 represents the gallons of solvent emissions reduced per dollar saved when a technology option is compared with the baseline emissions from a dry-to-dry machine with no carbon adsorber or refrigerated condenser control (Option PCE-B1). The dry-to-dry closed-loop machine with unvented integral secondary carbon adsorber (PCE-D) appears to be the most cost-effective option, using the above definition, followed by PCE-B2 (carbon adsorber vent control). PCE-B3 (dry-to-dry machine converted to closed-loop controls) and PCE-C (closed-loop with no carbon adsorber or with door fan and small carbon adsorber) seem to have the smallest reductions in emissions per dollar saved.

This presentation illustrates the most cost-effective way to reduce emissions, given the assumptions made in the analysis. It does not, however, present the complete benefits derived from that reduction. These may include reduced health risk to workers, customers, and nearby residents, as well as reduced potential liability from waste disposal.

Exhibit 10-10. Estimated Cost Effectiveness of PCE Transfer Drycleaning Alternatives Compared to PCE Transfer with No Vent Control (PCE-A1)

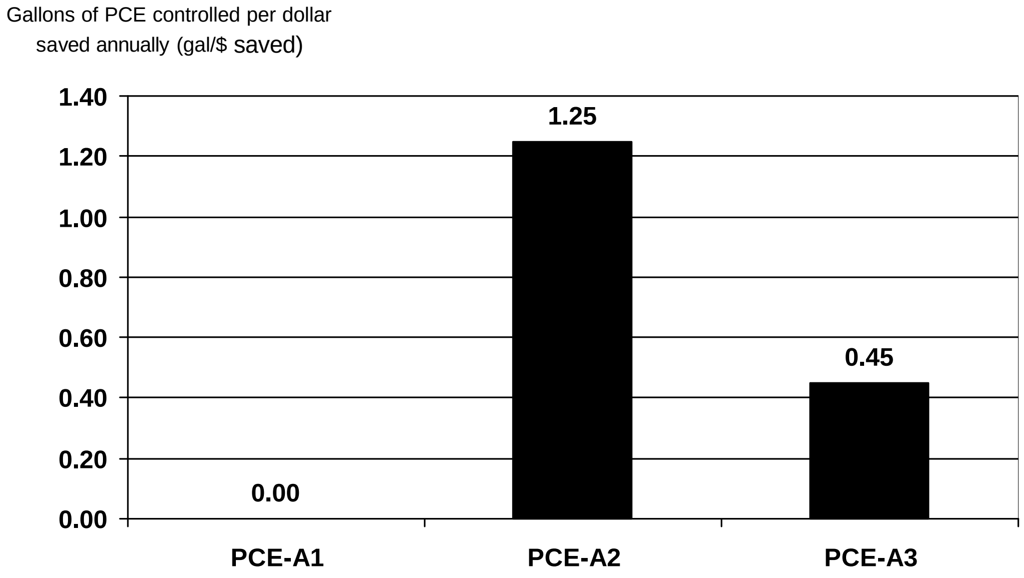
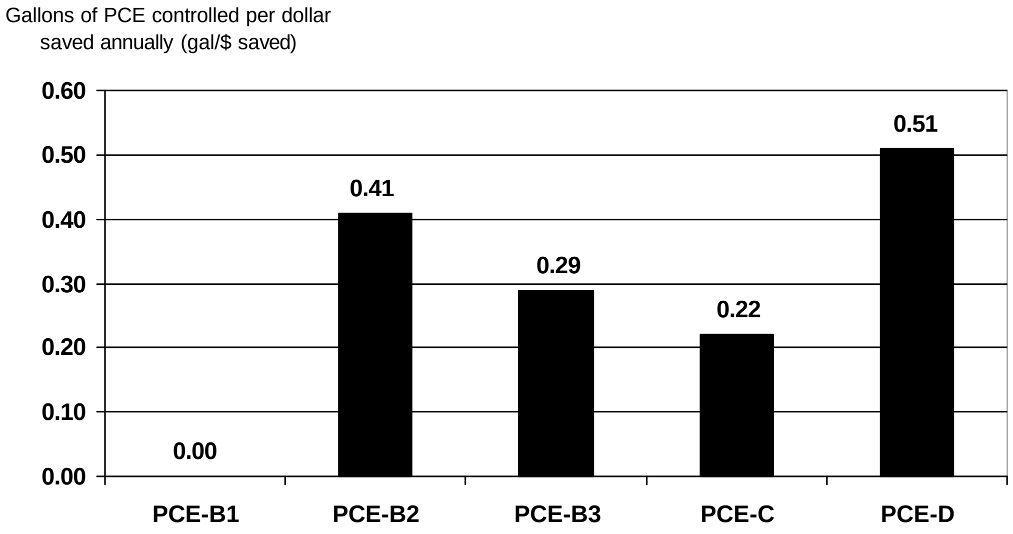


Exhibit 10-11. Estimated Cost Effectiveness of PCE Dry-to-Dry Cleaning Alternatives Compared to PCE Dry-to-Dry with No Vent Control (PCE-B1)



10.2.4 A Comparison of Alternative Hydrocarbon Solvent-Based Technologies

Risks, Release Reduction Performance, and Cost Characteristics

HC solvents dominated the drycleaning market in the United States in the 1950s, but their use has gradually declined, partly due to concerns of fire and explosion hazards. The NFPA classifies drycleaners by the petroleum solvent (HC) they use, and solvents by their flashpoint. Class II solvents (flashpoints between 100°F and 140°F, often termed Stoddard solvent) and Class IIIA solvents (flashpoints 140°F and above, often termed 140°F solvent) are the primary solvents used in this industry. NFPA codes limit Class II solvents to use in free-standing buildings (i.e, not in multi-dwelling buildings) only.

Exhibit 10-12 summarizes the solvent releases, performance characteristics, and cost characteristics, including capital and operating costs, of HC drycleaning machine configurations, as well as both health and environmental risks using solvent releases as a surrogate for potential risk. The estimated solvent use per year and a relative ranking of solvent mileage is provided for each of three HC drycleaning machine types. Solvent releases also are detailed as well as cost information regarding maintenance and energy use. Other issues, such as garment cleanliness and damage, which may be considered performance issues in the drycleaning industry, are not evaluated, and are not expected to vary significantly across machine configurations.

Based on the model facility[3] (see Chapters 4 and 7), the use of a closed-loop dry-to-dry machine with a refrigerated condenser (HC-B) shows a reduction in solvent consumption compared to a transfer machine with conventional dryer (Option HC-A1). This higher mileage decreases solvent air emissions and lowers the corresponding exposures and health risks. Replacing an uncontrolled HC transfer machine with a dry-to-dry closed-loop machine with a refrigerated condenser decreases both the HC solvent use and the release to workplace air by 1,645 gallons per year, although wastewater releases increase by 414 gallons.

Cost-Effectiveness

Reduction in solvent losses may offset the cost of control technology in some HC solvent options. Exhibit 10-13 compares the cost effectiveness of alternative hydrocarbon cleaning technologies in controlling HC) solvent releases. As was the case in the two PCE-based cost-effectiveness comparisons (Exhibits 10-10 and 10-11), the alternatives have both lower total annual cost and lower solvent releases (in gallons/year) than the baseline technology option (HC-A1). Each bar therefore represents the gallons of solvent emissions reduced per dollar saved when a technology option is compared with the baseline option, a transfer machine with standard dryer (Option HC-A1). For example, there is a 1.88 gallon reduction in PCE emissions for every dollar saved by switching to Option HC-B. This measure of cost effectiveness is calculated by dividing the difference in the number of gallons of HC released (1,645) by the savings in total annual cost in moving from Option HC-A1 to Option HC-B ($874). As shown in Exhibit 10-13, Option HC-B is the most cost-effective hydrocarbon option considered, using the above measure of cost-effectiveness.

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[3] The model facility processes 53,333 pounds of clothes per year operating six days a week for 52 weeks a year.

Exhibit 10-12. Estimated Release Reduction, Performance, and Cost Characteristics of HC Drycleaning Machine Configurations[a]

Release Reduction Performance and Cost Characteristics	**HC-A1 Transfer with Conventional Dryer**	**HC-A2 Transfer with Recovery Dryer**	**HC-B Dry-to-Dry with Condenser**
Total Solvent Use (gal/year)	2,159	998	514
Solvent Mileage Rank (Best = 1; Worst = 3)	3	2	1
Solvent Releases (gal/year)	2,159	998	514
HC to air	1,839	678	194
HC in wastewater (total wastewater)	5×10^{-6} (415)	1×10^{-5} (829)	1×10^{-5} (829)
HC in solid waste (total solid waste)	320 (1,415)	320 (1,415)	320 (1,415)
Relative Health Risks	High	Medium-High	Low
Relative Environmental Risks	High	Medium-High	Low
Degree of Required Maintenance	NA	Low	Low
Impact of Poor Maintenance	NA	Increased HC Use	Machine Failure
Capital Costs[b]	$27,830	$37,432	$52,082
Annual Operating Costs[c]	$22,207	$19,607	$18,671
Total Annual Costs[d]	$25,263	$23,717	$24,389

NA means data are not available at this time.

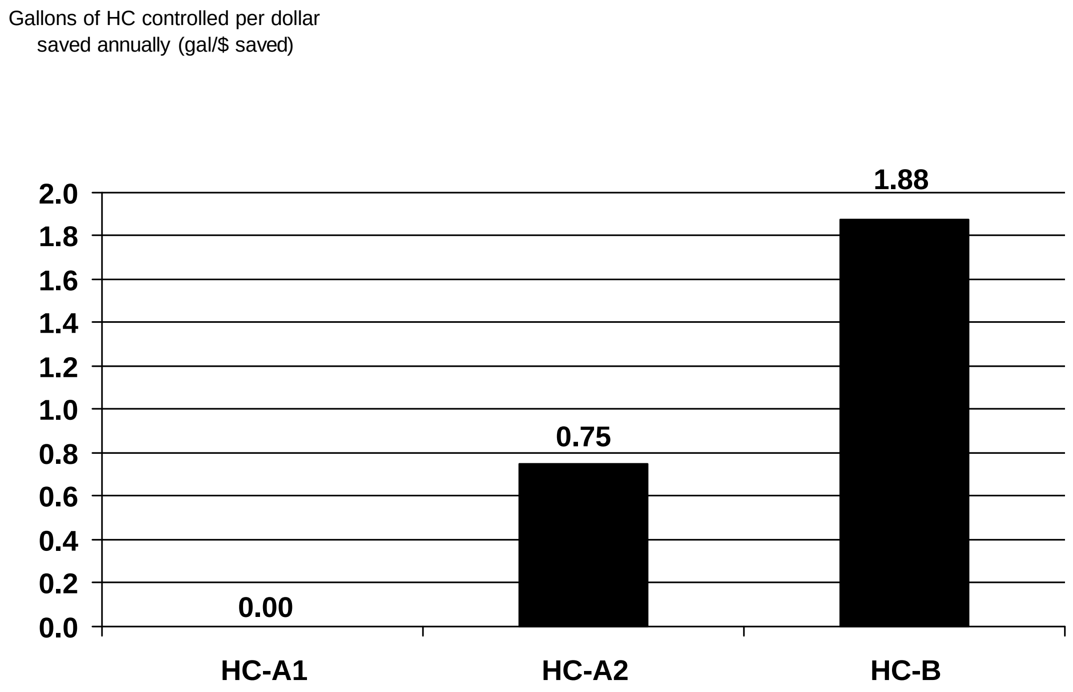
[a] The value includes the price of equipment and services directly related to the various drycleaning processes, but excludes costs for expenses such as pressing, storefront operations, and rent. All values are reported in 1997 dollars and all calculations assume a 53,333-pound (24,191 kg) annual volume of clothes cleaned per facility.

[b] The list price of a 35- to 40-pound drycleaning machine (or system) with control equipment as shown. The price includes filters and an explosion kit where applicable.

[c] The estimate includes solvent, energy, hazardous waste, filters, detergent, and maintenance costs. The cost of labor, another component of annual operating costs, is omitted due to lack of data.

[d] The estimate includes all operating costs and annual capital costs.

Exhibit 10-13. Estimated Cost Effectiveness of HC Cleaning Alternatives Compared to HC Transfer with Standard Dryer



This presentation identifies the most cost-effective way to reduce emissions, given the assumptions made in this analysis. It does not, however, present the complete benefits that are derived from that reduction. These may include reduced health risk to workers, customers, and nearby residents, as well as reduced potential liability from waste disposal.

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CHAPTER 11
EMERGING TECHNOLOGIES

CHAPTER CONTENTS

There are several new technologies under development. Some involve substituting solvents coupled with modifications to existing machinery, while others involve the use of newer machinery. The Cleaner Technologies Substitute Assessment (CTSA) briefly describes liquid carbon dioxide (CO_2) and aqueous ultrasonic fabricare technologies and the solvents Rynex and Biotex. There may be others, but these are the only ones USEPA currently has information on. These technologies are in various stages of commercial development, therefore, information is limited and may be speculative.

11.1 LIQUID CARBON DIOXIDE PROCESS

A carbon dioxide (CO_2) process that uses CO_2 in a liquid state is being developed for fabric cleaning. Liquid CO_2 seems to have adequate characteristics for drycleaning garments. Ongoing studies should present a clear determination of the capabilities of drycleaning with liquid CO_2 (Williams et al., Undated). The level of detail on each technology is reflective of its state of development.

Because liquid CO_2 processes are in the pre-commercial stage of development, little information on these processes is available. The information that is available is highly vulnerable to change. Those persons interested in this technology are advised to determine whether more recent information on this technology are available. The following process description summarizes the information available as of December 1997.

Hughes Environmental Systems and Los Alamos National Laboratories (supported by USEPA and the US Department of Energy), have conducted research on this technology, which Global Technologies, Inc. is attempting to commercialize. MiCELL Technologies, Inc. is also developing a liquid CO_2 process (MiCELL, 1997). Although both closed-loop and open-loop liquid CO_2 clothes cleaning were initially investigated (Chao, 1994), pre-commercial machines have been closed-loop. The closed-loop configuration significantly reduces CO_2 emissions by recovering and recycling the solvent in which garments are washed. Because these developing technologies are proprietary, complete process operating parameters are not available.

A problem that is being addressed is how solid materials that are not soluble in liquid CO_2 can be removed from fabric. Liquid CO_2 removes inorganic compounds such as salts even more poorly than PCE. The liquid CO_2 process developers are researching and developing cleaning additives (e.g., detergents) (Caled, 1995; DeSimone and Smith, 1996; and MiCELL, 1997). These cleaning additives may have to be specially formulated for use with liquid CO_2 (Chao, 1994).

The Hughes process was the only process for which process details adequate to describe the unit operations and their configuration were readily available. This pre-commercial Hughes-specific process is described below; if and when a liquid CO_2 process is commercialized, it may differ from that described.

Equipment sizes have not yet been fully determined for the Hughes process, but will probably be similar to those of PCE systems (USEPA, 1996). The following unit operations comprise the Hughes pre-commercial liquid CO_2 process: stationary cylinder, or drum, for washing, extracting, and drying; cooler(s); solvent tanks; a still; filters; a pump; and a compressor. The cleaning cylinder, or drum, is initially charged with about one-half gallon of liquid CO_2 per pound of clothes to be cleaned (Hughes, 1994). In conventional drycleaning, the rotating cylinder provides mechanical agitation of the clothes. In the pre-commercial Hughes-specific liquid CO_2 process, high velocity fluid jets provide mechanical agitation of the clothes during cleaning (Caled, 1995).

The soiled solvent, loaded with both soluble and insoluble (particulate) soils, will circulate in a closed loop, through the cleaning vessel, a filter train, and lint trap, to remove the particulates and lint. At the end of the cleaning cycle, the filtered cleaning fluid is returned to a storage tank. The cylinder will be depressurized, and CO_2 will vaporize from the cleaned clothes. A compressor and condenser will recover much of the CO_2 vapor from the cylinder during depressurization. Some CO_2 vapor loss will occur at the decompression. This loss will require periodic make-up in liquid CO_2 storage. The stored liquid CO_2 will be distilled to remove the soluble soils and detergents. The developer expects the distilling frequency to be similar to that of PCE drycleaning, per unit weight of cleaned garments. To reduce solvent loss, the still “bottoms” (i.e., concentrated mixture of soils and detergents) will be drained without still decompression and stored for recovery and disposal (Caled, 1995).

Global Technologies’ DryWash^{TM} cleaning process developmental prototype “Alpha Unit” was displayed during the “Clean ‘97 Show” in Las Vegas, Nevada. Global Technologies has the right to license seven manufacturers (including Raytheon Commercial Laundry and MVE, Inc.), five chemical additive manufacturers (including Caled Chemical), and one fluid manufacturer (DryWash^{TM} fluid manufacturing corporation headquarters is AGA AB in Stockholm, Sweden) (Global Technologies, 1998). Global Technologies aspires to open test sites and have all its manufacturers in the market in 1998. They estimate that the capital production price of machines with DryWash^{TM} will be $80,000 (Kinsman, 1998). Cycle times for these machines will be 30 minutes.

MiCell Technologies expects the MiCARE process to be available in 1998 (USEPA, undated). The estimated commercial price for their MiCare^{TM} machine is approximately $150,000 (Lienhart, 1998).

The NIOSH Criteria Document for CO_2 provides the following hazard information (SRI, 1976). A large body of human experimental information suggests the potential for CO_2 exposure to cause respiratory, cardiovascular, central nervous system, behavioral, electrolyte balance, and muscle effects over a variety of concentrations and durations. Inhalation of carbon dioxide at concentrations greater than 17% is lethal to humans.

No irritation or sensitization studies were reported in the literature discussed by NIOSH. Continuous exposure to 1.5–3% CO_2 (15,000 to 30,000 ppm in air) does not result in serious toxicity to humans. Physiological effects at these exposure levels include increased CO_2 and bicarbonate ion levels in blood, changes in other electrolyte levels, and increased ventilation rates.

Two weeks of exposure to 4% CO_2 in an environmental chamber showed no psychomotor impairment and no decrement in complex-task performance by six healthy male human subjects. Exposure of an unspecified number of men to 3% CO_2 for 8 days, however, showed a progression through mental stimulation and euphoria at day 1 to exhaustion and confusion on days 2 through 8. NIOSH does not summarize any human studies focusing on reproductive and/or developmental toxicity, although some studies in laboratory animals have shown these effects at very high doses.

No mutagenicity studies are summarized by NIOSH. There were no reports of carcinogenicity in animals or in humans from inhalation of gaseous CO_2.

Williams et al. (undated) conducted a study using liquid CO_2 in both small-scale and pilot-scale test systems to address fabric compatibility with this alternative cleaning method, compared with drycleaning using PCE. The study concluded that the liquid CO_2 technology is not necessarily a “drop-in” replacement for PCE drycleaning, although liquid CO_2 is an effective solvent for removal of common types of organic soils. Researchers noted that liquid CO_2 processing had no deleterious effects on test fabrics, had acceptable shrinkage, and removed more soil than standard PCE drycleaning. The next step, according to the study, would be to evaluate full scale prototype cleaning units, which are currently under development.

11.2 ULTRASONIC CLEANING PROCESS

Aqueous-based ultrasonic washing processes have been used in industrial cleaning applications for many years. It is now being researched for garment cleaning. Ultrasonic cleaning uses high intensity sound waves in a fluid medium to create mechanical forces that dissolve and displace contaminants on clothing. No ultrasonic process equipment description is available. This section discusses several of the concepts and issues involved in the development of this process.

Surfactants, detergents and/or ozone may theoretically be used in an ultrasonically agitated aqueous solution to clean stationary garments. Free-floating items tend to severely dampen ultrasonic energy in solutions, and this dampening would not allow for needed mechanical agitation. Transducers create cavitation, which may dislodge insoluble particles from the garments in the cleaning solution. A combination of blended detergents and ultrasonics may allow polar and non-polar contaminants to be removed at temperatures between 90°F to 122°F (32°C to 50°C) without fabric damage (Abt, 1994). If developed, a machine that could accomplish such cleaning would achieve similar results to the washer in the machine wetcleaning system. Extraction and drying would need to be incorporated into this ultrasonic system.

Cavitation creates the mechanical agitation in ultrasonic cleaning. Cavitation is energy created by the conversion of electrical pulses to acoustic energy via transducers which are bottom- or side-mounted in the cleaning system. This energy exists in the cleaning solution as alternative rarefactions and compressions of the liquid. During the rarefaction, small vacuum cavities are formed that collapse or implode during compression. This continuing process, called cavitation, is responsible for the scrubbing effect that dislodges contaminating particles (Abt, 1994). According to one source who has conducted small-scale research in ultrasonic cleaning, three areas of change must be researched for this process:

- Optimizing the time and temperature of washing, the ultrasonic agitation, and the detergents needed to provide adequate cleaning;
- Designing systems for rinsing, dewatering, and drying; and

- Designing a material handling system (Porter et al., 1995).

Proponents of ultrasonic cleaning claim that it is faster, uses less water and energy, and performs more thorough cleaning than conventional fabricare cleaning methods (Hoffman, 1998). The Department of Energy provided funding for a test of ultrasonic cleaning in 1993. Since that time, further work has been conducted at North Carolina State University using continuous processing. Currently, the Fraunhofer Technology Center, a joint venture of the City of Hialeah, Florida and Fraunhofer USA, is raising funds to develop a prototype ultrasonic clothes cleaning machine.

11.3 RYNEX SOLVENT

Rynex Corporation currently is developing a drycleaning solvent named Rynex for substitution in existing PCE machines. This solvent is a mixture containing one or more propylene glycol ethers. The following process information summary contains the information available as of December 1997, with the exception of a personal contact from April 1998.

Rynex Corporation intends this solvent to be a drop-in substitute for PCE in modified PCE machinery. The company claims that PCE drycleaners could use this mixture by modifying cycle times and temperatures, installing a new water separator, and cleaning the PCE from the machinery, and filling the machine with the mixture (Colletti, 1998). A water separator change would apparently be necessary because the Rynex mixture has a lower density than water (Rynex, 1997). The Rynex mixture would then be removed from the top of the separator, and water would be removed from the bottom. The Rynex mixture and water phase separation would be opposite to that of PCE and water because PCE has a higher density than water. In the PCE separator, PCE is removed from the bottom of the separator, and water is removed from the top.

Rynex is currently being studied in five test sites. Although official performance reports have not yet been released, the company claims that the chemical has the following advantageous characteristics: biodegradablity, contains no hazardous materials or carcinogens, recyclable via distillation, and a flashpoint higher than HC solvents (Colletti, 1998).

Rynex is considered a volatile organic compound (VOC), its use by cleaners may be regulated by state and Federal air pollution legislation. However, Rynex is not regulated as a hazardous air pollutant (HAP) under the Clean Air Act (Hayday, 1998).

Hazard data are available for a variety of propylene glycol ethers. Proprietary information precludes identification of the particular solvent used in Rynex, but it is known to be a propylene glycol ether. USEPA has published a review of the hazard information on several propylene glycol ethers (USEPA, 1986), however, and also recently derived a reference concentration (RfC) on a specific propylene glycol ether, propylene glycol monomethyl ether (PGME) (IRIS, 1998).

Propylene glycol ethers appear to be extensively absorbed following either oral or inhalation exposure. There is no information on absorption following contact with the skin. A study with a small number of human volunteers exposed to moderate levels of PGME in air resulted in eye, nose, and throat irritation and headaches, but there were no controls in the study.

In animal studies, exposure (via drinking water, oral intubation, or inhalation) to high concentrations of PGME resulted in general toxicity (lowered body weights) and specific effects on the liver and the central nervous system (narcosis/sedation effects).

Limited studies in animals suggest no developmental or reproductive effects following exposure to several different propylene glycol ethers. No studies reviewed in either USEPA document were designed to examine whether these chemicals interact with genetic material or cause cancer.

11.4 BIOTEX SOLVENT

Another new cleaning process still in development is based on a new solvent, tentatively named “Biotex,” by the developer Bio-Clean Ventures. In a May 27, 1998 communication to USEPA, Dieter Berndt, PhD, Director of R&D for Bio-Clean indicates their plans to market “Biotex” as an alternative to PCE and HC solvents. The company claims “Biotex” is non-carcinogenic, not a VOC, its use will not result in the production of secondary hazardous waste, and that its distillation residue will be dischargeable into ordinary sewage (Berndt, 1998) although these claims are unsubstantiated by USEPA.

Bio-Clean Ventures states that “Biotex” will be “...a little higher [priced] than Perc” and makes the following claims, based on their “extensive” testing program:

- Drycleaners will be able to use “Biotex” in existing PCE machines, with certain modifications to their equipment;
- “Biotex” can also be used in existing HC machinery without modification.;
- The solvent will not attack or pull dyes of any type, even at temperatures over 150°F, nor will it shrink garments;
- It has a degreasing ability of around 58-63, as compared to PCE at 90 and HC at 31;
- It has a surface tension of 16 dynes/square cm, as compared to PCE at 36; and
- It is slightly lighter than water.

No studies have been found to verify these claims, and the commercial status of this solvent is currently unknown.

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APPENDIX A
CHEMISTRY AND FATE

This appendix discusses the physical nature of specific chemicals used in dry and machine wetcleaning operations. Perchloroethylene (PCE) and hydrocarbon (HC) solvents are used at high concentrations in drycleaning. In machine wetcleaning, the detergents and soaps are chemical mixtures, typically containing numerous chemicals and water. Most of the formulations are trade secrets; therefore, the individual chemical concentrations are unknown. Nor is it known how representative the formulations considered in this report will be of the potential universe of formulations in existence. The following provides information on PCE, HC, and various chemicals that machine wetcleaning (MWC) formulations may contain. It is important to remember that the actual constituents of MWC formulations may vary significantly. First, this appendix describes the types of information that are provided for each chemical, including a glossary of chemical properties, or terms, presented in Exhibit A-1. These descriptions highlight chemical and physical properties, safety hazard factors, and environmental consequences. Following these descriptions, Exhibit A-2 lists the name, Chemical Abstracts Service (CAS) Registry Number, and common synonyms for each chemical. A Chemical Properties and Information Summary for each chemical lists its physical properties and safety hazard factors. Sections A.2, A.3, and A.4 summarize the environmental fate of PCE, HC, and machine wetcleaning chemicals, respectively.

A.1 CHEMICAL PROPERTIES AND INFORMATION

For each chemical identified, there is a corresponding summary of its chemical properties and relevant information. All information in these summaries was obtained by searching standard references, listed at the end of this chapter. These summaries contain information on the chemical and physical properties listed in Exhibit A-1.

The summaries of the chemicals' property values acquired from the standard references are designated as measured (M) (i.e., the data in these references were experimentally determined) or estimated (E). Terms and concepts such as synonyms and the role of the chemical in the cleaning process have no such designation since these are not values that can be measured.

Because information was proprietary, and therefore confidential, there were negligible or no data in the standard references for certain chemicals. Therefore, many of the values for the physical and chemical properties of these chemicals needed to be estimated. These estimations were obtained using several programs accessed through the Estimation Programs Interface (EPI), available from Syracuse Research Corporation (SRC, 1993a and 1993b). The EPI uses the structure of the chemical for input to eight chemical property estimation programs. The programs used to complete the individual Chemical Properties and Information summaries are as follows:

- Octanol-Water Partition Coefficient Program (LOGKOW) (Meylan and Howard, 1995).
- Henry's Law Constant Program (HENRY) (Meylan and Howard, 1991).
- Soil Sorption Coefficient Program (PCKOC) (Meylan et al., 1992).
- Melting Point, Boiling Point, Vapor Pressure Estimation Program (MPBPVP).

Exhibit A-1. Glossary of Chemical and Physical Properties

Term	Definition
Chemical Abstracts Service Registry Number (CAS#)	A unique identification code, up to ten digits long, assigned to each chemical registered by the Chemical Abstracts Service. The CAS# is useful when searching for information on a chemical with more than one name.
Synonyms	Alternative names commonly used for the chemical.
Molecular Weight	A summation of the individual atomic weights based on the numbers and kinds of atoms present in a molecule of a chemical substance. For polymers, this may included molecular weight distributions, ranges, and averages. Typical unit is grams per mole (g/mol).
Melting Point	The temperature at which a substance changes from the solid to the liquid state. Typical unit is °C.
Vapor Pressure	The pressure exerted by a chemical in the vapor phase in equilibrium with its solid or liquid forms. It provides an indication of the relative tendency of a substance to volatilize. Typical unit is mm Hg.
Octanol-Water Partition Coefficient ($\mathrm{Log}_{10}K_{ow}$)	Provides a measure of the extent to which a chemical partitions between water and octanol (as a surrogate for lipids) at equilibrium. It is an important parameter because it provides an indication of a chemical's water solubility and its propensity to partition in aquatic organisms or sorb to soil and sediment. The higher the Log K_{ow}, the more likely a chemical is to move from water to lipids.
Bioconcentration Factor (BCF)	Provides a measure of the extent of chemical partitioning at equilibrium between a biological medium such as fish tissue or plant tissue and an external medium such as water. The higher the BCF, the greater the accumulation in living tissue is likely to be.
Henry's Law Constant	Provides a measure of the extent of chemical partitioning between air and water at equilibrium; estimated by dividing the vapor pressure of a sparingly water soluble chemical substance by its water solubility. The higher the Henry's Law constant, the more likely a chemical is to volatilize than to remain in water.
Applicable Function	The primary function(s) of the chemical in the cleaning operation.
Molecular Formula and Physical Structure of the Chemical	A description of the number and type of each atom in the chemical, how the atoms are arranged, and the types of bonds between atoms.
Boiling Point	The temperature at which a liquid under standard atmospheric pressure (or other specified pressure) changes from a liquid to a gaseous state. It is an indication of the volatility of a substance. The distillation range in a separation process, the temperature at which the more volatile liquid of a mixture forms a vapor, is used for mixtures in the absence of a boiling point. Typical unit is °C.
Density	The mass of a liquid, solid, or gas per unit volume of that substance, i.e., the mass in grams contained in 1 cubic centimeter of a substance at 20°C and 1 atmosphere. Typical unit is g/cm^3.
Flash Point	The minimum temperature at which a liquid gives off sufficient vapor to form an ignitible mixture with air near the surface of the liquid or within the test vessel used.
Safety Hazard Factors	Discussed in detail below.

- Water Solubility Estimation Program (WSKOW) (Meylan et al., 1996).

- Sewage Treatment Plant Model (STP), a fugacity model for estimating the efficiency of pollutant removal (Clark et al., 1995).

The accuracy of these programs is not established in all cases, but the listed programs are considered the best methods currently available. The reference section at the end of this appendix lists journal articles discussing the development and use of these programs (except the MPBPVP program). A user's guide also is available for the EPI and each program. Any property values determined using these programs are designated as estimated (E). It should be noted that the water solubility estimation program has an anticipated margin of error of plus or minus one order of magnitude. The Log K_{OW} is expected to be accurate to 0.1 log units for most compounds, although the PCK_{OC} is likely to be somewhat less accurate due to the complex nature of the soil/sediment sorption phenomena.

For several chemicals, data were not available in any of the primary sources, and EPI estimation methods were not performed because the complex nature of the chemical (e.g., chemicals with ranges of carbon atoms) skewed the estimation results. For these chemicals, chemical and physical data had to be estimated based on structure-activity relationships (i.e., comparison with analogous chemicals with known properties). In addition, some properties were estimated from best chemical judgment based on the class of compounds to which the specific chemical belongs. Any property values determined by this comparison method are designated by an E. Any chemical and physical property values that still could not be estimated have been designated as not available.

Exhibit A-2 contains the dry and machine wetcleaning chemicals under consideration with their common synonyms and specified CAS Registry Number (CAS, 1993). Immediately following the exhibit are individual Chemical Properties and Information summaries for each chemical.

Exhibit A-2. Chemicals Utilized in Dry and Machine Wetcleaning Operations

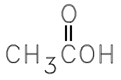
Chemical Name	CAS No.	Chemical Synonyms
Acetic acid (WC)	64-19-7	Acetic acid glacial; vinegar; ethanoic acid
Cellulose gum (WC)	9004-32-4	Sodium carboxymethylcellulose; CMC; carboxymethylcellulose, sodium salt; CM cellulose
Citric acid (WC)	77-92-9	1,2,3-Propane tricarboxylic acid; 2-hydroxy-hydroxytricarballylic acid
Cocamidopropyl betaine (WC)	61789-40-0	1-Propanaminium, 3-amino-N-(carboxymethyl)-N, N-dimethyl-, N-coco acyl derivates, inner salts; cocamidopropyl dimethyl glycine
Ethoxylated sorbitan monodecanoate (WC)	9005-64-5	Polyoxyethylene (20) sorbitan monolaurate; sorbitan, monodecanoate, poly(oxy-1, 2-ethanediyl) derivatives
Lauric acid diethanolamide (WC)	120-40-1	Lauramide DEA; N,N-bis (2-hydroxyethyl) lauramide
Methyl 2-sulfolaurate, sodium salt (WC)	4337-75-1	Sodium methyl 2-sulfolaurate; N-lauroyl-N-methyl-taurine, sodium salt; ethanesulfonic acid, 2-[methyl (1-oxododecyl) amino]-, sodium salt
Perchloroethylene (DC)	127-18-4	Tetrachloroethylene; perchlor; perc; carbon bichloride; carbon dichloride; ethylene tetrachloride; tetrachloroethene
Sodium carbonate (WC)	497-19-8	Carbonic acid; sodium salt; soda ash; Solvay soda
Sodium citrate (WC)	68-04-2	Trisodium citrate; 1,2,3-propane tricarboxylic acid; 2-hydroxy-trisodium salt
Sodium laureth sulfate (WC)	9004-82-4	Ethoxylated sodium laureth sulfate; ethoxylated sodium lauryl ethyl sulfate; poly(oxy-1, 2-ethanediyl)-sulfo-(dodecyloxy)-, sodium salt
Sodium lauryl isethionate (WC)	7381-01-3	Sodium ethyl 2-sulfolaurate; sodium dodecoylisethionate; dodecanoic acid, 2-sulfoethylester, sodium salt
Stoddard solvent (Petroleum) (DC)	8052-41-3	Solvent naphtha; white spirits; mineral spirits
140°F solvent (Petroleum) (DC)	64742-88-7	Solvent naphtha (petroleum), medium aliphatic
DF-2000 solvent (DC)		Hydrotreated heavy naphtha (petroleum); naphtha (petroleum), hydrotreated and heavy, nonaromatic

Acetic Acid

CAS# 64-19-7

Chemical Properties and Information

Synonyms: Acetic acid glacial, vinegar, ethanoic acid



$CH_3\overset{\overset{O}{\|}}{C}OH$

Molecular Weight: 60.05
Melting Point: 16.7°C (M)
Boiling Point: 118°C (M)
Flash Point: 103°F (closed cup) (M)

Molecular Formula: $C_2H_4O_2$

Vapor Pressure: 10mg Hg (at 17.1°C) (M)

Physical State: Liquid

Water Solubility: Miscible in water in all proportions (M)

Density: 1.049 g/L (at 25°C) (M)

Other Solubilities: Miscible with alcohol, glycerol, ether, carbon tetrachloride

$Log_{10}K_{OW:}$ - 0.09
$Log_{10}BCF$: <1

Applicable Function: pH adjuster

Cellulose Gum

CAS# 9004-32-4

Chemical Properties and Information

Synonyms: sodium carboxymethylcellulose; CMC; carboxymethylcellulose, sodium salt; CM cellulose

R-O-CH_2 COONa
R=(C6H1005)

Molecular Weight: High (>10,000)

Molecular Formula: varies

Melting Point: not available

Physical State: Solid

Boiling Point: not available

Density: 0.75 g/cm^3

Flash Point: Not available

$Log_{10}K_{OW:}$ n/a

Vapor Pressure: <10^{-6} mm Hg (E)

$Log_{10}BCF$: n/a

Water Solubility: Soluble (M)

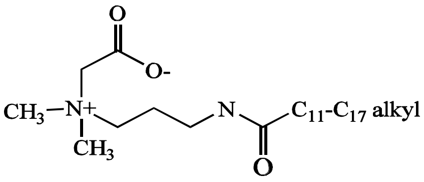
Other Solubilities: Insoluble in organic liquids

Applicable Function: soil suspender

Citric Acid
CAS# 77-92-9

Chemical Properties and Information	
Synonyms: 1, 2, 3-Propane tricarboxylic acid, 2-hydroxy-hydroxytricarballylic acid	HOC (CH$_2$COOH)2COOH *Molecular Formula*: $C_6H_8O_7$
Molecular Weight: 191.12	*Physical State*: solid
Melting Point: 153°C (loses water) (M)	*Density*: 1.542 g/cm^3
Boiling Point: Decomposes (M)	$\mathit{Log}_{10}K_{OW:}$ -1.67
Flash Point: Not available	$\mathit{Log}_{10}\mathit{BCF}$: <1
Vapor Pressure: <10^{-6} mm Hg	*Water Solubility*: 592 g/L @20°C (M)
Applicable Function: pH control	*Other Solubilities*: Soluble in alcohol and ether.

Cocamidopropyl betaine
CAS# 61789-40-0

Chemical Properties and Information	
Synonyms: 1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-, N-coco acyl derivatives, inner salts; cocamidopropyl dimethyl glycine	
Molecular Weight: 342.53	*Molecular Formula*: C19H38N2O3 (for C-11)
Vapor Pressure: Negligible (E)	*Physical State:* Solid (E)
Water Solubility: > 200 g/L at 25°C (E) (dispersible)	$\mathrm{Log}_{10}K_{OW:}$ -4.9
Other Solubilities: Slightly soluble in some organic solvents	$\mathrm{Log}_{10}\mathrm{BCF}$: <1
Applicable Function: amphoteric surfactants	

Ethoxylated Sorbitan Monodecanoate
CAS# 9004-64-5

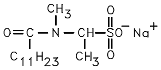
Chemical Properties and Information	
Synonyms: Polyoxyethylene (20) sorbitan monolaurate; sorbitan, monodecanoate, poly(oxy-1, 2-ethanediyl) derivatives	*Molecular Formula*: $C_5H_{114}O_{26}$ *Molecular Weight*: 1180 *Physical State*: Liquid *Density*: 1.1g/cm^3
Melting Point: Not available	$Log_{10}K_{OW}$: n/a
Boiling Point: Not available	$Log_{10}BCF$: n/a
Flash Point: 148°C (closed cup) (M)	*Vapor Pressure*: $<10^{-6}$ mm HG
Water Solubility: completely soluble (M); 1000 g/L (E)	*Applicable Function:* non-ionic surfactant
Other Solubilities: Soluble in alcohol, ethyl acetate, and dioxane. Insoluble in mineral oil and mineral spirits.	

Lauric Acid Diethanolamide
CAS# 120-40-1

Chemical Properties and Information	
Synonyms: Lauramide DEA; N, N-bis (2-hydroxyethyl) lauramide; N, N-bis (2-hydroxyethyl) Dodecanamide	*Molecular Formula:* $C_{16}H_{33}NO_3$ *Structural Formula:* $CH_3(CH_2)_{10}CON(CH_2CH_2OH)_2$
Molecular Weight: 287.17	*Physical State:* Solid
Melting Point: 50°C (E)	*Density:* 0.979 g/cm^3
Boiling Point: 359°C (M)	$Log_{10}K_{OW}$: *n/a*
Flash Point: Not Available	$Log_{10}BCF$: *n/a*
Vapor Pressure: $<10^{-6}$mm Hg (E)	*Water Solubility: 0.69 g/L (M)*
Other Solubilities: Soluble in polar organic solvents	*Applicable Function:* surfactant

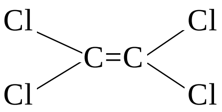
Methyl 2-Sulfolaurate, Sodium Salt

CAS# 4337-75-1

Chemical Properties and Information	
Synonyms: sodium methyl 2-sulfolaurate; N-lauroyl-N-methyl-taurine, sodium salt; ethanesulfonic acid, 2-[methyl (1-oxododecyl) amino]-, sodium salt	
Molecular Weight: 343.2	*Molecular Formula*: $C_{15}H_{30}NO_4S_?Na$
Melting Point: 207 - 208°C	*Physical State*: solid
Boiling Point: Decomposes (E)	*Density*: >1g/cm^3
Flash Point: n/a	*Log$_{10}$K$_{OW:}$* n/a
Vapor Pressure: <10^{-6} mm Hg (E)	*Log$_{10}$BCF*: n/a
Other Solubilities: Soluble in polar organic solvents	*Water Solubility*: Dispersible (E)
Applicable Function: dispersant	

Perchloroethylene

CAS# 127-18-4

Chemical Properties and Information	
Synonyms: tetrachloroethylene, perchlor, perc, carbon bichloride, carbon dichloride, ethylene tetrachloride, tetrachloroethene	*Molecular Formula*: C_2Cl_4 
Molecular Weight: 165.82	*Physical State*: Liquid
Boiling Point: 121.07°C	*$Log_{10}K_{OW}$*: 3.40
Vapor Pressure: 18.5 mm Hg@25°C	*BCF:* 49/40 (M)
Other Solubilities: Soluble in most organic solvents; dissolves a wide range of organic compounds including organic acids, fats, oils, rubber, tars, and resins; solubilizes a number of inorganic materials including sulfur, iodine, mercuric chloride, and aluminum chloride	*Henry's Law Constant*: 0.0184 atm/m^3-mole *Water Solubility*: 150 mg/Kg *Hildebrand Solubility* is 9.3 $cal^{1/2}/cm^{3/2}$ *Surface Tension*: 31.3 $dynes/cm^2$
Freezing Point: -22.35°C *Flashpoint:* Not flammable *Specific Gravity*: 1.6@25°C *Refractive Index*: 1.503 *Viscosity*: 0.798 cP@30°C *Evaporation Rate*: 2.10 (butyl acetate=1) *Odor Threshold*: 50 ppm	*Dielectric Constant*: 2.280 *Vapor Density*: 5.8 (air=1) *Heat of Vaporization*: 9.47 cal/g@25°C *Specific Heat*: 35.01 cal/°K-mole *Kauri Butanol Number*: 90
Applicable Function: solvent	

Sodium Carbonate

CAS# 497-19-8

Chemical Properties and Information

Synonyms: carbonic acid, sodium salt, soda ash, Solvay soda

Molecular Formula: $NaCO_3$

Molecular Weight: 83

Physical State: Solid

Melting Point: 851°C (M)

Density: 2.53 g/cm^3 (M)

Boiling Point: Decomposes (M)

$Log_{10}K_{OW}$: 0.0

Flash Point: Not Available

$Log_{10}BCF$: <1

Vapor Pressure: <10^{-6} mm Hg (E)

Water Solubility: 71 g/L (M)

Other Solubilities: Soluble in glycerol; insoluble in alcohol and acetone

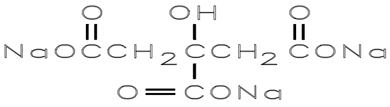
Applicable Function: solubilizer, detergent aid

Sodium Citrate

CAS# 68-04-2

Chemical Properties and Information

Synonyms: Trisodium citrate; 1, 2, 3-propane tricarboxylic acid, 2-hydroxy-trisodium salt



$$\mathrm{NaO\overset{\overset{O}{\|}}{C}CH_2\underset{\underset{O=CONa}{|}}{\overset{\overset{OH}{|}}{C}}CH_2\overset{\overset{O}{\|}}{C}ONa}$$

Molecular Weight: 258.07

Molecular Formula: $C_6H_5NaO_7$

Melting Point: Becomes anhydrous at 150°C (M)

Physical State: solid

Boiling Point: Not Applicable

Density: Not Available

Flash Point: Not Available

$Log_{10}K_{OW}$: - 1.67

Vapor Pressure: Not Available

$Log_{10}BCF$: <1

Water Solubility: 760 g/L (M)

Other Solubilities: Insoluble in alcohol

Applicable Function: emulsifier aid

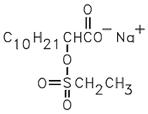
Sodium Laureth Sulfate

CAS# 9004-82-4

Chemical Properties and Information	
Synonyms: Ethoxylated sodium laureth sulfate; ethoxylated sodium lauryl ethyl sulfate; poly(oxy-1, 2-ethanediyl)-sulfo-(dodecyloxy)-, sodium salt	*Molecular Formula:* $(C_2H_4O)_nC_{12}H_{25}O_4S_?Na$ *Molecular Weight*: varies with degree of ethoxylation (>330) *Physical State*: solid
Melting Point: not available	*Density*: >1 g/cm^3
Boiling Point: not available	$Log_{10}K_{OW}$: n/a
Flash Point: not available	$Log_{10}BCF$: n/a
Water Solubility: dispersible (E)	*Vapor Pressure*: <10^{-6} mm Hg (E)
Other Solubilities: Soluble in polar organic solvents and alcohols	*Applicable Function:* surfactant

Sodium Lauryl Isethionate

CAS# 7381-01-3

Chemical Properties and Information	
Synonyms: sodium ethyl 2-sulfolaurate; sodiumdodecyl-isethionate; dodecanoic acid, 2-sulfoethylester, sodium salt	
Molecular Weight: 330.3	*Molecular Formula*: $C_14H_{27}O_5S_?Na$
Melting Point: 216 - 218 °C	*Physical State*: solid
Boiling Point: decomposes (E)	*Density*: >1 g/cm^3
Flash Point: not available	$Log_{10}K_{OW}$: n/a
Vapor Pressure: <10^{-6} mm Hg (E)	$Log_{10}BCF$: n/a
Water Solubility: Dispersible (E)	*Other Solubilities*: soluble in polar organics
Applicable Function: surfactant	

Stoddard Solvent
CAS# 8052-41-3

Chemical Properties and Information	
Synonyms: Solvent naphtha; white spirits; that mineral spirits	*Definition*: A colorless, refined petroleum distillate is free from rancid or objectionable odors and that boils in the range of approx. 149 - 205 °C.
Molecular Weight: 126.24 (LOWWT, C_9H_{18})	*Molecular Formula:* C_n2_{n+2} (paraffins) and C_nH_{2n} (cycloparaffins) (typical)
Boiling Point: 150-210 °C; 149-208 °C (Merck) *Freezing Point:* -70 °C	*$Log_{10}K_{ow}$:* 4.76*
Vapor Pressure: 2 mm Hg at 20 °C	*Water Solubility:* 0.0024 g/L*
Vapor Density: 4.9 (air = 1)	*Specific Gravity:* 0.75 - 0.85
Surface Tension: 0.027 - 0.05 N/m	*Refractive Index:* 1.4278
Flash Point: 41 °C; 38 °C (Merck)	*Evaporation Rate:* 0.12 (butyl acetate = 1)
Heat of Vaporization: 284.3 J/g *Upper Explosive Limit:* 6.0% (Chemcentral) *Lower Explosive Limit:* 1.0%	*Reactivity:* 0 *Flammability:* 2 *Ignitability:* Y; Autoignition temp: 232 °C
Kauri Butanol Number: 27 - 45 *Dielectric Constant:* 2.00 - 3.00	*Applicable Function:* Cleaning solvent

*Water solubility and log K_{ow} were estimated using the EPI program (SRC) for nonane (C_9H_{20}) representing the most soluble component of Stoddard solvent. The water solubility average estimate for 23 C_9 paraffins and cycloparaffins is 2.5 - 4.7x10^{-5} g/kg.

140^oF Solvent
CAS# 64742-88-7

Chemical Properties and Information	
Synonyms: Solvent naphtha (petroleum), medium aliphatic predominantly range	*Definition*: Saturated hydrocarbons obtained from the distillation of crude oil or natural gasoline having carbon numbers in the range of C9-C12 and boiling in the of 140 - 220 °C.
Molecular Weight: 126.24 (LOWWT, C_9H_{18})	*Molecular Formula*: C_n2_{n+2} (paraffins) and C_nH_{2n} (cycloparaffins) (typical)
Boiling Point: 183 - 199 °C Ashland 140) 191 - 203 °C (Chemcentral 140) 187-206 °C (Shell Sol 140)	$Log_{10}K_{ow}$: 4.76*
Vapor Pressure: 0.5 mm Hg at 20 °C (Chemcentral 140)	*Water Solubility*: 0.0024 g/L*
Vapor Density: 5.4 (air = 1) (Ashland 140)	*Specific Gravity*: 0.78 at 25 °C (typical)
Flash Point: 60 - 62.2 °C (typical)	*Refractive Index*: 1.43 (Chemcentral 140)
Hildebrand Solubility Parameter: 7.6 $cal^{1/2}/cm^{3/2}$ (Chemcentral 140)	*Evaporation Rate*: 0.08<X<0.1 (typical, butyl acetate = 1)
	Reactivity: 0 *Flammability*: 2 *Ignitability*: Y
Kauri Butanol Number: 30 - 31 *Dielectric Constant*: 2.04 (Shell Sol 140)	*Applicable Function*: Lower flash point alternative to drycleaning chemicals

*Water solubility and log K_{ow} were estimated using the EPI program (SRC) for nonane (C_9H_{20}) representing the most soluble component of 140°F solvent. The water solubility average estimate for 23 C_9 paraffins and cycloparaffins is 2.5 - $4.7x10^{-5}$ g/Kg.

DF-2000 Solvent

Chemical Properties and Information	
Synonyms: Hydrotreated heavy naphtha (petroleum); Naphtha (petroleum), hydrotreated and heavy, nonarom.	*Definition*: A complex combination of hydrocarbons obtained by treating a petroleum fraction with hydrogen and catalyst. It consists of hydrocarbons having carbon numbers predominantly in the range of C6-C13 and boiling in the range of approx. 65-230 °C.
Molecular Weight: 84.16 (LOWWT, C_6H_{12})	*Molecular Formula:* C_n2_{n+2} (paraffins) and C_nH_{2n} (cycloparaffins) (typical)
Boiling Point: 191 - 205 °C (Exxon Chemical) *Freezing/Melting Point*: <-60 °C	*$Log_{10}K_{ow}$*: 3.9*
	Water Solubility: <0.01 at 15 °C
Vapor Pressure: 1 at 20 °C (E)	*Specific Gravity:* 0.77 at 15 °C
Vapor Density: 5.90 (Air = 1) (calculated)	*Refractive Index:* n/a
Flash Point: 64 °C (TCC) (typical)	*Evaporation Rate:* <0.1 (n-butyl acetate = 1)
Viscosity: 2.1 cSt at 15 °C (E)	*Reactivity:* 0 *Flammability:* 2 (LEL: 1.3; UEL 8.8 @ 25
°C)(E)	
	Ignitability: Y; Autoignition temp: 338 °C (E)
	Applicable Function: Cleaning solvent

*Log K_{ow} was estimated using the EPI program (SRC) for hexane (C_6H_{12}) representing the most soluble component of DF-2000 Solvent.

A.2 PERCHLOROETHYLENE ENVIRONMENTAL FATE SUMMARY

PCE is expected to biodegrade slowly in water and in soils. Aerobic and anaerobic biodegradation, in water and soil, respectively, are estimated as taking months and hydrolysis as taking years. Actual biodegradation rates will depend upon local soil conditions. In one study, trichloroethylene, cis-1,2-dichloroethene, trans-1,2-dichloroethene, chloroethene, and dichlormethane were produced as PCE biodegraded over a 21-day period.

Groundwater contaminated by PCE has been found in a number of places; the contamination may take place because PCE is more dense and less viscous than water. PCE's migration potential from a landfill to groundwater is estimated as negligible to moderate and depends on local conditions. PCE is a classic groundwater contaminant.

PCE's rate of volatilization depends upon the depth and turbulence of surface water. Using a model that assumes a standard 1-meter depth stream, the volatilization potential is estimated as moderate. Sorption to soil and sediment is low. The estimated half-life of PCE in stream or river water is 1.4 hours. The estimated wastewater treatment removal efficiency, which depends mainly on volatilization, is 88 percent. Hydrolysis of PCE is expected to be slow compared with volatilization from surface water (Versar, 1987). In the presence of sunlight, PCE is also expected to photooxidize in water (Versar, 1987).

A.3 HYDROCARBON SOLVENT ENVIRONMENTAL FATE SUMMARY

Stoddard solvent is expected to biodegrade slowly, with aerobic and anaerobic biodegradation taking weeks to months. Migration to groundwater is negligible, and sorption to soil and sediment is very strong. The estimated half-life for volatilization from water in rivers is 1.58 hours; the half-life for volatilization from water in lakes is 6.11 days. The estimated removal efficiency in wastewater treatment is 95 percent. The estimated half-life resulting from atmospheric oxidation is five hours.

Stoddard solvent's stratospheric ozone depletion potential is zero (USEPA, 1992). However, Stoddard solvent is a potential VOC (lower level ozone) contributor and has global warming potential (USEPA, 1992).

The 140°F solvent is expected to biodegrade rapidly, with aerobic and anaerobic biodegradation taking days to weeks. Migration to groundwater is negligible, and sorption to soil and sediment is strong. The estimated half-life for volatilization from water in rivers is 1.3 hours; the half-life for volatilization from water in lakes is 5.2 days. The estimated removal efficiency in wastewater treatment is 99.9 percent due to high volatilization and biodegradation. The estimated half-life resulting from atmospheric oxidation is 9.4 hours.

The stratospheric ozone depletion potential of 140°F solvent is zero (USEPA, 1992). It is also a potential VOC (lower level ozone) contributor and has global warming potential (USEPA, 1992).

A.4 MACHINE WETCLEANING ENVIRONMENTAL FATE SUMMARY

Partial removal of chemicals from water often occurs during treatment in publicly owned treatment works (POTWs). Two frequently encountered removal mechanisms are adsorption to sludge and hydrolysis. Others include biodegradation and volatilization. An environmental fate summary (see Exhibit A-3) presents information on adsorption to soils and sediments, ultimate biodegradation, and percent removal in wastewater treatment and removal process.

Adsorption to soil and sediment is the tendency of a chemical to bind to the material at the bottom layer of a water body (e.g., a river bed). This is significant because chemicals trapped at the bottom of a river bed generally do not contaminate the drinking water supply.

Ultimate biodegradation, which occurs in water and soils, is the conversion of the carbon in an organic chemical to carbon dioxide. This occurs when microorganisms break down a chemical to its elemental state (e.g., carbon dioxide and ammonia). Once the chemical is in its elemental state, it is no longer of concern.

Exhibit A-3. Environmental Fate Information for Machine Wetcleaning Chemicals[a]

Chemical Name	CAS Number	Adsorption to Soil and Sediment	Time for Biodegradation	% Removal in Wastewater Treatment
Acetic acid	64-19-7	low	days	90
Cellulose gum	9004-32-4	strong	weeks to months	50
Citric acid	77-92-9	low	days	90
Ethoxylated sorbitan monodecanoate	9005-64-5	moderate	days to weeks	90
Lauric acid diethanolamide	120-40-1	low	days to weeks	90
Methyl 2-sulfolaurate, sodium salt	4337-75-1	moderate	days to weeks	90
Sodium carbonate	497-19-8	unspecified	unspecified	zero
Sodium citrate	68-04-2	low	days	90
Sodium laureth sulfate	9004-82-4	unspecified	days to weeks	90
Sodium lauryl isethionate	7381-01-3	moderate	days to weeks	90

[a] No information is available for cocoamidopropyl betaine.

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APPENDIX B
ECOLOGICAL HAZARD METHODOLOGY

This appendix provides further background on the development of hazard profiles and determination of the concern concentration.

B.1 DEVELOPMENT OF HAZARD PROFILE

Chapter 3 presented a hazard profile consisting of three chronic and three acute effective concentrations representing acute and chronic values for fish, aquatic invertebrates (daphnid), and algae for each chemical. For most of the chemicals in the Cleaner Technologies Substitutes Assessment, measured values from studies were generally not available, and structure-activity relationships (SARs) were used instead as predictive measures.

SAR methods include Quantitative Structure Activity Relationships (QSARs), qualitative SARs, or use of the best analog. The use of SARs by USEPA's Office of Pollution Prevention and Toxics (OPPT) has been described (Clements, 1988). The use and application of QSARs for the hazard assessment of new chemicals has been presented (Clements et al., 1993a). The development, validation and application of SARs in OPPT have been presented by OPPT staff (Boethling, 1993; Clements et al., 1993b; Lipnick, 1993; Nabholz et al., 1993; Newsome et al., 1993; Zeeman et al., 1993).

The predictive equations (QSARs) are used in lieu of test data to estimate a toxicity value for aquatic organisms within a specific chemical class. The equations are derived from correlation and linear regression analysis based on measured data; however, the confidence interval associated with the equation is not used to provide a range of toxicity values.

B.2 DETERMINATION OF CONCERN CONCENTRATION

Concern concentration (CC) is the concentration of a chemical in the aquatic environment that, if exceeded, may result in a significant risk. Concern concentrations are determined by applying assessment factors (USEPA, 1984) to the effect concentrations in the hazard profile. These assessment factors incorporate the uncertainty associated with toxicity data, laboratory tests versus field tests, measured versus estimated data, and species sensitivity. For example, if only a single LC_{50} value for a single species is available, there are several uncertainties to consider. First, how good is the value itself? If the same laboratory or a different laboratory were to redo the test, would the value differ? Second, there are differences in sensitivity (toxicity) among and between species that have to be considered. Is the species tested the most or the least sensitive? In general, if only a single toxicity value is available, there is a large uncertainty about the applicability of this value to other organisms in the environment, and a large assessment factor (e.g., 1,000) is applied to cover the range of sensitivity known to exist among and between organisms in the environment. Conversely, more information results in more certainty concerning the toxicity values and allows the use of a smaller assessment factor. For example, if toxicity values are derived from field tests, then an assessment factor of one is used.

USEPA uses four assessment factors to set a CC for chronic risk: one, 10, 100, and 1,000. The assessment factor used depends on the amount and type of toxicity data contained in the hazard profile and reflects the amount of uncertainty about the potential effects associated with a toxicity value. In general, the more complete the hazard profile and the greater the quality of the toxicity data, the more likely that a smaller assessment factor is used. The following describes the use and application of the assessment factors:

1. If the hazard profile only contains one or two acute toxicity values, the CC is set at 1/1,000 of the acute value.

2. If the hazard profile contains three acute values (base set), the CC is set at 1/100 of the lowest acute value.

3. If the hazard profile contains one chronic value, the CC is set at 1/10 of the chronic value if the value is for the most sensitive species. Otherwise, it is 1/100 of the acute value for the most sensitive species.

4. If the hazard profile contains three chronic values, the CC is set at 1/10 of the lowest chronic value.

5. If the hazard profile contains a measured chronic value from a field study, then an assessment factor of 1 is used.

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APPENDIX C
HEALTH HAZARD SUMMARIES

This appendix reviews the available human health hazard data for each chemical/process associated with commercial clothes cleaning. “Hazard” data include information from animal and/or human studies on the inherent toxicity of a chemical/process. The data are presented under one of two general categories: drycleaning (non-aqueous based) and wetcleaning (aqueous-based).

C.1 DRYCLEANING

Hazard data are presented on perchloroethylene and hydrocarbon solvents (data are presented for Stoddard solvent, which is assumed to be a representative hydrocarbon used in drycleaning).

C.1.1 Perchloroethylene

Summary

Inhalation of perchloroethylene (PCE) has caused neurotoxic effects; may cause cancer in liver, kidney, and other organs; and may have developmental and reproductive effects. This section details these hazards in the following subsections: absorption/metabolism; acute toxicity; irritation/sensitization; subchronic/chronic toxicity; neurotoxicity; developmental/reproductive toxicity; mutagenicity; and carcinogenicity. Appendix D contains the dose-response assessment for PCE, for both non-carcinogenic and carcinogenic effects.

PCE does not have marked acute toxicity by inhalation. Lethal concentrations for laboratory animals are in the range of several thousand parts per million (ppm). Deaths have been reported in humans following unmeasured, but likely high, levels of exposure.

Neurotoxic effects are well established in both humans and animals following inhalation of air containing PCE at a few hundred ppm for several hours. Humans exposed to short-term, non-lethal inhalation exposures of PCE have exhibited neurotoxic effects (dizziness, drowsiness, and other signs of central nervous system depression). Developmental effects have been seen in laboratory animals exposed to several hundred ppm PCE by inhalation for 7 hours/day during the critical period of gestation and suggest a potential for developmental effects in the fetuses of exposed pregnant women. But human data regarding the potential of PCE to cause developmental and reproductive effects are inconclusive.

Chronic (long-term) exposure to PCE adds concern for carcinogenicity and kidney and liver effects to those already mentioned. Kidney and liver effects have been seen in rats and mice exposed to PCE at concentrations ranging from 10 to 20 ppm and above. Increased incidences of tumors have been found in laboratory rats and mice following inhalation or ingestion exposure to PCE; however, controversy surrounds each of the tumor end points concerning their relevance to humans. Existing epidemiologic studies suggest there is “limited evidence” (IARC, 1995) for establishing a causal relationship between PCE exposure and cancer in humans.

Available animal data indicate that PCE itself is not mutagenic, but the following PCE metabolites have been shown to be mutagenic: perchloroethylene epoxide, trichloroacetaldehyde, dichloroacetaldehyde, monochloroacetaldehyde, trichloroacetic acid, and S-(1,2,2-trichlorovinyl) glutathione. Some of the metabolic pathways that generate mutagenic metabolites of PCE in animals may not be operative in humans. The relevance of the mutagenic metabolites, therefore, to PCE's potential as a human carcinogen is not firmly established. Recently, the the International Agency for Research on Cancer (IARC) has classified PCE as a Group 2A carcinogen (probably carcinogenic to humans). Overall, USEPA has judged the existing evidence as sufficient for classifying PCE as a probable human carcinogen (group B2). USEPA's Science Advisory Board (the preface in USEPA, 1991) stated that the evidence of PCE's toxicity places PCE on the continuum from group C (possible human carcinogen) to group B2 (probable human carcinogen). Their view was framed to encompass a concern for high PCE exposures, which is consistent with the uncertainties regarding the modes of action associated with the several tumor types.

Absorption/Metabolism

Absorption

Human data indicate that PCE is absorbed well following inhalation exposure (ATSDR, 1993) although good, measured data on absorbed dose are not readily available. Dermal absorption, relative to inhalation, can be approximately equal to the amount absorbed via inhalation at low exposure levels (e.g., 60 ppm) or can be as low as 1% of the amount absorbed via inhalation at higher doses (e.g., 600 ppm) (Riihimaki and Pfaffli, 1978; McDougal et al., 1990). While inhalation is expected to be the principal route by which PCE enters the body, and is expected to be the principal route of exposure in the drycleaning industry, dermal absorption cannot be ruled out as a potentially important route of entry of PCE into the body.

Data from studies in rats and mice indicate that PCE is also absorbed well by the oral route (USEPA, 1985).

Metabolism—General Considerations

Once PCE is absorbed into the body, its metabolism is important, as much of the toxicity of PCE is generally considered to result from its reactive metabolites. For example, studies show that several parameters of liver toxicity (liver weight increase, liver triglyceride accumulation, serum SGPT activity) vary linearly with the amount of PCE metabolized.

There are major differences among mice, rats, and humans in their ability to metabolize PCE. Humans appear to metabolize PCE to a lesser degree than rats, and rats metabolize PCE to a lesser degree than mice. One study shows that the amount of PCE undergoing metabolism is five to 10 times greater in the mouse than in the rat (Schumann et al., 1980).

Human data indicate that the metabolism of PCE overall is relatively limited, as evidenced by the fact that a high percentage of the chemical is excreted unchanged in the breath. In one study, volunteers exposed to 72 or 144 ppm of PCE for 4 hours excreted 80-100% of the total uptake of PCE unchanged (ATSDR, 1993).

The metabolism of PCE appears to be saturable in both humans and rodents. In humans and in rats, saturation begins to occur at levels greater than or equal to 100 ppm (ACGIH, 1986). In mice, saturation occurs at much higher levels, but the inhalation exposure level at which this process begins could not be found. In one study (Odum et al., 1988, as reported in ECETOC, 1990), saturation had not occurred in mice exposed to 400 ppm PCE for six hours.

Metabolism—Pathways (from USEPA, 1991, unless noted otherwise)

PCE is metabolized through at least two distinct pathways. Oxidative metabolism via the cytochrome P-450 system, which probably occurs mainly in the liver, is believed to be the primary pathway. This pathway is operative in both humans and rodents. The major metabolite of this pathway is trichloroacetic acid, which is excreted in the urine. Trichloroacetic acid and other metabolites that have been demonstrated or postulated to occur by this pathway—dichloroacetic acid (DCA), PCE epoxide, and mono-, di-, and trichloroacetaldehyde (or, chloral hydrate)—are cytotoxic/genotoxic or carcinogenic (trichloracetic acid, DCA, and chloral hydrate produce liver tumors in mice).

A secondary but potentially important pathway of PCE metabolism is glutathione conjugation, by which the liver conjugates PCE with glutathione to form 1,2,2-trichlorovinylglutathione (TCVG). This metabolite, in turn, is transformed in the kidney to 1,2,2-trichlorovinylcysteine (TCVC). TCVC is further metabolized in the kidney by β-lyase to yield an unstable thiol that may give rise to cytotoxic and mutagenic intermediates.

In vitro studies (Green et al., 1990) on human liver samples failed to detect glutathione conjugation with PCE, although glutathione conjugation has been demonstrated in rats and mice (*in vivo* and *in vitro*). Because of the very low levels of enzyme activity being measured and the limited number of human liver samples tested, however, it is premature to conclude that humans are unlikely to carry out this metabolic step. In a more recent study, TCVC has been identified in the urine of workers exposed to PCE, indicating that glutathione-dependent bioactivation of PCE is operative in humans (Birner et al., 1996).

The β-lyase pathway has also been demonstrated to exist in human kidney (proximal tubule) cells in two *in vitro* studies. In one of these studies, the rate of metabolism of chemically synthesized TCVC by β-lyase was up to 10 times higher in the rat kidney than either the mouse or human kidney (Green et al., 1990, as reported in ECETOC, 1990). Although only 11 human kidney samples were used in this study, the variation in β-lyase activity was remarkably small—rates ranged from 0.1 to 0.56 nmol/minute/mg protein.

Acute Toxicity

The LD_{50}/LC_{50} values for PCE in mice and rats show that the chemical does not have marked acute toxicity. A 4-hour inhalation LC_{50} of 5,200 ppm (35.3 mg/L) for female albino mice was established in an earlier study (ATSDR, 1993). In an NTP (1986, as cited in ATSDR, 1993) study, the highest concentration for a 4-hour exposure that did not produce death in B6C3F1 mice or F344 rats was 2,445 ppm; the lowest concentrations producing mortality were 2,613 ppm in mice and 3,786 ppm in rats. Single oral LD_{50} values of 3,835 and 3,005 mg/kg were determined for male and female rats treated by gavage. Death occurred within 24 hours after dosing and was preceded by tremors, ataxia, and central nervous system depression (ATSDR, 1993). In other studies (Regulatory Toxicology and Pharmacology, 1994), oral LD_{50} values ranged from 8,800 to 10,800 mg/kg for mice.

Death has been reported in humans following unmeasured, but likely high, levels of exposure (Lukaszewski, 1979; Levine et al., 1981, both as reported in ATSDR, 1993).

Irritation/Sensitization

No data have been located regarding the irritation/sensitization potential of PCE exposure in humans or animals.

Subchronic/Chronic Toxicity

Kidney

In rodents, renal toxicity has been demonstrated after short-term and chronic inhalation exposures. Male rats exposed to 1,000 ppm for 10 days developed hyaline droplets in proximal tubules, but no lesions were present after exposure to 400 ppm for 28 days. Renal tubular karyomegaly occurred in both sexes of mice exposed to 200, 400, 800, and 1,600 ppm for 13 weeks, but did not occur in mice exposed to 100 ppm. Kidney lesions did not occur in rats similarly exposed to 1,600 ppm (NTP, 1986, as cited in ATSDR, 1993). In the chronic inhalation study, both sexes of F344 rats and B6C3F1 mice developed renal tubular cell karyomegaly at all exposure concentrations. This alteration was accompanied by low incidence of renal tubular cell hyperplasia in male rats. Thus, a no-observed-adverse-effect level (NOAEL) for renal toxicity was not established in a lifetime bioassay.

Compound related kidney damage has been reported in animals after oral exposure. Daily administration of 1,000 mg/kg by gavage to male F344 rats for 10 days produced an increase in protein droplets correlated with an increased amount of α-2μ-globulin and peroxisomal proliferation; these effects were not seen in female rats. Male rats exposed to 1,500 mg/kg by gavage for 42 days developed male-specific nephropathy. Male B6C3F1 mice exposed to 1,000 mg/kg by gavage for 10 days had peroxisomal proliferation in the kidneys. Osborne-Mendel rats and B6C3F1 mice of each sex were exposed by gavage for 78 weeks, followed by observation periods of 32 weeks (rats) and 12 weeks (mice) in a carcinogenicity bioassay (NCI, 1977, as cited in USEPA, 1985). Average doses for the study were 536 and 1,072 mg/kg/day for male mice, 386 and 772 mg/kg/day for female mice, 471 and 941 mg/kg/day for male rats, and 474 and 949 mg/kg/day for female rats. Toxic nephropathy occurred at all dose levels in both sexes. The nephropathy was characterized by degenerative changes in the proximal convoluted tubules with cloudy swelling, fatty degeneration, and necrosis of the tubular epithelium and hyalin intraluminal casts. Thus, the lowest dose levels in this study (386 to 536 mg/kg/day for mice and 471 to 474 mg/kg/day for rats) produced nephrotoxicity.

Symptoms of renal dysfunction, including proteinuria and hematuria, have been associated with accidental exposure of humans to anesthetic concentrations of PCE vapor. Weak or no renal effects, depending on the parameters evaluated, were reported in people with chronic occupational exposure (average exposures of 10 to 21 ppm). No studies were found regarding renal effects in humans after oral exposure (ATSDR, 1993).

Mutti et al. (1992) recently evaluated a variety of parameters in blood (4) and urine (19) potentially indicative of kidney damage in PCE-exposed drycleaning workers (n=50) versus matched controls. PCE exposure was evaluated by measuring PCE in the workplace air (ranging from trace to 85 ppm, median = 15 ppm) and concomitant analysis of PCE in blood. Results showed significant differences between exposed and control groups for 2/4 blood parameters and 9/19 urinary parameters; however, the authors noted a lack of association between kidney dysfunction and duration of PCE exposure.

Liver

The hepatotoxic effects of PCE have been characterized in a number of laboratory studies. In general, fatty degeneration, enlargement, cellular vacuolization, and necrosis have been observed in rodents following inhalation or oral exposure for about 90 days or longer. Mice appear to be more susceptible to hepatotoxic effects than rats. In a 14-day inhalation study, male B6C3F1 mice exposed to 875 or 1,750 ppm had hepatocellular vacuolization; females exposed to the highest dose also showed this lesion. Liver lesions differed markedly between mice and rats after longer duration exposure. In a 13-week study (6 hours/day, 5 days/week), male mice exposed to 200 ppm and higher concentrations had mitotic alterations in the liver, while both sexes had leukocytic infiltrations, centrilobular necrosis, and bile stasis at 400, 800, and 1,600 ppm. Rats, however, had liver congestion at 200 ppm but no other lesions at any exposure concentration. Hepatocellular degeneration and necrosis occurred in male mice exposed to 100 and 200 ppm for 103 weeks and in females exposed to 200 ppm. Liver lesions were not reported in rats chronically exposed to these concentrations (NTP, 1986, as cited in ATSDR, 1993). The hepatic lesions in male mice were dose-dependent, and no NOAEL was established for the hepatotoxic effects.

Another shorter-term (30-day) inhalation study with NMRI mice showed liver effects at the lowest concentration, 9 ppm. Mice continuously (24 hours/day) exposed to 37, 75, or 150 ppm developed hepatocellular vacuolization and enlargement. Absolute liver weights were significantly elevated at exposure concentrations of 9 ppm and higher. Liver weights were still increased (10%) 120 days after exposure to the highest concentration. In another study with mice and rats, light microscopic and ultra-structural liver lesions were correlated with levels of cyanide-insensitive palmitoyl CoA oxidase, a marker for peroxisomal β-oxidation (ATSDR, 1993). Animals were exposed to 200 ppm for 28 days or 400 ppm for 14, 21, or 28 days. In all exposed mice, centrilobular hepatocellular vacuolization corresponded to lipid accumulation, and cytoplasmic eosinophilia corresponded to peroxisomal proliferation with a significant increase in the marker enzyme. Exposed male rats in both dosage groups and female rats at 400 ppm had hepatocellular hypertrophy but no increase in peroxisomes (ATSDR, 1993).

The lowest effective doses in the chronic exposure study and the shorter-term (30 day) inhalation study differ by approximately an order of magnitude. Nine ppm may be close to a NOAEL since no microscopic lesions were observed at this dose. The quantitative differences in the lowest effective dose between the two studies may be related to the length of exposure each day (6 versus 24 hours) and/or the strain of mice.

The liver is also a target organ in rodents after oral administration of PCE (ATSDR, 1993). Gavage doses of 1,000 mg/kg/day for 10 days to male B6C3F1 mice increased relative liver weights and elevated cyanide-insensitive palmitoyl CoA oxidase levels. The same dose given to F344 rats did not increase enzyme levels above controls, although relative liver weights increased. Toxic effects induced in male Swiss Cox mice by oral gavage at doses of 20, 100, 200, 500, 1,000, 1,500, or 2,000 mg/kg/day, 5 days/week, for 6 weeks, were increased relative liver weights and triglycerides beginning at 100 mg/kg/day, decreased glucose-6-phosphate and increased serum alanine aminotransferase at 500 mg/kg/day, and hepatic lesions. Lesions consisted of hepatocellular hypertrophy, karyorrhexis, necrosis, polyploidy, and vacuolization. The NOAEL for this study was 20 mg/kg/day.

The liver is a target organ in humans, particularly in those exposed in occupational settings. There have been two recent occupational exposure studies that reported subtle liver effects in PCE-exposed drycleaning workers (Gennari et al., 1992, and Brodkin et al., 1995). Gennari et al. found a statistically significant increase in total serum gamma glutamyltransferase (GGT) in PCE-exposed workers (n=141) versus controls (n=130) drawn from unexposed university staff/students with a similar age/sex composition. A similar difference was not observed in other enzyme levels measured (alkaline phosphatase [ALP], lactic acid dehydrogenase [LDH], aspartate aminotransferase [AST], alanine aminotransferase [ALT], and 5'-nucleotidase [5'-NU]). Also, none of the workers showed any clinical signs of liver disease. The reported levels of PCE in the workplace air on the day the blood samples were drawn was 11.3 ppm ± 4.0 ppm.

Brodkin et al. (1995) report a new technique (ultrasonography) to assess subclinical liver toxicity in PCE-exposed workers. The authors compared the ultrasonographic results with the results of traditional liver function tests (serum measurements of ALT, GGT, AST, and ALP). Results suggest that ultrasonography, in which parenchymal changes were noted, was more sensitive than the serum liver enzyme levels in showing a difference between exposed drycleaning operators (n=29, mean PCE exposure = 16 ppm) and non-exposed laundry workers (n=29).

Saland (1967) reported on nine firemen who were exposed to high concentrations of PCE fumes for approximately 3 minutes in the cellar of a drycleaning facility. Transient increases in SGOT (8/9), decreases in white blood count (3/9), and hepatomegaly (1/9) were observed.

There is only one report of adverse effects on the liver from oral ingestion in humans; obstructive jaundice and hepatomegaly were reported in an infant exposed via breast milk (ATSDR, 1993). The concentrations that produced hepatotoxic effects in the infant are not known.

Other Effects

Osborne-Mendel rats received PCE in corn oil by gavage at doses of 316, 562, 1,000, 1,780, or 3,160 mg/kg for 6 weeks. Deaths (number unspecified) occurred in both males and females at the two highest doses but not at 1,000 mg/kg or lower (NCI, 1977, as cited in ATSDR, 1993). In a 14-day inhalation exposure study, mortality occurred in rats exposed to 1,750 ppm but not in mice. Compound related mortality did not occur in either species at exposure concentrations of 875 ppm or lower. In a 13-week inhalation study, mortality occurred in rats and mice exposed to 1,600 ppm but not to concentrations of 800 ppm or lower (NTP, 1986, as cited in ATSDR, 1993).

There have been case reports of cardiovascular, immunologic, or respiratory toxic effects in humans. For the first two systems, alternative explanations preclude evaluating the significance of the findings in the case reports. Respiratory irritation appears to occur in humans exposed to concentrations of PCE as low as 216 ppm for 45 minutes to 2 hours (ATSDR, 1993).

Neurotoxicity

The brain is a major target organ in humans exposed to PCE by inhalation. It is generally agreed that acute exposure to high concentrations can result in narcosis (Regulatory Toxicology and Pharmacology, 1994) and other reversible mood and behavioral changes, (Coler and Rossmiller, 1953; Lob, 1957; Eberhardt and Freundt, 1966; Gold, 1969; Stewart, 1969; Bagnell and Ellenberger, 1977, all as reported in USEPA, 1985). No behavioral effects were reported in humans after exposure to 106 ppm for 1 hour, and symptoms of dizziness and drowsiness were reported after exposure to 216 ppm for 45 minutes to 2 hours. Coordination was impaired after exposure to 280 ppm for 2 hours or 600 ppm for 10 minutes (see USEPA, 1985).

More recent human studies have supported earlier findings with animals indicating that chronic exposure to low doses of PCE may have adverse effects on the nervous system. Stewart et al. (1981) and Hake and Stewart (1977, as cited in ATSDR, 1993) found that electroencephalogram (EEG) responses reflect a very sensitive measure of central nervous system depression. These controlled studies in healthy human adults indicate significant EEG effects following PCE exposures of 100 ppm for 7.5 hours/day over 5 days; and no effects following PCE exposures of 20 ppm for 7.5 hours/day over 5 days. In a clinical study of 65 drycleaning personnel, Echeverria et al. (1995) reported neurobehavioral deficits after 3 or more years of exposure to concentrations below 50 ppm. Deficits were seen on behavioral tasks designed to measure frontal and limbic lobe functions of the brain.

Concentrations between 216 and 1,000 ppm PCE over varying exposure durations result in reports of dizziness, faintness, headache and nausea (see ATSDR, 1993). Collapse, coma, and seizures have occurred following exposure to higher concentrations of PCE fumes, such as 2,000 ppm after as little as 5 to 7 minutes (Carpenter, 1937; Hake and Stewart, 1977; Morgan, 1969; all as cited in ATSDR, 1993).

Animal studies have reported similar neurological effects of inhaled PCE. At high concentrations (greater than 1,750 ppm), effects of hyperactivity, ataxia, hypoactivity, and loss of consciousness have been reported in rodents (Friberg et al., 1953; NTP, 1986; Rowe et al., 1952, all as reported in ATSDR, 1993).

Developmental/Reproductive Toxicity

Most of the information presented in this section was obtained from review documents prepared by USEPA (USEPA, 1985, 1988) and other organizations (ATSDR, 1993). This report focuses on the effects of PCE via inhalation, as this route is of primary concern for human exposure.

Available human data have been inconclusive with regard to the potential of PCE exposure to cause developmental and reproductive toxicity. In animals, however, PCE was shown to be developmentally toxic by causing decreased fetal body weights in mice (altered growth) and increased resorptions in rats (death of the developing organism) exposed by inhalation at the only dose tested, 300 ppm.

Human Data

Some of the available human data suggest that occupational exposure to PCE in the drycleaning industry may be associated with adverse developmental/reproductive effects (e.g., an increase in spontaneous abortions and menstrual disorders). Other studies have been unable to find any such association. Due to the discrepancy in findings and the numerous limitations associated with these studies (i.e., small sample populations, failure to account for confounding factors, poor or no exposure data, inadequate study methodology, etc.) no definitive conclusions can be drawn.

Eskenazi et al. (1991a) compared the reproductive outcomes of wives of men exposed to PCE in the drycleaning industry with wives of laundry workers. The numbers of pregnancies, the standardized fertility ratios, and the rates of spontaneous abortions were similar for both groups, after consideration of a variety of possible contributing factors. Wives of drycleaners did have a slightly longer time to conception compared with the wives of laundry workers, but inadequate sample size and broad exposure indices prevent definite conclusions from being drawn. Sallmen et al. (1995) reported a similar effect, defined as the number of menstrual cycles that occurred prior to a desired pregnancy, in women exposed to drycleaning solvents, including PCE.

Subtle changes in semen quality were noted in specimens from drycleaning workers compared with those from laundry workers (Eskenazi et al., 1991b). On average, standard clinical measurements showed that the drycleaners' semen was within normal limits. However, sperm of drycleaners were significantly more likely to be round and less likely to be narrow. These effects were related to expired air levels of PCE and to an exposure index based on job tasks. Also, sperm of drycleaners tended to swim with greater amplitude of lateral head displacement (a finding that correlated with expired air levels of PCE). The authors concluded that additional studies are required to determine whether these changes are associated with changes in fertility.

A small scale exploratory study described menstrual disorders in drycleaning workers (Zielhuis et al., 1989, as cited in ATSDR, 1993). Limitations of the study include lack of exposure measurement data, methodological problems (self-administered questionnaire with no follow-up, and failure to account for various confounding factors such as smoking, alcohol consumption, and medicinal drugs), and a relatively small study population.

Several recent case control studies of female drycleaning workers in Nordic countries suggest that these women had an increased risk of spontaneous abortion (Ahlborg, 1990; Kyyroenen et al., 1989; both as cited in ATSDR, 1993). Limiting factors include a low number of pregnancies among exposed women (Ahlborg, 1990), as well as a small group of exposed affected workers and biological monitoring not concurrent with the first trimester of pregnancy (Kyyroenen et al., 1989).

Olsen et al. (1990) conducted a combined analysis of data from Norway, Sweden, Denmark, and Finland, which includes data from the Ahlborg and Kyyroenen et al. studies mentioned above. They used meta-analysis (a statistical procedure which combines quantitative results across studies) and other statistical procedures to evaluate the data. Practical problems, however, caused several differences in the study design and precluded use of a common Nordic study protocol. Risks for reproductive failures in relation to births (congenital malformations, still births, and low birth weights) showed no elevated risk related to exposure in the studies from Sweden, Norway, or Finland when analyzed together. The relative risk (odds ratio) was significantly elevated for all types of reproductive failures combined (reproductive failures in relation to births plus spontaneous abortions) for the high exposure group (drycleaning plus spot removal at least 1 hour/day) for Sweden, Denmark, and Finland combined, and for spontaneous abortions in the high exposure group for Finland only. Because of the low plant participation rate for Sweden, Norway and Finland combined (54%), inability to control for various lifestyle factors known to influence pregnancy outcome, and the questionable utility of combining data sets in the meta-analysis (i.e., heterogeneity of the studies with respect to their design, methodology, cohort selection, exposure criteria, endpoints, sample sizes, etc.), interpretations of these findings should be viewed with caution.

Spontaneous abortions and birth defects occurred at a higher incidence in Italian drycleaning workers than in housewives, but this difference was not statistically significant (Bosco et al., 1987, as cited in ATSDR, 1993). No increase in spontaneous abortion rates for laundry and drycleaning workers in Canada was detected in a cross-sectional study (McDonald et al., 1986, as cited in ATSDR, 1993).

Animal Data

Several studies on the developmental and reproductive toxicity of perchloroethylene (PCE) have been found. In one of these studies, PCE caused a statistically significant decrease in fetal body weights in mice, and increased resorptions in pregnant rats exposed to 300 ppm PCE for 7 hours/day on gestation days 6-15 (Schwetz et al., 1975). Although this is a single-dose study, the slight maternal toxicity (slightly reduced body weight gain) seen indicates that the dose was not excessively high.

Another developmental toxicity study in rats showed, in the absence of maternal toxicity, a statistically significant reduction of body weight plus excess skeletal and soft tissue variations in fetuses of dams exposed to 1,000 ppm (Tepe et al., 1982, as cited in USEPA, 1985).

Hardin et al. (1981, as cited in ATSDR, 1993) evaluated the developmental toxicity for a selected group of chemicals using a single concentration of 500 ppm PCE in Sprague Dawley rats and New Zealand white rabbits, exposed 6-7 hours/day on gestation days 1-19 and 1-24, respectively. There was no evidence of feto/maternal toxicity; however, the study had limitations. It used only one dose level, and portions of the study were done in different laboratories.

Narotsky and Kavlock (1995) tested nine pesticides, solvents, and industrial chemicals, in timed-pregnant Fischer 344 rats given PCE once daily by gavage at doses of 0, 900, or 1,200 mg/kg/day on gestation day 6-19. Litters delivered by dams were examined on postnatal day 1, 3, and 6. All compounds exhibited dose-related maternal toxicity as manifested by alterations in weight gain. Observed developmental effects for PCE consisted of micro-/anophthalmia (eye defects), dose-related full-litter resorption, delayed parturition, increased post-natal losses, and reductions in fetal weights. The authors state this is the first report of developmental malformations for PCE, although previously reported studies used doses not shown to be maternally toxic. In this study, PCE produced developmental toxicity at doses that were also maternally toxic. However, full-litter resorption was not observed with other chemicals tested in the presence of maternal toxicity, and therefore the authors suggest there may not be a causal relationship, for PCE, between maternal and developmental effects.

Moreover, the data are consistent with effects observed in Long Evans rats when trichloroacetic acid, a metabolite of PCE, was administered by gavage at doses of 0, 330, 800, 1,200, and 1,800 mg/kg/day

(Smith et al., 1989, as cited in Davidson and Beliles, 1991). In that study, the authors concluded the lowest-observed-adverse-effect level (LOAEL) for developmental toxicity to be 300 mg/kg/day, based on effects such as full-litter resorption, cardiac malformations, and micro-/anophthalmia. Given this, Narotsky and Kavlock (1995) suggested that trichloroacetic acid may be the primary developmental toxicant associated with PCE exposure.

Two studies on the reproductive toxicity of PCE have been found. Carpenter (1937), as cited in ATSDR (1993), exposed rats to 70, 230, and 470 ppm PCE by inhalation for 28 weeks. Although this study has numerous limitations, including nonstandard protocols and inadequate controls, no adverse effects on reproductive performance, as measured by the number of pregnancies, numbers of litters conceived, and number of offspring per litter, were observed.

The second study is a reproductive toxicity study of PCE by the inhalation route (Tinston, 1995). Initially, groups of 24 male and female F_0 parental Sprague Dawley rats were exposed for 6 hours/day to 0, 100, 300, or 1,000 ppm PCE vapor. Prior to being housed for mating, the rats were exposed to these dosages 5 days/week for 11 weeks and were then exposed daily for up to 21 days. Following mating, males and females were exposed daily until termination and gestation day 20, respectively. An F_1A litter was produced from the first generation by daily exposure of dams and their litters to the dosages on post-partum day 6-29, at which time a second generation of parents, F_1, was selected and then subsequently exposed to the same dosages of PCE 5 days/week for 11 more weeks prior to mating.

Three additional litters were produced from the F_1 parental matings, F_2A, F_2B, and F_2C. Each of these three litters were exposed to different dosing regimes. Dams and litters from the F_2A litter were exposed during lactation on post-partum day 6-29 to 0 and100 ppm or on post partum day 7-20 to 300 ppm. No exposure was conducted at the 1,000 ppm dose level. The F_2B dams and their litters, which were obtained from mating the control, 300, and 1,000 ppm dose groups of the F_1, were not exposed to PCE during lactation. The F_2C litter was produced by mating males in both the control and 1,000 ppm dose groups with unexposed females.

A LOAEL of 300 ppm for adult toxicity was established based on central nervous system depression, decreased respiration rate during or immediately following exposure, decreased parental body weight gain, increased kidney weight with associated histopathological effects, and increased absolute liver weight. In addition, the effect on kidney and liver weights was more pronounced in adult males.

A LOAEL of 300 ppm was indicated for reproductive toxicity based on statistically significant reductions in number of live births, litter sizes, post-natal survival indices, and pup and testis weight.

Mutagenicity

Available data on PCE have not clearly demonstrated it to be mutagenic (USEPA, 1985, 1991). Most of those data indicate that it is not mutagenic, or at most weakly mutagenic. It is believed that certain commercial or technical preparations of PCE may contain mutagenic impurities and/or stabilizers that contribute to the mutagenicity of PCE under test conditions.

However, available data on metabolites (perchloroethylene epoxide, trichloroacetaldehyde, dichloroacetaldehyde, monochloroacetaldehyde, trichloroacetic acid, S-(1,2,2-trichlorovinyl) glutathione) of PCE indicate that these metabolites are mutagenic.

Carcinogenicity

Human Data

A variety of epidemiologic studies have been carried out in occupational and residential populations. Most of these studies have been conducted in populations exposed to a mixture of solvents, making it difficult to ascribe the results to PCE alone. In addition, limitations in the study designs, exposure characterization, impact of potential confounding factors (e.g., smoking, alcohol consumption, ethnicity, and socioeconomic status) and statistical considerations (e.g., having multiple endpoints) make these studies inadequate overall for establishing a causal relationship between PCE exposure and cancer in humans.

Occupational Studies

USEPA (1985) reviewed a number of occupational studies (Blair et al., 1979; Duh and Asal, 1984; Kaplan, 1980; Katz and Jowett, 1981; and Lin and Kessler, 1981; all as cited in USEPA, 1985); however, only the Kaplan (1980) study could verify exposure to PCE. The 1985 USEPA review acknowledged an association between cancer and employment in the drycleaning industry, but the lack of PCE-specific exposure information precluded identifying PCE as a causative agent. A more recent review of the epidemiologic studies of PCE also concluded that they provide inadequate evidence for an increased cancer risk associated with PCE (ATSDR, 1993).

Since the ATSDR review was completed, at least one epidemiologic study has been updated. In the original report, its overall cohort (i.e., 1,690 drycleaning workers exposed to PCE as well as other solvents) had a significant excess of mortality from bladder, kidney, and cervical cancer, the latter being attributed to the low socioeconomic status of the cohort (Brown and Kaplan, 1987, as reported in ATSDR, 1993). A subcohort of 615 workers employed only in shops where PCE was the primary solvent (referred to as the PCE-only cohort), were not found to be at any increased risk for cancer mortality at any site analyzed. In an 8-year follow-up (Ruder et al., 1994), statistically significant excesses of bladder, esophageal, and intestinal cancer deaths were observed in the overall cohort. In the PCE-only subcohort, no increases in mortality were identified for any cancer site. When duration (greater than or equal to five years' employment) and latency (greater than or equal to 20 years from first exposure to diagnosis of disease) were considered in the analysis, however, a significant excess of esophageal cancer was noted in the subcohort (Ruder et al., 1994). Although smoking and alcohol are both potential risk factors for esophageal cancer, the investigators failed to determine the smoking and alcohol habits of the cohort. The authors indirectly explored the possible influence of these confounding factors and concluded that they were not important, based largely on the low lung cancer mortality rates and the low liver cirrhosis rates; both of which would have been expected to be higher if either heavy smoking or heavy alcohol use were involved. Coupled with other study weaknesses, such as the lack of quantitative exposure information, these confounding factors limit the interpretation of the findings.

Finally, IARC (1995) recently reviewed the cancer epidemiology on PCE alone, and the drycleaning industry as an occupation. IARC concluded there was limited evidence in humans for the carcinogenicity of PCE, based on studies showing elevated risks for esophageal cancer, non-Hodgkin's lymphoma, and cervical cancer (IARC, 1995).

Residential Studies

A study conducted among Upper Cape Cod, Massachusetts, residents exposed to PCE-contaminated well water (Aschengrau et al., 1993) explored the relationship between exposure and the incidence of bladder and kidney cancers and leukemia. The authors noted an elevated relative risk for both leukemia (with and without consideration of latency) and bladder cancer (without consideration of latency) among "ever-exposed" subjects as compared to a control group. However, these results are difficult to interpret due to poor exposure measurements/modeling and the lack of substantial differences in exposure between the cases and controls.

Animal Data

The evidence of carcinogenicity of PCE is based primarily on the results of two long-term bioassays in rodents. An earlier study conducted by NCI (1977, as cited in USEPA, 1985) reported increased hepatocellular carcinomas in male and female mice following PCE exposure by gavage. In a more recent bioassay by inhalation (NTP, 1986, as cited in ATSDR, 1993), there were also significantly increased incidences of liver tumors in male and female mice exposed to PCE. In addition, marginally increased incidences of mononuclear cell leukemia were found in male and female rats; low incidences of kidney tumors occurred in treated male rats.

In the gavage study (NCI, 1977), groups of 50 Osborne-Mendel rats and 50 B6C3F1 mice of each sex were exposed to PCE in corn oil 5 days/week for 78 weeks, followed by observation periods of 32 weeks (rats) and 12 weeks (mice). Time weighted average (TWA) doses were 471 or 941 mg/kg/day for male rats, 474 or 949 mg/kg/day for female rats, 536 or 1,072 mg/kg/day for male mice, and 386 or 772 mg/kg/day for female mice. Groups of 20 untreated and vehicle-treated rats and mice of each sex served as controls. PCE induced a statistically significant increase in the incidence of hepatocellular carcinomas in both high- and low-dose male and female mice. Incidences in the untreated control, vehicle control, low-dose, and high-dose groups were 2/17, 2/20, 32/49, and 27/48, respectively, in male mice, and 2/20, 0/20, 19/48, and 19/48, respectively, in female mice. No increases in tumor incidences were observed in treated rats. However, the rat study was deemed inconclusive because of high mortality of the animals.

In the inhalation study (NTP, 1986), groups of 50 F344/N rats of each sex were exposed to 0, 200, or 400 ppm PCE, and groups of 50 B6C3F1 mice of each sex were exposed to 0, 100, or 200 ppm PCE. Exposures were 6 hours/day, 5 days/week, for 103 weeks. Increased incidences of mononuclear cell leukemia were found in the treated male rats (28/50 in controls, 37/50 at low dose, 37/50 at high dose) and female rats (18/50 in controls, 30/50 at low dose, and 29/50 at high dose). The increased incidences in the males were borderline significant; the increases in females were clearly significant. Low incidences of renal tubular cell adenomas or adenocarcinomas (1/49, 3/49, 4/50) occurred in male rats. The kidney tumor incidence was not statistically significant; however, such tumors are rare in control F344/N rats. In mice, there were significantly increased incidences of hepatocellular carcinomas in males (7/49, 25/49, 26/50, respectively) and in females (1/48, 13/50, 36/50, respectively).

Overall Evidence

Based on these bioassay data, which show increased incidences of tumors at three different sites and in two animal species, together with its evaluation of several epidemiological studies including Ruder et al. (1994), IARC (1995) classified PCE as a group 2A carcinogen; i.e., probably carcinogenic to humans.

Although PCE increased the incidence of tumors at three different sites and in two rodent species, controversy surrounds each of the tumor endpoints regarding their relevance to humans. Mononuclear cell leukemia is a common tumor that occurs spontaneously in F344/N rats. Furthermore, mononuclear cell leukemia is a rodent-specific tumor with no human correlate. Therefore, the biological significance of the marginally increased incidences of mononuclear cell leukemia observed in rats is considered by some to be questionable. Subsequent studies on the mechanisms of PCE carcinogenesis have suggested that the mouse liver tumors and male rat kidney tumors observed in the bioassays may be species specific; uncertainties exist regarding their relevance to humans.

In both carcinogenicity bioassays of PCE, a significant increase in hepatocellular carcinoma was observed in male and female mice but not rats. Based on species differences in metabolism of PCE to trichloroacetic acid and in hepatic peroxisome proliferation between rats and mice, it has been suggested that PCE-induced hepatic carcinogenesis may be related to peroxisome proliferation and toxicity of trichloroacetic acid (Odum et al., 1988, as cited in ECETOC, 1990). As human liver cells are even less efficient metabolizers of PCE (to trichloroacetic acid) than rats and are generally unresponsive to peroxisome proliferating agents, it would be unlikely that PCE exposure could lead to liver cancer in humans if this is the mechanism of action in mice.

Several studies have sought an explanation for the kidney tumors seen in male rats exposed to PCE. Male rats given high doses of PCE by gavage have been found to accumulate the protein α-2μ-globulin in renal proximal tubular cells and to exhibit the features of protein droplet nephropathy. The strong correlation between this toxic effect and kidney tumor formation specifically in male rats has led to the suggestion that this is the mechanism responsible (Goldsworthy et al., 1988, as cited in USEPA, 1991). Evidence of a minor metabolic pathway for PCE, which may be related to the development of kidney tumors, has also been reported. A glutathione-β-lyase conjugation pathway of PCE metabolism has been discovered in rodents. This minor pathway leads to the formation of a cytotoxic/mutagenic metabolite, 1,2,2-trichlorovinylcysteine (TCVC). The detection of low levels of TCVC in the urine of workers exposed to PCE in a recent study (Birner, 1996) appears to indicate that this glutathione-dependent bioactivation of PCE is operative in humans.

While there is some evidence to support each of the proposed mechanisms, there are also quantitative and qualitative gaps in the supporting data (USEPA, 1991). Several other mechanisms may contribute to the carcinogenicity of PCE. Although mutagenicity data are predominantly negative for the parent compound, the possibility that there may be mutagenic metabolite(s) of PCE in the development of tumors cannot be entirely ruled out. Since the mechanisms of PCE carcinogenesis are not clearly understood, USEPA has considered the inclusive animal data for PCE, taken as a whole, to be sufficient evidence for classifying PCE as a group B2 substance (probable human carcinogen) (USEPA, 1991).

The Health Assessment Document for PCE (USEPA, 1985) and its Addendum (USEPA, 1986) were reviewed by USEPA's Science Advisory Board (SAB), which subsequently also considered USEPA's response to the mechanistic data and issues of PCE (USEPA, 1991). The SAB expressed the view that the PCE evidence falls on the continuum from group C (possible human carcinogen) to group B2 (probable human carcinogen). These positions were expressed prior to the publication of epidemiological studies (particularly, Anttila et al., 1995; Ruder et al., 1994; both as cited in IARC, 1995) that IARC (1995) recently reviewed. Anttila et al. (1995) does not appear to add statistically significant elevations to the evidence; while Ruder et al. (1994), as discussed earlier in this section, saw significant duration and latency-related incidence of esophageal cancer, limitations remained in their conclusions. IARC, however, considered the pattern of endpoints to be important, despite the individual lack of statistical significance of some of them. Meanwhile, the view of USEPA's SAB was framed to encompass a concern for high PCE exposures, which is consistent with the uncertainties regarding the modes of action associated with the several tumor types.

C.1.2 Hydrocarbon Solvents

A variety of hydrocarbon solvents (e.g., Stoddard solvent, 140°F solvent, naphtha, and DF-2000, to name a few) may be used as drycleaning agents. Each solvent is a unique mixture of carbon and hydrogen molecules that co-exist as linear and branched chains, as well as in cyclic forms. In this CTSA, hazard data are presented on Stoddard solvent, which is assumed to qualitatively represent the hazard of the other, similar solvents used in drycleaning.

Summary

The information presented on Stoddard solvent is based primarily on ATSDR (1995). In humans, Stoddard solvent has been shown to be an irritant to eyes, skin, and mucous membranes (the membranes lining all bodily channels that communicate with the air, such as the nose and throat). Neurological effects (i.e., headaches, the feeling of euphoria, color blindness, cerebral atrophy, memory deficits, and fatigue) have been observed in humans occupationally exposed to Stoddard solvent either by breathing or skin contact; however, these studies contain poor exposure information and multiple solvent exposures, making it difficult to draw any definitive conclusions.

Limited information prevents any conclusions regarding developmental/reproductive toxicity. A study of individuals with prostate cancer, lung cancer, and Hodgkin's lymphoma suggested associations of those cancers with chronic inhalation exposure to mineral spirit, an often used synonym for Stoddard solvent. Interpretation of these findings is limited, however, and no other studies of human experience have been located.

The primary toxic effects following acute exposures to high concentrations of Stoddard solvent in animals (observed variously in rats, dogs, and cats) consist of eye irritation, irritation to the upper membranes of the respiratory tract, salivation, loss of coordination, muscle spasms, tremors, convulsions, and death. Skin contact has been associated with skin irritation in rabbits and guinea pigs.

One study in which Stoddard solvent together with two other components was applied to the skin of mice repeatedly over their lifetime showed some skin cancers. This result can not be attributed solely to the Stoddard solvent. Stoddard solvent does not appear to be mutagenic in bacteria or in mammalian systems. Kidney effects were observed in exposed male rats but were not considered to be clinically relevant to humans.

Absorption/Metabolism

Very limited data are available concerning the pharmacokinetics of Stoddard solvent. Stoddard solvent is readily absorbed by inhalation based on the results of two studies dealing with the kinetics of Stoddard solvent in human volunteers (Pedersen et al., 1984, 1987, both as cited in ATSDR, 1995). The calculated pulmonary uptake from humans (eight males) exposed to 600 mg/m^3 (about 100 ppm) for 3 hours was approximately 400 mg (133 mg/hour) (Pedersen et al., 1984). Stoddard solvent was detected in the blood and subcutaneous fat. The estimated mean half-life in fat, associated with this single short-term exposure, was 2 days. Using a multi-compartmental analysis (simulated model) of the data obtained from blood and fat samples of seven male volunteers exposed to 600 mg/m^3 Stoddard solvent 6 hours/day for 5 consecutive days, the authors estimated minimum and maximum steady-state concentrations of Stoddard solvent in the brain to be 0.6 and 5-11 mg/kg, respectively (Pedersen et al., 1984, 1987). The half-life was estimated to be 18-19 hours in the brain and 7 days in fat (Pedersen et al., 1984).

Although there are no data on the oral absorption rate of Stoddard solvent, it is known that other petroleum distillates with longer carbon chains, such as kerosene (C_{10}-C_{16}), are very poorly absorbed from the gastrointestinal tract (Dice et al., 1982; Mann et al., 1977; Wolfsdorf and Kundig, 1972, all as cited in USEPA, 1993), whereas gasoline, a smaller chain petroleum distillate (C_4-C_{12}), appears to be relatively completely absorbed (NESCAUM, 1989). The smaller (C_9-C_{11}), alkane or aromatic hydrocarbons (10-20% in Stoddard solvent) may be absorbed readily (Litovitz and Greene, 1988). The rate and extent of gastrointestinal absorption of Stoddard solvent would, therefore, likely be dependent on the lipophilicity and size of various components and the amount of food in the stomach (USEPA, 1993).

No information on the absorption following dermal exposure was located. However, Stoddard solvent (absorbed dose of 210 mg) applied to the tails of rats daily for 6 weeks was associated with axonal prenodal swelling, an indication that dermal absorption had occurred (Verkkala et al., 1984).

Elevated levels of dimethylbenzoic acid (a marker of exposure) were found in the urine of men occupationally exposed to Stoddard solvent mist (Pfaffli et al., 1985), and in rats dermally exposed by daily applications to their tails for 6 weeks (Verkkala et al., 1984), showing that this solvent is indeed metabolized.

Acute Toxicity

An acute inhalation LC_{50} greater than 5,500 mg/m^3 and an acute oral LD_{50} greater than 5 g/kg have been estimated for rats (Vernot et al., 1990, as cited in ATSDR, 1995). An acute dermal LD_{50} in rabbits was reported to be greater than 3 g/kg (Vernot et al., 1990, as cited in ATSDR, 1995). The primary symptoms observed in animals consist of eye irritation, irritation to the upper membranes of the respiratory tract, salivation, loss of coordination, clonic spasms, tremors, convulsions, and death. No additional data have been located pertaining to the potential oral or dermal toxicity of Stoddard solvent in animals.

Groups of 15 rats inhaled various concentrations (420 to 1,400 ppm) of Stoddard solvent for single 8 hour periods followed by either immediate necropsy (n=5) or necropsy after 14 days of observation (n=10) (Carpenter et al., 1975a, 1975b). Effects observed in rats exposed to 1,400 ppm (8,000 mg/m^3) included loss of coordination, eye irritation, and bloody exudate around the nostrils. Similar signs, without loss of coordination, were observed at 800 ppm (4,600 mg/m^3). No effects were observed during or after exposure at 420 ppm (2,400 mg/m^3). A female dog exposed to 1,400 ppm (8,000 mg/m^3) Stoddard solvent for 8 hours displayed eye irritation at 1 hour, increased salivation at 3 hours, tremors at 4 hours, and clonic spasms at 5 hours, whereas a second female dog exposed to the same level under the same conditions was asymptomatic during and after exposure (Carpenter et al., 1975a, 1975b).

Histopathological changes in the nasal cavity, trachea, and larynx were observed in three rats exposed to atmospheric levels of 214 mg/m^3 Stoddard solvent (a level selected to represent one half the TLV of 525 mg/m^3 for Stoddard solvent) 4 hours/day for 4 days compared to no changes in the control (Riley et al., 1984, as cited in ATSDR, 1995).

Irritation/Sensitization

In humans, Stoddard solvent is an irritant to the eyes, mucous membranes, and skin. One of six human volunteers exposed to 850 mg/m^3 (150 ppm) Stoddard solvent vapors for 15 minutes/day for 3 days experienced slight eye irritation (Carpenter et al., 1975a, 1975b); all subjects experienced eye irritation following exposure to 2,700 mg/m^3 (470 ppm). Additionally, one subject exposed to 2700 mg/m^3 showed throat irritation; two volunteers experienced slight dizziness at this concentration. No eye or throat irritation was seen in the subjects after exposure to 140 mg/m^3 (24 ppm). Minor irritation was reported in 50 male volunteers exposed to 600 mg/m^3 Stoddard solvent; however, there was no observable difference between cases and controls with respect to eye-blink rate, swallowing rate, or respiration rate (Hastings et al., 1984).

One man working with Stoddard solvent in a drycleaning factory, who had his forearms and hands wetted with or immersed in the solvent, developed follicular dermatitis of the exposed skin after 2 weeks (Braunstein, 1940), and a positive skin sensitization response to Stoddard solvent was observed. Five men wearing coveralls damp from drycleaning with Stoddard solvent developed sores on their genitals and buttocks (Nethercott et al., 1980, as cited in ATSDR, 1995). The limited information makes it impossible to determine whether Stoddard solvent is a cause of contact dermatitis in humans.

Stoddard solvent has been classified as a moderate irritant to the skin in rabbits (Vernot et al., 1990, as cited in ATSDR, 1995). Dermal exposure to Stoddard solvent, three times daily for 3 days, resulted in skin irritation in guinea pigs as evidenced by an increase in mean epidermal thickness, visible redness, palpable induration, and evident swelling (Anderson et al., 1986, as cited in ATSDR, 1995). A dermal sensitization study in guinea pigs did not show positive results (Vernot et al., 1990, as cited in ATSDR, 1995); the details of this study are not clear.

Subchronic/Chronic Toxicity

There have been a few case reports associating occupational exposure to Stoddard solvent (boiling point 150-200°C) and other higher-boiling-point petroleum distillates with the development of aplastic anemia (Prager and Peters, 1970, and Scott et al., 1959, both as cited in ATSDR, 1995), but no epidemiological studies appear to have been done.

A young man (29 years old), exposed to direct dermal contact and inhalation of Stoddard solvent 6 hours a day for 1 year, developed glomerulonephritis (Daniell et al., 1988, as cited in ATSDR, 1995). Exposure concentrations were not reported. This isolated case report is inadequate for assessing the risk of kidney effects.

No hepatic effects were observed in a laboratory study of 12 men exposed to 610 mg/m^3 of vaporized Stoddard solvents for 6 hours (Pedersen et al., 1984, as cited in ATSDR, 1995), or among a group of house painters compared to controls (Hane et al., 1977, as cited in ATSDR, 1995).

No statistically significant differences were observed in dogs exposed to 480, 1,100 or 1,900 mg/m^3 (84, 190, and 330 ppm, respectively) of Stoddard solvent for 6 hours/day, 5 days/week for 13 weeks compared to controls (Carpenter et al., 1975a, 1975b). Nephropathic effects (i.e., kidney damage) have been observed in groups of 25 male rats exposed to up to 1,900 mg/m^3 (330 ppm) of Stoddard solvent for 13 weeks (Carpenter et al., 1975a, 1975b). This type of “hydrocarbon nephropathy” appears to be unique to the male rat (Alden, 1986, and Rothman and Emmett, 1988, both as cited in ATSDR, 1995).

Neurotoxicity

A number of studies have reported neurological findings in humans who have been chronically exposed to Stoddard solvent via the inhalation or dermal routes at the workplace; however, details of exposure concentrations and/or exposure duration were not reported. In addition, workers were often exposed to other solvents, making it difficult to identify which solvent (or combination of solvents) may be responsible for the neurological effects. Neurological effects that have been reported include bifrontal headaches and the feeling of euphoria (Daniell et al., 1988, as cited in ATSDR, 1995), color blindness (Mergler et al., 1988, as cited in ATSDR, 1995), cerebral atrophy (Mikkelsen et al., 1988, as cited in ATSDR, 1995), memory deficits, and fatigue (Arlien-Soberg, et al. 1979; Flodin et al., 1984; Gregersen et al., 1984; and Hane et al., 1977, all as cited in ATSDR, 1995; Olson, 1982). Gregersen (1988) has also reported significantly more symptoms of chronic encephalopathy, in particular memory and concentration impairment in a group of solvent-exposed workers (n=59) compared to controls (n=30).

Exposure of eight male volunteers to 4,000 mg/m^3 (about 698 ppm) Stoddard solvent vapor for 50 minutes resulted in a prolonged reaction time and a possible impairment of short-term memory in performance tests (Gamberale et al., 1975). These men (plus six others) remained unaffected by exposure to 625, 1,250, 1,850 and 2,500 mg/m^3. Human subjects exposed to 2,400 mg/m^3 (419 ppm) Stoddard solvent for 30 minutes displayed no problems with visual-motor tasks (Hastings et al., 1984). No adverse systemic, immunological, or neurological effects were observed in human subjects exposed to 570 mg/m^3 (about 100 ppm) Stoddard solvent for 6 hours/day for 5 days (Pedersen et al., 1987, as cited in ATSDR, 1995).

Incoordination at 8,200 mg/m^3, and tremors and convulsions at 8,000 mg/m^3 were observed in rats and dogs, respectively, exposed for 8 hours (Carpenter et al., 1975a, 1975b; for more details see acute section above). Exposure of cats to 10,000 mg/m^3 (1,700 ppm) Stoddard solvent for 2.5 to 7.5 hours resulted in slowed reaction to light at 20 minutes, tremors at 26 to 74 minutes, clonic convulsions at 1.75 to 7.5 hours, and deaths at 2.5 to 7.5 hours (Carpenter et al., 1975a, 1975b); only one concentration was examined.

Developmental/Reproductive Toxicity

Sperm counts, motility, and morphology measured over a period of 2 months were normal in 11 men occupationally exposed to a mixture of organic solvents, including 50 ppm Stoddard solvent, in a printing factory (Tuohimaa and Wichmann, 1981, as cited in ATSDR, 1995).

No signs of toxicity were exhibited in fetuses of three groups of 20 to 27 female rats exposed from day 6 to 15 of gestation, 6 hours/day, to Stoddard solvent at concentrations from zero to 2,356 mg/m^3 (400 ppm) (API, 1977, as cited in ATSDR, 1995). No embryonic or teratogenic effects were seen in mated female rats exposed to 100 or 300 ppm Stoddard solvents 6 hours/day by inhalation from day 6 to day 15 of gestation (Phillips and Egan, 1981). Pregnancy rates, implantation efficiency and rates, and fetal deaths for female rats mated to fertile male rats exposed to 100 or 300 ppm Stoddard solvent 6 hours/day, 5 days/week for 8 consecutive weeks prior to mating, were comparable to those of controls (Phillips and Egan, 1981). No further information is available regarding exposures to Stoddard solvent and reproductive/developmental effects in animals or humans.

Mutagenicity

Based on data derived from several types of assays, Stoddard solvent does not appear to be mutagenic in bacteria or in mammalian systems. Stoddard solvent has been tested for genotoxic potential in several *in vitro* assays (two Ames tests, two mouse lymphoma tests, and a chromosomal aberration assay using human peripheral lymphocytes), and *in vivo* assays (mouse micronucleus test, mouse and rat dominant lethal tests, and chromosomal aberration test using rat bone marrow) (Conaway et al., 1984; Gochet et al., 1984; API, 1982; API, 1987). No significant increase in sister chromatid exchange in human peripheral lymphocytes was observed. No chromosomal aberrations were found in bone marrow cells. Negative results were obtained in the dominant lethal assays. The Ames and lymphoma tests support the negative results observed in the mammalian *in vivo* and human *in vitro* studies.

Carcinogenicity

There is limited information available regarding the potential carcinogenic effects of Stoddard solvent in humans and animals. Although lung cancer, prostate cancer, and Hodgkin's lymphoma were observed in humans exposed to mineral spirits and skin cancer in mice exposed to Stoddard solvent, limitations of these studies preclude their usefulness in assessing risk. Therefore, no conclusions regarding the carcinogenic potential of Stoddard solvent can be drawn at this time.

In a case-referent study of 3,762 cancer patients, associations of prostate cancer, lung cancer, or Hodgkin's lymphoma with chronic inhalation exposure to mineral spirit (a common synonym for Stoddard solvent) were seen (Siemiatycki et al., 1987). The absence of exposure information, multiple comparisons, lack of control for confounding factors, use of other cancer patients as referents, and other limitations of this study make it unsuitable for risk determinations.

In a lifetime (864 days) skin-painting study, squamous cell carcinomas were observed in 6 of 50 mice exposed to a mixture of 90% Stoddard solvent, 7% calcium petroleum sulfonate, and 3% ethylene glycol monobutyl ether compared to none of the 50 controls (USEPA, 1984); this is a statistically significant increased incidence. It is not possible, however, to assess the carcinogenic potential of

Stoddard solvent in this study because the test substance contained additional components that could have contributed to the result, and only one dose level was used. No inhalation or oral animal studies appear to be available.

C.2 MACHINE WETCLEANING EXAMPLE DETERGENT CHEMICALS

Wetcleaning detergent formulations are complex mixtures typically containing water plus several chemicals. Most formulations are trade secrets, and the concentrations of the individual chemicals are unknown to all but the manufacturer. Hazard summaries are presented for 10 constituents of the two sample detergents used in the exposure assessment (see Chapter 4 and Appendix E) portion of this CTSA[1]. They are meant to provide illustrative information on the types of hazards that could be related to chemicals potentially found in machine wetcleaning detergent formulations. It is not known how representative these effects are of the chemicals that may be found in actual detergent formulation.

The detergents considered in this hazard assessment are grouped into surfactants and surfactant aids. It should be noted that especially for surfactants (e.g., CAPB and lauramide DEA), the substances discussed herein are rarely used by themselves, and the variety of formulations makes it difficult to establish general toxicity conclusions.

C.2.1 Surfactants

Cellulose Gum (CG)

A number of studies in both animals and humans have been conducted by the manufacturers of products containing cellulose gum in concentrations of less than or equal to 0.1% to up to 10% (concentrations most frequently used range between 0.1 and 1.0%). Results of these studies have been voluntarily submitted to the Cosmetic, Toiletry and Fragrance Association (CTFA) and reviewed by the Cosmetic Ingredient Review (CIR, 1986a) panel. The following information (studies and conclusions) used to compile this health hazard review was adapted from the published materials of the CIR panel, unless otherwise cited.

Summary

Cellulose gum (CG) is used as a thickener, suspending agent, film former, stabilizer, emulsifier, emollient, and binder or water retention agent in a wide variety of cosmetic and toiletry products, and is one of a number of water-soluble cellulose ethers (carboxymethyl cellulose [CMC], methylcellulose [MC], hydroxypropylmethylcellulose [HPMC], hydroxyethylcellulose [HEC], and hydroxypropylcellulose [HPC]). All of these ethers have been reported to be nonirritating and nonsensitizing, exhibiting very low oral toxicity, and no neurologic, reproductive, or mutagenic effects have been reported. Cellulose gums are largely negative for developmental effects. Rat oral LD_{50} values ranging from greater than 3.0 to 27 g/kg have been reported. NOAELS of 20 and 10 g/kg were reported in rats and guinea pigs, respectively.

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[1] Hazard summaries are not provided for lauryl polyglucose, Aveda's fragrance, cocamphocarboxyproprionate, diazolidinyl urea, and methyl-2-sulfolaurate

Absorption/Metabolism

Cellulose gum does not appear to be absorbed by humans, rats, or dogs and so is excreted unchanged. The lack of absorption is also inferred from wide use in concentrations from less than 0.1% to 1% as bulk laxative, protective colloid, surgical and dental adhesive, and binder in dietary supplements. Some CGs are soluble in water and organic solvents, and some are not; thus, solubility does not help infer humans' susceptibility (Clayton and Clayton 1982; CIR, 1986a).

Acute Toxicity

Oral LD_{50} values in rats range from 3 to 27 g/kg. Acute toxicity studies have not been identified for dermal exposure routes.

Irritation/Sensitization

Cellulose gum, as well as the other cellulose polymers tested, was found to be non-irritating or slightly irritating to the skin and eyes of humans and animals (rabbits).

Humans

CG and MC were evaluated for irritation and sensitization in groups of 200 volunteers by patch test and/or challenge tests. All results were negative. Twenty-four-hour patches containing 100% or 5.0% HEC, or 10% HPC, applied every other day to the skin of 50 subjects, for a total of 10 exposures, produced no irritation or sensitization. Of the 48 studies presented in the CIR review assessing the irritancy and sensitization potential of the various cellulose derivatives, only five studies showed any indication of an effect, which was classified as mild at worst.

No irritation occurred to the eyes of 10 volunteers given four artificial tear drops (5 minutes apart) containing a 2.0% concentration of HPMC or HEC or to an unspecified number of individuals administered an eye lotion containing 0.5% CG.

Animals

Following applications of 23- and 24-hour occlusive patches, no or slight skin irritation was observed in rabbits exposed to various cosmetic products containing CG, CMC, HEC, HPC, and HPMC ranging in concentrations from 0.3 to 3.0%, and to 2.0% aqueous solutions of HEC, HPC, and MC. A single occlusive patch containing 5.0 g/kg HPC (a dermal dose 500 times the expected human exposure), applied to each of six rabbits, resulted in no deaths, no irritation, and no gross effects.

Repeated application (5 days/week for 4 or 6 weeks) of CG (1.0, 4.0, or 10% in aqueous solution) to the shaved backs of rabbits was observed to be either nonirritating or "slightly irritating and relatively well tolerated" (CIR, 1986a).

No or minimal eye irritation was seen in rabbits exposed to various cosmetic products containing CG or CMC ranging in concentrations from 0.3 to 3.0%. The majority of tests, using a variety of different protocols, showed no eye irritation following exposures of rabbits to various levels of HEC, HPC, MC, CMC, HPMC, and CG, although some showed slight irritancy.

Subchronic/Chronic Toxicity

The CIR panel found oral exposures to cellulose derivatives in both humans and animals (rats, chicken, dogs, rabbits, mice, and guinea pigs) to be basically non-toxic. Only two dermal studies were reported, both 13 weeks in rats; neither showed significant adverse systemic or dermal toxicity.

Humans

Humans ingesting 10 g CG daily over a 6-month period exhibited no hematological or other toxic effects and no mucosal irritation. Cellulose gum given as a laxative to 250 subjects in twice-daily doses of 2.0-18 g over a period of 3 years produced no toxic effects.

Although no clinical inhalation studies have been conducted, occupational long-term exposure to the dust of cellulose ether generated in manufacturing operations has not led to any known adverse effects.

Animals

No effects with reference to survival rates, body weights, hematological endpoints, urinary function analysis, or gross or microscopic examination of tissues were noted in rats receiving daily applications of 886 mg/kg of a 3% CG product in a vehicle containing sodium silicate (groups of 15) or receiving daily applications of a 1.1% CG lotion, 2,900 mg/kg (male and female groups of 10) for 13 weeks. As cited by Clayton and Clayton (1982) no evidence of toxicity was seen in either rats or dogs (unspecified numbers) fed 6.0% MC or 10% HPMC for 90 days.

Neurotoxicity

No behavioral or other toxic effects were observed in rats fed 0.2, 1.0, or 5.0% HPC (three groups of 10) or HEC (three groups of 20) for 90 days. No other information has been located regarding the neurotoxicity of cellulose derivatives in animals or humans.

Developmental/Reproductive Toxicity

No significant developmental or reproductive effects were found in studies in which cellulose derivatives were administered orally to rats, rabbits, mice, and hamsters.

Mutagenicity

Cellulose gum and its derivatives have not been found to be mutagenic. In a series of short-term tests for CG using several strains of *Salmonella*, *Bacillus*, and silkworm for assessing mutations, and hamster lung fibroblast cells (without metabolic activation) for assessing chromosomal aberrations, all results were negative. Carboxymethyl cellulose gave negative results in several strains of *Salmonella*, with and without metabolic activation. Using the dominant lethal assay, MC was non-mutagenic in rats dosed with up to 5,000 mg/kg.

Carcinogenicity

No animal studies on the carcinogenicity of CG were reported.

Cocamidopropyl Betaine (CAPB)

The CIR panel (CIR, 1991) concluded, based on the data available at the time of its report, that CAPB is safe for use in rinse-off cosmetic products at the current levels of use. They recommended that the concentration of use for products designed to remain on the skin for prolonged periods of time should not exceed 3.0%. The latter is expressed as 10% dilution of a full-strength cocamidopropyl betaine solution that has an activity of 30%. The main toxic effect by dermal application or ingestion is irritation.

A number of studies in both animals and humans have been conducted by the manufacturers of products containing cocamidopropyl betaine in concentrations as high as 50% of full strength (which is considered to be 30% activity). Results of these studies have been voluntarily submitted to the CTFA and reviewed by the CIR panel. The following information (studies and conclusions) used to compile this health hazard review was adapted from the published materials of the CIR panel, unless otherwise cited.

Summary

CAPB, primarily used in hair shampoos but also in formulations used as hair conditioners, hair dyes and colors, bath soaps/detergents, skin cleansing preparations, and bubble baths, is reported as a potentially irritating substance. Concentrations of CAPB in these formulations range from 0.1 to 50% (expressed as a percent dilution of commercially supplied CAPB that is 30% active). CAPB does not appear to have undergone any studies of reproductive or developmental toxicity or neurotoxicity or chronic studies of systemic effects. The single carcinogenicity study employed CAPB in a formulation. Without any remarkable response, its results suggest that CAPB does not increase systemic tumors above background, but are not enough to be conclusive. Although no dermal subchronic toxicity testing appears to have been performed, results of a 28-day oral test suggest a CAPB potential for irritation, which is consistent with outcomes from a collection of patch and ocular animal tests.

Absorption/Metabolism

No studies were found on the absorption, distribution, metabolism, and excretion of CAPB. It is unclear whether the amide bond of CAPB can be hydrolyzed to yield the fatty acids and 3-aminopropylbetaine. No metabolism data are available on the latter compound.

Acute Toxicity

Humans

No studies have been located discussing acute effects of CAPB in humans by any route of administration.

Animals

All reported studies are by gavage or intubation, in mice or rats. An oral LD_{50} of 6.45 ml/kg was calculated for mice from a study of a full-strength CAPB solution, 30% active, administered by gastric intubation. For rats, the acute oral LD_{50} for full-strength CAPB was 4.91 g/kg. Gross necropsy findings in rats showed redness of the stomach and intestinal mucosa, suggesting irritation.

Irritation/Sensitization

Responses of humans to dermal exposure have ranged from none to moderate in voluntary test and case report contexts. More recently than CIR (1991), there have been several reports of apparent contact dermatitis, but these instances are not necessarily exclusively the result of CAPB exposure, and the amounts of any compound that may have sensitized the individuals are uncertain. Consequently, while irritation occurs at certain levels of exposure, sensitization initially attributed to CAPB has since been identified with another chemical in the same surfactant.

Humans

A 1.0% aqueous dilution of a product formulation containing 6.0% active CAPB was tested for skin irritation using a single insult occlusive patch and 19 panelists. The formulation was considered “practically nonirritating.”

Daily doses of 0.2 ml of an 8% aqueous dilution of a liquid soap formulation containing 6.5% active CAPB were applied via occlusive patches to the forearms of 12 subjects for 5 days. An erythema score of 0.48 (scale 0-4) was calculated.

In a study of cumulative irritation, 0.3 ml of two soap formulations, described as “cream colored” or “white liquid,” were applied to skin sites on the backs of 10 panelists using occlusive patches. Each contained 1.9% active CAPB. Daily 23-hour patches were applied for 21 consecutive days. Across all applications, the total irritation scores for all subjects were 588 and 581, respectively, of a maximum of 630. The average irritation times were 1.48 and 1.69 days, with medians of 2 days.

A repeated open application procedure was performed with a 10% aqueous dilution of a shampoo containing 18.7% active CAPB using 30 volunteers to determine skin sensitization. The same procedures were performed on additional subjects with another test substance containing an identical concentration of CAPB. No sensitization was seen in any of the 88 subjects exposed to the test materials in a shampoo base under any open patching conditions in both the induction and challenge applications.

Other skin sensitization potential studies similar to the above study were performed. Induction applications generally were repeated to the same site and scored following a 48-hour period. An alternate site was used for the challenge test and was scored after 48 and 96 hours. In one study, a 0.9% active aqueous solution of CAPB was tested on 93 volunteers who had slight responses to the test material. These responses were attributed to primary irritation, rather than sensitization, during both the induction and challenge tests. In another similar study, the skin sensitization potential of a formulation containing 10% active CAPB was tested on 100 volunteers. No evidence of sensitization was observed with the test material.

An investigation of the potential of CAPB to induce contact skin sensitization was conducted using 141 subjects. All applications initially contained a concentration of 1.5% active CAPB in distilled water, until a protocol modification changed the concentration to 3.0% active CAPB. Subjects who began the study a week earlier received two applications at a concentration of 1.5%, and all other applications of the test material at a concentration of 3.0%. Induction applications were made to the same, previously untreated site on the back three times per week for 3 successive weeks. Gauze patches were applied and then removed after 24 hours. A challenge application was applied to a previously untreated site for 24 hours 10-15 days later, and the site was scored 24 and 72 hours after patch removal. No responses were observed during either the induction or challenge tests.

Subsequent to CIR (1991), several case studies of individuals apparently presenting with contact dermatitis based on exposure to CAPB were reported (Korting et al., 1992, 1% aqueous, activity unspecified, standard patch; Fowler, 1993, 1% aqueous, activity unspecified, standard patch; Peter and Hoting, 1992, standard patch, and 5% aqueous, 0.1-0.2% active; Cameli et al., 1991, 1% aqueous patches; and Ross and White, 1991, standard patch). Several instances were initiated by contact lens solution exposure, others were in hairdressers or recipients of shampoo exposure over extended periods (Taniguchi et al., 1992). Peter and Hoting (1992) used their findings to hypothesize that the increased apparent allergenic activity could be attributed to some recent manufacturing process change that introduced impurities. Subsequently, it has been confirmed that the major allergen is the impurity dimethylaminopropylamine used in the synthesis of CAPB (Angelini et al., 1995; Pigatto et al., 1995).

In another study, five dilutions (0.15, 0.30, 0.75, 1.5, and 3.0% w/v) of three quality levels of CAPB (ranging from 29.5 to 29.8% active) were applied simultaneously to separate dorsal locations of up to 67 volunteers using a 48-hour occlusive patch (Vilaplana et al., 1992). The study's purpose was to examine three different noninvasive evaluative methods. The qualities were based on amounts of free amidoamine and sodium monochloro-acetate. None showed excessive irritant response, but the formulation with greatest free amidoamine content showed a statistically significantly greater preponderance of higher responses at 0.75% w/v and above. The authors concluded that the response "can be described as an irritant contact dermatitis but not as an allergic contact dermatitis."

An additional study investigated the potential of a 3.0% active solution of CAPB to induce contact photoallergy. There was no response to the challenge tests except for those exposed to both UVA and UVB radiation, who had mild to moderate erythemic responses that were not uncommon and were said to have resulted from the sunburn derived from UVB exposure (CIR, 1991).

Animals

Six studies applied occlusive patches with CAPB solutions of various activity (7.5% to 30%) to intact and abraded sites on the backs or abdomens of groups of rabbits. The responses ranged from no irritation (7.5% active) to a Primary Irritation Index of 3.75 (scale 0-8) with eschar (scab) formation (30% active).

Ten ocular irritation studies in rabbits, employing concentrations ranging from 2.0% to 30% active in water or in soap formulations, showed mostly conjunctival irritation and mild to moderate corneal irritation to treated, unrinsed eyes.

Two studies in guinea pigs followed intradermal injections with topical induction and challenge applications to identify the potential for skin sensitization. Fifteen male guinea pigs were injected (at three separate sites) with 0.1 ml of 0.5% (v/v) CAPB dilution in saline, 0.1 ml in saline and Freund's complete adjuvant, and 0.1 ml of 50% Freund's complete adjuvant in water, followed by a 48-hour occlusive patch on each site of 60% (v/v) CAPB 1 week later (induction). Five control animals received the treatment series without CAPB content. Two weeks following induction, a 10% (v/v) CAPB challenge patch showed no evidence of delayed contact hypersensitivity.

In another similar test, 20 guinea pigs (sex unspecified) received a 10% aqueous dilution of a 30% active CAPB sample in a 48-hour patch, following a 0.1% dilution injection. The challenge was a 10% aqueous dilution. Microscopic changes in the treated skin indicated slight delayed-type contact sensitization.

Subchronic/Chronic Toxicity

In a 28-day gavage short-term study in rats, with full-strength solution (30% CAPB), treatment-induced lesions were produced in the nonglandular portion of the stomach in the high-dose group but not in the low-dose group.

No other studies discussing subchronic effects of CAPB in humans or animals have been located.

Neurotoxicity

No studies have been located discussing neurotoxic effects of CAPB in humans or animals.

Developmental/Reproductive Toxicity

No studies have been located discussing reproductive or developmental effects of CAPB in humans or animals.

Mutagenicity

The mutagenic potential of a 31% active CAPB formulation was tested in five strains of the *Salmonella*/mammalian microsome mutagenicity assay, with and without activation, and the L5178Y TK +/- mouse lymphoma assay. CAPB was nonmutagenic in these assays.

Carcinogenicity

CAPB was not carcinogenic in a skin-painting study in mice. An aqueous preparation of a non-oxidative hair dye formulation containing an unspecified grade of CAPB at a concentration of 0.09% active CAPB was tested for carcinogenicity using groups of 60 male and female mice. The formulation also contained 5% propylene glycol, 4% benzyl alcohol, 0.6% Kelzan, 0.9% lactic acid, and less than 0.5% or each of fragrance and the disperse brown, red, yellow, and blue dyes. A dose of 0.05 ml per mouse was applied three times weekly for 20 months to clipped, shaven interscapular skin. Mortality, behavior, and physical appearance of the mice were observed daily. Dermal changes in particular were noted. Body weights were recorded weekly. Ten males and 10 females from each group were killed at 9 months for a hematological study and necropsy. Urinalysis was also performed.

At termination, all mice were necropsied, and the tissues were examined microscopically. No adverse effects were noted on average body weight gains, survival, hematological, or urinalysis values in any group. Varying degrees of chronic inflammation of the skin were seen in all groups, including controls. Other lesions occurred, but were considered unrelated to treatment. Pulmonary adenomas, hepatic hemangiomas, and malignant lymphomas were observed in the 60 treated female mice and in the 59 treated male mice (no information was given on whether any were observed in the early sacrifice). However, the incidences of these systemic neoplasms did not differ statistically significantly from those in the two control groups (numbers unspecified) that were shaved and received no topical treatment.

Ethoxylated Sorbitan Monodecanoate (Polysorbate 20 or P-20)

The information (studies and conclusions) used in preparing this health hazard section has been adapted from a report issued by the CIR panel (CIR, 1984), unless cited otherwise.

Summary

Polysorbates are commonly used as surfactants in a variety of cosmetic products at concentrations ranging from less than or equal to 0.1% to greater than 50% for polysorbate 20 (P-20). The majority of product formulations (95%) fall into the range of less than 0.1% to 5.0% P-20. In both animals and humans P-20 has been found to be essentially nontoxic following acute and long-term oral ingestion and to exhibit little or no potential for skin irritation or sensitization. No inhalation studies are available; however, this is not an expected route of exposure. LD_{50}s in animals range from 18 to 36.7 ml/kg and greater than 5.0 to 38.9 g/kg following oral exposure, and from 0.7 to 3.5 ml/kg and 1.45 to 3.85 g/kg following injection routes of exposure. By analogy to other polysorbates, P-20 is not expected to be mutagenic. While not carcinogenic itself, P-20 has been shown to enhance the activity of known chemical carcinogens, and to inhibit tumor growth activity under certain conditions. No animal or human data regarding reproductive, developmental, or neurotoxic effects associated with P-20 exposures were located.

Absorption/Metabolism

The most common routes of exposure are oral and dermal. There is little likelihood of inhalation exposure of this substance. P-20 is one of a series of polyoxyethylenated sorbitan esters. It is hydrolyzed by enzymes in the pancreas and blood. The fatty acid moiety (the ester portion of the molecule) is readily absorbed and metabolized, whereas the other portion of the molecule (the polyoxyethylenated sorbitan moiety) is very poorly absorbed and excreted unchanged. Clinical tests have shown essentially the same pattern in humans as in rats.

Acute Toxicity

No acute toxicity data are available on dermal exposures.

Humans

For therapeutic reasons, 13 premature and 2 full-term infants with steatorrhea (abnormal fecal fat loss) were given four daily doses of 200 mg undiluted P-20. Although no increase in fat absorption was observed, it was noted that P-20 produced no adverse effects with respect to anorexia, vomiting, defecation, or growth.

Animals

A 24-hour occlusive patch containing 3.0 g/kg of P-20 was applied to the clipped intact or abraded skin of the back and flank of six albino guinea pigs and observed for 7 days. No deaths occurred and no adverse effects were observed before and after necropsy.

Oral LD_{50}s for rats, mice, and hamsters range from greater than 5.0 to 38.9 g/kg.

Irritation/Sensitization

There is no evidence of sensitization in humans following P-20 exposures. No dermal irritation was observed in humans exposed to a 100% concentration of P-20, whereas some product formulations containing P-20 produced a range of irritancy, but no sensitization. It is impossible to interpret the meaning of these results, however, without knowledge of the other ingredients in the formulations. P-20 produced no or mild eye irritation and no to moderate skin irritation in rabbits, depending on the length of the study, and moderate or strong skin sensitization in guinea pigs.

Humans

No evidence of irritation or sensitization was observed in several human studies: 50 persons administered two 72-hour occlusive patches containing undiluted P-20 (applied 7 days apart); two groups of 10 persons receiving two 48-hour occlusive patches containing undiluted or 30% aqueous concentrations of P-20; or among 19 persons tested in 24-hour single insult patch tests exposed to 40% aqueous dilutions of P-20. In three separate tests, no to mild irritation was observed in subjects (18, 19, or 20) tested with a 24-hour single insult patch of unspecified product formulation containing 2.0, 6.0, or 8.4% P-20. Cumulative irritancy tests (daily 23-hour occlusive patches applied for 21 days), in 10 to 12 subjects, of a bubble bath containing 6.0% P-20 produced moderately to highly irritating results. CIR (1984) concluded that these results cannot be interpreted due to the absence of information regarding other ingredients in the formulations.

No photosensitization reactions were observed in 103 persons exposed (open and closed 48-hour patches, repeated after 2 weeks) to a bubble bath containing 0.3% P-20.

Animals

In three separate studies, undiluted (100% concentration) 0.5 ml patches of P-20 occluded for 24 hours produced no or only minimal skin irritation in the one, six, or nine rabbits tested. The same results were seen for rabbits (one to six) receiving 0.1 ml sample of 100% P-20 instilled in the eye either with or without a water wash and observed for 7 days. No inflammation was seen when P-20 was applied to the cheek pouch mucosa of hamsters (unspecified number of animals, volume, and concentration of P-20).

Polysorbates 20, 60, 80, and 85 were applied undiluted or diluted in water, petrolatum, or a hydrophilic ointment (1.0, 5.0, or 10%) daily to the backs of rabbits (unspecified number) for 30 days. For the undiluted P-20, erythema was observed by day 3, skin thickening by day 10 accompanied by minimal to mild irritation, and mild to moderate inflammation with acanthosis by day 30. At all dilutions, the polysorbates tested induced erythema and minimal irritation by day 10 and minimal to marked irritation at day 30, depending on the polysorbate.

To determine the sensitization potential of P-20, five guinea pig assays (unspecified number of animals per assay) were performed with three different batches of P-20. Following one to three challenge(s) with undiluted P-20, four of the five assays evoked responses indicative of moderate sensitization, and one batch of P-20 produced strong sensitization under the test conditions.

Subchronic/Chronic Toxicity

Humans

No dermal studies are available. There have been a number of long-term human feeding studies evaluating the use of polysorbates for therapy in liquid malabsorption syndromes (CIR, 1984). Many studies are reviewed in CIR (1984), and CIR concluded that long-term use (up to several years) of polysorbate 20 or polysorbate 80 for this purpose was not harmful to humans.

Animals

No dermal studies are available. In several long-term studies (7 weeks to 2 years), levels from less than 1 up to 25% P-20 in the diet were fed to chickens, rats, monkeys, and hamsters, in some cases over multiple generations. No adverse effects were seen in chickens, monkeys, or rats with the exception of a single fatality in rats (1/10) fed 25% P-20 for 21 weeks. Hamsters, on the other hand, fed diets containing 15% P-20, showed numerous gross and histopathologic findings in the bladder, kidney, spleen, and gastrointestinal tract. Results of these and other studies led the FOA/WHO Committee on Food Additives to conclude that polysorbates cause no toxicological effects in the animals at daily dietary levels of 5.0% (CIR, 1984).

Neurotoxicity

No data have been located discussing the neurotoxic potential of P-20 in either humans or animals.

Developmental/Reproductive Toxicity

No data have been located in humans or animals regarding developmental/reproductive toxicity associated with P-20 exposures.

Mutagenicity

While there are no data available for P-20, polysorbate 80 was negative in both the micronucleus and Ames assays for mutagenicity.

Carcinogenicity

From studies of limited duration, there was no evidence of carcinogenic activity following oral exposure to P-20. In one study, benign tumors with a tendency to regression were reported following dermal exposure; however, the overall evidence suggests that P-20 is not carcinogenic when applied to the skin. On the other hand, polysorbates have been shown to be both tumor enhancers (i.e., involved in tumor promotion and cocarcinogenesis) and, under certain experimental conditions, tumor growth inhibitors. Thus, they are able to enhance the activity of known chemical carcinogens although they may not be carcinogenic themselves.

No tumors were observed in rats (groups of 10 or 14) or hamsters (groups of 10 or 36) fed diets containing 5.0 to 25.0% P-20 for periods ranging from 8 to 21 weeks. In two separate studies, groups of 50 mice received dermal applications of 100% P-20 (unspecified dose) 6 days/week for 24 or 52 weeks. In the 24-week study, no tumors were produced. In the 52-week study, one mouse developed a benign skin tumor at 36 weeks. Both studies, however, are of short duration for determining cancer effects. After reviewing these results, as well as those of several other studies, Setala (1960, as cited in CIR, 1984) concluded that polysorbates are not carcinogenic when applied to the skin.

Dermal application of 0.125 mg 1,2-dimethylbenz[a]anthracene (DMBA), a carcinogenic agent, followed by repeated applications of 0.2 ml 0.3-3.0% P-20 (duration not provided) in ICR Swiss mice (no number given) resulted in weak tumor promotion. In another study of Wistar rats (no number given) given drinking water containing 50 mg/L of the carcinogen N-methyl-N’-nitro-N-nitrosoguanidine (MNNG) and 0.4% P-20 for 26 to 30 weeks, an increased incidence of stomach tumors as compared to MNNG controls was observed.

In vitro tests with P-20 on mouse carcinoma cells showed tumor growth inhibition activity, whereas *in vivo* tests with P-20 did not exhibit tumor growth inhibition activity when tested on the same mouse cancer cells.

Lauric Acid Diethanolamide (Lauramide DEA)

There is limited information available on the toxicity of lauramide DEA. A number of formulations (soaps, shampoos and bubble baths) containing concentrations ranging from 4.5 to greater than 50% lauramide DEA have been tested by the manufacturers in both animals and humans. Results of these tests have been voluntarily submitted to the CTFA and reviewed by the CIR panel (CIR, 1986b), which was used to compile this health hazard section, unless otherwise cited.

Summary

Acute dermal exposures of humans to various concentrations (4.0 to 10%) of lauramide DEA were found to result in no to moderate skin irritation depending on the formulation. No evidence of dermal sensitization, regardless of the formulation or dose, was observed. No human studies were located regarding the potential toxicity of lauramide DEA following oral or inhalation exposure. In rats, LD_{50}s ranging from 2.7 to 9.63 g/kg were identified following single oral dose exposures; and NOAELs of 50 and 250 mg/kg/day were reported following subchronic exposure to lauramide DEA. No systemic effects were observed following dermal exposures in animals, although a dose-related increase in both skin and eye irritancy was reported in animals following exposure to solutions containing 1.0 to 25% lauramide DEA. Lauramide DEA was not found to be mutagenic. The carcinogenic potential of lauramide DEA is currently being investigated (NTP, 1998). No data were located regarding reproductive, developmental or neurological effects of lauramide DEA in animals or humans.

Absorption/Metabolism

No human or animal studies were located discussing absorption or metabolism of lauramide DEA by any route of exposure.

Acute Toxicity

Humans

No studies have been located discussing acute effects of lauramide DEA in humans.

Animals

A 24-hour patch containing 6.0 ml/kg of 50% lauramide DEA in a corn oil vehicle was applied to the shaved backs of six guinea pigs. Body weights, apparently reduced on day 7, were back to, or above, expected values by day 14 (CTFA, 1978b). Authors concluded that lauramide DEA was nontoxic by percutaneous absorption, following skin patch testing in guinea pigs.

In a series of acute studies (CTFA, 1977a, 1978a, 1979a,b,c), groups of five rats each were administered a single oral (gavage) dose ranging from 0.252 to 15 g/kg of lauramide DEA (0.25% in corn oil, 10% aqueous solution, or formulations containing 6.0 to 8.0%). LD_{50}s of 2.7, 9.63, and greater than 15 g/kg were reported. Based on their findings, investigators concluded that lauramide DEA was nontoxic or slightly toxic, depending on the dose.

Irritation/Sensitization

Humans

Compared to an equal number of controls, human subjects (17, 18 or 19) exposed to products containing 5.0, 6.0, or 8.0% lauramide DEA (tested as a 1.0 or 1.25% aqueous solution below an occlusive patch) were found to have mild to minimal skin irritation (CTFA, 1977c, 1979d, 1981a).

Each of three soaps containing 10% lauramide DEA (tested at 8% aqueous solutions) were applied to the forearms of groups of 12 or 15 subjects for 5 consecutive days (CTFA, 1980b, 1982b,c). Two soaps were determined to be mild skin irritants, and the third was non-irritating.

In a 21-day cumulative irritation study, a 25% solution of a soap containing 5% lauramide DEA applied daily under an occlusive patch was found to be moderately irritating in the seven persons tested (CTFA, 1977d).

Several products containing 4.0 to 10% lauramide DEA were tested for sensitization in humans (41, 52, 86, or 159 subjects) using multiple 24- to 72-hour occlusive patches over 6 weeks, followed by a 48-hour challenge. No products were shown to be sensitizers (CTFA, 1977d, 1979e, 1980c,d; RTL, 1978, 1980).

Animals

Concentrations of 1.0, 5.0, and 25% lauramide DEA in water were applied (5.0 ml each) to the shaved abdominal area (at one intact and one abraded site) of rabbits (number not specified). A dose-related increase in severity (i.e., no, moderate or severe irritation for 1.0, 5.0, and 25% lauramide DEA, respectively) was observed following 10 or 3 applications over a period of 14 days to the intact sites and abraded areas, respectively. A similar dose-related increase in severity (practically non-irritating to slightly irritating to markedly irritating) was observed in five groups of rabbits (nine per group) administered a single 24-hour occlusive patch containing 1.25, 10, or 20% aqueous lauramide DEA (CTFA, 1976, 1977b, 1979e) and observed 2 and 24 hours following patch removal.

Aqueous emulsions of 1.0, 5.0, and 25% lauramide DEA in the unwashed compared to washed eyes of rabbits (three/group) showed no to slight effects (some conjunctival irritation), disappearing within 24 hours following exposure to the 1.0% emulsion; slight to moderate effects (appreciable conjunctival irritation and superficial corneal injury with no vision loss) disappearing within a week following exposure to the 5.0% emulsion; and moderate to severe corneal and conjunctival injury with some vision impairment after exposure to the 25% emulsion.

Subchronic/Chronic Toxicity

Humans

No studies have been located discussing chronic effects of lauramide DEA in humans.

Animals

NOAELs of 50 mg/kg/day (equivalent to 0.1% lauramide DEA) and 250 mg/kg/day were identified for rats orally exposed to lauramide DEA for 90 days in the following studies, respectively. In the first study, groups of 15 male and 15 female rats were fed diets containing 0 (controls), 0.1, 0.5, 1.0, or 2.0% lauramide DEA for 90 days. Growth was normal in the 0.1% group, slightly reduced in the 0.5% group, and moderately reduced in the 1.0 and 2.0% groups. Growth retardation associated with a decrease in food intake and some hematological differences was observed at and above the 0.5% level (statistical significance not provided). Test animals were comparable to controls for bone marrow cytological values, kidney function tests, and gross and microscopic findings. In the second study, groups of 20 male and 20 female rats were fed diets containing 0 (controls), 25, 80 or 250 mg/kg/day lauramide DEA for 13 weeks. With the exception of a transient increase in blood glucose concentrations noted at 6 weeks in male rats fed 250 mg/kg/day, all other endpoints measured were comparable to controls (general health, body weight, food consumption, hematologic values, organ weights, mortality (no deaths), and gross and microscopic findings) (CIR, 1986b).

In the first of two subchronic dermal studies, a medicated cleanser containing 5.0% lauramide DEA (2.0 ml/kg applied as a 4.8% aqueous solution) was applied to the shaved backs of 10 male and 10 female rats 5 days/week for 13 weeks (CTFA, 1980a). With the exception of minimal skin irritation in females during the first week only, all other indices measured were reported comparable to controls (e.g., body weight, appearance, behavior, survival, gross necropsy, and histology). Blood and urine samples, analyzed at 7 and 10 weeks, were within the normal range. In the second study, 15 female rats received a daily 2.0 ml/kg dose of a cream cleanser containing 4.0% lauramide DEA administered as a 0.45 aqueous solution, 5 days/week for 13 weeks (CTFA, 1982a). No deaths occurred. As in the previous study, gross and histopathologic findings were reported comparable to the untreated controls, and blood and urine levels were within normal limits. The investigators concluded that there was no evidence of dermal or cumulative, systemic toxicity associated with either of these products.

Neurotoxicity

No studies have been located discussing the neurotoxic effects of lauramide DEA in either humans or animals.

Developmental/Reproductive Toxicity

No studies have been located discussing developmental or reproductive effects of lauramide DEA in humans or animals.

Mutagenicity

Lauramide DEA was not found to be mutagenic in four separate Ames-type *Salmonella* assays, a DNA-damage assay or in two studies on *in vitro* transformation of hamster embryo cells. In a spot test performed with and without metabolic activation in five strains of bacteria, 50 µg lauramide DEA was judged to be mutagenic in two of five strains without metabolic activations, but quantitative results were not provided.

Carcinogenicity

The National Toxicology Program has recently completed a 2-year skin painting bioassay using rats and mice to determine the carcinogenicity of lauramide DEA condensate (NTP, 1998). Although the technical report is not yet published, NTP (1998) reports that post-peer review results indicate no evidence of carcinogenicity in either mice or rats. No other carcinogenicity studies were located in the published literature.

Sodium Laureth Sulfate

There is limited information available on the toxicity of sodium laureth sulfate. A number of studies in both animals and humans have been conducted by the manufacturers of products containing sodium laureth sulfate ranging from concentrations of less than or equal to 0.1% to greater than 50%.

Results of these studies have been voluntarily submitted to the CTFA and reviewed by the CIR panel (CIR, 1983). The following information (studies and conclusions) used to compile this health hazard review was adapted from the published materials of the CIR panel, unless otherwise cited.

Summary

Sodium laureth sulfate is a commonly used component in bath and hair preparations. Products containing sodium laureth sulfate may be expected to remain in contact with the skin up to an hour and are likely to be used repeatedly over a period of several years. Sodium laureth sulfate has been shown to produce eye and skin irritation at concentrations above 5% in animals and skin irritation at concentrations as low as 0.7% repeated over 21 days in humans.

Sodium laureth sulfate, following oral exposures, is “moderately to slightly toxic” (CIR, 1983) in acutely exposed animals and virtually non-toxic in chronically exposed animals. The severity of the effect shows a trend to increase with increasing doses, although there are some unexplained inconsistencies in this observation. Oral LD_{50}s range from greater than 0.28 to 3.55 g/kg. A NOAEL of 1000 ppm was identified for a 13-week study in rats fed dietary levels of 24% w/w sodium laureth sulfate. Sodium laureth sulfate does not appear to exhibit any reproductive, developmental or carcinogenic effects in animals. No data were located discussing the neurological or mutagenic effects of sodium laureth sulfate exposure in humans or animals.

Absorption/Metabolism

Sodium laureth sulfate is poorly absorbed through the skin. CIR (1983) suggests that the ingredient’s ethoxylation decreases its biological activity. When oral exposures occur, the majority of compound is excreted in the urine, with small amounts appearing in the feces and in expired CO_2. In rats given sodium laureth sulfate by oral intubation or parenteral injection (unspecified length of time), the urine contained high concentrations of the compound, and the carcass retained less than 1% of the dose.

Acute Toxicity

Humans

Acute toxicity studies of sodium laureth sulfate in dilute solution have not been identified for dermal exposure routes.

Animals

In 10 studies of albino rats (groups of 5 or 10) orally exposed to 2.0 to 64 ml/kg test solution (unspecified dosing regime) containing concentrations of 5.6 to 58% sodium laureth sulfate, effects ranged from no effect to moderate effects. At high doses (16-64 g/kg) observed effects included unkempt coats, lethargy, diarrhea, rectal and nasal hemorrhage, and impaired locomotion; however, in all cases, the animals showed no gross or microscopic abnormalities attributable to the test compound. Oral LD_{50}s for sodium laureth sulfate identified from these studies range from greater than 0.28 to 3.55 g/kg.

Irritation/Sensitization

Dermal exposure to sodium laureth sulfate appears to cause mild to severe irritation to both humans and animals (somewhat dependent on the dose), but not sensitization. Eye irritation was observed in animals, but there were no human studies addressing this endpoint.

Humans

In two studies, 24-hour occlusive patches containing a 60% aqueous solution of 30% sodium laureth sulfate (18% active sodium laureth sulfate) produced mild irritation in 2/20 and 11/20 of test subjects. A repeat insult patch test of a dandruff shampoo containing 0.5% sodium laureth sulfate produced minimal irritation and no sensitization in 196 test subjects. No evidence of contact sensitization was seen in 25 persons exposed to a product containing 14.3% sodium laureth sulfate.

In two separate 21-day cumulative irritancy tests, products containing 0.7 or 1.25% active concentrations of sodium laureth sulfate were tested in 10 (although only 4 completed the study) and 13 subjects, respectively. Daily applications of 1.25% sodium laureth sulfate resulted in severe irritation, whereas the 0.7% sodium laureth sulfate produced mild irritation.

Animals

In a number of studies sharing similar protocols, one 0.5 ml sample each of various test solutions containing concentrations of 5.0 to 58.0% sodium laureth sulfate was applied to intact and abraded skin of albino rabbits for a period of 2, 3, or 7 days. No irritation was observed at concentrations of 5.0-5.6%; mild erythema and edema, sometimes transient in nature, were seen at concentrations of 6.0, 7.5, 10, 17.5, and 26%, whereas severe irritation occurred in test solutions containing 15, 25, 28, and 30% sodium laureth sulfate. In the tests using a concentration of 58% sodium laureth sulfate, no irritation occurred. The discrepancy in these findings seen at higher doses (greater than 15%) was not discussed. No deaths were reported at any dose or concentration.

A 0.25 molar solution of sodium laureth sulfate (approximately 5.0-10.0% solution by weight) applied for 3 consecutive days to the shaved skin of weanling rats produced no irritation after 1 day and slight erythema and edema after 3 days.

The ocular toxicity of sodium laureth sulfate was tested in groups of three, six, or nine albino rabbits, using a standardized Draize test. In 18 separate studies, 0.1 ml of test material instilled in the eyes, with or without rinse, and observed for 1 week produced responses ranging from no irritation to severe eye damage independent of the concentration range (1.3 to 58%) of sodium laureth sulfate in the test solution. No discussion was provided for these findings.

To test for skin sensitization, a 0.1% aqueous solution of sodium laureth sulfate was applied topically (3 times/week for 3 weeks) to 10 guinea pigs. Ten days after the final administration, when topically challenged, no skin sensitization was evident; however, when challenged by intradermal injections, the animals showed a positive reaction 1 hour following the challenge, which increased in intensity in three of the animals. At 48 hours six of the animals continued to show a positive reaction, while the other four demonstrated only a slight reaction.

Subchronic/Chronic Toxicity

Humans

No studies of sodium laureth sulfate in solution have been identified for dermal exposure routes.

Animals

A subchronic study on the effect of an anion-active sodium laureth sulfate detergent on the skin and hair cycles of rats was conducted. Various concentrations of the detergent dissolved in tap water were applied daily for 65 days to the shaved backs of five groups (totaling 65) 7- to 8-week-old male rats. Concentrations were as follows: Group-1 received pure detergent (60% sodium laureth sulfate); group-2, 30% sodium laureth sulfate; group-3, 9.0%; group-4, 0.9%; group-5 (controls), 0%. The group exposed to the 60% solution experienced inflammatory changes, epidermal hyperplasia, epidermoid cyst formation, and diffuse hair loss. Seven animals died between days 12 and 15. The 30% solution group had similar, though less severe, skin changes, but had no deaths. No effect was seen for any other concentration.

A NOAEL of 1,000 ppm was identified for a study of rats fed dietary levels of 24% w/w sodium laureth sulfate. Groups of 12 male and 12 female 5-week-old rats were fed diets containing 40, 200, 1,000, or 5,000 ppm of active material for 13 weeks. Compared to controls (18 male and 18 female rats receiving a standard diet), the behavior, body weights, food intake, hematological results, plasma proteins, urinary findings, and urea concentrations were within normal limits. No pathology changes were observed at necropsy. Kidney weights in males, and heart, liver, and kidney weights in females were increased in rats fed 5,000 ppm, but increases in relative organ weights were not found to be statistically significantly elevated.

In a long-term study (105 weeks) in groups of 30 rats fed diets containing 0 (controls), 0.5, or 0.1% sodium laureth sulfate, findings were essentially normal. There were no differences between treated animals and controls with respect to appearance, behavior, organ weights, organ to body ratios, growth rates, food consumption, and survival, with the exception of the male rats who had an unexplained weight loss in the last 8 weeks of the study. Clinical laboratory studies, gross and microscopic pathology, and the appearance of tumors assessed at 52 weeks (10 rats sacrificed from each group) and 105 weeks (the remaining rats were sacrificed) were comparable between treated and control animals.

Neurotoxicity

No data have been located regarding the neurotoxic potential of sodium laureth sulfate exposure in humans or animals.

Developmental/Reproductive Toxicity

Ten male and 10 female rats were fed diets containing 0.1% or no sodium laureth sulfate for 14 weeks, then mated. Their offspring (F_1 generation) were maintained on the same diet as their parents, and mated at approximately 100 days old. Their (F_1) progeny (F_2 generation) were also kept on the same diet for 5 weeks after weaning. No adverse effects on fertility, litter size, lactation, or survival of offspring, no changes in the blood or urine of the F_1 and F_2 generations, and no gross or microscopic changes that could be attributable to the test compound were observed.

Mutagenicity

No data have been located regarding the mutagenic or genotoxic potential of sodium laureth sulfate exposure in humans or animals.

Carcinogenicity

The carcinogenicity potential of sodium laureth sulfate was tested in mice (two groups of 30 each). A dose of 0.1 ml of 5.0% aqueous solution of sodium laureth sulfate (5.0 mg) was applied twice a week for 105 weeks to the skin of 30 female mice. The total quantity of sodium laureth sulfate applied to each mouse was approximately 1 g. No skin tumors appeared, and the mortality did not differ substantially between the two groups of mice, but sample sizes were too small to detect most elevations.

Additionally, the long-term dietary study described above (see Chronic Toxicity section) found no differences in tumor prevalence at 52 or 105 weeks between treated groups and controls.

Sodium Lauryl Isethionate (SLI)

Summary

The limited information on sodium lauryl isethionate suggests that this chemical may not be a skin irritant and is not mutagenic. No other data were located on any other health endpoints for this compound (CCRIS, 1995).

Absorption/Metabolism

No data have been located regarding the absorption/metabolism potential of SLI exposure in humans or animals.

Acute Toxicity

No data have been located regarding the acute toxicity of SLI in humans or animals.

Irritation/Sensitization

One *in vitro* penetration cell experiment is reported, mentioning the irritancy of several surfactants; no enzymes were released from rat skin slices *(stratum corneum)* following 3-5 hours of exposure to SLI (24 hours incubation). The authors reported this was consistent with their prior knowledge that SLI does not have irritant potential (CCRIS, 1995). No other data are reported regarding any dermal properties or toxicity of SLI.

Subchronic/Chronic Toxicity

No data have been located regarding the subchronic/chronic toxicity of SLI exposure in humans or animals.

Neurotoxicity

No data have been located regarding the neurotoxic potential of SLI exposure in humans or animals.

Developmental/Reproductive Toxicity

No data have been located regarding the developmental/reproductive toxicity of SLI exposure in humans or animals.

Mutagenicity

SLI tested negative in the Ames test using several strains of *Salmonella* with and without metabolic activation at dose ranges of 16 to 2000 µg/plate (CCRIS, 1995).

Carcinogenicity

No data have been located regarding the carcinogenic potential of SLI exposure in humans or animals.

C.2.2 Surfactant Aids

Acetic Acid

Summary

Acetic acid is a common substance added directly at 5% dilution to human food (i.e., baked goods, cheeses, dairy product analogs, chewing gum, condiments, relishes, fats, oils, gravies, sauces, and meat products). It is Generally Recognized As Safe (GRAS) for food use by the Food and Drug Administration (FDA).

All studies reported relate to concentrations at least twice and as much as 16 times as great as acetic acid in vinegar (typically under 6% dilution). Acute exposures to strong solutions (10-20%) of acetic acid resulted in physiologic effects in humans. Splashes of vinegar (4-10% acetic acid solution) have been reported to cause ocular pain and injury. At high concentrations dermal contact with acetic acid, depending on the length of exposure, resulted in severe irritation in both humans and animals. At low concentrations (under 10%) no dermal irritation was seen. Effects such as bronchitis, pharyngitis, erosion of the teeth, conjunctivitis, palpebral edema and conjunctival hyperemia, digestive disorders, dry skin, and blackening and hyperkeratosis of the skin have been reported in workers chronically exposed to high air concentrations of acetic acid. No chronic effect was noted in animals. No neurologic effects were reported in the literature used for this review. There is no evidence of mutagenicity related to acetic acid exposure. Although no direct information on the carcinogenicity of acetic acid was located, one chronic study in rats that were fed 350 mg/kg sodium acetate found no evidence of tumors. No reproductive studies were located.

Absorption/Metabolism

Undiluted acetic acid is absorbed from the gastrointestinal tract and through the lungs (Clayton and Clayton, 1982). It is readily metabolized by most tissues and may give rise to ketone bodies as intermediates (Clayton and Clayton, 1982). No discussion is available regarding dermal absorption at 5% solution.

Acute Toxicity

Humans

Splashes of vinegar (4-10% acetic acid solution) have been reported to cause ocular pain and injury (HSDB, 1994).

Animals

Data are not reported on results of exposures to solutions of less than 10%.

Irritation/Sensitization

Humans

Acetic acid (undiluted) is caustic to the skin. It can cause dermatitis, ulceration and burns. Based on animal experiments and industrial exposure, it is believed that human exposure (8 hours) to 10 ppm could produce some eye, nose, and throat irritation, and exposure to 100 ppm could produce lung irritation and possible damage to the lung, eyes, and skin (Clayton and Clayton, 1982). Skin sensitization, though rare, has been reported in humans at as low as 1% (HSDB, 1994).

Immediate pain, conjunctival hyperemia, and sometimes injury to the cornea have resulted from a splash of vinegar (4-10% acetic acid) to the eye. Exposures to air concentrations below 10 ppm have resulted in conjunctivitis in some exposed persons (HSDB, 1994). Permanent corneal anesthesia and opacity occurred in two individuals with accidental exposure of glacial (100%) acetic acid to the eyes, even though they were immediately rinsed with water after the exposure occurred (HSDB, 1994).

Animals

No effect was seen following an application of 10% acetic acid to intact or abraded skin patches in guinea pigs or rabbits (unspecified numbers and study length) (Clayton and Clayton, 1982). No discussion is available regarding dermal exposures at 5% solution. Dermal application of 20 mg undilute acetic acid applied to guinea pigs and rabbits (unspecified numbers) for 24 hours produced mild irritation (Clayton and Clayton, 1982). A larger application of 0.5 ml of 525 mg undilute acetic acid in rabbits (unspecified number) showed no corrosive effects after 4 hours but produced severe irritation (with necrosis) after 24 hours (Clayton and Clayton, 1982).

Subchronic/Chronic Toxicity

Human

All reports relate to high concentrations in the workplace. The principal finding among five workers exposed for 7-12 years to high concentrations (80-200 ppm at peak concentration) of acetic acid was blackening and hyperkeratosis of the skin (HSDB, 1994). In another study, bronchitis, pharyngitis, erosion of the teeth and conjunctivitis were reported among workers (unspecified number) exposed for 7-12 years to concentrations of 60 ppm, plus 1 hour daily to concentrations in the range of 100-200 ppm (HSDB, 1994). Other effects reported among workers (unspecified numbers) exposed for a number of years to air concentrations of up to 200 ppm include palpebral edema, with hypertrophy of lymph nodes, and conjunctival hyperemia (HSDB, 1994). Digestive disorders and dry skin have been reported in workers (unspecified numbers or occupation) following repeated exposures (unspecified levels) (HSDB, 1994).

Animals

No information is reported on dermal exposures to solutions of less than 10%. Rats (unspecified number) receiving daily doses of up to 390 mg/kg acetic acid in their drinking water (up to 5.0%) for 2 to 4 months, were found to experience weight loss (apparently due to anorexia) at the highest dose. The NOAEL was 195 mg/kg/day; no deaths occurred in any dose group. Gastric lesions, forestomach wall thickening, and inflammatory changes were observed in some (proportion unspecified) rats fed 4.5 g/kg/day for 30 days.

Neurotoxicity

No data regarding neurologic effects related to acetic acid exposures in humans or animals were located.

Developmental/Reproductive Toxicity

No studies focusing on reproductive effects were located. Pregnant rats (unspecified number) administered 1.6 g/kg/day apple cider vinegar (5.0% acetic acid) showed no increased mortality or fetal abnormalities compared to sham-treated controls (unspecified study length and number of animals) (Clayton and Clayton, 1982).

Mutagenicity

Acetic acid was not found to be mutagenic in two *in vitro* mutagenicity tests with or without metabolic activation preparations from mice, rats, or monkeys (Clayton and Clayton, 1982).

Carcinogenicity

Male rats (unspecified number) fed 350 mg/kg sodium acetate, a salt of acetic acid, three times/week for 63 weeks, followed by a dose of 140 mg/kg three times/week for 72 days (10+ weeks) showed no histological evidence of tumors (Clayton and Clayton, 1982). This is insufficient to conclude anything about the carcinogenicity of acetic acid.

Citric Acid and Sodium Citrate

Summary

Citric acid is a normal metabolite in humans and occurs naturally in many foods. It is generally considered to be largely innocuous except in the case of ingestion of large quantities (i.e., levels well above 500 mg/kg, the estimated average daily intake) or chronic exposures. Chronic oral exposures in humans may result in tooth erosion, local irritation, and some ulceration. Gastrointestinal irritation has also been observed following ingestion of sodas containing citric acid. Citric acid dust may also be irritating to the nose and throat. Citric acid has been shown to be a mild to moderate skin and eye irritant in humans following inhalation or dermal exposures. Acute high dose exposures in animals have resulted in mild skin and severe eye irritation. Limited animal data suggest that exposure to citric acid does not result in developmental or reproductive effects. No information has been located discussing neurotoxic, mutagenic, or carcinogenic effects associated with citric acid exposures in animals or humans.

The alkaline salt of citric acid, sodium citrate, is expected to behave chemically like the acid systemically. Unlike the acid, however, this alkaline salt may not have irritant properties.

Absorption/Metabolism

Citric acid is a normal metabolite and an intermediate in cellular oxidative metabolism. It is formed in the mitochondrion and successfully degraded to a series of four-carbon acids used in the oxidative process of the cell (Clayton and Clayton, 1982). Sodium citrate is oxidized to bicarbonate in the body and excreted in the urine (HSDB, 1994; no other details provided). No absorption by the skin is expected following dermal exposures (USEPA, 1994).

Acute Toxicity

Humans

No reports relate to dermal exposure.

Animals

No tests reported relate to dermal exposure.

Irritation/Sensitization

Humans

Citric acid, in humans, may be a mild to moderate irritant if inhaled as an aerosol, or if in direct contact with the eyes or skin (HSDB, 1994). Citric acid dust may also be irritating to the nose and throat (HSDB, 1994). Citrate, about 1-2 g/day usually prescribed for ingestion in the form of citric acid and sodium citrate solution, has been reported occasionally to result in gastrointestinal irritation (i.e., irritant effect on the oral mucosa and necrotic and ulcerative lesions) (HSDB, 1994).

Animals

In rabbits (unspecified number), a moderate reaction was observed at 24 hours following a 500 mg application of citric acid to the skin, whereas a severe eye effect was seen after a 750 µg application (relation of amounts in application to potential amounts in formulation unknown) (Clayton and Clayton, 1982). In another study, a single drop of 2.0 to 5.0% solution of citric acid in water caused little or no injury to rabbit eyes (unspecified number); however, irrigation of a 0.5 to 2.0% solution resulted in severe eye injury (HSDB, 1994).

Subchronic/Chronic Toxicity

Humans

Frequent or excessive intake (unspecified) of citric acid in humans may result in tooth erosion and local irritation (Clayton and Clayton, 1982) and some ulceration (HSDB, 1994). These have been seen with lemon juice, about 7% citric acid (Clayton and Clayton, 1982). No dermal exposure responses are discussed in the literature used for this review.

Animals

No dermal exposure studies are discussed in the literature used for this review.

Neurotoxicity

No data have been located regarding the neurotoxic potential of citric acid exposure in humans or animals.

Developmental/Reproductive Toxicity

Citric acid has not been shown to be a reproductive hazard (HSDB, 1994). No studies involving dermal exposure are reported. No reproductive effects were found in a study where two successive generations of rats (unspecified number) were fed diets containing 1.2% citric acid over a 90-week period (Clayton and Clayton, 1982). No effect was detected on litter size or survival up to weaning age in young rats or mice (unspecified numbers) fed diets containing 5.0% citric acid (no study length provided) (Clayton and Clayton, 1982).

Mutagenicity

No data have been located regarding the mutagenic or genotoxic potential of citric acid exposure in humans or animals.

Carcinogenicity

No data have been located regarding the carcinogenic potential of citric acid exposure in humans or animals.

Sodium Carbonate

The information (studies and conclusions) used in this health hazard have been adapted from a report issued by the CIR panel (CIR, 1987), unless otherwise stated.

Summary

Sodium carbonate is a commonly used component in bath, skin, and hair preparations. Products containing sodium carbonate may be expected to remain in contact with the skin up to an hour and are likely to be used repeatedly over a period of several years. Sodium carbonate is also used as a GRAS (generally regarded as safe) direct food ingredient. The CIR panel concluded that due to its alkaline nature, sodium carbonate is a skin and eye irritant. Human skin exposures to products containing 0.0025% active sodium carbonate were not considered to be strong irritants or sensitizers.

Repeated exposure of humans (a dockworker study) to dusts of sodium carbonate resulted in severe skin irritation, as well as upper respiratory irritation. Repeated exposure to high concentrations of aerosols containing sodium carbonate resulted in pathological changes to the lungs and respiratory tract of mice, rats, and guinea pigs. LC_{50}s ranging from 0.8 to 2.3 mg/l (aerosols) were identified in rats, mice, and guinea pigs. Sodium carbonate was not developmentally toxic to mice, rats, or rabbits. No information was available discussing reproductive, neurotoxic, mutagenic, or carcinogenic toxicity following sodium carbonate exposure to humans or animals.

Absorption/Metabolism

Because it is a solid, sodium carbonate is not expected to be absorbed through the skin but is expected to be absorbed (in dissociated form) from the lung. In the stomach, the compound will react with stomach acid to produce carbon dioxide, which is released in expired air (USEPA, 1994). In general, solids such as sodium carbonate with high melting points (851°C) do not penetrate the skin unless present as very fine particles. In addition, inorganic salts, such as sodium carbonate, are generally considered not to penetrate the skin (Schaefer et al., 1982).

Acute Toxicity

Acute toxicity studies of sodium carbonate in dilute solution have not been identified for dermal exposure routes.

Humans

Available acute toxicity data on humans indicate that sodium carbonate may be irritating to mucous membranes. Kamaldinova et al. (1976; as cited in Rom et al., 1983a) report an irritancy threshold (presumably irritation to the upper respiratory tract) of 40 mg/m^3 sodium carbonate in 14 volunteers exposed by inhalation for 1 minute.

Animals

Sodium carbonate aerosols are moderately toxic to rodents (USEPA, 1994). Whole-body inhalation exposure of adult male rats, mice or albino guinea pigs (unspecified numbers) to aerosols of sodium carbonate (91-95% pure) for 2 hours resulted in LC$_{50}$s of 2.3 mg/l for rats, 1.2 mg/l for mice, and 0.8 mg/l for guinea pigs (Busch et al., 1983, as cited in USEPA, 1992). Immediately after exposure, clinical signs included dyspnea, wheezing, excessive salivation, and distention of the abdomen. Within 3 to 4 hours post exposure, all clinical signs subsided. Animals that died during or shortly after exposure showed accumulation of mucus in, and vesiculation and mucosal edema of, the pharynx and larynx. Edema and vesiculation of the anterior trachea, hemorrhage in the lungs, and severe gastric tympany were also observed. Basal epithelial cells of the posterior pharynx and anterior trachea had enlarged mitochondria following exposures of 1 hour or more. Clinical signs and pathologic changes in all animals were similar regardless of dose level.

Irritation/Sensitization

Humans

The irritancy potential of three bar-soap products containing 0.25% sodium carbonate at a concentration of 1.0% were tested in three groups of 107 to 109 male and female volunteers (CIR, 1987). In all studies, following applications of two occlusive 24-hour patches (induction patch and challenge patch) applied 24 hours apart, investigators concluded that observed reactions indicated weak, nonspecific irritation; thus, this soap was neither a strong irritant nor contact sensitizer. Clayton and Clayton (1982) summarize a human study in which a 50% solution of sodium carbonate was applied to the intact and abraded skins of the volunteers. The solution produced no erythema, edema, or corrosion of intact skin. Abraded skin showed moderate erythema and edema, and one-third of the human volunteers showed tissue destruction at the abraded areas. Rom et al. (1983b, as cited in CIR, 1987) identified no further irritation or sensitization by 10% aqueous sodium carbonate applied to miners suffering pruritic, erythematous lesions from exposure to dust of trona ore (sodium sesquicarbonate, about 45-50% sodium carbonate).

Animals

A 50% (weight/volume) aqueous solution of sodium carbonate was applied to the intact and abraded skin of rabbits and guinea pigs, (CIR, 1987). The sites were examined at 4-, 24-, and 48-hours. The solution produced no erythema, edema, or corrosion of intact skin. Abraded skins of guinea pigs were negligibly affected, but abraded rabbit skins showed moderate erythema and edema.

Sodium carbonate produced ocular irritation in rabbits (two groups of six or more) administered 0.1 ml powdered sodium carbonate, although observed opacities and iritis were transient in the group that received eye rinses after exposure (CIR, 1987). Conjunctivitis persisted in both groups.

Subchronic/Chronic Toxicity

Humans

Kamaldinova et al. (1976, as cited in Rom et al., 1983a) reported that dockworkers exposed to soda ash (sodium carbonate) in ship holds and freight cars at dust levels greater than 300 mg/m^3 exhibited "soda ash burns," a 1.5-fold increase in the incidence (unspecified comparison group) of skin diseases (ulcers, erosion, eczema), and lost work days due to skin inflammation. Rhinitis, pharyngitis, and conjunctivitis were also reported.

Animals

Male rats (number unspecified) were exposed to an aerosol of a 2.0% aqueous solution of sodium carbonate (particles less than 5.0 µm diameter) 4 hours/day, 5 days/week, for 3.5 months. A concentration of 10 to 20 mg/m^3 did not cause any pronounced effect. Histological examination of the lungs of animals exposed to higher doses (approximately 70 mg/m^3) showed thickening of the intra-alveolar walls, hyperemia, lymphoid infiltration, and desquamation (Clayton and Clayton, 1982).

In another study, 10 rats, 20 mice, and 10 guinea pigs were exposed for 2 hours to aerosols consisting predominately of sodium carbonate at the following respective concentration ranges: 800-4,600 mg/m^3, 600-3,000 mg/m^3, and 500-3,000 mg/m^3. For all aerosol concentrations, all animals show clinical sign of toxicity (respiratory impairment, dyspnea, wheezing, excessive salivation, and distention of the abdomen) immediately after exposure, sometimes resulting in death (unspecified number) (CIR, 1987). Respiratory lesions in those that died were observed in the pharynx, larynx, trachea, and lungs. For animals that survived the study, respiratory lesions were limited to the laryngeal mucosa.

Neurotoxicity

There are no data on the neurotoxicity of sodium carbonate.

Developmental/Reproductive Toxicity

Humans

There are no data on the reproductive or developmental toxicity of sodium carbonate in the literature used for this review.

Animals

There are no data on the reproductive toxicity of sodium carbonate. Available data on developmental toxicity in animals indicate that the compound is not a developmental toxicant.

Pregnant mice (number not specified) were dosed daily by oral intubation with aqueous solutions of sodium carbonate at levels of 3.4 to 340 mg/kg during days 6 through 15 of gestation (Clayton and Clayton, 1982; CIR, 1987). There were no effects on implantation or survival of the dams or fetuses. The numbers of abnormalities in soft and skeletal tissues in the experimental group did not differ from those for sham-treated controls. Similar results were observed in rats and rabbits dosed at 245 mg/kg and 179 mg/kg, respectively (CIR, 1987).

Mutagenicity

No data on mutagenicity as it related to sodium carbonate exposure were located in the literature.

Carcinogenicity

No human or animal studies were available to assess the carcinogenic potential of sodium carbonate.

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APPENDIX D
DOSE-RESPONSE ASSESSMENTS

This appendix presents dose-response assessments for drycleaning (perchloroethylene and hydrocarbon solvents) and for machine wetcleaning chemicals.

D.1 DRYCLEANING

This section presents dose-response assessments for perchloroethylene (PCE) and hydrocarbon (HC) solvents (specifically, Stoddard solvent).

D.1.1 Perchloroethylene

Cancer

A specific cancer dose-response assessment is developed under the assumption that an agent is a human carcinogen. The dose-response assessment is intended to quantitatively define the relationship between the dose of the agent and the likelihood of a carcinogenic effect. First, an attempt is made to predict the relationship from epidemiologic studies. In the case of PCE, the epidemiology is insufficient to define the relationship.

Turning to the animal data, hepatocellular adenomas and carcinomas were produced in PCE-exposed mice of both sexes (NTP, 1986) and mononuclear cell leukemia and kidney tumors were seen in male and female rats (NTP, 1986). As discussed in the hazard assessment, the mechanisms by which PCE induces these endpoints are not clearly understood. More than one mechanism has been proposed by which PCE might cause each of these responses; the available data do not clearly support any of the various mechanistic views. The leukemia and liver responses in rodents suggest a general, accelerating influence on underlying neoplastic processes. The kidney tumors in male rats might be associated with the toxic effects of PCE in the kidney and/or with mutagenic activity of a secondary (mutagenic) metabolite of PCE, dichloro-vinyl cysteine; the data do not reveal an answer. As a whole, the data do not point to the linearity at low doses generally expected of mutagenic compounds, although the elevated responses in high background tumors could suggest an activity that builds on background processes. This would give the appearance of linearity at doses producing responses close to background rates, regardless of mutagenic activity.

Although the data are not strongly linear, they are also not strong enough to describe how PCE might have a threshold or a non-linear dose-response relationship at low doses, nor do they assist in building an alternative model for response in that range. Consequently, the Cleaner Technologies Substitutes Assessment presents two assessments of dose response: one uses a procedure that assumes linearity at low doses; the second a procedure that stops short of projecting response to low doses and examines the extent to which anticipated exposures differ from study levels (sometimes called margins of exposure or MOEs) to characterize human risk. This latter utilizes a quantity called the ED_{10} (see explanation below).

This section uses several existing analyses, supplemented by analyses along the philosophy of the recent proposed revision (USEPA, 1996) of USEPA's Carcinogen Risk Assessment Guidelines (USEPA, 1986b). Both approaches use the animal data in hand (NTP, 1986) and rely on analyses carried out and published in the Addendum to the Health Assessment Document (USEPA, 1986a). These analyses first examined the data in the experimental range. Following the approach used in the Addendum, exposure concentrations for the experimental animals were transformed to human equivalent metabolized dose.[1] Owing to the date of the Addendum's analyses, these equivalents are based on a species proportionality with (body weight)$^{2/3}$.[2]

The CTSA uses human equivalent metabolized doses with the mouse and rat tumor responses to establish predicted dose-response relationships in the range of the experiment. The tumor prevalence data are the same as in USEPA (1986a) but the slope factor is not, since USEPA (1986a) averaged results from six data sets using a geometric mean. To avoid double counting animals with adenomas and carcinomas, the mouse carcinoma-only data sets have been omitted for this assessment. Thus, the analyses are based on incidence of male and female mouse liver adenomas and/or carcinomas and male and female rat mononuclear cell leukemia by taking the geometric mean of the unit risks of the four individually modeled species-sex combinations.[3]

The first step in establishing a predicted relationship is to fit a model to the data. As mentioned at the outset of this section, data are insufficient to support an agent-specific model reflecting a presumed mode of action. In the range of observation, most quantal models used for curve-fitting will be equivalent and USEPA used a so-called multistage model in its earlier analyses (USEPA, 1986a; USEPA, 1991).[4]

Linear-at-Low-Doses Approach

Linear-at-low-doses approaches address the range in which excess risk is expected to be at most 1%. Historically, USEPA has estimated an upper bound for low-dose risk by incorporating an appropriate linear term into the statistical bound to the multistage curve. At sufficiently small exposures, any higher-order terms in the polynomial will contribute negligibly, and the graph of the upper bound will look like a straight line. That gives a unit risk that can be multiplied by exposures to estimate upper bounds on excess

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[1] This transformation represented a direct transformation from a human study with urinary metabolized dose. The Addendum also presents results based on crude use of a four-compartment model, with no allowance for variability or uncertainty. Subsequent work in the literature (e.g., Hattis et al., 1986; Chen and Blancato, 1987; Bois et al., 1996) has expanded the horizons for transformation and incorporation of variability and uncertainty.

[2] USEPA is considering the use of an alternate factor, proportional with (body weight)$^{3/4}$ (USEPA, 1992) but has not yet adopted it (although it was proposed in USEPA [1996]). Because many technology options and scenarios as well as several dose-response relationships will be considered in the PCE risk characterization, this alternate factor has not been applied here. Its effect on comparisons is expected to be less than half an order of magnitude.

[3] That is, the geometric mean of female and male mouse liver adenomas and carcinomas and female and male rat mononuclear cell leukemia. An alternate view could consider the female results corroboratively or in conjunction with the more sensitive male results within species. As an example, despite the higher background rate in male mice that contributes to differences in response shapes, the results are within an order of magnitude for the two sexes.

[4] This is an exponential model approaching 100 percent risk at high doses with a shape at low doses described by a polynomial function.

lifetime cancer risk for specific scenarios. This “linear-at-low-doses” unit risk would be 7.1 x 10^{-7} per µg/m^3 of PCE in air. This unit risk should not be used for lifetime average daily exposures greater than 1.4 x 10^4 µg/m^3 (risk of 1%). (These values may be compared to the unit risk of 5.78 x 10^{-7} per µg/m^3 of PCE in air and its corresponding use ceiling of 1.7 x 10^4 µg/m^3 from the double-counting calculations in USEPA [1986a], Table 4-6.)

Nonprojection Approach

The method that does not project response to low doses or exposures relies on an ED_{10}, or the dose associated with an estimated excess tumor response in 10% of an experimental group. A multistage model (here, a two-stage model, or exponential with quadratic argument model, as used in the linear-at-low-doses approach) is used to obtain the ED_{10}. Response rates below this percentage are beyond the resolution of most experiments, and the various possible model shapes that might have been fitted to the data begin to diverge.

In addition to the ED_{10}, a lower bound on that 10%-response-dose is calculated to provide a sense of some of the properties of the experiment(s)/studies from which risk is characterized. Because the PCE modeling used units of human equivalent metabolized doses, the ED_{10} and its lower bound are divided by 7.83 x 10^{-6} mg/(body weight)$^{2/3}$/day[5] to obtain units of the inhaled concentration (µg/m^3, human exposure) equivalents (details in USEPA, 1986a). The ED_{10} is 2.7 x 10^5 µg/m^3; the lower bound on the ED_{10} is 1.4 x 10^5 µg/m^3. These figures are compared to projected exposures to assess the MOE ratios as described in Chapter 5. A recent proposal (USEPA, 1996) would take a straight line from the response at the ED_{10} to the background response.[6] There is still discussion about this proposed approach and it has not been adopted for this assessment.[7]

Effects Other Than Cancer

Non-cancer effects vary widely in the characteristics of their manifestation. To provide a common vocabulary for comparing substances, regardless of the effect that may be of most concern, a value called the Reference Dose (RfD; for ingested or dermally applied substances) or Reference Concentration (RfC; for inhaled substances) is derived. The standard approach to the RfD/RfC calls for the identification of the spectrum of effects associated with a given chemical, typically giving primary attention to a “critical effect” exhibiting the lowest No-Observed-(Adverse-)Effect Level (NOAEL or, since this is really an experiment-related term, its conceptual equivalent from epidemiology, studies of humans). Effects are identified using “principal studies,” which “are those that contribute most significantly to the qualitative assessment of whether or not a particular chemical is potentially a systemic toxicant in humans. In addition, they may be used in the quantitative dose-response assessment phase of the risk assessment” (IRIS, 1998).

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[5] This is the estimated amount metabolized over a 24-hour period when an individual is exposed to 1 µg/m^3 continuously.

[6] Whether a line is drawn to background from the ED_{10} or a “linearized” upper bound on a multistage model is utilized, the estimated risks are presumed to be upper bounds on risks owing to the way a straight line will include most S-shaped curves.

[7] The ED_{10}-line would give a unit risk of 3.7 x 10^{-7} per µg/m^3; its bound would give 6.9 x 10^{-7} per µg/m^3. These differ by approximately less than one order of magnitude from the “linearized multistage procedure” result.

An RfD for PCE is published in IRIS (1998). A value of 0.01 mg/kg/day, in which there is medium confidence, is based on the critical effect, hepatotoxicity in mice, from a study by Buben and O'Flaherty (1985). The NOAEL for this effect is corroborated by weight gain in rats at the same level in a study (Hayes et al., 1986) where rats lost weight at higher doses.

For the CTSA, USEPA has derived a provisional RfC of 0.17 mg/m^3, in which there is medium confidence, based on the critical effect, mild renal tubule damage, as reported in Franchini et al. (1983). This RfC is provisional because it was derived by a single USEPA program office with limited cross-office review. Vu (1997) describes the derivation in standard USEPA format.

The RfD/RfC is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis, but may not exist for other toxic effects such as carcinogenicity. In general, the RfD/RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure without an appreciable risk of deleterious effects during a lifetime. RFDs/RfCs can be derived for the non-carcinogenic health effects of compounds that are also carcinogens.

Discussion of Principal and Supporting Studies

Detailed discussion of the data contributing to derivation of the RfD appears in IRIS (1998). All the studies available for derivation were carried out in animals. Buben and O'Flaherty (1985) exposed Swiss-Cox mice to PCE in corn oil by gavage at six doses (20, 100, 200, 500, 1,000 or 1,500 mg/kg) and control, 5 days/week for 6 weeks. The NOAEL from this study was 20 mg/kg/day or 14 mg/kg/day when adjusted for continuous exposure. Hayes et al. (1986) also established 14 mg/kg/day as a NOAEL. Administered PCE in drinking water, the group of Sprague-Dawley rats receiving the least of three positive doses (14, 400, or 1,400 mg/kg/day) showed no difference from the control group.

The CTSA has identified Franchini et al. (1983), Lauwerys et al. (1983), and Solet and Robins (1991) as the principal studies for the RfC. These studies have been carried out in drycleaning workers. The basis for the RfC is (Franchini et al., 1983), a cross-sectional study carried out across four exposure venues relating to organic solvents, including 57 workers exposed to PCE in 29 drycleaning shops. Their average exposure time was 13.9 years (standard deviation 9.8). The exposure intensity was assessed by measuring the end-shift excretion of trichloroacetic acid (TCA). The study authors converted the mean TCA level for the group to a breathing-zone, time-weighted average (TWA) of about 10 ppm (PCE) in air. Renal function impairment indicators (four types of urinalysis outcome) were compared between these subjects and control subjects selected to be biologically and socially similar, but unexposed. Controls were drawn from factories associated with the other three exposure types (painters/benzene in metal working, styrene workers, workers exposed to short-chain alkanes) and considered as two reference groups, one predominantly female, one predominantly male.

The subjects showed mean values of lysozymuria and urinary β-glucuronidase significantly elevated above both reference groups. This testing was carried out by a statistical method that may have identified sources of group differences incorrectly. The authors suggested that increased urinary β-glucuronidase might be related to a faster cellular turnover in tubular epithelium due to a mild toxic effect, whereas lysozymuria might be a marker of more definite lesions throughout the renal tubules. Thus the level of 10 ppm is considered as a Lowest-Observed-Adverse-Effect-Level (LOAEL) equivalent.

The Lauwerys et al. (1983) study is also cross-sectional, including 26 drycleaning workers (24 female) who had been exposed to PCE over a 6-year period in six shops. Certain urinary enzymatic levels were measured, albeit not the same ones as Franchini et al. (1983), as were certain plasma enzymatic levels. Three psychomotor tests were administered. No differences were attributed by the investigators to exposure to PCE. Average exposure was approximately 20 ppm PCE.

Solet and Robins (1991) studied 197 drycleaning workers and found no evidence of adverse effects on renal function, as measured by levels of urinary protein, albumin, and n-acetyl-glucosaminidase (NAG). They did not look at urinary β-glucuronidase. These workers were exposed to a mean PCE concentration of 14 ppm. No control group was studied; thus, the investigators concentrated their effort on modeling the variability among exposed individuals.

Derivation of RfD

The steps to derive the RfD from the principal study include: (1) selecting a critical effect, (2) identifying the highest level consistent with the resolution of the study at which that effect is not seen or the level at which that effect first appears, taking possible confounding factors into account, (3) associating a measure of exposure with that level, and (4) applying scientific judgment to select uncertainty factors (UFs). If the measure of exposure is not an applied or potential dose for the individual, some relationship between that measure and applied/potential dose is needed.

USEPA's RfD/RfC Workgroup carried out these steps, which are reflected in the IRIS (1998) discussion of uncertainty and modifying factors, additional comments, and confidence pertaining to the RfD. Uncertainty factors were incorporated reflecting intraspecies variability, interspecies variability, and inference from a subchronic (6-week) study to chronic exposures. Although confidence in the Buben and O'Flaherty (1985) study was low, owing to incomplete histopathology at the NOAEL, no single study had the necessary combination of desirable characteristics for derivation; confidence in the database as a whole was medium, contributing to a medium confidence in the RfD.

Derivation of Provisional RfC

The steps to derive the RfC from the principal study include the same four as for the RfD: (1) selecting a critical effect, (2) identifying the highest level consistent with the resolution of the study at which that effect is not seen or the level at which that effect first appears, taking possible confounding factors into account, (3) associating a measure of exposure with that level, and (4) applying scientific judgment to select UFs. Again, if the measure of exposure is not an applied or potential dose for the individual, some relationship between that measure and applied/potential dose is needed. For an RfC, however, internal dosimetric considerations may be related to several classes of inhaled substances.

For PCE, the study from which a critical effect was selected was Franchini et al. (1983), and that effect is mild renal tubule damage. It was reported to have been seen at exposures as low as 10 ppm (in air, TWA over work-shift) based on authors' calculations from TCA. The reported derived average level of 10 ppm is equivalent to 70 mg/m^3; this is a LOAEL-equivalent for this study. Adjustment to continuous exposure, assuming no dose rate effects, involves averaging the duration of occupational exposure (40 hours) over the 168 hours in a week, and gives an adjusted daily exposure of 17 mg/m^3. Because this is an occupational study, a 10-fold factor is applied to account for sensitive individuals, and a factor of 10 is applied in order to use a LOAEL as a NOAEL. For use in the CTSA in an occupational setting, only the factor of 10 to adjust a LOAEL to a NOAEL was used.

Additional Comments/Studies for the RfC

Another human study provided a possible explanation for some of the differences among the three principal studies, concerning the appropriate metric of PCE exposure for the RfC. Stewart et al. (1981) studied volunteers exposed 5 days/week for 1 month to PCE concentrations of 20, 100, and 150 ppm. Their subjects were mostly sedentary during exposure except for brief periods of exercise, presumably less active than if they had been exposed occupationally. Based largely on one individual's observed exercise experience and post-activity measurements, the study authors concluded that TWA concentrations may not reflect an individual's true body burden from PCE exposure. The apparent discordance among the three principal studies may be partly due to different approaches to estimating cross-sectional PCE exposure, as well as to misclassification of exposure due to a lack of direct measurements of historical exposure.

The Stewart et al. study could be used to estimate an approximate RfC. The study, however, is especially small. Individuals served as their own control subjects in an experimental context, where volunteers were exposed for a varied number of hours. The study authors stated that exposure to 100 ppm PCE led to major changes in electroencephalogram results of three of four male subjects and four of five female subjects, and that the altered EEG pattern was similar to that seen in healthy adults during drowsiness, light sleep, and the first stages of anesthesia. Application of the same uncertainty factors as above, for using a LOAEL as a NOAEL and to account for sensitive individuals, as well as an uncertainty factor to allow for chronic exposure, leads to an RfC lower than using the Franchini et al. study. By the study authors' arguments, however, this TWA of 100 ppm reflects a lower PCE body burden than would be expected of workers exposed at 100 ppm, suggesting a further adjustment would be necessary.

Use of the TWA of 10 ppm from the Franchini et al. study requires assuming that the TWA represents the typical range of exposures the subjects experienced. If the TWA had been higher than 10 ppm in earlier years of the subjects' exposures, and this higher TWA were more causally linked to the increase in urinary enzymes than the TWA measured in the study, then the RfC here would be overly protective. On the other hand, because no measure of variability in exposure concentrations is available, the UF adjustment for sensitive populations may be an insufficient reflection of the range of human response. No additional UF was applied for extension to lifetime exposure; the inhaled PCE exposures are unlikely to accumulate indefinitely to produce this endpoint, the duration of exposure of 13.9 years with a standard deviation of 9.8 years applied to the mean age of 43 (standard deviation 9.1) covers a substantial part of the subjects' adult lives, and the modifying factor is less than the variability in the derived exposure.

Several more recent studies (Altmann et al., 1990, 1992, 1995; Ferroni et al., 1992; Cavalleri et al., 1994) have examined neurobehavioral endpoints. These have included cognitive deficits, deficits in visual evoked potentials and visual acuity, and prolonged reaction times. Difficulties in using these studies for deriving a provisional RfC include an experimental setting in which the control group was exposed at 10 ppm (the derived mean level at which effects were seen in Franchini et al., 1983) or occupational exposures at means above 10 ppm, large standard deviations on reported exposure levels, and poor association of the exposure levels with the effects. The New York State Department of Health (NYSDOH, 1997) used a collection of studies including these and several others together with its own methods to derive several endpoint-specific criteria for evaluating non-carcinogenic effects for adults and children. Its possible adult values range from 0.28 mg/m^3 to 0.36 mg/m^3, with an overall recommendation that the criterion for ambient air be 0.1 mg/m^3. This value is consistent with the above derived provisional RfC.

Animal data support the endpoint choice and conclusions from human data. NTP (1986) reported renal and hepatic effects, including tumors, in rodents exposed by inhalation for 2 years to high levels of PCE (100 and 200 ppm in mice, and 200 and 400 ppm in rats). It reported that 100 ppm (approximately 700 mg/m^3), the lowest concentration tested, was a LOAEL for mice. Exposure to 100 to 1,600 ppm for 6 hours/day, 5 days/week, for 13 weeks was associated with hepatic and renal effects; a concentration of 1,600 ppm was fatal to 20-70% of rats and mice and was associated with reduced body weights. Exposure of rats to 0, 200, or 400 ppm, and of mice to 0, 100, or 200 ppm for 2 years was associated with a dose-related decrease in survival in male rats and both sexes of mice. Long-term exposure to PCE was associated with leukemia in rats at 100 and 200 ppm and in rats at 200 and 400 ppm, karyomegaly (in rats of both sexes), and hyperplasia in renal tubular cells (in male rats). No tumors of the respiratory tract were reported. A NOAEL was not established by this study. Although the appearance of increased mortality at 100 ppm in male mice could suggest this as a Frank Effect Level (FEL), this increase was not in evidence until after 74 weeks.

Discussion of Confidence in the RfC

PCE has been studied for a variety of endpoints, and human and animal studies are available relating to systemic toxicity and reproductive and developmental effects. The animal literature is extensive; the human literature has gaps. On balance the database is of medium quality. This RfC is based on humans, exposed in a most typical setting. The Franchini et al. (1983) study does not permit a quantitative dose-response relationship to be derived and does not characterize the variability of the exposure concentrations. Thus, some lower exposures may still demonstrate effects, and the Solet and Robins (1991) study, lacking a control group, cannot be used to establish a NOAEL in lieu of the Franchini et al. (1983) LOAEL. A rough calculation of an RfC from Stewart (1981), based on a neurotoxicity outcome, is slightly lower than the RfC derived from Franchini et al. (1983), based on renal function, suggesting the magnitude is reasonable. An RfC based on the (animal) NTP (1986) study without any dose conversions would be of the same order of magnitude (based on a LOAEL of 100 ppm, or approximately 125 mg/m^3 for continuous exposure, and applying an uncertainty factor and a modifying factor of 1,000 and 1, respectively).

D.1.2 Hydrocarbon Solvents

No oral RfD, inhalation RfC, cancer unit risk, or slope factor has been established to date for Stoddard solvent or any other hydrocarbon solvent. ATSDR (1995) determined that it did not have human or animal studies suitable for developing what it calls Minimum Risk Levels, which resemble RfD/RfCs, for intermediate- or chronic-duration exposures to Stoddard solvent in air.

For purposes of the CTSA, a non-cancer comparison value has been derived from Carpenter et al. (1975a, 1975b). As discussed for PCE, the standard approach to the RfD/RfC calls for the identification of the spectrum of effects associated with a given chemical, with primary attention given typically to a “critical effect” exhibiting the lowest NOAEL (or, since this is really an experiment-related term, its conceptual equivalent from epidemiology, studies of humans). Effects are identified using “principal studies," which "are those that contribute most significantly to the qualitative assessment of whether or not a particular chemical is potentially a systemic toxicant in humans."

The spectrum of effects that has been associated with Stoddard solvent is described in Chapter 3 and Appendix C. Because the human observations provide poor exposure information when occupationally based and are at relatively high levels when experimental, a comparison value was selected from the animal literature. Rather than develop a provisional level for the CTSA without critical review, a level was chosen directly from a study. A 13-week study (Carpenter et al., 1975a, 1975b) in dogs showed no statistically significant clinical and histopathological differences as low as 480 mg/m^3 (84 ppm) and as high as 1,900 mg/m^3 (330 ppm). Because a parallel study in male rats showed kidney tubular regeneration at both 1,100 mg/m^3 (190 ppm) and 1,900 mg/m^3 (330 ppm), but none at 480 mg/m^3 (84 ppm), 480 mg/m^3 is identified as a NOAEL, with the recognition that it is from a subchronic study.

D.2 MACHINE WETCLEANING CHEMICALS

No oral RfD, inhalation RfC, cancer unit risk, or slope factor has been established to date for any of the sample machine wetcleaning chemicals reviewed for the CTSA, and their data do not provide the necessary information to derive provisional levels for the CTSA. This makes quantitative assessment of their risks moot. Nonetheless, the principles in quantitative considerations of mixtures are pertinent to their qualitative assessment.

Under ideal circumstances, information would be available for the mixture or formulation as a whole. More typically, information is available on the ingredients (components) or on just some of them (in this case, on none). Often, certain components are exchangeable, with selection based on their function in the process, but with exposure and toxicity properties unique to the selection. In Section 3.3, some information on examples of these selections was provided for the wetcleaning process. Many of the aqueous-based ingredients have, themselves, been tested in mixtures that may resemble the formulations for use in machine wetcleaning. Such tests are helpful to the extent that the tested mixture is known and resembles the expected wetcleaning formulation. Details of the tested formulations, unfortunately, were not available for most of the components described in the CTSA.

Quantitative assessment of mixtures using their components in the absence of specific interaction information would typically rely on an assumption that the components produce their toxicities independently; information on ways one or more components may modify others is incorporated qualitatively. Mixtures with just a few ingredients may be characterized quantitatively and qualitatively more readily than mixtures with many dissimilar ingredients.

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APPENDIX E
RELEASE AND EXPOSURE METHODOLOGY AND DATA

Exhibit E-1. PCE Emissions by Machine Type[a]

Machine Type with Typical Controls	Emissions for a Typical Cleaner (gal/yr)
Transfer	330
Vented	220
Converted	170
Closed-loop	80

[a] Source: CEPA, 1993. These emissions data were used in estimating releases to air in Exhibit 4-1.

Exhibit E-2. Emission Factors Used to Estimate Releases of Solvent from Hydrocarbon Dry Cleaning Facilities[a]

- Dryer - 18 kg VOC is released to air per 100 kg dry weight of articles cleaned based on an average of three studies conducted between 1975 and 1980. The rate of emission is highly dependent on the amount of solvent absorbed and subsequently released during extraction (e.g., loose weaves absorb and release solvents more readily), the efficiency of the extractor, and the size of the dryer load. 3.5 kg VOC is released to air per 100 kg dry weight of articles cleaned with a condenser/solvent recovery dryer.

  The recovery dryer also generates separator water which is discharged to the sewer and received by a POTW. Water enters the solvent bath, through adsorption from the clothes and the air, at a rate of 0.004 - 0.02 gals/lb articles cleaned (USEPA, 1982). This water may be recovered in the recovery dryer separator or in the distillation separator.

- Filter - After draining a diatomaceous earth filter, the filter muck contains approximately 8 kg solvent per 100 kg dry weight of articles cleaned (USEPA, 1982). This average depends on the type of filter used (i.e., the amount of diatomaceous earth required by the filter), and the soil loading of the clothes. When cartridge filters are used, less than 1.0 kg solvent per 100 kg dry weight of articles cleaned is found in the spent filter medium.

- Settling Tanks - No emission factor available. Settling tanks may be used instead of filters for highly contaminated solvent. The solvent content may be from 80 to 200 percent, by weight, of settling tank waste. Settling tank waste may be burned in a boiler, discarded with general drycleaning waste, or sold to a solvent reprocessor. It is generally too contaminated to treat in the vacuum still.

- Vacuum Stills - 1-7 kg solvent per 100 kg dry weight of articles dry cleaned (average of 3 kg solvent) is disposed with the still residue. Solvent is also discharged with the wastewater generated from the still overhead separator, though the quantity is unknown.

- Fugitive Emissions - At least 1 kg of VOC emissions per 100 kg dry weight of articles. This factor is assumed to be the total emissions per 100 kg articles less all other emission factors.

[a] Source: USEPA, 1982.

Exhibit E-3. Environmental Release Estimates of Example Detergent #1 Constituents[a]

	Constituent	Weight Percent[b]	Density[c] (g/cm^3)	Releases to water[d] (kg/site-day)
1	water	54	1	0.195 - 0.631
2A	methyl 2-sulfolaurate, sodium salt	3.75	1	0.013 - 0.044
2B	sodium lauryl isethionate	3.75	1	0.013 - 0.044
3	ethoxylated sorbitan monodecanoate	7.5	1.1	0.027 - 0.088
4	lauryl polyglucose	7.5	1	0.027 - 0.088
5	Aveda's fragrance	1	1	0.004 - 0.012
6	sodium citrate	2.5	1	0.009 - 0.029
7	cellulose gum	5	0.75	0.018 - 0.058
8	acetic acid	5	1.049	0.018 - 0.058
9	citric acid	2.5	1.542	0.009 - 0.029
10	diazolidinyl urea	7.5	1	0.027 - 0.088
	totals	100	1.01	0.360 - 1.169
	Total release minus water			0.165 - 0.538

[a] These release estimates correspond to 29.5 to 95.4 gallons/year total detergent use and release rates (from the Machine Wetcleaning Release Assessment in Section 4.2.2) and are based on assumptions that: example detergent #1 contains the constituents listed for All-Purpose Cleanser (Aveda, 1992) from the Multi-Process Wetcleaning Report (USEPA, 1993); all of the formulation used is released to water; and, a CTSA model facility operates for 312 days/year and the annual estimated release to water is divided equally over the operating days.

[b] Assumed based on assumed function of constituent.

[c] From Chemical Properties and Information tables in Appendix A; if no data available, assumed 1 g/cm^3.

[d] For the risk assessment, these total detergent releases were converted from volume (gallons per day) to weight (kilograms per day [kg/site-day]) using the total formulation density. The total weight was then distributed among the constituents using the weight percents of the constituents.

Exhibit E-4. Environmental Release Estimates of Example Detergent #2 Constituents[a]

	Constituent	Weight Percent[b]	Density[c] (g/cm^3)	Releases to Water[d] (kg/site-day)
1	water	54	1	0.225 - 0.728
2	lauryl polyglucose	4.28	1	0.018 - 0.058
3	lauric acid diethanolamide	4.28	0.979	0.018 - 0.058
4A	methyl 2-sulfolaurate, sodium salt	2.14	1	0.009 - 0.029
4B	sodium lauryl isethionate	2.14	1	0.009 - 0.29
5	sodium laureth sulfate	4.28	1	0.018 - 0.058
6	sodium citrate	2.5	1	0.010 - 0.034
7	cocamidopropyl betaine	4.28	1	0.018 - 0.058
8	Aveda’s fragrance (orange)	1	1	0.004 - 0.013
9	cocoamphocarboxyproprionate	4.28	1	0.018 - 0.058
10	sodium carbonate	10	2.53	0.042 - 0.135
11	citric acid	2.5	1.542	0.010 - 0.034
12	diazolidinyl urea	4.28	1	0.018 - 0.058
	totals	100	1.17	0.417 - 1.350
			Total releases minus water	0.192 - 0.622

[a] These release estimates correspond to 29.5 to 95.4 gallons/year total detergent use and release rates (from the Machine Wetcleaning Release Assessment in Section 4.2.2) and are based on assumptions that: example detergent #2 contains the constituents listed for Fabric Cleanser (Aveda, 1992) from the Multi-Process Wetcleaning Report (USEPA, 1993); all of the formulation used is released to water; and, a CTSA model facility operates for 312 days/year and the annual estimated release to water is divided equally over the operating days.

[b] Assumed based on assumed function of constituent.

[c] From Chemical Properties and Information tables in Appendix A; if no data available, assumed 1 g/cm^3.

[d] For the risk assessment, these total detergent releases were converted from volume (gallons per day) to weight (kilograms per day [kg/site-day]) using the total formulation density. The total weight was then distributed among the constituents using the weight percents of the constituents.

Summary of Dry Cleaning Worker Population and Subpopulation

Exhibits E-5, E-6, and E-7 contain data and assumptions used to estimate the numbers of workers in perchloroethylene and hydrocarbon dry cleaning facilities and percentages of these workers by job title. Exhibit E-5 shows the original data that were the bases for final CTSA estimates of numbers of workers. This exhibit also shows the calculation of estimated number of drop-off/ pick-up sites.

Exhibit E-5. Summary of American Business Information (ABI) 1994 Dry Cleaning Worker Population Data[a,b]

Size Category (number of shop workers)	Number of Shops	% Age of all Shops	Fraction of Known Shops	Minimum Workers	Maximum Workers
1 to 4	33,853	70	0.72	33,853	135,412
5 to 9	8,252	17	0.18	41,260	74,268
10 to 19	3,482	7	0.07	34,820	66,158
20 to 49	1,095	2	0.02	21,900	53,655
50 to 99	175	0.4	0.004	8,750	17,325
100 to 249	62	0.1	0.001	6,200	15,438
250 to 499	6	0.01	0.0001	1,500	2,994
500 to 999	1	0.002	0.00002	500	999
unknown	1,161	2	NA	1,161	1,161
Totals	48,087	100	1	149,944	367,410

[a] Source: ABI (1994) as cited in NIOSH (1997).

Exhibit E-6. Summary of Estimated Dry Cleaning Worker Population Data[a]

Size Category (number of shop workers)	Number of Shops	Percent of all Shops	Minimum Workers	Maximum Workers
1 to 4	22,604	63	22,604	90,414
5 to 9	8,456	23	42,281	76,105
10 to 19	3,568	10	35,681	67,795
20 to 49	1,122	3	22,442	54,982
50 to 99	179	0.5	8,966	17,754
100 to 249	64	0.2	6,353	15,820
250 to 499	6	0.02	1,537	3,068
500 to 999	1	0.003	512	1,024

	Number of Shops	Percent of all Shops	Minimum Workers	Midpoint Workers	Maximum Workers
Revised Total	36,000	100	140,377	233,670	326,962
Allotted to PCE (85% PCE)	30,600		119,320	198,619	277,918
Allotted to HC (15% HC)	5,400		21,057	35,050	49,044
Average number of employees per site			3.9	6.5	9.1

[a] For the CTSA, the ABI data from Exhibit E-4 were adjusted: (1) to exclude drop-off/pick-up (DO/PU) sites; (2) to proportionally distribute the 1,161 shops in “unknown” size category above into the known size categories. DO/PU sites were assumed to be the difference between the total number of shops (48,087) from Exhibit E-4 and the total number of shops (36,000) estimated for the CTSA to perform drycleaning. Therefore, 12,087 sites are estimated to be DO/PU sites. DO/PU sites are all assumed to be in the 1-4 size category. Adjustment (1) was then accomplished by subtracting the 12,087 DO/PU sites from the 33,853 shops in the 1-4 size category. Adjustment (2) was accomplished for each size category by adding to the number of shops for that category the product of 1,161 times the fraction of known shops for the category. The results of these adjustments are in Exhibit E-5. The numbers of workers from this exhibit were rounded before being reported in the text (Section 4.4.1 for PCE and Section 4.4.2 for HC).

Exhibit E-7. Dry Cleaning Worker Subpopulation Estimation[a,b]

Job Title	Estimated Number of Workers	Percent of all Workers[c]
Mgr/Admin	1,655	3.8
Bookkeeper	208	0.5
Clerk	8,068	18.5
Foreman	84	0.2
Installer	86	0.2
Engineers	23	0.1
Tailors	4,306	9.9
Presser	6,759	15.5
Seamstress	246	0.6
Operator	21,240	48.7
Sewer	296	0.7
Driver	644	1.5
PEI Total	43,615	100

[a] Source: PEI, 1985.

[b] Exhibit E-6 shows the data used to estimate percentages of dry cleaning workers by job title. The percentages of workers for the job titles from this exhibit were reported in Section 4.4.1 for PCE and Section 4.4.2 for HC.

[c] Note: 3.6 is the percent of workers other than those titled manager, operator, presser, tailor, and clerk.

Exhibit E-8. Determination of Estimated Dermal Exposure Durations for Potential Liquid PCE Contact[a]

Activities	Avg. Frequency, Duration
1. loading/ unloading machine (transfer machines)	6/day (CTSA), 2 min/event (NIOSH)
2. waterproofing (not all shops)	1-2/day (assumed*), 2 min/event (NIOSH)
3. changing filters	demand (NIOSH); 5 min/event (NIOSH)
4. cleaning still	1/day (NIOSH); 5 min/event (NIOSH)
5. emptying button trap	1/day (NIOSH); < 1 min/event (assumed*)
6. filling storage tank	demand (NIOSH); < 1 min/event (assumed*)
7. changing rag filter (not all shops)	1/week (IFI); < 1 min/event (assumed*)
8. cleaning muck cooker (powder filters only)	assume same as still cleaning

Assumptions: Assumed* in above list indicates no source of estimate was found, and the value was based on an assumption of the amount of time to complete the activity. Operators are primary workers who perform the above activities which have potential for liquid PCE contact. For each transfer contact, add two minutes to account for time prior to total PCE evaporation; for each non-transfer contact, add 1 minute.

Summation (estimated total time of contact plus post-contact evaporation of liquid PCE)

Transfer machine operators: 6x4+5+2 = 31 min/day daily routine
Dry-to-dry operators: 5+2 = 7 min/day daily routine
Non-routine add-ons: 5-6 min/week = 1 min/day avg. assumed

Transfer operators: < 32 min/day total (routine plus non-routine)
Dry-to-dry operators: < 8 min/day total

[a] Source: NIOSH, 1997; IFI, 1994.

Exhibit E-9. Exposure Assessment Methodology- Background on Worker Exposure

The USEPA/OPPT/Chemical Engineering Branch (CEB) standard methods and procedures for assessing worker exposure were used for this CTSA and are presented in *Preparation of Engineering Assessment, Volume I: CEB Engineering Manual* (USEPA, 1991). For many worker exposure assessments, data are unavailable or incomplete, and screening-level methods must be used. Screening-level assessments rely on the use of readily available information and data and are generally considered to be conservative (protective) in nature. However, screening-level estimates are often quite uncertain and may over- or under-estimate exposures by one or more orders of magnitude.

Key elements of the worker exposure assessment include, for a given worker population, such as perchloroethylene process operator: the number of workers in that population; routes of exposure; measures of amounts of exposure to a chemical or set of chemicals, such as potential dose rates (PDRs)(e.g., milligrams per day [mg/day]), or the amounts of chemicals to which a worker may be exposed over a given period of time via a given route) , or, alternately, exposure concentrations (ECs)(e.g., parts per million (ppm) time-weighted average [TWA]), which may be translated to PDRs; and, the frequency of exposure (e.g., days/yr) for each dose rate. The following paragraphs briefly describe the assessment methods.

The National Occupational Exposure Survey (NOES) database is frequently used to estimate the number of workers potentially exposed to substances during industrial and commercial operations. The survey was conducted in 1980 - 1983 and information was extrapolated to make national estimates of numbers of workers potentially exposed and numbers of facilities where the substance is present. Because of the age of the data, the survey itself, and the extrapolation to national averages, there are several uncertainties associated with the data. NOES estimates are fairly uncertain estimates . The NOES survey data were not used to estimate the numbers of workers for established cleaning processes because a number of other data sources indicated that the NOES data were extremely inaccurate for this industry. Data documented in other sources were used to estimate the number of workers per site because those sources were expected to be more up-to-date and accurate than the NOES data.

There are two primary routes of worker exposure assessed in this CTSA. Inhalation exposure, or workers breathing workplace air containing significant concentrations of volatile solvents, is expected to be the most significant route for solvents used in dry cleaning. 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. Dermal exposure is also a route of worker exposure for solvents. Ingestion may be a route of exposure for workers who may, for example, eat food contaminated with cleaning chemicals from the workers' hands. However, no data or estimation method is known to make an estimation of worker exposure via this route, and this route would be generally expected to be a much less significant route relative to the inhalation and dermal routes.

When assessing the amounts of chemicals to which workers are exposed, an order of preference of data or methods is used. The first preference is personal monitoring data on chemical being assessed for the population being assessed, and this type of data was available for the worker inhalation exposures assessed in the Cleaner Technologies Substitutes Assessment. Given that monitoring data was not available for worker dermal exposures, modeling was used. The models used are based on some limited studies conducted on retention of liquids.

Exhibit E-10. Worker Exposure - Inhalation

Regarding worker inhalation exposures, several monitoring data sets were found for airborne solvent exposure concentrations (ECs) in dry cleaning facilities. Only personal (not area, bulk or other) samples were included and short-duration (< 1 hour) measurements were not included in the CTSA. To include non-detect (i.e., zero) measurements in the mean EC estimates based on OSHA OCIS data, non-detects were assigned the value of the detection limits (DLs) divided by the square root of 2 (reflecting that these data sets appear to be skewed) (OCIS, 1994, 1998). However, DLs were not provided with these data sets. Therefore, the lowest measured value in each data set was assumed to be slightly higher than the DL for that set, resulting in the following assumed DLs: 0.01 ppm for PCE, 5 mg/m^3 for Stoddard solvent. All inhalation ECs to solvent vapors (PCE and HC processes) may be converted to potential dose rates (PDRs) based on the assumption that workers may be exposed to the measured time-weighted average (TWA) concentrations of the solvent for eight hr/day and that the workers have an average breathing rate of 1.25 m^3/hr. It should be noted that a number of the monitored data points are less than 8-hour TWAs, but it was assumed that these observed TWA were the same as an 8-hour TWA.

Example calculation for inhalation EC conversion is presented below.

Inhalation Exposure

For EC units conversion from ppm to mg/m^3, we use the ideal gas law. The general equation is

$$\text{ppm (PCE in air)} \times \text{MW PCE} \times 1{,}000\ \text{mg/g} / \text{Vmol} \times 1{,}000\ \text{L/m}^3 = \text{mg/m}^3\ \text{(PCE in air)}$$

where

ppm = g-mol PCE per 1,000,000 g-mol air;
MW = molecular weight of PCE in g/g-mol (165.8);
Vmol = molar volume at ambient conditions (1 atmosphere and 25°C) (24.45).

The general equation reduces to ppm x MW / Vmol = mg/m^3. For example, the exposure concentration for workers in facilities using transfer machines before 1/1/87 from Exhibit 4-6 is 55.3 ppm. The following calculation shows the conversion:

$$55.3\ \text{ppm PCE} \times (165.8/24.45)\ \text{mg/m}^3/\text{ppm}$$

$$= 375\ \text{mg/m}^3\ \text{PCE.}$$

Exhibit E-11. Worker Exposure - Dermal

Dermal PDRs to solvents and detergents were estimated using standard assumptions, as described in *Preparation of Engineering Assessment, Volume I: CEB Engineering Manual* (USEPA, 1991). Dermal PDRs are presented as bounding estimates based on limited data and engineering judgment. These estimates assume: 1 contact per day for low-volatility chemicals and that workers wash up at meal times and/or end of the shift; contact or immersion of 1 or 2 hands depending on the activity; no use of protective clothing, such as gloves, or other controls to mitigate exposure. For a given worker activity, this method assumes a specific surface area contacted by chemical and a specific surface density of that chemical to estimate a PDR. Only one contact per day is assumed for low-volatility chemicals because the surface density for those chemicals is not expected to be significantly affected either by wiping excess from skin or by repeated contact(s) with additional chemical; i.e., wiping does not remove a significant fraction of the small layer of chemical adhering to the skin, and additional contacts with the chemical do not add a significant fraction to the layer of chemical on the skin.

Example calculation for dermal PDR estimations is presented below.

Dermal Exposure

Potential dose rates for occupational dermal exposure to PCE on pages 4-21 and 4-22 are based upon OPPT's Occupational Dermal Exposure Model and are calculated as follows:

(1) Article transfer from washer to dryer: 1300 cm^2 (skin area exposed) x 14mg solvent/cm^2/contact x 1 mg PCE/mg solvent = 18,000 mg/contact

(2) Other Activities: 1300 cm^2 x 3 mg solvent/cm^2/contact x 1 mg PCE/mg solvent = 3,900 mg/contact

For wet cleaning detergent components, the above potential dose rates estimated for PCE are simply assumed to be the same for the detergent formulation multiplied by 1 contact per day (this assumption is discussed above) and the weight fraction of the component in the formulation (or diluted formulation). An example using "constituent Z" of the detergent formulation is as follows:

3,900 mg detergent/contact x 1 contact/day x 0.5 mg constituent Z/mg detergent = 2,000 mg constituent Z/day

Exhibit E-12. Exposure Assessment Methodology - Non Worker Populations

Exposures to non-worker populations were estimated using Agency guidance published in the Federal Register (USEPA, 1992). Exposure estimates were developed based on available data from monitoring studies as well as exposure models. Monitoring data were used wherever possible. Inhalation, dermal, and ingestion exposures to PCE were estimated for various exposed populations. These populations include co-located residents, children, the elderly, persons wearing dry cleaned clothing, and persons exposed to ambient levels of PCE.

Much less information was available for use in assessing hydrocarbon exposures. In this case, a model was used to estimate chronic exposures received by members of the general public. In the case of machine wet cleaning (MWC) chemicals, there were no human health concerns. However, in this case releases to surface water were used to estimate predicted environmental concentrations in water.

The equations used to estimate human exposures are shown below:

(1) Inhalation Exposure

Inhalation exposures to non-worker populations are expressed as potential doses in the form of LADCs (for PCE) or ADCs (for hydrocarbons).

(1) LADC or ADC (mg/m^3) = [C (mg/m^3) x ED (days)]/ [AT (days)]

where C = Chemical concentration
ED = Exposure duration
AT = Averaging time (for LADC: number of days per lifetime, 25550 days; for ADC, one day)

(2) Ingestion Exposure

Exposure to clothes cleaning chemicals via ingestion of contaminated drinking water is presented, where relevant, as a potential dose rate expressed as a Lifetime Average Daily Dose (LADD). LADDs are averaged over a person's lifetime. The equation for drinking water ingestion is as follows:

(2) LADD (mg/kg/day) = [C (µg/L) x 0.001 µg/mg x Am (L/day) x ED (days)] / BW (kg) x AT (days)

where C = Chemical concentration (µg/L)
Am = Amount of water ingested per day; 2 Liters
BW = Body weight
ED = Exposure Duration
AT = Averaging Time; 70 years

Exhibit E-13. Estimates of Workers' Dermal Exposures to Example Detergent #1 Constituents[a]

	Constituent	Weight Percent[b]	Contacting Dilute Formulation via Wet Clothes Transfer[c] (mg/day)	Contacting Full-Strength Formulation (mg/day)
1	water	54	18,000	2,100
2A	methyl 2-sulfolaurate, sodium salt	3.75	0.05	150
2B	sodium lauryl isethionate	3.75	0.05	150
3	ethoxylated sorbitan monodecanoate	7.5	0.10	290
4	lauryl polyglucose	7.5	0.10	290
5	Aveda's fragrance	1	0.01	39
6	sodium citrate	2.5	0.03	98
7	cellulose gum	5	0.06	195
8	acetic acid	5	0.06	195
9	citric acid	2.5	0.03	98
10	diazolidinyl urea	7.5	0.10	290

[a] These estimated dermal PDRs correspond to the estimates presented in section 4.4.3.1 and are based on assumption that example detergent #1 contains the constituents listed for All-Purpose Cleanser from the Multi-Process Wet Cleaning Report (USEPA, 1993).

[b] Assumed based on assumed function of constituent.

[c] Detergent weight fraction of 0.00007 in rinse water based on 150 mL detergent per 20 lb clothes, wash and rinse volumes of 1.35 L water per lb clothes, 5% of wash water remaining in clothes after extraction.

Exhibit E-14. Estimates of Workers' Dermal Exposures to Example Detergent #2 Constituents[a]

	Constituent	Weight Percent[b]	Contacting Dilute Formulation via Wet Clothes Transfer[c] (mg/day)	Contacting Full Strength Formulation (mg/day)
1	water	54	18,000	2,100
2	lauryl polyglucose	4.28	0.05	170
3	lauric acid diethanolamide	4.28	0.05	170
4A	methyl 2-sulfolaurate, sodium salt	2.14	0.03	83
4B	sodium lauryl isethionate	2.14	0.03	83
5	sodium laureth sulfate	4.28	0.05	170
6	sodium citrate	2.5	0.03	98
7	cocamidopropyl betaine	4.28	0.05	170
8	Aveda's fragrance (orange)	1	0.01	39
9	cocoamphocarboxyproprionate	4.28	0.05	170
10	sodium carbonate	10	0.13	390
11	citric acid	2.5	0.03	98
12	diazolidinyl urea	4.28	0.05	170

[a] These estimated dermal PDRs correspond to the estimates presented in section 4.4.3.1 and are based on assumption that example detergent #2 contains the constituents listed for 100% Fabric Cleanser from the Multi-Process Wet Cleaning Report (USEPA, 1993).

[b] Assumed based on assumed function of constituent.

[c] Detergent weight fraction of 0.00007 in rinse water based on 150 mL detergent per 20 lb clothes, wash and rinse volumes of 1.35 L water per lb clothes, 5% of wash water remaining in clothes after extraction.

Exhibit E-15. Exposure to Co-located Residents: Information on Monitoring Studies - Capital District Survey (Schreiber et al., 1993)

Background: The Capital District Survey was undertaken by the New York State Department of Health in the summer of 1990 to determine if elevated PCE concentrations were present in residences above dry cleaners. When the 102 dry cleaners in Capital District, New York (this is the area around Albany) were surveyed, it was found that 6% (six facilities) used PCE on the premises and were located below occupied apartments (Schreiber et al., 1993). Measurements of PCE concentrations were taken in the room in each building “most likely to have the highest PCE levels” (Schreiber et al., 1993).

Methodology: Dry cleaning facilities were located through the telephone book. The Capital District Yellow Pages listed 102 dry cleaners. Sixty-seven of these facilities cleaned or pressed clothing in the facility. Fourteen drycleaners were located in residential buildings with a total of twenty apartments above them. However, in some of these buildings the apartments were empty or were only used for storage. In two other cases, dry cleaning using PCE did not occur on the premises. This left a total of six co-located drycleaners that used PCE.

In each of these six buildings, the rooms were surveyed to determine where the highest concentrations of PCE were likely to be found. These determinations were made based on location of pathways through which PCE emissions could travel from the drycleaners to the apartments, and the locations of PCE odors in the apartments, if any.

PCE concentration samples were taken during the day (A.M. concentrations, 7:00 A.M. to 7:00 P.M.) and in the evening (P.M. concentrations, taken between 7:00 P.M. and 7:00 A.M.). Sampling in the six control homes was done at the same time. Each control home was located at least 100 meters from one of the six dry cleaning facilities and they were chosen based on their similarity to the study homes. Stainless steel evacuated canisters were used to collect the samples. Samples were analyzed by gas chromatography/mass spectrometry. The detection limit was 0.0015 mg/m^3.

Results: Concentrations in these six apartments (referred to as ‹study homes’) were compared with measurements taken at the control homes. Average daily PCE concentrations in the study homes 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).

In three of the control homes, average measured concentrations were less than 0.0067 mg/m^3. A resident of one control home worked in a chemical laboratory; measured concentrations in this home ranged from 0.077 to 0.103 mg/m^3. Another control home resident worked in a dry cleaner’s; measured concentrations in this home ranged from 0.044 to 0.056 mg/m^3. These persons lived in the two control homes with the highest PCE concentrations. In the sixth control home, measured concentrations ranged from 0.0097 to 0.022 mg/m^3 (Schreiber et al., 1993).

Outdoor PCE concentrations were measured near the study homes and the control homes. The outdoor concentrations near the study homes were almost always lower than concentrations measured inside them. In some instances, outdoor concentrations were one to two orders of magnitude lower. Concentrations outside the study homes ranged from 0.066 to 2.6 mg/m^3. Corresponding concentrations inside the study homes ranged from 0.16 to 55.0 mg/m^3. The highest PCE concentration outside a control home was 0.021 mg/m^3. Most PCE concentrations outside control homes were less than 0.0067 mg/m^3 (Schreiber et al., 1993).

Uncertainties: Apartment residents were asked not to bring newly dry cleaned 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 study homes windows were open during the sampling period (Schreiber et al., 1993). This could have lowered measured concentrations by introducing a downward bias.

Exhibit E-16. Exposure to Co-located Residents: Information on Monitoring Studies - Consumers Union (Wallace et al., 1995)

Background: 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 dry cleaner. Measurements were taken from December 1994 to May 1995. Sampling in each apartment occurred over four 24-hour periods, with Sundays included if possible. Results were averaged over the four days of sampling in each apartment. Samples were also taken in control apartments, located at least one block from a dry cleaner (Wallace et al., 1995).

Methodology: Consumers Union identified 12 dry cleaners who used dry-to-dry, nonvented machines. Each cleaner was located in a separate residential building in Brooklyn or Manhattan. Residents of these 12 apartment buildings were asked to participate in the study. In each residential building, Consumers Union attempted to sample in different locations at varying distance from the dry cleaner. Samples were taken in twenty-nine apartments using a passive personal monitor. According to Consumers Union, “Samplers were placed in areas with good air circulation, and usually in heavily used rooms (living room, kitchen, bedroom). If residents said they had smelled solvent odors, the monitors were sited in a room where odors had been smelled, or near a likely entry point for vapors” (Wallace et al., 1995). Samples were analyzed using gas chromatography coupled with electron capture detection, with a carbon disulfide eluent. Samples were also taken in ten control apartments, located at least one block from a dry cleaner.

Results: A total of 116 individual 24-hour samples were taken in co-located apartments. 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 25.086 mg/m^3. The four-day average concentrations represent the average PCE measured value in each apartment over the four days of sampling. In 83% of the apartments, average concentrations exceeded 0.1 mg/m^3; in 28% of the apartments average concentrations exceeded 1 mg/m^3; in 10% of apartments, average concentrations exceeded 5 mg/m^3. The median value for these four-day average PCE levels in co-located apartments was 0.441 mg/m^3. The mean value was 1.85 mg/m^3. Consumers Union concluded that “more modern dry-cleaning equipment does not adequately protect the health of apartment residents from the risks perc poses” (Wallace et al., 1995).

The highest PCE concentrations were measured above a dry cleaner 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 measured in apartments at some distance from the dry cleaners, even though they were in the same building. In one case in which measured PCE concentrations were low, the apartment was located “on the far side of a large building from the cleaner, essentially a block away from it” (Wallace et al., 1995).

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).

Uncertainties: Residents of the apartments tested volunteered for the study and it is possible that people who thought their apartment was 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 they were more likely to find perc problems in the tested buildings than any other.

Testing was limited to one location in each apartment, and testing was limited to only four (usually consecutive) days, which does not provide a complete picture of a resident's exposure over an entire year, or longer. It is not known whether the monitor was placed in the best spot to measure perc exposure in each apartment. CU commented on possible limitations of its monitor placement and study duration.

Results appear to apply to unvented dry-to-dry equipment, although there are numerous variations in the design and type of machines in this class. It was not possible to differentiate among varieties of modern unvented dry-to-dry equipment.

Finally, the study did not attempt to determine whether additional control strategies (e.g., installation of vapor barriers) could consistently keep perc levels in apartments at or below 0.100 mg/m^3, which Consumers Union chose because it is the New York State Department of Health guideline for non-cancer health effects.

Other Uncertainties: Residents were instructed not to bring any drycleaned clothes into the tested apartment during the sampling periods. It is not stated whether all of the apartment dwellers complied with this request. Additionally, New York City Department of Health (NYCDOH) officials had investigated complaints in six of the 12 drycleaners before the study began, and five of those were inspected several times. However, Consumers Union argued that this is not unusual, because the NYCDOH investigates many facilities each year (for example, 133 facilities were investigated in 1993). Therefore, CU claimed it is not unreasonable that six of the 12 drycleaners were investigated before the study began. Four other dry cleaners were investigated by NYCDOH after the study began; Consumers Union provided residents with a copy of the results, and encouraged them to call the NYCDOH if measured concentrations were above 0.100 mg/m^3.

Exhibit E-17. Exposure to Co-located Residents: Information on Monitoring Studies - New York State Health Department Data, Unpublished

Background: Data on PCE concentrations have been collected in New York State by the New York City and State Departments of Health (NYCSDOH) in response to residential complaints. These data consist mainly of four-hour samples taken during the daytime, although a few sets of twenty-four hour samples are also available.

Methodology: Because these data have not been published by their collectors, they are accompanied by minimal descriptive information. More than fifty samples above 23 machines were taken in New York in response to residential complaints between 1991 and 1993 (NYSDOH, 1993).

Results: PCE concentrations ranged from less than 0.02 mg/m^3 to 2.5 mg/m^3.

Uncertainties: These samples were based on complaints. That means, among other considerations, sampling was not carried out due to machine characteristics, which varied tremendously. Several of the dry cleaners were closed down after these concentrations were measured. They were allowed to reopen after they made improvements to their facilities. Resampling after remediation efforts were made generally showed a decrease in PCE concentrations in co-located apartments.

Exhibit E-18. Exposure to Co-located Residents: Information on Monitoring Studies - San Francisco Bay Area (BAAQMD, 1993)

Background: The Bay Area Air Quality Management District in San Francisco, CA, measured PCE concentrations in the hallways of apartments above four non-vented dry-to-dry machines with refrigerated condensers. These measurements were made to determine if new machines with advanced controls also caused co-located residents to be exposed to high levels of PCE.

Three of the four drycleaners had taken other precautions to minimize fugitive emissions. Two of the dry cleaners had isolation rooms with fans. Emissions were vented into these isolation rooms, which enclose the back of the machines. The fans vent to a stack which exhausts the emissions 10 feet above the building, which minimizes PCE concentrations in the neighborhood.

The other dry cleaner had “a double layer of gypsum board on the ceiling with all joints sealed with aluminized tape to minimize diffusion” (BAAQMD, 1993). The room also contained a window fan.

Methodology: Four buildings were chosen for analysis. Each building contained a new dry-to-dry non-vented machine which had been installed fewer than two years prior to the study. The dry cleaners were located in residential buildings. Two concurrent samples in each building were taken during consecutive drying cycles, which lasted for about 40 minutes. Samples were taken using evacuated stainless steel canisters and analyzed using gas chromatography. No comparison values were taken in unexposed residences (BAAQMD, 1993). These samples were taken over two 40-minute periods; the arithmetic mean was reported (BAAQMD, 1993). PCE concentrations were also measured in the corresponding dry cleaning shops.

Results: PCE concentrations ranged from 0.00224 mg/m^3 to 0.673 mg/m^3. The highest PCE concentrations was taken above a drycleaner that was the subject of a prior PCE odor complaint. This facility did not have room enclosures or fans. Its ventilation was effected by opening the windows and doors (BAAQMD, 1993).

Uncertainties: This study is based on a small sample size, and sampling occurred over a limited duration. In estimating exposure to co-located residents, the assumption is made that PCE concentrations measured in hallways could represent actual exposures to co-located residents. Because these cleaners were selected subjectively from new dry-to-dry machine facilities including one that had already been the subject of an odor complaint, it is not clear whether the group reflects likely exposure levels for properly installed and operating machinery.

Exhibit E-19. Exposure to Co-located Residents: Information on Monitoring Studies - Concentrations Measured in Germany and Netherlands
(Fast, 1993; USEPA, 1992; Staub et al., 1992)

Additional data are available on PCE concentrations in residences above drycleaners in Germany and the Netherlands. Unlike the US 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 show no difference in PCE concentrations above vented and non-vented dry-to-dry machines. (Transfer machines are not used in Europe.) Concentrations measured in Baden-Wurttemberg, Germany, ranged from less than one mg/m^3 to 130 mg/m^3, with more than 70% of the measured values less than 5 mg/m^3. The median concentrations measured in co-located apartments in Amsterdam was from 2.2 mg/m^3; the 90th percentile concentration was 17.8 mg/m3, and the maximum measured concentration was 29.9 mg/m^3. These data were not used in this assessment, which is limited to assessing exposures in the United States.

Exhibit E-20. Inhalation Exposure From a Hypothetical Hydrocarbon Facility

Releases to air result from evaporation of chemicals during the drycleaning process. Hydrocarbon vapors released from dry cleaning facilities 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 plant. Under windy conditions, the vapors will be carried away faster, reducing the local concentrations. The number of people may increase or decrease with distance from the facility.

For our model facility, we assume a building height of three meters, and a width of 10 meters. This is a building approximately the size of a one-car garage. We then pick sample weather conditions to determine what the air concentration of a chemical will be at a set distance from the printing facility. Los Angeles is used because the weather conditions there will result in the highest average concentrations around the facility of any of the approximately 500 weather stations in the United States. The average concentrations around Los Angeles are within an order of magnitude (power of ten) of concentrations expected anywhere else in the country. If the Los Angeles average concentration were estimated as 10 $\mu g/m^3$, then the average concentration anywhere in the country would be greater than 1 $\mu g/m^3$.

The model used is called Industrial Source Complex Long Term (ISCLT). It was developed as a regulatory model by USEPA's Office of Air and Radiation. The Office of Pollution Prevention and Toxics uses an implementation of ISCLT in the Graphical Exposure Modeling System (GEMS). Except for items identified, the parameters entered are the regulatory defaults.

In order to obtain the concentration at 100 meters, a special polar grid was entered. The ring distances specified were 100 meters, 200 meters, 300 meters, 400 meters, 500 meters, 600 meters, 700 meters, 800 meters, 900 meters and a kilometer. The air dispersion model calculates the average air concentrations of the chemical vapors in the specified sectors. The sectors are defined by the rings and the compass points, forming an arc-shaped area. There were three calculations per sector. The compass point with the highest concentration at 100 meters was then used to determine exposure. The location was at 90°, that is, east.

The following table, shows the conversion of air releases from kg/site/day to $g/m^2/s$.

Conversion of Air Releases

	Transfer Machine		
Variable	With Conventional Dryer	With Recovery Dryer	Dry-to-Dry Machine
Release in kg/site/day	17.8	6.6	1.9
Days/year	312	312	312
Release in kg/site/year	5,554	2,059	593
Release in g/site/second	0.18	0.07	0.02

From the concentration in the air, the amount with which an individual may actually come in contact can be calculated by knowing the breathing rate. A moderately active adult breathes 20 m^3 per day. The formula for an annual dose is:

Annual Dose = Concentration x Daily Inhalation Rate x Days per year where the concentration is in μg/m^3, and the breathing rate is in cubic meters per day. The potential dose normalized for body mass calculated per day for the entire lifetime, is called the Lifetime Average Daily Dose or LADD (Table 3-3). The formula for this dose rate is:

$$\text{LADD} = \frac{\text{Concentration x Daily Inhalation Rate x 0.001 mg/}\mu\text{g}}{\text{Average Body Weight}}$$

The average body weight used in this assessment is 70 kg (an average adult). Since there is no ratio for the percentage of days spent breathing air containing evaporated blanket wash chemicals, this calculation assumes that a person will be breathing this concentration every day of their life.

Exhibit E-21. Estimating Concentrations in Surface Water

Aquatic life is exposed to PMN substances that are dissolved or suspended in surface waters including rivers and streams, bays and estuaries, and lakes and ponds. Calculations of concentrations in surface water depend on the nature of the water body. Estimated concentrations in surface water are calculated using the rate of release of the MWC chemicals and the flow rate of the stream into which they are discharged.

For the CTSA, generic releases have been estimated for the use of MWC chemicals in wet cleaning facilities. These estimates do not contain any information on specific sites at which those processes will occur. When releases are expected to occur from an unidentified group of processors or users, the assessor must identify the general industry to which that group belongs. These industries and their flow rates are grouped by Standard Industrial Classification (SIC) code. The SIC code for discharges to Publicly Owned Treatment Works (POTWs) is used in this assessment.

Removal of the PMN substance from water can occur during treatment. Two frequently encountered removal mechanisms are adsorption to sludge and hydrolysis. Others include biodegradation and volatilization. Exhibit A-3, which shows the estimated removal of MWC chemicals in wastewater treatment is shown on page A-17. To calculate concentrations after discharge under these circumstances, the quantity released after treatment in kilograms per site per day is multiplied by a conversion factor of 1,000 and the result is divided by the stream flow in million liters per day (MLD), as shown below:

$$\text{Stream Concentration} = \frac{\text{Release after treatment in kg/site/day x 1000}}{\text{Streamflow in million liters per day}}$$

To assess the potential impact of MWC chemicals on aquatic life, a conservative streamflow estimated is provided. Because facility sizes vary, there are variations in stream flows, and stream flows vary with time. In this CTSA, concentrations which occur under low flow conditions in small streams were estimated. Specifically, low flow is the lowest flow that continues for seven consecutive days in ten years. This provides conservative estimates of stream concentrations that are compared with Concern Concentrations. The low flow value used in this assessment was 0.7 million liters per day.

Exhibit E-22. Description of the Storage and Retrieval of U.S. Waterways Parametric Data System (STORET)

A search strategy was implemented to determine if there were any additional information available for perchloroethylene concentrations in groundwater. The search statement consisted of "Perchloroethylene or PCE or tetrachloroethylene" and "concentrations or levels" and groundwater. Dialog, STORET, and the Internet were searched (Schaeffer, 1998).

Information found in STORET (all taken from Schaeffer, 1998):

The Storage and Retrieval of U.S. Waterways Parametric Data System (STORET) is the National repository for water quality information on ambient levels of contaminants in water bodies, sediments, fish, and groundwater. It was decided that the emphasis on this STORET retrieval should be placed on public water supplies. The retrieval was based on the terms: municipal, intake, nonambient, ambient, well and supply. All observations across the continental United States from 1988 to 1998 for the following station types were retrieved:

- <u>Nonambient</u> spring and wells (groundwater) that are municipal water supplies/treatment facilities.

- <u>Ambient</u> springs and wells (groundwater) that are municipal water supplies/treatment facilities.

Data are not available *per se* in STORET for Public Water Supplies (STORET Support). The majority of the data is for monitoring. However, using the appropriate keywords, data for tetrachloroethylene (total) was retrieved from STORET for the period 1988 to present in the Continental United States.

- 266 Stations in Utah - 318 observations were identified from 1988 to 1994 but quantifiable concentrations of PCE were only found in 2 of the samples (at 4.8 and 5.7 μg/L). The other 316 observations had PCE at or below the detection limits, with a maximum of 2.9 μg/L, a minimum of 0.07 μg/L, and a mean of 0.66 μg/L.

- 56 Stations in Utah and Georgia - 247 observations were identified from 1988 to 1997, with quantifiable levels of PCE found in 5 samples. These detected samples ranged in concentration from 1.50 μg/L to 8.0 μg/L with a mean of 4.34 μg/L. Of the remaining samples, 13 were at or below detection limits, with a maximum of 0.5 μg/L a min of 0.07 μg/L, and a mean of 0.33 μg/L. The 229 remaining samples were non-detected for PCE.

Information found on the Internet (all from Schaeffer, 1998):

ATSDR Toxicological Profiles (copyright 1997) stated that results from an EPA Groundwater Supply Survey of 945 water supplies from groundwater sources nationwide showed tetrachloroethylene in 79 water supplies. The median concentration of the positive samples was about 0.75 μg/L (0.75 ppb), with a maximum level of 69 μg/L (69 ppb).

Massachusetts Military Reservation, Cape Cod, Mass. (dated March 28, 1997) - The Air Force Center for Environmental Excellence (AFCEE) announced that perchloroethylene (PCE) had been detected at 18 ppb (parts per billion) in a groundwater monitoring well in East Falmouth, MA. Residential private well sample collection was proceeding. As of March 27, 1997, samples from 76 residences were collected in the area.

City of Los Angeles Water Services (copyright 1996) - The North Hollywood Operable Unit (NHOU) began routine full-time operation of their facility January 1, 1990. The NHOU treats 2000 gpm (gallons per minute) groundwater with typical contaminant levels of 120 μg/L trichloroethylene (TCE) and 5.0 μg/L of PCE. The effluent water has about 2 μg/L of TCE and non detectable levels of PCE.

As discussed in Chapter 4, these data were not used in the exposure assessment, because the source of the PCE contamination is unclear. However, these data further document PCE contamination of groundwater supplies.

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APPENDIX F
SUMMARY OF EXTERNAL TECHNICAL PEER REVIEW

In January 1993, responding to recommendations in the report *Safeguarding the Future: Credible Science, Credible Decisions*, Administrator William Reilly issued an Agency-wide policy for peer review. Administrator Carol Browner confirmed and reissued the policy on June 7, 1994. As a result, USEPA established a Standard Operating Procedure (SOP) for the organization and conduct of peer reviews. This peer review procedure is contained in the *Standard Operation Procedures for Peer Review of Major Scientific and Technical Documents,* Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency, October 1, 1996 - September 30, 1997.

The objective of the peer review is to uncover any technical problems or unresolved issues for use in revising a preliminary work product so that the final work product will reflect sound technical information and analyses. Peer review is also considered a process for enhancing a scientific or technical work product. A peer review is an objective, critical review of an Agency scientific and technical work product by an independent peer reviewer or reviewers. An independent peer reviewer is an expert who was not associated with the generation of the specific work product either directly, by substantial contribution to its development, or indirectly, by consultation during the development of the specific product. The Agency chose 'a balanced *ad hoc* panel of independent experts from outside the Agency' as the mechanism for obtaining a peer review panel. The objective of a 'well balanced panel of independent peer reviewers' is to assure an objective, fair, and responsible evaluation of the work product.

Over the past six years, the EPA Design for the Environment Garment and Textile Care Program (GTCP) has collaborated with a group of key stakeholders, including representatives of industry, research, environmental, labor and public interest groups. At EPA's request, these stakeholders nominated technical peer reviewers that had expertise in one or more areas: Technology and Economics; Exposure Assessment; Hazard Assessment; and Risk Assessment. Thirty-nine reviewers were selected from the list and the official peer review period began on June 24, 1997 with a conference call with stakeholders. All of the stakeholders' first and/or second and/or third choice nominees in each area of expertise were chosen for the review. The reviewers were given four weeks to complete their review and return comments. Thirty-six reviewers provided comments on the draft CTSA. In the course of the review, four reviewers withdrew from the panel. Reasons for withdrawal from the peer review process included lack of available time for a thorough review, or lack of specialized expertise necessary to adequately review the material presented in the CTSA document.

This report presents the general approach and considerations taken into account for conducting the peer review of the *Cleaner Technologies Substitutes Assessment for Professional Fabricare Processes*. The objective of the peer review was to uncover any technical problems or unresolved issues so that the final will reflect sound technical information and analyses. The peer review was also used to enhance the scientific and technical content of the CTSA. According to the *Standard Operating Procedures for Peer Review of Major Scientific and Technical Documents,* the Cleaner Technologies Substitutes Assessment was considered to be a major scientific and technical work product, and as such required an independent peer review. A multi-disciplinary group of experts corresponding to the disciplines that contribute to complex Agency decisions was necessary for a full and complete peer review. This Appendix describes the procedures used for obtaining the expert review of the CTSA.

During the development of the CTSA, EPA's Design for the Environment Garment and Textile Care Program collaborated with a group of stakeholders, including manufacturers of chemicals used in the dry cleaning process, formulators, dry cleaners, and others to assist EPA in characterizing the hazards, uses, exposures, and risks of substances used in the dry cleaning industry, as well as economic considerations and the identification of pollution prevention opportunities. The group of stakeholders which contributed to the development of the CTSA document were contacted in late May and early June of 1997. Stakeholders were asked to submit a list of peer review panelists in order of preference for each of the major technical areas of the CTSA: Technology and Economics; Exposure Assessment; Hazard Assessment; and Risk Assessment. Each proposed candidate peer reviewer was required to have training and/or experience in one or more of the following areas: 1) occupational and general exposure assessment; 2) exposure modeling techniques; 3) chemical monitoring; 4) occupational health; 5) industrial hygiene; 6) toxicology, including environmental (aquatic); 7) environmental epidemiology; 8) risk assessment; 9) economics, finance, accounting; 10) marketing; 11) comparative cleaning technologies (e.g., wet methods); 12) the dry cleaning industry, including equipment and processes used, practices employed, etc.; and 13) chemistry (product, engineering, environmental fate).

At a minimum, candidate peer reviewers were required to be free of conflict of interest, be considered experts within their respective fields of study, have specific knowledge of the methodologies employed in the development of risk assessments (e.g., modeling techniques), have specific knowledge of the chemicals of concern (e.g., PCE), and, where appropriate, have some knowledge of the dry cleaning industry. EPA attempted to contact candidate peer reviewers to confirm their interest in reviewing the document and their availability throughout the months of July and August. For each stakeholder group that nominated candidate peer reviewers and ranked their nominees, at least their first, second, and third ranked nominees in each area of expertise were called. Candidate reviewers were contacted to determine their availability and willingness to take part in the peer review process. The CTSA peer review panel consisting of 40 peer reviewers was finalized by EPA on July 21, 1997. A list of the individuals on the peer review panel is contained in Exhibit F-1. This final peer review panel incorporated a large and well balanced independent panel of experts from the dry cleaning industry and the environmental and scientific communities.

EPA prepared a separate packet of documentation for the peer reviewers, including a confirmation letter and non-disclosure agreement. Packets were sent out to all 40 peer reviewers by Federal Express on July 21, 1997. All reviewers were requested to fax their signed non-disclosure agreements to USEPA by July 24, 1997.

A conference call took place on July 24, 1997. Participants included EPA and key stakeholders listed in Exhibit F-2. During the call, EPA announced the release of the CTSA document for peer review. In the call, EPA stated that a well-balanced panel was chosen since all of the stakeholders' first and/or second and/or third choice nominees in each area of expertise were chosen for the review.

Exhibit F-1. Final CTSA Peer Review Panel

Mr. Ken C. Adamson, General Manager
Langley Parisian

Frank Arnold, Ph.D.

Charlene Bayer, Ph.D.
Georgia Tech Research Institute

Arnold Brown. M.D.

Pamela Christenson
Wisconsin Dept of Dev

Dick Clapp, Sc.D., M.P.H.
Boston University School of Public Health
Dept of Environmental Health

James Cone, M.D., M.P.H.

Elden Dickinson
Michigan Department of Environmental Quality

Paul Dugard, Ph.D.‡
ICI Americas, Inc.

Diane Echeverria
Battelle Seattle Operations

Adam Finkel, Ph.D.
Director, OSHA Health Standards Directorate
US Department of Labor

George Gray, Ph.D.
Harvard Center for Risk Analysis
Harvard School of Public Health

Dale Hattis, Ph.D.
Center for Technology, Environment, & Development (CENTED)
Clark University

Ms. Chris Hayes
Greater Chicago P2 Program, MWRD

Denny Hjeresen, Ph.D.
Los Alamos National Labs

Rudolf Jaeger, Ph.D.
Environmental Medicine, Incorporated

Ellen Kirrane
Hunter College Center for Occup & Envir Health

Dr. Josef Kurz ‡
Schloss Hohenstein

Jack Lauber, P.E.-D.A.A.E.E.
Consulting Engineer

James Melius, M.D., Ph.D.
Director
NY State Laborer's Health & Saftey Trust Fund

Frank Mirer, Ph.D.
Director, Health & Safety Dept., UAW

Kenneth Mundt, Ph.D.
Umass, Dept. Of Biostatistics & Epidemiology
School of Public Health & Health Sciences

D. Warner North, Ph.D.
Decision Focus Inc.

Peter Orris, M.D.
Div. Of Occup. Med/Cook County Hospital

David Ozonoff, M.D., M.P.H.
Boston University School of Public Health
Dept of Environmental Health

Andrew Persily, Ph.D.‡
NIST

Routt Reigart, M.D.‡
Medical University of South Carolina

Charles Riggs, Ph.D.
Texas Women's University, Department of Fashion & Textiles

Judy Schreiber, Ph.D.
NY Dept of Health

Tom Starr, Ph. D.
Environ Corp.

Exhibit F-1. Final CTSA Peer Review Panel (Continued)

Mike Tatch
Tatch Technical Services

Kimberly Thompson, Sc.D.
Consultant
Harvard Center for Risk Analysis

Joel Tickner
MSC/U Massachusetts Lowell

Greg Traynor
T. Marshall Associates

Arthur Upton, M.D.
Environmental & Occupational Health Sciences Inst.

David Votaw
Education and Information Division (C15)
National Institute for Occupational Safety and Health

Deborah Wallace
Consumers Union Technical Division

Clifford Weisel, Ph.D.
Associate Professor
Deputy Director
Exposure Measurement and Assessment Division
Environmental and Occupational Health Sciences
Institute

Noel Weiss, M.D., Dr. P.H.
University of Washington
School of Health & Comm. Med.
Department Of Epidemiology

Manfred Wentz, Ph.D.
Chairperson, AATCC Research Committee
RA43: Dry Cleaning

Kathleen Wolf, Ph.D.
Institute for Research and Technical Assistance

‡ Reviewer did not submit peer review comments to EPA.

Note: No conflicts existed with any peer reviewers.

Exhibit F-2. Teleconference Attendees for CTSA Announcement - Held July 24, 1997

Name	Affiliation/Address
Mary Scalco, Bill Fisher	International Fabricare Institute
Bill Seitz	Neighborhood Cleaners Assoc., Intnl.
Ross Beard	Fabricare Legislative & Regulatory
Steve Risotto	Centers for Emission Control
Gary Baise	Baise & Miller
Eric Frumin	Union of Needletrades, Industrial and Textile Employees
David DeRosa, Jack Weinberg	Greenpeace
Moon Jong Chun	Federation of Korean Drycleaning Association
Cindy Stroup, Lynne Blake-Hedges, Mary Ellen Weber	U.S. Environmental Protection Agency
Melinda Armbruster, Brandon Wood	Battelle Memorial Institute

Copies of the peer review CTSA document were sent to peer reviewers by Federal Express on July 24, 1997. Enclosed in each package sent to the peer reviewer was a letter of transmittal, a reminder to return their signed non-disclosure agreement, a peer review guidance document, and an alphabetized list of CTSA references. The peer review guidance document was a statement of work seeking informed comment on identified issues to properly focus the efforts of the peer reviewers and to assist them in their review.

Peer reviewers were asked to return their comments by August 25, 1997. Verbatim comments from peer reviewers were compiled and sorted by reviewer and by CTSA chapter to which they referred. Attribution of each reviewer’s comments was kept anonymous. In a few cases, text was omitted from the original comment in order to facilitate reviewer anonymity. Where a comment cited a reference that was not complete, the reference was listed in square brackets following the comment.

In order to ensure correct transcription of all comments, all comments were checked against the original reviewer’s submission to ensure that the text remained unchanged.

During the course of the review, four reviewers withdrew from the panel. Dr. Routt Reigart withdrew from the peer review process on August 1, 1997, Dr. Andrew Persily withdrew on August 22, 1997, Dr. Josef Kurz withdrew on August 28, 1997, and Dr. Paul Dugard did not respond. It was not possible to replace these four reviews since there was not adequate time remaining in the review cycle for replacements to complete a substantive review. Because the peer review panel was so large, the attrition of the four reviewers during the review process did not affect the balance of the panel nor the integrity of the review.

Exhibit F-3 presents summary statistics on the number of comments and number of pages of comments received. These statistics are separated into the following categories: general comments on CTSA document, comments on the executive summary, Chapters 1-8, and Appendixes A-D. There was a total of 1,855 comments comprising 340 pages. Of these 1,855 comments, there was a total of 208 editorial comments. The editorial comments included spelling changes and other minor structural modifications to the document.

The reviewers were given 4 weeks to complete their review and return comments to USEPA. Peer reviewer comments were compiled and sent to the USEPA CTSA Workgroup for disposition. The USEPA CTSA Workgroup reviewed all comments to determine the necessary changes to the CTSA as a result of the comments. The workgroup drafted responses to every peer review comment. The peer review comments and responses are included in the USEPA document, *Response to Technical Peer Review Comments,* EPA 744-P-98-001, June 1998.

USEPA feels that this extensive and rigorous technical review by a stellar panel of stakeholder-nominated reviewers has improved the quality of the CTSA and ensured that its conclusions are valid and based on sound science.

Exhibit F-3. Summary Statistics on CTSA Comments from CTSA Peer Review Panel

	Complete Set of Comments	
Section	**# of Pages**	**# of Comments**
General	49	181
Executive Summary	12	67
Chapter 1	56	328
Chapter 2	32	194
Chapter 3	60	357
Chapter 4	61	375
Chapter 5	12	61
Chapter 6	17	82
Chapter 7	10	50
Chapter 8	12	71
Appendix A	13	62
Appendix B	1	6
Appendix C	4	20
Appendix D	1	1
Total	340	1855

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16. Abstract (Limit 200 words)

The *Cleaner Technologies Substitutes Assessment (CTSA): Professional Fabricare Processes* was developed as part of an effort to explore opportunities for pollution prevention and reduced exposure to traditional drycleaning chemicals (primarily perchloroethylene [PCE]). The intended audience for the CTSA is technically informed and might consist of individuals such as environmental health and safety personnel, cleaning facility owners, equipment manufacturers, and other decision makers. It is expected to be used as a technical supplement by USEPA and stakeholders to develop information products suitable for a broad audience. These products will help professional cleaners make informed technology choices that incorporate environmental concerns.

The CTSA compares the cost, human health and environmental risks and performance of professional fabricare technologies based on readily available information and using simplified assumptions and conventional models to provide general conclusions. Eight PCE technology alternatives, three hydrocarbon technology alternatives and machine wet cleaning are evaluated in depth. Qualitative information is provided on four emergent technologies, liquid carbon dioxide drycleaning, propylene glycol ether (Rynex) solvent, ultrasonic wetcleaning, and Biotex solvent.

17. Document Analysis
a. Descriptors: Drycleaning, wetcleaning, clothes cleaning, perchloroethylene, perchloroethene, PCE, Perc, Stoddard solvent, chlorinated solvents, petroleum solvents, hydrocarbon solvents, alternative solvents, dry cleaning, wet cleaning, DF 2000, liquid carbon dioxide, Rynex, propylene glycol ether, Biotex, ultrasonic cleaning, drycleaning cost, drycleaning performance, wetcleaning cost, wetcleaning performance.
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