The Dry Cleaning Dilemma

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Introduction

Few of us give it a moment's thought: the crisp look of a freshly pressed shirt, the scent of a dry-cleaned suit, the sparkle of table linens just back from the cleaners. Dry cleaning has become an indispensible part of our daily lives. Yet, at what cost? Whoever thought that the faint, sweet fragrance of dry-cleaned garments could possibly be harmful to our health *and* our environment?

Most of us have never stopped to consider the health risks we may face by exposure to dry-cleaned garments or those faced by workers occupationally exposed to the harsh dry-cleaning chemicals used in today's commercial operations. Neither have we stopped to contemplate the environmental impacts of an industry that releases tens of millions of kilograms of volatile petroleum-based solvents into the atmosphere each year. Moreover, few of us have probably bothered to investigate whether there are other *environmentally friendly* alternatives to today's industry standard that can be supported through our consumer dollar.

This article will review the health and environmental risks associated with today's commercial dry-cleaning operations and will investigate emerging technologies that promise to mitigate the harm caused by the harsh chemical reagents commonly used today. By doing so, it will become evident that, as informed consumers, we can learn to leverage our buying power as an instrument for environmental and social change to make a better and safer world. All it takes is *informed* choice.

Historical Perspective

Dry-cleaning is any cleaning process for clothing and textiles that employs an organic solvent instead of water. Jean Baptiste Jolly, a 19th Century French dye-maker who spilled kerosene on a tablecloth and found that it removed stubborn stains, discovered the process serendipitously. Jolly called it *nettoyage à sec* and the dry-cleaning industry was born.

Up until the early 1900s, dry-cleaners used raw gasoline and kerosene as solvents. You can imagine how your clothes smelled when they came home from *these* establishments! Frequent fires and explosions soon encouraged the industry to seek less "volatile"

alternatives.[1] William Stoddard developed a less flammable solvent in 1924, which includes a blend of petroleum distillates (naphtha compounds) composed of aliphatic (long-chain) and aromatic (benzene-containing) hydrocarbons. The Stoddard solvent became the industry standard until the 1950s. Similar to kerosene, it contains small amounts of known carcinogens and atmospheric contaminants. The solvent has a fairly low acute toxicity by inhalation, dermal absorption or ingestion. However, acute exposure can lead to central nervous system depression resulting in lack of coordination and slowed reactions. Oral ingestion presents a high aspiration hazard and prolonged skin exposure can result in severe contact dermatitis. Other solvents have since supplanted its use.[2]

In the 1930s, carbon tetrachloride (CCl_4) became the first chlorinated solvent employed in dry-cleaning. A central nervous system depressant and known carcinogen, chronic exposure to CCl_4 can damage both the liver and kidneys.[3-6] Due to its high toxicity and corrosive nature, CCl_4 was phased-out as a dry-cleaning solvent by the 1950s.

Trichloroethylene (TCE), another noxious chlorine-containing hydrocarbon introduced in the 1930s, was found to cause bleeding of acetate dyes; its use is now limited as a spotting agent and water repellent. For a time, the industry even played with 1,1,1 trichloroethane (methyl chloroform) as a wash solvent. Also a central nervous system depressant, it can cause dizziness, confusion, and in sufficiently high concentrations, unconsciousness and death.[7] Consequently, it is now relegated to use as a pre-cleaning and spotting agent.

Tetrachloroethylene (also called perchloroethylene or Perc), synthesized by Michael Faraday in 1821, came into commercial production in the U.S. in 1925 and was first used as a dry-cleaning solvent in 1934.[8] Non-flammable and chemically stable, with excellent cleaning power and yet gentle on fabrics, Perc soon surpassed CCl_4 as the dry-cleaning solvent of choice. In 1964, DuPont introduced 1,1,2-trichlorofluoroethane (Freon®) under the trade name, Valclene,® to try to unseat Perc from its industry dominance; however, this ozone-depleting fluorocarbon was banned by the 1989 Montreal Protocol as a dangerous atmospheric pollutant. A highly oxidized compound, Perc is the most stable of all the chlorinated solvents. Its non-flammability and relatively high vapour pressure means it can be safely extracted from garments. By 1980, 87% of U.S. dry-cleaners were using Perc and it remains the 'solvent of choice' for the industry today — it also became the first product to be classified as a carcinogen by the U.S. Consumer Product Safety Commission.[1]

Today's Dry-cleaning Industry

The following discussion will provide a brief overview of the major solvents used by the industry today and will detail some of their health and environmental impacts. Several other

solvents (many of which are the most toxic chemicals used in industry today) have not been covered, as their uses are restricted to pre-cleaning and spotting agents.

Tetrachloroethylene (Perc)

Perc remains the industry standard for dry-cleaning solvents; however, concerns about its toxicity to humans and its notoriety as a heat-trapping, greenhouse gas are slowly eroding its market share. While still used by over 80% of the 30,000 dry-cleaning establishments in the United States, today, emerging technologies with lower health and environmental impacts are becoming more and more prevalent.

According to the U.S. Environmental Protection Agency (EPA), 80-85% of the Perc used annually is released into the air, primarily through evaporation from commercial dry-cleaning facilities. In 1992, more than 5.6 million kilograms of Perc were released from U.S. operations.[9] While Perc does not contribute to ground level ozone, nor deplete stratospheric ozone, it is listed as one of the 200 most hazardous air pollutants and a major contributor to global warming. In humans, the main route for absorption is through the respiratory tract; from there absorption into the blood and fatty tissues is rapid.[9]

The International Agency for Research on Cancer classifies Perc as a Group 2 carcinogen (probably carcinogenic to humans). The U.S. Office of Environmental Health Hazard Assessment (OEHHA) concludes that Perc is a possible human carcinogen "with no identifiable limit below which no carcinogenic effects are likely to occur." [10] A central nervous system (CNS) depressant, it can enter the body through respiratory and dermal exposure. In fact, exposure to Perc can be measured with a breathalyser test, much like alcohol. Stored in the fat, Perc is released slowly into the bloodstream and can be detected for weeks after heavy exposure.

Short-term adverse effects associated with exposure include headaches, dizziness, rapid heart rate, skin irritations, and irritation of the eyes and respiratory tract. Chronic effects include impaired color vision, judgement and perception; damage to kidneys and liver; behavioural and neurological affects; and cancers.[10] The State of California listed Perc as a known carcinogen in 1988 and has more recently mandated its phase-out for commercial dry-cleaning by 2023. As of 2007, commercial operations in California can no longer purchase Perc washer/extractors for their operations. New Jersey, Massachusetts, New York, Texas, and the city of Toronto have similar bans under consideration.

Animal studies confirm that exposure to Perc contributes to increased risk of tumors. Human exposures can produce oesophageal cancer, cervical cancer, non-Hodgkin's lymphoma, and urinary bladder cancer and leukemia, likely through modulations of specific

genes involved in the body's inflammatory response mechanisms.[11] There is no evidence that the fetus may be uniquely sensitive to maternal exposures to Perc; however, there is some evidence that prenatal and occupational exposures to Perc can induce deficits in color vision, with impairments of blue-yellow and red-green discrimination.[12-14] Although Perc has been associated with neurobehavioral dysfunction in humans,[15] prenatal and early post-natal exposures do not appear to be associated with any learning disabilities.[16] While industry-sponsored studies show no significant neurotoxicity at long-term exposures to 800 parts per million (ppm),[17-19] this is disputed by other research that does reveal evidence of harm.[20-24] In one occupational exposure study, clinical examinations of neuroses revealed organic lesions of the central nervous systems of exposed workers.[25] Exposure to Perc vapors can also reduce cellular glutathione and antioxidant enzyme levels,[26] increase cellular peroxide levels,[27] and increase oxidative damage to biological macromolecules.[28, 29] Exposure can also induce hepatotoxicity (liver damage) through increased lipid peroxidation, an effect that can be accentuated by certain prescription drugs.[28] Oxidative degradation of lipids appears to be the mechanism by which exposure to Perc vapors can damage the skin.[30, 31]

Exposure toxicity

At 1,000 parts per million (ppm), Perc vapors emit a very strong odor, causing respiratory distress, cardiac irregularities, nausea, and dizziness within two minutes. At 400 ppm, loss of coordination occurs within two hours. Short-term exposure at 200 ppm causes light-headedness and moderate eye irritation; at 50 ppm, there is a very faint odor and no acute physiological effects.[32, 33] The threshold dose for acute effects on the central nervous system in humans is 100 ppm;[32] acute exposures at low concentrations have also been found to invoke behavioural changes, impairment of coordination, headache, and drowsiness. Chronic inhalation causes cognitive and motor skill dysfunction, cardiac arrhythmia, and liver and kidney damage.[34]

While odor was considered a reliable indicator of exposure above the Permissible Exposure Limit (PEL) of 100 ppm, set by the Occupational Safety and Health Administration (OSHA), chronic exposure to Perc has been found to de-sensitize the olfactory senses.[35] Moreover, in some jurisdictions, such as California, where exposure limits have been set as low as 25 ppm, odor cannot be considered a reliable indicator of exposure hazard. In fact, the Agency for Toxic Substance and Disease Registry (ATSDR) has determined a chronic-duration minimum risk level (MRL) as low as 0.04 ppm or 0.3 mg/m^3. This is a lower limit above which exposure to Perc is considered to have increasing risk.

Dry-cleaning facilities are integrated in urban environments (shopping malls, residential buildings) and can contribute to exposure for customers and residents alike.[36] For those in the industry, work-related exposures to Perc can vary from 60 to 150 ppm depending on job

type,[37] levels at which chronic adverse effects have been noted. Consequently, in the U.S. today nearly 500,000 workers remain at high risk of exposure.[38] Adverse liver and kidney functions, lung irritation, and pulmonary edema (fluid accumulation in the lungs) have been observed in workers exposed to Perc, and prolonged exposures will de-fat the skin, causing irritation, pain and dermatitis. While information on developmental and reproductive toxicity in workers is limited, some studies suggest that women occupationally exposed to Perc experience an increase in menstrual disorders, including spontaneous abortions and congenital malformations.[32, 39] As well, wives of dry-cleaning workers experience over twice the difficulty in conceiving as do workers in other industries, an effect seemingly related to a subtle deterioration in the sperm quality of exposed male workers.[40, 41]

Perc vapors, once inhaled and absorbed into the blood, are able to cross the placental barrier of expectant mothers and infiltrate the breast milk of nursing mothers.[35, 35] Results from epidemiological studies of workers occupationally exposed indicate an increased risk for several types of cancer.[34] Long-term exposures in some workplaces have been as high as 6 orders of magnitude (1 million times) ambient air levels, grossly exceeding safe exposure limits. The ironing of freshly dry-cleaned shirts, for example, can result in a 500-fold increase in Perc vapors within the immediate surroundings.[42] Even low level exposures can induce a dose-related impairment of color vision, with sub-clinical color impairment found at levels well below established occupational exposure limits of 170 mg/m^3 or 25 ppm.[43, 44]

Perc in the Home

Family members of occupationally exposed workers and those living in the immediate vicinity of dry-cleaning operations are also at increased risk for adverse health effects from Perc.[45-47] Fugitive releases of Perc vapors from neighbouring dry-cleaning facilities, and from the clothes and breath of occupationally exposed workers, can markedly elevate levels in the home environment.[48, 49] A German epidemiological study showed that persons who lived near a dry-cleaning facility or who stored dry-cleaned clothes at home showed significantly higher exposures to Perc. In some cases, these levels far exceeded the average exposure for the general population.[50] A 1999 Italian study confirmed that some neurological functions, including reaction time and visual memory, were significantly impacted in subjects living close to commercial dry-cleaning facilities for several years.[44]

Garments subjected to commercial dry-cleaning with Perc are a significant source of indoor air pollution.[51-53] Freshly dry-cleaned clothes can release Perc into the air for several hours after processing; unfortunately, it appears that "airing out" at room temperature for up to five hours does not appreciably reduce the total emissions of perchloroethylene from fabrics.[54] One study on residential air quality in New Jersey examined the effect of bringing dry-cleaned clothes into the home. Elevated levels of Perc reached the ATSDR dose limit of

0.3 mg/m^3 and persisted for up to 48 hours. During that time, breath levels of Perc increased two- to six-fold for participants in the exposed homes. As would be expected, the increased exposures were related to both the number of dry-cleaned garments and residential air volumes.[52] The findings support an earlier Japanese study that indentified a large amount of residual Perc — up to 13.6 mg/g of clothing — in commercially dry-cleaned clothes.[51]

Let's use these numbers to determine what the potential off-gassing could be for a freshly dry-cleaned down duvet weighing 3 kg and placed in an enclosed bedroom (4m x 5m x 2.5m in volume).

Amount of Perc in duvet = (13.6 mg/g)(10^3 g/kg)(3 kg) = **4.08×10^4 mg**
Volume of the bedroom = (4 x 5 x 2.5) m^3 = **50 m^3**
Potential room concentration of Perc = (4.08×10^4 mg)/(50 m^3) = **8.16×10^2 mg/m^3**

If we assume that the bedroom door is closed (thereby restricting the venting of the off-gassed Perc), it is feasible to reach a maximum Perc vapour concentration of **816 mg/m^3**. Since 1mg/m^3 is equivalent to 0.15 ppm of Perc vapor,[9] 816 mg/m^3 is equivalent to a room concentration of **122 ppm** of Perc vapour. Thus, we can see that allowing the duvet to off-gas in an enclosed bedroom could potentially subject a person sleeping in that room to vapour levels that *exceed* both the established level of **100 ppm** for observable neurological effects and the OSHA 8-hour permissible exposure limit of **685 mg/m^3**.[34] Furthermore, the calculated maximum exposure level is almost five-fold higher than the of State of California's exposure limit of 25 ppm and over 3,000 times greater than the State of New York's recommended ambient air level for community exposure of 0.25 mg/m^3.[44]

Lest one think that the chances of home poisoning from dry-cleaning are overstated, one case study reports a 2-year-old boy found dead in his bed, with a strong odor of solvent in the room. Toxicological analysis confirmed poisoning from Perc solvent retained in the bedroom curtains that had been dry-cleaned in a coin-operated establishment the same day.[55] One shudders to think what toxic levels could be encountered by hanging freshly dry-cleaned draperies in your living room.

Hydrocarbon Cleaning Solutions

The second-most prevalent solvents employed by the commercial dry-cleaning industry — and safer alternatives to Perc — are the paraffin solvents. While less toxic than Perc, these petroleum-based cleaning solutions are potent greenhouse gas emitters and also contribute to the problem of industrial smog. Unlike Perc, there is very little health information on these hydrocarbon mixtures, except for those using mineral spirits, such as the Stoddard solvent, which was discussed earlier. These solutions are composed principally of paraffins,

long-chain saturated hydrocarbons noted for their low biological activity and low flammability.

DF 2000® Fluid was introduced by Exxon-Mobile in 1994 as an alternative to both the Stoddard solvent and Perc and has developed a reputation among dry-cleaning professionals as the best available alternative dry-cleaning agent. A mixture of isoparaffins and cycloparaffins, it does not require OSHA exposure limits and is classified by the EPA as non-hazardous. Pure Dry®, developed by 3M, is a blend of isoparaffinic hydrocarbons and odourless mineral spirits consisting of aliphatic carbon compounds. Although toxicity data on this solvent were not found, it is known that mineral spirits contained in the mixture can cause neurotoxicity, eye and respiratory irritations at high concentrations.[10] Chevron-Phillips manufactures EcoSolv,® a 100% isoparaffin mixture with a butylated hydroxytoluene antioxidant stabilizer. ShellSol® 140 HT is a high flash point hydrocarbon listed as a hazardous material because of its combustibility. No pertinent toxicity data were found regarding these solvents.

Emerging Alternatives

A number of environmentally responsible alternatives have recently emerged to challenge the industry dominance of Perc and the paraffin-based solvents. With jurisdictions such as California imposing increasingly stringent environmental restrictions on volatile organic compounds (VOCs) it is likely we will see these sensible alternatives gaining prominence.

Methyl Siloxane Cleaning

Decamethylcyclopentasiloxane (D5), or volatile methyl siloxane, is an odorless, colorless liquid commonly used in antiperspirants, shampoos, roll-on deodorants, soap products and body lotions. Manufactured by Dow Corning and sold as GreenEarth,® the solvent is considerably more environmentally friendly than the petroleum-based products currently dominating the industry. OSHA does not have a Permissible Exposure Limit for D5.

According to the Silicones Environmental Safety Council, over 50 studies confirm D5's low toxicity and general lack of adverse effects.[56] While some studies indicate that D5 exposure at vapour saturation levels increases the incidence of tumors in rats, other studies suggest that the effect is not relevant in humans because of differences in respective degradation pathways for D5.[1, 56] Sustained high levels of exposure (up to 224 ppm, 6 hours/day for up to 3 months) can cause discreet biochemical changes to liver enzymes along with adverse physiological changes to lung tissues, including inflammation and macrophage (white blood cell) accumulation, which did not resolve after a one-month

recovery period.[57, 58] Other animal studies confirm that D5 at high concentrations acts like a weak phenobarbital-like inducer, activating several hepatic (liver) detoxification enzymes.[59, 60] A two-generation reproductive study of long-term exposure to whole-body vapour inhalation of D5 (at up to 160 ppm) showed no exposure-related mortality, no clinical symptoms of toxicity, no significant microscopic changes and no significant changes to reproductive parameters.[61] Although D5 accumulation targets both lung and fatty tissues, bioaccumulation tests reveal that D5 does not accumulate in blood or systemic tissues with repeated exposures.[62, 63] Animal experiments on the potential of D5 to alter female and male sex hormones reveal that exposure to D5 does not induce either estrogenic or androgenic activity.[64]

In the atmosphere, D5 degrades within days and soil degradation is complete within a week. Because the chemical breaks down into simple CO_2 and water, it does not affect atmospheric ozone levels; however, it does add to atmospheric CO_2 levels, thus contributing to greenhouse gas emissions. There are no identified bioaccumulation risks for air, water and terrestrial environments from the production and use of D5 and no identified risks for human exposure.[65]

Propylene Glycol Ethers (PGEs)

Although very few dry-cleaning facilities currently use propylene glycol ether (PGE) solvents, their relative lack of toxicity and ease of environmental degradation suggest PGEs will soon come into greater public favour. PGEs are currently marketed under various trade names, including: Rynex® and Impress® (both of which employ a mixture of propylene glycol ethers), Gen-X® (which uses a mixture of propylene glycol ethers and mineral spirits) and Solvair® (propylene glycol-n-butyl ether solvent with liquid carbon dioxide as a rinse agent). These solvents are particularly effective for water-based stains.

As a category, PGEs are noted for their low systemic toxicity, whether by oral, dermal or inhalation routes. Clinical chemistry and urinalysis following exposures show no adverse effects.[66] According to a 2005 industry report, a robust toxicity database provides strong product safety support.[67] While slightly irritating to the eyes, few adverse effects, even at high exposures, have been reported and those that have were generally mild.[68] High-level exposure can cause depression of the central nervous system, resulting in headache, weakness, slurred speech, tremor and blurred vision.[69] At very high concentrations, PGE vapors can create erythema, edema, weeping, hyperpigmentation, photosensitization and mucosal irritation. Reproductive toxicity testing has found no adverse effects and no evidence that these chemicals would pose a reproductive hazard. As well, there are no reported incidences of developmental or teratogenic effects, nor is there any evidence of genotoxicity;[67, 70] however, one recent animal study did report evidence of decreased sperm

count as a result of acute daily exposure.[71] Generally speaking, the weight of evidence suggests that PGEs pose relatively little concern with regard to adverse biological effects in exposed individuals.[68] Furthermore, PGEs demonstrate a low propensity for bioaccumulation in the environment and, because they are readily biodegradable, are unlikely to persist in either aquatic or terrestrial ecosystems.[72] The United Nations Environmental Programme has categorized PGEs as "low priority" for further toxicity screening.[68]

Liquid Carbon Dioxide (CO_2)

First used commercially in 1999, liquid CO_2 has proved to be an effective and non-toxic dry-cleaning solvent. Furthermore, because the CO_2 used is a by-product of other industrial processes, there is no net production of the gas and therefore no added environmental impact. Toxicity concerns are negligible because CO_2 is a naturally occurring metabolite of the human respiratory process and disperses rapidly into the environment. *Consumer Reports* rates liquid CO_2 cleaning technology as superior to all other methods of dry-cleaning. Both the U.S. Environmental Protection Agency and the textile industry recognize liquid CO_2 as an *environmentally friendly* alternative to today's commercial cleaners.

The process uses liquid CO_2 as a non-polar chemical solvent that is effective in removing oil-based and greasy stains. At room temperature, CO_2 can exist as a liquid if kept in a closed system at an elevated pressure. Liquid CO_2 has a gas-like consistency and a low surface tension, allowing it to function as a very effective cleaning medium when combined with detergents. The liquid is injected under a pressure of 700-800 psi, which releases dirt and debris from garments. Once the cleaning process is complete, the liquid is allowed to evaporate into the atmosphere. While effective and completely non-toxic, the cost of machinery is prohibitive for smaller operators; therefore, there are few commercial machines currently in operation.

Minimizing Your Exposure

Few of us consider the chemical stew that we subject our garments to when we take them to the cleaners. Neither do we stop to consider the health and environmental impacts of our consumer decisions when we employ commercial cleaners to 'clean up our act.' Here are a few points to ponder the next time you decide to clean house:

1) Most garments — even those that state "dry-clean only" — can be cleaned effectively with traditional water-based cleaning products if done carefully and under low heat.

2) If you can smell a chemical odor on your garments when you bring them home from the cleaners DO NOT wear or use them until they have been thoroughly aired out.

3) DO NOT air out your garments in the closet or in any enclosed space; instead, allow them to off-gas for a day or two (or three) in an open-air space such as a garage or covered area where the air can freely circulate — remember to remove the plastic covering to allow proper venting.

4) For heavier fabrics, such as draperies, duvets, and winter coats, allow plenty of extra time for Perc vapours to off-gas before bringing these fabrics into the house. Do the sniff test and let smell be your guide.

5) Consider supporting dry-cleaners in your area who employ less toxic paraffin-based cleaning agents such as DF 2000®, Pure Dry,® and EcoSolv,® or who use any of the propylene glycol ethers marketed as Rynex,® Impress,® Gen-X,® and Solvair.®

6) Better yet, consider supporting any commercial cleaner in your area who uses even more environmentally friendly alternatives, such as GreenEarth's methylsiloxane solvent.

7) Those fortunate enough to have a commercial cleaner who uses liquid CO_2 technology need look no further — they deserve your support.

8) Consider supporting commercial cleaners who have introduced advanced "wet-cleaning" technology; the process uses good old water as a solvent, along with biodegradable detergents, in a computer-controlled process that ensures humidity-controlled drying to preserve fabric integrity.

Conclusions

While dry-cleaning has certainly added a measure of quality to our modern lifestyle, the convenience comes at a cost to both personal and environmental health. In this regard, awareness is *half* the battle. Now that you understand more clearly the consequences of your consumer decisions, you are better able to choose what is best for you and your family. In making that choice, also consider the environmental consequences of your decisions

After all, we're all in this together.

Reference List

(1) Dry Cleaning. *Wikipedia* 2009;Available at: URL: http://en.wikipedia.org/wiki/Dry_cleaning. Accessed December 21, 2009.

(2) White Spirit. *Wikipedia* 2010;Available at: URL: http://en.wikipedia.org/wiki/White_spirit. Accessed January 4, 2010.

(3) Seifert WF, Bosma A, Brouwer A et al. Vitamin A deficiency potentiates carbon tetrachloride-induced liver fibrosis in rats. *Hepatology* 1994 January;19(1):193-201.

(4) Liu KX, Kato Y, Yamazaki M, Higuchi O, Nakamura T, Sugiyama Y. Decrease in the hepatic clearance of hepatocyte growth factor in carbon tetrachloride-intoxicated rats. *Hepatology* 1993 April;17(4):651-60.

(5) Recknagel RO, Glende EA, Jr., Dolak JA, Waller RL. Mechanisms of carbon tetrachloride toxicity. *Pharmacol Ther* 1989;43(1):139-54.

(6) Recknagel RO. Carbon tetrachloride hepatotoxicity. *Pharmacol Rev* 1967 June;19(2):145-208.

(7) Toxicological Profile for 1,1,1-Trichloroethane. *Agency for Toxic Substances and Disease Registry* 2009;Available at: URL: http://www.atsdr.cdc.gov/toxprofiles/tp70.html.

(8) Chemicals Used in Drycleaning Operations. *Dryclean Coalition* 2009;Available at: URL: http://www.drycleancoalition.org/chemicals/ChemicalsUsedInDrycleaningOperations.pdf. Accessed December 21, 2009.

(9) Chemical Summary for Perchloroethylene. *Office of Pollution Prevention and Toxics, U S Environmental Protection Agency* 1994 August;Available at: URL: http://www.epa.gov/chemfact/s_perchl.txt. Accessed December 21, 2009.

(10) California Dry Cleaning Industry Techincal Assessment Report. *California Environmental Protection Agency Air Resources Board* 2005;Available at: URL: http://www.arb.ca.gov/toxics/dryclean/draftdrycleantechreport.pdf. Accessed December 21, 2009.

(11) Diodovich C, Ferrario D, Casati B et al. Sensitivity of human cord blood cells to tetrachloroethylene: cellular and molecular endpoints. *Arch Toxicol* 2005 September;79(9):508-14.

(12) Gobba F, Cavalleri A. Color vision impairment in workers exposed to neurotoxic chemicals. *Neurotoxicology* 2003 August;24(4-5):693-702.

(13) Iregren A, Andersson M, Nylen P. Color vision and occupational chemical exposures: I. An overview of tests and effects. *Neurotoxicology* 2002 December;23(6):719-33.

(14) Till C, Rovet JF, Koren G, Westall CA. Assessment of visual functions following prenatal exposure to organic solvents. *Neurotoxicology* 2003 August;24(4-5):725-31.

(15) Oshiro WM, Krantz QT, Bushnell PJ. Characterization of the effects of inhaled perchloroethylene on sustained attention in rats performing a visual signal detection task. *Neurotoxicol Teratol* 2008 May;30(3):167-74.

(16) Janulewicz PA, White RF, Winter MR et al. Risk of learning and behavioral disorders following prenatal and early postnatal exposure to tetrachloroethylene (PCE)-contaminated drinking water. *Neurotoxicol Teratol* 2008 May;30(3):175-85.

(17) Halogenated Solvents Industry Perchloroethylene White Paper. *Halogentaed Solvents Industry* 2008 November;Available at: URL: http://www.hsia.org/white_papers/perc%20wp%202008.htm. Accessed December 21, 2009.

(18) Mattsson JL, Albee RR, Yano BL, Bradley G, Spencer PJ. Neurotoxicologic examination of rats exposed to 1,1,2,2-tetrachloroethylene (perchloroethylene) vapor for 13 weeks. *Neurotoxicol Teratol* 1998 January;20(1):83-98.

(19) Lauwerys R, Herbrand J, Buchet JP, Bernard A, Gaussin J. Health surveillance of workers exposed to tetrachloroethylene in dry-cleaning shops. *Int Arch Occup Environ Health* 1983;52(1):69-77.

(20) Beliles RP. Concordance across species in the reproductive and developmental toxicity of tetrachloroethylene. *Toxicol Ind Health* 2002 March;18(2):91-106.

(21) Chen HH, Chan MH, Fu SH. Behavioural effects of tetrachloroethylene exposure in rats: acute and subchronic studies. *Toxicology* 2002 January 25;170(3):201-9.

(22) Kilburn KH. Is neurotoxicity associated with environmental trichloroethylene (TCE)? *Arch Environ Health* 2002 March;57(2):113-20.

(23) Motohashi Y, Miyazaki Y, Takano T. Assessment of behavioral effects of tetrachloroethylene using a set of time-series analyses. *Neurotoxicol Teratol* 1993 January;15(1):3-10.

(24) Perrin MC, Opler MG, Harlap S et al. Tetrachloroethylene exposure and risk of schizophrenia: offspring of dry cleaners in a population birth cohort, preliminary findings. *Schizophr Res* 2007 February;90(1-3):251-4.

(25) Sinczuk-Walczak H. [Status of the nervous system and bioelectric activity of the brain in dry cleaning plant workers exposed to tetrachloroethylene]. *Med Pr* 1988;39(2):91-9.

(26) Costa C, Barbaro M, Catania S, Silvari V, Germano MP. Cytotoxicity evaluation after coexposure to perchloroethylene and selected peroxidant drugs in rat hepatocytes. *Toxicol In Vitro* 2004 February;18(1):37-44.

(27) Chen SJ, Wang JL, Chen JH, Huang RN. Possible involvement of glutathione and p53 in trichloroethylene- and perchloroethylene-induced lipid peroxidation and apoptosis in human lung cancer cells. *Free Radic Biol Med* 2002 August 15;33(4):464-72.

(28) Costa C, Barbaro M, Catania S, Silvari V, Germano MP. Cytotoxicity evaluation after coexposure to perchloroethylene and selected peroxidant drugs in rat hepatocytes. *Toxicol In Vitro* 2004 February;18(1):37-44.

(29) Costa C, Pasquale RD, Silvari V, Barbaro M, Catania S. In vitro evaluation of oxidative damage from organic solvent vapours on human skin. *Toxicol In Vitro* 2006 April;20(3):324-31.

(30) Ding R, Shen T, Zhu QX. [Effects of TCE and PCE on cultured human keratinocyte lipid peroxidation and protective effect of vitamin E on it]. *Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi* 2006 November;24(11):662-5.

(31) Zhu QX, Shen T, Ding R, Liang ZZ, Zhang XJ. Cytotoxicity of trichloroethylene and perchloroethylene on normal human epidermal keratinocytes and protective role of vitamin E. *Toxicology* 2005 April 1;209(1):55-67.

(32) Office of Pollution Prevention. Chemical Summary for Perchloroethylene. *U S Environmental Protection Agency* 2010;Available at: URL: http://www.epa.gov/chemfact/s_perchl.txt. Accessed December 21, 2009.

(33) Torkelson TR, Rowe VK. Halogenated Aliphatics. In: Clayton GD, Clayton FE, editors. *Patty's Industrial Hygeine and Toxicology*. 3 Vol 2B ed. New York: John Wiley and Sons; 1981. p. 3560-8.

(34) Tetrachloroethylene (Perchloroethylene). *Technology Transfer NetworkAir Toxics Web Site* 2000 January;Available at: URL: http://www.epa.gov/ttn/atw/hlthef/tet-ethy.html. Accessed January 2, 2010.

(35) Perchloroethylene. *Toxics Use Reduction Institute* 2009 August 17;Available at: URL: http://www.turi.org/library/turi_publications/five_chemicals_study/final_report/chapter_5_perchloroethylene. Accessed December 21, 2009.

(36) Chiappini L, Delery L, Leoz E, Brouard B, Fagault Y. A first French assessment of population exposure to tetrachloroethylene from small dry-cleaning facilities. *Indoor Air* 2009 June;19(3):226-33.

(37) Gold LS, De Roos AJ, Waters M, Stewart P. Systematic literature review of uses and levels of occupational exposure to tetrachloroethylene. *J Occup Environ Hyg* 2008 December;5(12):807-39.

(38) Tetrachloroethylene. *Metcalf Institute for Marine and Environmental Reporting* 2010;Available at: URL: http://www.environmentwriter.org/resources/backissues/chemicals/tetrachloroethylene.htm. Accessed December 21, 2009.

(39) Kyyronen P, Taskinen H, Lindbohm ML, Hemminki K, Heinonen OP. Spontaneous abortions and congenital malformations among women exposed to tetrachloroethylene in dry cleaning. *J Epidemiol Community Health* 1989 December;43(4):346-51.

(40) Eskenazi B, Wyrobek AJ, Fenster L et al. A study of the effect of perchloroethylene exposure on semen quality in dry cleaning workers. *Am J Ind Med* 1991;20(5):575-91.

(41) Eskenazi B, Fenster L, Hudes M et al. A study of the effect of perchloroethylene exposure on the reproductive outcomes of wives of dry-cleaning workers. *Am J Ind Med* 1991;20(5):593-600.

(42) Onofrj M, Thomas A, Paci C, Rotilio D. Optic neuritis with residual tunnel vision in perchloroethylene toxicity. *J Toxicol Clin Toxicol* 1998;36(6):603-7.

(43) Cavalleri A, Gobba F, Paltrinieri M, Fantuzzi G, Righi E, Aggazzotti G. Perchloroethylene exposure can induce colour vision loss. *Neurosci Lett* 1994 September 26;179(1-2):162-6.

(44) Aggazzotti G, Righi E, Fantuzzi G, Predieri G, Gobba F. Assessment of indoor exposure to Perchloroethylene (PCE) in dry-cleaners' family members. *J Prev Med Hygeine* 1999;40:43-8.

(45) Aggazzotti G, Fantuzzi G, Righi E et al. Occupational and environmental exposure to perchloroethylene (PCE) in dry cleaners and their family members. *Arch Environ Health* 1994 November;49(6):487-93.

(46) Ashley DL, Bonin MA, Cardinali FL, McCraw JM, Wooten JV. Blood concentrations of volatile organic compounds in a nonoccupationally exposed US population and in groups with suspected exposure. *Clin Chem* 1994 July;40(7 Pt 2):1401-4.

(47) Gulyas H, Hemmerling L. Tetrachloroethene air pollution originating from coin-operated dry cleaning establishments. *Environ Res* 1990 October;53(1):90-9.

(48) McDermott MJ, Mazor KA, Shost SJ, Narang RS, Aldous KM, Storm JE. Tetrachloroethylene (PCE, Perc) levels in residential dry cleaner buildings in diverse communities in New York City. *Environ Health Perspect* 2005 October;113(10):1336-43.

(49) Thompson KM, Evans JS. Workers' breath as a source of perchloroethylene (Perc) in the home. *J Expo Anal Environ Epidemiol* 1993 October;3(4):417-30.

(50) Begerow J, Jermann E, Keles T, Freier I, Ranft U, Dunemann L. Internal and external tetrachloroethene exposure of persons living in differently polluted areas of Northrhine-Westphalia (Germany). *Zentralbl Hyg Umweltmed* 1996 May;198(5):394-406.

(51) Kawauchi T, Nishiyama K. Residual tetrachloroethylene in dry-cleaned clothes. *Environ Res* 1989 April;48(2):296-301.

(52) Thomas KW, Pellizzari ED, Perritt RL, Nelson WC. Effect of dry-cleaned clothes on tetrachloroethylene levels in indoor air, personal air, and breath for residents of several New Jersey homes. *J Expo Anal Environ Epidemiol* 1991 October;1(4):475-90.

(53) Weber L. Desorption Kinetics of Trichloroethylene and Perchloroethylene from Cotton Fabrics. *Indoor and Built Environment* 1992;1(4):219-23.

(54) Guo ZS, Tichenor BA, Mason MA, Plunket CM. The temperature dependence of the emission of perchloroethylene from dry cleaned fabrics. *Environ Res* 1990 June;52(1):107-15.

(55) Garnier R, Bedouin J, Pepin G, Gaillard Y. Coin-operated dry cleaning machines may be responsible for acute tetrachloroethylene poisoning: report of 26 cases including one death. *J Toxicol Clin Toxicol* 1996;34(2):191-7.

(56) Research on the Safety of D5. *Silicones Environment Safety Council of North America* 2008;Available at: URL: http://www.sehsc.com/PDFs/Fact_Sheet_Research_on_Safety_of_D5_01_Feb_08.pdf. Accessed December 28, 2009.

(57) Burns-Naas LA, Mast RW, Klykken PC et al. Toxicology and humoral immunity assessment of decamethylcyclopentasiloxane (D5) following a 1-month whole body inhalation exposure in Fischer 344 rats. *Toxicol Sci* 1998 May;43(1):28-38.

(58) Burns-Naas LA, Mast RW, Meeks RG, Mann PC, Thevenaz P. Inhalation toxicology of decamethylcyclopentasiloxane (D5) following a 3-month nose-only exposure in Fischer 344 rats. *Toxicol Sci* 1998 June;43(2):230-40.

(59) McKim JM, Jr., Choudhuri S, Wilga PC et al. Induction of hepatic xenobiotic metabolizing enzymes in female Fischer-344 rats following repeated inhalation exposure to decamethylcyclopentasiloxane (D5). *Toxicol Sci* 1999 July;50(1):10-9.

(60) Zhang J, Falany JL, Xie X, Falany CN. Induction of rat hepatic drug metabolizing enzymes by dimethylcyclosiloxanes. *Chem Biol Interact* 2000 January 15;124(2):133-47.

(61) Siddiqui WH, Stump DG, Reynolds VL, Plotzke KP, Holson JF, Meeks RG. A two-generation reproductive toxicity study of decamethylcyclopentasiloxane (D5) in rats exposed by whole-body vapor inhalation. *Reprod Toxicol* 2007 February;23(2):216-25.

(62) Andersen ME, Reddy MB, Plotzke KP. Are highly lipophilic volatile compounds expected to bioaccumulate with repeated exposures? *Toxicol Lett* 2008 June 30;179(2):85-92.

(63) Tobin JM, McNett DA, Durham JA, Plotzke KP. Disposition of decamethylcyclopentasiloxane in Fischer 344 rats following single or repeated inhalation exposure to 14C-decamethylcyclopentasiloxane (14C-D5). *Inhal Toxicol* 2008 March;20(5):513-31.

(64) Quinn AL, Regan JM, Tobin JM et al. In vitro and in vivo evaluation of the estrogenic, androgenic, and progestagenic potential of two cyclic siloxanes. *Toxicol Sci* 2007 March;96(1):145-53.

(65) Environmental Fate and Effects of D5. *Slicones Environmental Health and Safety Council* 2004;Available at: URL: http://www.sehsc.com/PDFs/SEHSC%20Fact%20Sheet-D5%20Environmental%20Fate%20and%20Effects-Dec%2004.pdf. Accessed December 28, 2009.

(66) Propylene Glycol Monoethyl Ethers. *Office of Environmental Health Hazard Assessment, Government of California* 2010;Available at: URL: http://oehha.ca.gov/air/chronic_rels/pdf/107982.pdf. Accessed January 4, 2010.

(67) Spencer PJ. New toxicity data for the propylene glycol ethers - a commitment to public health and safety. *Toxicol Lett* 2005 March 28;156(1):181-8.

(68) Propylene Glycol Ethers. *United Nations Environmental Programme* 2003;Available at: URL: http://www.chem.unep.ch/irptc/sids/OECDSIDS/PGEs.pdf. Accessed December 28, 2009.

(69) Glycol Ether. *Metcalf Institute for Marine and Environmental Reporting* 2009;Available at: URL: http://www.environmentwriter.org/resources/backissues/chemicals/glycol_ether.htm. Accessed December 20, 2009.

(70) Maldonado G, Delzell E, Tyl RW, Sever LE. Occupational exposure to glycol ethers and human congenital malformations. *Int Arch Occup Environ Health* 2003 July;76(6):405-23.

(71) Lemazurier E, Lecomte A, Robidel F, Bois FY. Propylene glycol monomethyl ether. A three-generation study of isomer beta effects on reproductive and developmental parameters in rats. *Toxicol Ind Health* 2005 March;21(1-2):33-40.

(72) Staples CA, Davis JW. An examination of the physical properties, fate, ecotoxicity and potential environmental risks for a series of propylene glycol ethers. *Chemosphere* 2002 October;49(1):61-73.