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# Systematic Literature Review of Uses and Levels of Occupational Exposure to Tetrachloroethylene

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*Tetrachloroethylene has been one of the most widely used chlorinated solvents in the United States. This review provides a basis for tetrachloroethylene exposure assessment in population-based case-control studies. We performed literature searches in MEDLINE, TOXLINE, NIOSHTIC, and the NIOSH Health Hazard Evaluation databases using relevant search terms. We calculated weighted arithmetic means from the measurement data and compiled these into three summary tables by type of operation: (1) dry cleaning, (2) degreasing, and (3) other operations. We identified 258 relevant documents, of which 179 (69%) contained useful descriptive information. Within the dry cleaning industry, the overall arithmetic mean (AM) for personal tetrachloroethylene exposures was 59 ppm (range: 0–4636, n = 1395). Machine operators who transferred wet garments to a dryer had the highest levels (AM = 150 ppm [range: 0–1000, n = 441]) of the jobs in this industry. The AM for personal measurements associated with degreasing was 95 ppm (range: 0–1800, n = 206). In addition, we identified several other sources of substantial tetrachloroethylene exposure, including cleaning mining equipment, testing coal, cleaning animal coats in taxidermy, and cleaning and duplicating film. Exposure assessment in population-based, case-control studies is a complex process requiring substantial resources. Researchers conducting these types of studies will be able to use results of the measurements to quantify tetrachloroethylene exposure levels for various jobs.*

**Keywords** case control study, chlorinated solvents, degreasing, dry cleaning, exposure assessment

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## INTRODUCTION

Tetrachloroethylene (also known as perchloroethylene, or PCE) has been one of the most widely used solvents in the United States since its production in the early 1920s. Its major use has been as a dry cleaning solvent, but it also has

been important as a degreaser for metal parts in a variety of industries. More recently, PCE has been used in the chemical production industry as an intermediate in the fabrication of fluorinated compounds, such as chlorofluorocarbon (CFC)-113 and hydrofluorocarbon (HFC)-134a.<sup>(1)</sup> Although its use and manufacture peaked around 1980, many occupations, especially dry cleaning, continue to use PCE.

This article describes the major uses of PCE as reported in the published literature. This review can provide a basis for PCE exposure assessment in population-based, case-control studies. It will be useful because these studies tend to encompass a variety of jobs and industries (as opposed to cohort studies in a particular industry). In addition, unlike prospective studies, measurements of exposure to specific agents cannot be obtained in retrospective, case-control studies. A summary of PCE uses and air measurements can provide information about possible exposures encountered by cases and controls and can increase consistency in assessments of exposure.

## METHODS

We performed searches in MEDLINE, TOXLINE, NIOSHTIC, and the National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluation database using the search terms “chlorinated solvents,” “perchloroethylene,” and “tetrachloroethylene.” We used MEDLINE and TOXLINE literature published from 1900 to 2006 and NIOSHTIC and the NIOSH Health Hazard Evaluation documents published from 1980 (the earliest publication identified) to 2000. We also used other reviews, such as documents from the International Agency for Research on Cancer (IARC) and the Agency for Toxic Substances and Disease Registry (ATSDR). We also used articles obtained from personal archives not searchable in the databases.

We examined these documents for descriptive information about PCE uses and how these changed over time. We also abstracted information on determinants of PCE exposure,

which were almost exclusively limited to dry cleaning and degreasing. Generally, the information found was from the United States.

We compiled the abstracted measurement data regarding occupational exposure to PCE into a database organized by Standard Industry Classification code (SIC).<sup>(2)</sup> We used SIC codes instead of the newer North American Industry Classification System (NAICS) because the jobs in the epidemiologic study, which was the impetus for conducting this review, were coded to the 1980 SIC system, which is more relevant than the NAICS codes to the time period in which those study subjects worked.

We included, when available, the country in which the measurement took place; the measurement year (if not provided, this was estimated as one year before publication); the exposure source; the job title (JT) or area measured; whether the sample was a personal or an area sample or a summary of both; the sample duration (categorized as <1 hr, 1–6 hr, or >6 hr); the reason for sampling (request of worker/union), the number of samples taken; the arithmetic mean (AM); the minimum; the maximum; the geometric mean (GM); and the geometric standard deviation (GSD) of the reported measurements.

If data was given in units of  $\text{mg}/\text{m}^3$  or  $\mu\text{g}/\text{m}^3$ , we converted these to parts per million (ppm) assuming standard temperature ( $15^\circ\text{Celsius}$  [ $59^\circ\text{Fahrenheit}$ ]) and pressure. If the AM but not GM was given and the data was published, we calculated the GSD using  $\text{GSD} = \exp([\sum(\ln(y) - \ln(\text{GM}))^2/n]^{1/2})$ . If the GM and GSD were given but not the AM, we calculated the AM using the formula  $\text{AM} = \text{GM} * \exp[1/2 * (\ln(\text{GSD}))^2]$ . We calculated AMs, weighted by the number of measurements, across studies into categories by duration, JT, area and personal measurement, and decade. If the number of measurements was not given, we did not include the study in the AMs across studies, but we presented means and/or ranges from those studies in the Appendix. We presented GSDs when available; in some cases they represent only one study or are equal to 1 because the report listed identical measurements. We compiled the data into three summary tables by source of PCE exposure: (1) dry cleaning, (2) degreasing, and (3) other sources. For dry cleaning and degreasing, we also calculated separate weighted AMs for peer reviewed publications and NIOSH reports.

Some papers ( $n = 43$ ) reported at least one PCE measurement below the limit of detection (LOD). We excluded 15 industries from our measurement database because all measurements were <LOD, and no PCE source was identified (SICs 2822, 3662, 4512, 4731, 7922, 8062, 8111, 8210, 8221, 8222, 8249, 8611, 9190, 9431, and 9621). In addition, we identified three reports that included only measurements <LOD that mentioned a source of PCE; these were SIC 2645 from adhesives;<sup>(3)</sup> SIC 3079 from cleaning plastic molds;<sup>(4)</sup> and SIC 4171 from paints.<sup>(5)</sup> We estimated mean PCE levels for other industries that reported some, but not all, values <LOD for which we identified a PCE source (SICs 1094, 1200, 1629, 2300, 2321, 2610, 2751, 2770, 3452, 3479, 3600, 3722, 3911, 4952, 7216, 7699, and 9224) by dividing the reported LOD (or lowest PCE measurement if no LOD was reported) by the square root of 2.<sup>(6)</sup>

We excluded papers from outside the United States ( $n = 27$ ) from our summary tables because this review was designed to aid exposure assessments for U.S. case-control studies. We cited these studies in the text if we did not find any U.S. information regarding those industries or exposures. We included summaries of these measurements in the Appendix.

We did not conduct a thorough search for non occupational exposures to PCE; however, some reports of exposures to PCE from food, water, ambient air, and hobbies are presented for comparison with occupational sources. Although we did not find any measurement data regarding dermal exposures, one was mentioned in a publication about the dry cleaning industry and is described.

## RESULTS

We identified 258 relevant documents, of which 5% were published from 1920–1940, 3% were published in the 1950s, 6% in the 1960s, 11% in the 1970s, 39% in the 1980s, 29% in the 1990s, and 7% were published after 2000. Of these, 179 (69%) contained useful descriptive information about PCE. We identified 109 papers with quantitative data that we abstracted into our database. Of the 82 papers reporting measurements taken in the United States, 20 (24%) were from peer reviewed publications, and 62 (76%) were from NIOSH reports. Of the 27 papers that described measurements taken outside the United States, 25 (93%) were from peer reviewed publications.

### General Trends of PCE Use

Trends in PCE production are shown in Table I. PCE was first produced in the United States as a byproduct of carbon tetrachloride manufacture in the early 1900s.<sup>(1)</sup> The first widespread use of PCE was in the dry cleaning industry in the late 1930s. Petroleum distillates, however, were more commonly used until the late 1940s.<sup>(1)</sup> Production of PCE increased during the 1950s, with U.S. plants producing approximately 90 million kg annually by the end of the decade.<sup>(1)</sup> Throughout this decade, about 80% of this PCE was used for dry cleaning and 15% for metal cleaning and degreasing.<sup>(1)</sup>

By 1962, the dry cleaning industry accounted for about 90% of PCE consumption as large dry cleaning plants began favoring PCE over flammable petroleum solvents.<sup>(1,7)</sup> Throughout the remainder of the 1960s, PCE production expanded, but overall use of PCE in the United States began to decline because of improvements in dry cleaning equipment and vapor recovery systems.<sup>(1)</sup> Whereas a 50-gal (227-L) drum of PCE cleaned about 500 pounds (227 kg) of clothing in 1959,<sup>(8)</sup> advances in technology allowed the same amount of PCE to clean 8000 pounds (3630 kg) of clothing in 1975 and 16,000 (7260 kg) pounds by 1993.<sup>(9)</sup>

After peaking in 1978, production and use of PCE decreased, probably as a result of its classification as a hazardous waste by the U.S. Environmental Protection Agency (EPA).<sup>(1)</sup> Additionally, the phase-out of ozone depleting CFCs led to a decline of PCE use as a chemical intermediate for production of

**TABLE I. PCE Uses and Production in the United States in Select Years**

Year	Kilograms of PCE Produced in United States (millions)	Reference
1940	<2.3	1
1950	45	1
1952	50	1
1955	81	66
1956	84	66
1957	89	66
1958	84	66
1959	92	66
1960	95	66
1961	102	66
1962	145	10
1963	163	114
1964	166	10
1965	194	10
1966	210	10
1967	242	10
1968	289	10
1969	288	10
1970	321	10
1971	320	10
1972	318	1
1973	320	10
1974	333	10,115
1975	308	1,10
1976	303	10,115
1977	301	10
1978	333	10,115
1979	329	116,117
1980	295	62
1981	313	10
1982	241	115
1983	248	118
1984	236	115
1985	225	1,10,118
1986	171	115
1987	215	10
1988	204	115
1989	198	115
1990	169	10,115
1991	108	10
1992	111	10
1993	123	10
1994	112	10
1995	118	10
1996	130	10
1997	139	10
1998	156	10,40
2001	148	10

those agents.<sup>(1)</sup> However, after 1993, use of PCE as a chemical precursor for HFC-134a increased, as did demand for PCE as a metal degreaser.<sup>(10)</sup> Although the quantity of PCE used in dry cleaning facilities declined throughout the 1990s, it has remained the predominant solvent used by dry cleaners.<sup>(1)</sup>

### Non-Occupational Sources of Exposure to PCE

PCE has been identified in a wide variety of food items, including dairy products, meats, oils, fats, beverages, fruits, and vegetables in values ranging from 0.01–13  $\mu\text{g}/\text{kg}$  (0.002–0.3 ppm).<sup>(11)</sup> PCE has also been detected in U.S. drinking water with the median level in one study of New Jersey households of 0.07 ng/mL (0.01 ppm).<sup>(12)</sup> PCE measurements in ambient air have ranged from 0.007 parts per billion (ppb) in the northeast Atlantic Ocean;<sup>(13)</sup> 0.19 ppb in the White Face Mountains, New York;<sup>(14)</sup> and 30.9 ppb in New Jersey.<sup>(15)</sup>

PCE was not a major solvent used for hobbies.<sup>(16)</sup> Other sources of non-occupational PCE exposure include cleaning a car's carburetor (32 ppb), visiting a dry cleaning shop (7.7 ppb),<sup>(17)</sup> and keeping recently dry cleaned clothes at home (40 ppb).<sup>(18)</sup> Several incidents of PCE being intentionally inhaled to achieve a state of intoxication were documented in the U.K. in the 1970s.<sup>(19)</sup>

### OCCUPATIONAL EXPOSURES TO PCE

Tables II, III, and IV summarize air concentrations of PCE in a variety of industries, and the full database of measurements is presented in the Appendix. In total, we found 4468 measurements, of which 2680 (60%) were taken in the United States. Some of these were reported as individual measurements, while others were listed as means, medians, and/or ranges. About 2.1% of the U.S. measurements were taken from the 1930s to the 1950s, 10.0% were taken in the 1960s, 37.8% in the 1970s, 24.6% in the 1980s, 15.1% in the 1990s, 4.5% in 2000 or later, and 5.8% spanned more than a decade.

### PCE Use in Dry Cleaning (SIC 7215, 7216, 7218)

#### Process

Dry cleaning refers to the process of cleaning fabrics in which organic solvents are used rather than water. Dry cleaning is often preceded by the application of spotting fluids, which comprise a variety of chemicals including PCE, to stains. The textile is placed in the dry cleaning machine, the door is closed, and PCE is pumped in. The garments are agitated for 10–20 min and the PCE is recirculated and passed through a diatomite or cartridge filter for clarification.<sup>(20)</sup> The machine then spins to drain the excess PCE. The garments are rinsed with clean PCE and spun again.

Depending on the machine type, the garments may be manually transferred to a dryer or tumbled dry in the washing machine. Much of the PCE remaining in the clothes from washing is removed during drying, and this PCE-laden air

**TABLE II. Summary of PCE Measurements from Exposures in the Dry Cleaning Industry (SIC 721)**

Years	Job Title	Sample Duration (hrs)	Personal or Area Sample	N <sup>A</sup>	Arithmetic Mean (Range) ppm <sup>B</sup>	GSD <sup>B</sup>
All (1936–2001)	Any	Any	Either	1876	57 (0–4636)	1.1–5.5
			P	1395	59 (0–4636)	1.1–5.5
			A	481	54 (0–1648)	1.1–4.0
		<1	P	493	131 (0–4636)	1.2–3.4
		1–6	P	524	22 (0.2–211)	1.2–4.3
		>6	P	378	15 (0.01–303)	1.1–5.5
		<1	A	270	84 (0–1648)	1.6–2.1
	Operator (all machine types)	1–6	A	120	14 (0.1–114)	1.6–3.2
		>6	A	91	18 (0.3–239)	1.1–4.0
		Any	P	623	112 (0–2960)	1.2–3.5
		<1	P	406	157 (0–2960)	1.2–3.4
		1–6	P	93	24 (1–211)	1.2–3.5
		>6	P	124	32 (0.3–303)	1.5–2.6
	Operator (transfer)	Any	P	441	150 (0–1000)	1.2–3.4
		<1	P	344	179 (0–1000)	1.2–3.4
		1–6	P	45	35 (5–211)	1.2–2.3
	Operator (dry-to-dry)	>6	P	52	55 (4–303)	2.5
		Any	P	149	19 (0.3–257)	1.5–3.3
		<1	P	55	28 (4–257)	3.3
		1–6	P	43	15 (2.4–74)	1.7–2.1
	Spotter	>6	P	51	12 (0.3–83)	1.5–2.6
		>6	P	72	6.6 (0.01–39)	1.4
	Presser/seamstress	Any	P	179	5.6 (0.1–52)	1.1–4.3
		<1	P	36	8.1 <sup>C</sup>	NA
		1–6	P	57	3.5 (0.2–21)	1.6–4.3
		>6	P	86	6.0 (0.1–52)	1.1–3.5
	Counter clerk	Any	P	92	3.4 (0–15)	1.6–2.9
<1		P	48	0.3 <sup>C</sup>	NA	
1–6		P	8	0.8 (0.3–1.6)	1.6–2	
>6		P	36	8.0 (0–15)	2.7–2.9	
<1		P	3	119 (no min.–4636)	NA	
1936	Any	<1	P	3	119 (no min.–4636)	NA
1960–69	Any	<1	P	73	205 (3–350)	NA
			A	199	37 (0–300)	NA
			P	768	67 (0–1000)	1.1–4.3
1970–79	Any		A	93	30 (0.3–239)	1.6–4.0
		<1	P	236	167 (0–1000)	1.5–3.4
		1–6	P	442	25 (0.5–211)	1.6–4.3
		>6	P	90	14 (0.1–215)	1.1–3.5
		<1	A	4	39 (5.5–61)	NA
		1–6	A	64	22 (0.4–114)	1.6–3.2
		>6	A	25	48 (0.3–239)	4
	Operator (all machine types)	Any	P	329	129 (0–1000)	1.5–3.5
		Operator (transfer)	Any	P	262	152 (0–1000)
	Operator (dry-to-dry)	<1	P	198	190 (0–1000)	1.5–3.4
		1–6	P	42	36 (5–211)	1.6–2.3
		>6	P	22	35 (4–149)	2.5
		Any	P	50	35 (5–257)	1.5–3.3
		<1	P	32	41 (4–257)	3.3
		1–6	P	15	29 (5.2–74)	2.1
	Presser	>6	P	3	8.7 (5–14)	1.5
		Any	P	61	6.3 (0.1–52)	1.1–4.3

**TABLE II. Summary of PCE Measurements from Exposures in the Dry Cleaning Industry (SIC 721) (Continued)**

Years	Job Title	Sample Duration (hrs)	Personal or Area Sample	N <sup>A</sup>	Arithmetic Mean (Range) ppm <sup>B</sup>	GSD <sup>B</sup>
1980–89	Counter clerk	1–6	P	14	7.1 (0.5–21)	1.8–4.3
		>6	P	47	6.0 (0.1–52)	1.1–3.5
	Any	>6	P	5	1 (no min–3)	NA
		Any	P	208	31 (0–534)	1.2–5.5
			A	14	223 (12–597)	1.2–2.1
		<1	P	147	26 (0–534)	NA
			P	61	42 (3–303)	1.2–5.5
		<1	A	10	306 (68–597)	2.1
	Operator (all machine types)	>6	A	4	17 (12–20)	1.2
		Any	P	95	59 (3–534)	NA
	Operator (transfer)	Any	P	66	80 (11–534)	NA
		<1	P	40	82 (11–534)	NA
	Non-operator (transfer)	>6	P	26	77 (29–303)	NA
		<1	P	42	5.5 <sup>C</sup>	NA
	Operator (dry-to-dry)	>6	P	19	16 <sup>C</sup>	NA
		Any	P	29	13 (3–76)	NA
	Non-operator (dry-to-dry)	<1	P	23	11 <sup>C</sup>	NA
		>6	P	6	20 (3–76)	NA
	Presser/seamstress	<1	P	42	1.8 <sup>C</sup>	NA
		>6	P	8	6 <sup>C</sup>	NA
Counter clerk	<1	P	36	8.1 <sup>C</sup>	NA	
	>6	P	13	15 <sup>C</sup>	2.7	
Any	<1	P	48	0.3 <sup>C</sup>	NA	
	>6	P	12	12 <sup>C</sup>	NA	
1990–2002	Any	Any	P	318	10 (0.01–334)	1.2–2.7
			A	131	84 (0.1–1648)	1.1–3.1
		<1	P	9	119 (58–334)	1.2
		1–6	P	82	4.5 (0.2–22)	1.2–2.7
		>6	P	227	7.6 (0.01–83)	1.3–2.7
		<1	A	13	791 (306–1648)	1.6–1.9
	Operator (all machine types)	1–6	A	56	5.3 (0.1–23)	1.8–3.1
		>6	A	62	6.6 (0.5–25)	1.1–2.3
	Operator (transfer)	Any	P	100	19 (0.3–153)	1.2–2.6
		Any	P	15	57 (13–153)	1.2
	Operator (dry-to-dry)	<1	P	8	92 (58–153)	1.2
		1–6	P	3	15 (13–19)	1.2
	Spotter	>6	P	4	20 <sup>C</sup>	NA
		Any	P	70	9.5 (0.3–83)	1.5–2.6
	Presser/seamstress	1–6	P	28	7.8 (2.4–22)	1.7–2.0
		>6	P	42	11 (0.3–83)	1.5–2.6
	Counter clerk	>6	P	72	6.8 (0.01–39)	1.4
		1–6	P	43	2.3 (0.2–6.5)	1.6–2.7
	Maintenance worker	>6	P	26	1.3 (0.1–3.6)	2.3
		1–6	P	8	0.8 (0.3–1.6)	1.6–2.0
	>6	P	19	7.4 (0–15)	2.7	
	<1	P	1	334	NA	
	>6	P	2	11 <sup>C</sup>	NA	

<sup>A</sup>N = number of measurements. The number of measurements in specific categories may not add up to the number in the more general categories because of missing information on job title, duration, or type of sample.

<sup>B</sup>AM and GSD may have been reported in publication or may have been calculated.

<sup>C</sup>Range not given.

**TABLE III. Summary of PCE Measurements from Metal and Plastics Degreasing**

Source of Exposure	Years	SIC Code	Job Title	Sample Duration (hrs)	Personal or Area Sample	N <sup>A</sup>	Arithmetic Mean (Range) ppm <sup>B</sup>	GSD <sup>B</sup>							
Degreasing (all types)	All (1944–2001)	Any	Any	Any	Both	331	72 (0–1800)	1–6.5							
					P	206	95 (0–1800)	1–6.5							
					A	49	2.3 (0.1–37)	1–4.2							
						<1	P	29	28 (0.1–185)	1–6.5					
						1–6	P	45	16 (0.1–393)	1.3–3.5					
						>6	P	68	3.9 (0.1–82)	1–3.9					
						<1	A	1	0.1	NA					
						1–6	A	15	1.6 (0.1–7.4)	1–4.2					
						>6	A	20	1.4 (0.2–9)	2.2–3.6					
					1940s	Any	Any	NA	P	55	324 (20–1800)	1.7–2.6			
					1960s	Any	Any	1–6	P	1	393	NA			
					1970s	Any	Any	>6	P	2	18 (7–29)	2			
					1980s	Any	Any	Any	P	91	15 (0.1–185)	1–3.2			
								Any	A	20	4.3 (0.1–37)	1–4.2			
								<1	P	26	31 (0.2–185)	1–3.2			
								1–6	P	23	14 (0.1–84)	1.3–3.2			
								>6	P	41	4.7 (0.1–82)	1.0–2.0			
								1–6	A	7	1.7 (0.1–7.4)	1–4.2			
								>6	A	10	1.6 (0.3–9)	2.2			
								1990s	3670	Etching technician	>6	P	4	1.6 <sup>C</sup>	NA
											1–6	A	2	3.6 (3.6–3.6)	1
								>6	A	4	0.3 <sup>C</sup>	NA			
		2000s	Any	Any	Any	P	45	1.3 (0.1–17)	1.1–6.5						
					Any	A	13	1.3 (0.1–8.0)	2.3–3.6						
					<1	P	3	6.7 (0.1–17)	6.5						
					1–6	P	21	0.7 (0.1–5.7)	3.0–3.5						
					>6	P	21	1.1 (0.1–16)	1.1–3.9						
					<1	A	1	0.1							
					1–6	A	6	0.9 (0.2–1.5)	2.3						
					>6	A	6	1.9 (0.2–8.0)	3.6						
	Cold degreasing	1960	2800	No JT	1–6	P	1	393	NA						
2001		3559	Degreaser foreman	1–6	P	1	0.1	NA							
			Degreaser assistant	1–6	P	1	0.2	NA							
Vapor degreasing	All (1944–2001)	Any	Any	Any	Both	278	82 (0.04–1800)	1.0–6.5							
					P	171	110 (0.04–1800)	1.0–6.5							
					A	31	3.0 (0.1–37)	1.0–4.2							
					<1	P	25	23 (0.1–185)	1.0–6.5						
					1–6	P	33	5.7 (0.04–84)	1.3–3.5						
					>6	P	57	3.2 (0.1–82)	1.0–3.9						
					<1	A	1	0.1	NA						
					1–6	A	12	1.4 (0.1–7.4)	1.0–4.2						
					>6	A	15	1.2 (0.2–8.0)	2.2–3.6						
					Any	372,363	Degreaser operator	Any	P	21	1.1 (0.1–13)	2.0–3.0			

**TABLE III. Summary of PCE Measurements from Metal and Plastics Degreasing (Continued)**

Source of Exposure	Years	SIC Code	Job Title	Sample Duration (hrs)	Personal or Area Sample	N <sup>A</sup>	Arithmetic Mean (Range) ppm <sup>B</sup>	GSD <sup>B</sup>
	Any	372	Electroplater	Any	P	33	9.5 (0.1–66)	2.0–3.9
	1940s	Any	Any	NA	P	55	324 (20–1800)	1.7–2.6
	1980s	Any	Any	Any	P	73	12 (0.1–185)	1.0–3.2
				Any	A	18	4.2 (0.1–37)	1.0–4.2
				<1	P	22	25 (0.2–185)	1.0–3.2
				1–6	P	14	12 (0.1–84)	1.3–3.2
				>6	P	36	4.4 (0.1–82)	1.0–2.0
				1–6	A	6	2.0 (0.1–7.4)	1.0–4.2
				>6	A	9	0.7 (0.3–2.3)	2.2
	1980s	347	Reflow operator	<1	P	2	153 (120–185)	1.3
		347	Reflow operator	1–6	P	2	83 (82–84)	1.3
		347	Reflow operator	>6	P	1	82	NA
		363	Degreaser operator	NA	P	1	13	NA
		363	Group leader	>6	P	1	1.5	NA
		363	Paint stripper, spray painter, and paint mixer	>6	P	4	1.6 (1.2–2.1)	1.2
		363	Racker	>6	P	3	6.7 (5.5–7.4)	1.1
		372	Assembler	<1	P	3	0.6 (0.2–1.1)	2.0
		372	Assembler	>6	P	3	0.5 (0.5–0.5)	1.0
		372	Broach operator	>6	P	1	0.6	NA
		372	Cleaning processor	<1	P	1	0.5	NA
		372	Cleaning processor	>6	P	1	0.7	NA
		372	Electroplater	<1	P	9	26 (1.9–66)	3.2
		372	Electroplater	>6	P	11	3.4 (0.4–7.2)	2.0
		372	Inspector	>6	P	1	0.5	NA
		372	Mechanic	>6	P	2	1.5 (0.7–2.2)	1.8
		372	Sheet metal worker	<1	P	2	0.6 (0.2–0.9)	2.1
		372	Sheet metal worker	>6	P	2	0.9 (0.6–1.1)	1.4
		372	Tube bender	<1	P	4	0.2 (0.2–0.2)	1.0
		372	Tube bender	>6	P	4	0.4 (0.4–0.4)	1.0
		384	Electropolisher	1–6	P	1	3.5	NA
	2000s	Any	Any	Any	P	43	1.3 (0.1–17)	1.1–6.5
				Any	A	13	1.3 (0.2–8.0)	2.3–3.6
				<1	P	3	6.5 (0.1–17)	6.5
				1–6	P	19	0.8 (0.1–5.7)	3.0–3.5
				>6	P	21	1.1 (0.1–16)	1.1–3.9
				<1	A	1	0.1	NA
				1–6	A	6	0.9 (0.2–1.5)	2.3
				>6	A	6	2.0 (0.2–8.0)	3.6
	2000s	355	Degreaser assistant	Any	P	3	0.1 (0.1–0.1)	1.1
		355	Degreaser foreman	Any	P	3	0.1 (0.1–0.1)	1.2
		355	Lab technician	Any	P	2	0.1 (0.1–0.1)	NA

*(Continued on next page)*

**TABLE III. Summary of PCE Measurements from Metal and Plastics Degreasing (Continued)**

Source of Exposure	Years	SIC Code	Job Title	Sample Duration (hrs)	Personal or Area Sample	N <sup>A</sup>	Arithmetic Mean (Range) ppm <sup>B</sup>	GSD <sup>B</sup>					
		372	Degreaser operator	1-6	P	11	0.7 (0.1-0.8)	3.0					
		372	Degreaser operator	>6	P	9	0.4 (0.2-0.9)	2.0					
		372	Electroplater	<1	P	1	17	NA					
		372	Electroplater	1-6	P	5	1.5 (0.2-5.7)	3.5					
		372	Electroplater	>6	P	7	2.7 (0.1-16)	3.9					
		372	Maintenance worker	<1	P	2	1.3 (0.1-2.5)	6.5					
Unspecified type of degreasing	All (1950-1993)	Any		Any	Both	50	10 (0.2-103)	1.0-2.1					
					P	32	15 (0.2-103)	1.6-2.1					
					A	18	1.2 (0.3-9)	1.0					
					P	2	18 (7-29)	2.0					
					P	22	20 (0.2-103)	1.6-2.1					
					P	9	5.7 (1.6-10)	NA					
					P	4	63 (14-103)	2.1					
					P	9	15 (0.2-76)	1.6					
					P	11	7.9 (1.6-29)	2.0					
					A	3	2.5 (0.4-3.6)	1.0					
					A	5	2.0 (0.3-9)	NA					
					P	2	18 (7-29)	NA					
						1970s	384	Degreaser operator	>6	P	2	18 (7-29)	NA
						1980s	Any		Any	P	18	24 (0.2-103)	1.6-3.1
					P					4	63 (14-103)	2.1	
							Any	Any	1-6	P	9	15 (0.2-76)	1.6
							Any	Any	>6	P	5	9.0 (5-10)	NA
									Any	A	2	4.7 (0.4-9)	NA
									1-6	A	1	0.4	NA
									>6	A	1	9	NA
							335	Crane relief	>6	P	1	10	NA
							335	Entry end shear	>6	P	1	5	NA
							335	Flat sheet stacker	>6	P	1	10	NA
							335	Shear operator	>6	P	1	10	NA
							335	Supervisor	>6	P	1	10	NA
							371	Air filter assembler	1-6	P	1	13	NA
							371	Cleanup & trim	1-6	P	1	22	NA
		371	Cleanup	1-6	P	1	23	NA					
		371	Gasket & cleanup	1-6	P	1	76	NA					
		372	Core cutter mechanic	1-6	P	1	0.6	NA					
		372	Solvent sprayer	1-6	P	1	2.8	NA					
		372	Structural repairman	1-6	P	1	0.3	NA					
	1990s	367	Etching technician	>6	P	4	1.6 <sup>C</sup>	NA					
1-6				A	2	3.6 (3.6-3.6)	1.0						
>6				A	4	0.3 <sup>C</sup>	NA						

<sup>A</sup>N = number of measurements. The number of measurements in specific categories may not add up to the number in the more general categories because of missing information on job title, duration, or type of sample.

<sup>B</sup>AM and GSD may have been reported in publication or may have been calculated.

<sup>C</sup>Range not given.

**TABLE IV. Summary of PCE Measurements from Sources Other than Dry Cleaning or Degreasing**

Source of Exposure	Years	SIC	Sample Duration (hrs)	Personal or Area Sample	N <sup>A</sup>	Arithmetic Mean (Range) ppm <sup>B</sup>	GSD <sup>B</sup>
Spot remover	1996	23	>6	P	3	0.2 (0.03–0.3)	3.0
			>6	A	3	0.4 (0.03–1)	4.3
Printing ink	1983–93	2655, 27, 7399, 8399	Any	P	58	2 (0.001–22)	1.3–50
			<1	P	4	17 (6.4–22)	1.7
			1–6	P	50	0.7 (0.001–16)	1.5–50
			>6	P	4	2.8 (1.2–5)	1.3
			1–6	A	4	0.2 (0.001–0.6)	3.7
Cleaning printing plates	1978–83	27	>6	A	3	3.8 (3.2–4.6)	1
			Any	P	22	6.3 (1.9–16)	1.2–1.5
			<1	P	1	8.6	NA
			1–6	P	10	7.4 (1.9–16)	1.2–1.5
			>6	P	11	5.1 (2.8–10)	1.5
Chemical production	1983	28	1–6	A	4	1.2 (0.3–2.5)	2.5
			>6	P	17	0.01 <sup>C</sup>	1
			1–6	P	10	4.3 (0.001–25)	4.7–11
Paints	1978–86	1629, 3321, 4171, 7699	>6	A	4	0.3 (0.01–0.9)	1.7
			Any	A	12	0.4 (0–1.6)	1.4–3.4
Wastewater	1981–82	4952	<1	A	5	0.7 (0.1–1.6)	2.1
			1–6	A	7	0.1 (0–0.4)	1.4–3.4
			>6	B	55	0.06 (0.02–1.1)	NA
Cleaning mining equipment	1980	1094	1–6	P	4	245 (0–960)	6.0
			1–6	A	3	2 (0–5)	40
Float/sink testing coal	1980	1221	1–6	A	3	149 (110–194)	NA
			<1	P	7	0.1 (0.08–0.12)	NA
			1–6	A	2	0.3 (0.001–0.6)	NA
Adhesives	1981–94	2645, 3061	1–6	A	2	0.3 (0.001–0.6)	NA
Cleaning animal coats in taxidermy	1978	7699	<1	P	1	228	NA
			1–6	P	2	132 (113–151)	1.2
Cleaning plastic molds	1984	3079	1–6	P	4	0.03 <sup>C</sup>	NA
			>6	P	1	0.03	NA
Mold release agent	1983	3321	>6	A	4	0.1 (0.01–0.2)	3.1
Cleaning, duplicating film	1979–80	3681	<1	P	40	38 (0.8–236)	4.0
			1–6	P	63	22 (0.4–236)	4.2
			<1	A	2	14 (4–23)	2.4
			1–6	A	16	27 (0.7–142)	4.2
			>6	A	23	16 (0.3–129)	4.0
Smoke bomb	1986–87	9224	<1	A	About 50	No AM (0.1–88)	NA
Lacquers	1988	3911	1–6	Both	9	None (0.001–2)	NA

<sup>A</sup>N = number of measurements. The number of measurements in specific categories may not add up to the number in the more general categories because of missing information on job title, duration, or type of sample.

<sup>B</sup>AM and GSD may have been reported in publication or may have been calculated.

<sup>C</sup>Range not given.

passes over a water-cooled condenser so the PCE may be recovered and reused.<sup>(20)</sup> Fresh air is usually circulated through the dryer to deodorize the garments. They are removed and pressed or ironed, folded, and bagged.<sup>(21)</sup>

The most common dry cleaning establishments are firms that primarily clean clothing and household textiles. Most of these shops (about 78% in 1980) employ 10 or fewer people and have only one dry cleaning machine;<sup>(21)</sup> some do not have a machine on site and transfer dirty garments to other facilities. In a large survey of 44 dry cleaning facilities in five U.S. states, the typical store had one machine operator; two or three pressers; one seamstress; and two or three other workers who did customer service, general store cleaning, marked and bagged clothing, and made deliveries.<sup>(21)</sup> Industrial dry cleaning operations clean items such as uniforms, towels, and linens on a large scale for businesses, institutions, and industrial plants. Coin-operated or self-service dry cleaners designed for the general public were common in the 1960s and 1970s, but misuse of machines resulted in their decline by the 1980s.<sup>(22)</sup>

PCE was not widely used in the dry cleaning industry until the late 1940s when it gradually replaced Stoddard solvent.<sup>(21)</sup> Its use became more widespread throughout the 1950s and 1960s, and by the late 1970s, about 75% of dry cleaners used PCE.<sup>(21,23)</sup> As of the late 1980s, PCE was used in about 85% of dry cleaning facilities<sup>(24)</sup> and this trend continued into the 1990s, with 85–90% of facilities using PCE.<sup>(1)</sup>

The mean PCE exposure from all dry cleaning measurements (personal and area samples) was 57 ppm (range: 0–4636,  $n = 1876$ ) (Table II). As expected, personal exposure AMs were highest for short duration (<1 hr) measurements at 131 ppm (range: 0–4636,  $n = 493$ ) and lower for longer measurements (>6 hr: AM = 15 ppm [range: 0.01–303,  $n = 378$ ]). The >6-hr AM for exposure in industrial dry cleaning plants (SIC 7218) was 11 ppm (no range given) but this was based on only two measurements (Appendix).<sup>(25)</sup> A 15-min measurement of over 300 ppm also was reported in an industrial dry cleaning firm for a worker changing a filter (Appendix).<sup>(25)</sup> Commercial dry cleaning shops (SIC 7216) had an AM of 57 ppm (range: 0–4636,  $n = 1868$ ) for personal and area measurements of all durations. On average, peer reviewed publications had a higher personal weighted AM for all sample durations (73 ppm [range: 0–4636,  $n = 407$ ]) compared with NIOSH reports (AM = 52 ppm [range: 0–775,  $n = 993$ ]) (not shown), and this pattern was consistent by decade.

We found one report in which dermal exposure to PCE during waterproofing was described. Clothing was dipped in a tank of PCE, raised, allowed to drain, and hand carried to the dry cleaning machine.<sup>(26)</sup> This report also indicated that dermal exposures could occur from spotting fluids containing PCE.<sup>(26)</sup>

### *Determinants of Exposure*

Changes in dry cleaning technology over time improved recovery of PCE and reduced exposure to workers. Until the late 1960s, all dry cleaning machines required manual transfer

of solvent-saturated clothing between a washing and drying machine. One study found that workers in stores with this type of machine performed an average of 7.5 transfers per day.<sup>(22)</sup> Dry-to-dry machines eliminated the need to transfer garments, but as of 1984, this type of machine was present in only 28% of dry cleaning businesses in a study of 12 New Jersey communities.<sup>(22)</sup>

In the late 1970s and early 1980s, machines were introduced that recirculated the air during the drying process through a refrigerated condenser vapor recovery system, considerably reducing PCE emissions. The machines also had carbon adsorbers to recover PCE vapors.<sup>(21)</sup> A 1993 EPA ruling required all new dry cleaning establishments to install only dry-to-dry machines. Existing facilities had to replace transfer machines with dry-to-dry ones when the transfer machines became unusable.<sup>(10)</sup> Recently, machines have been introduced that include locks on the machines to prevent workers from opening them before the solvent air concentration has dropped below 300 ppm.<sup>(27)</sup>

In addition to the type of machine used, several other workplace characteristics are important determinants of PCE exposure. Local exhaust systems that are well maintained reduce exposure in facilities with transfer-type machines.<sup>(22)</sup> Throughout the 1960s and 1970s, many dry cleaning facilities had exhaust systems near the floor in the mistaken belief that PCE concentrations were highest there, since PCE is heavier than air. By the early 1980s, research showed that local exhaust systems functioned most efficiently when placed near the sources of the exposure, e.g., next to dry cleaning machines and spotting tables.<sup>(21)</sup> One study in 1984 found that 60% of the 67 dry cleaning firms inspected had inadequate ventilation.<sup>(22)</sup> Wall and ceiling fans can supplement local exhaust systems.

Maintenance of equipment is also important; gaskets that convey PCE must be checked often for leaks.<sup>(22)</sup> The same study in 1984 found that 15% of the gaskets needed replacement. Collection of PCE in uncovered containers (present in 48% of facilities in that study) allowed substantial evaporation of PCE into the workroom.

Several tasks are responsible for particularly high but usually short-term (30 min or less) exposures to PCE. The filters for recovering PCE periodically clog and must be changed. The lint and button traps also need to be cleaned out about once a day. High exposures (in one review, the AM was 172 ppm [range: 0–690,  $n = 129$ ] for personal samples taken <1 hr) were also seen during transfer of wet clothes to the dryer<sup>(21)</sup> and even higher exposures (AM = 677 ppm [range: 306–1204,  $n = 8$ ] for area samples taken <1 hr) were observed when loading dirty garments into the dry cleaning machine, presumably because the machine was not adequately ventilated after the previous cleaning.<sup>(28)</sup>

Real-time measurements showed that workers may have been exposed to >2000 ppm of PCE for about 30 sec when adding and removing items from a transfer-type dry cleaning washing machine.<sup>(28)</sup> Cleanup of PCE spills can also result in very high, short-term exposures (area samples ranged from

400–1600 ppm for several minutes).<sup>(28)</sup> Although the use of respirators can drastically reduce these exposures, in one study, less than 5% of workers used respirators during these tasks, and respirators were not available at 73% of the shops studied.<sup>(22)</sup>

Our review of the measurement data confirmed that several of these determinants had an effect on air concentrations of PCE. For example, PCE measurements varied by JT and type of machine. Machine operators had a personal AM (all durations) across all time periods of 112 ppm (range: 0–2960,  $n = 623$ ), but the AM for transfer machine operators' personal measurements for samples taken <1 hr was 179 ppm (range: 0–1000,  $n = 344$ ), much greater than measurements of dry-to-dry machine operators (AM = 28 ppm [range: 4–257,  $n = 55$ ]). However, the personal AMs were similar for the two types of operators for samples taken over 1–6 and >6 hr (Table II). Non-operator jobs (spotter, presser, seamstress, counter clerk) had substantially lower personal measurements of PCE (AM for <1 hr samples = 3.7 ppm [no range given,  $n = 84$ ]) (Table II).

One study examined variations in personal PCE levels of wet transfer machine operators and compared the adequacy of local exhaust systems. A functional ventilation system decreased PCE air concentrations drastically from an average of 160 ppm (range: 25–534,  $n = 14$ ) to 25 ppm (range: 11–43,  $n = 3$ ) for 5-min samples.<sup>(22)</sup> Local exhaust had a lesser effect on PCE concentrations for longer (55–433 min) samples; AMs decreased from 88 ppm (range: 31–303,  $n = 14$ ) to 81 ppm (range: 29–184,  $n = 3$ ) (Appendix).<sup>(22)</sup>

Similarly, in another study reporting 1- to 6-hr measurements for dry-to-dry machine operators, the presence of a local exhaust system made little difference. Without a ventilation system, the AM was 8.7 ppm (range: 2.4–20,  $n = 14$ ) and with ventilation, the AM was 6.8 ppm (range: 2.5–22,  $n = 14$ ) (Appendix).<sup>(29)</sup> This similarity is probably because the recovery systems that were inherent in the dry-to-dry machines reduced emissions of PCE, making ventilation less important.

These improvements over time are reflected in the operators' short-term (<1 hr) personal measurements: transfer operators' exposures fell from 190 ppm (range: 0–1000,  $n = 198$ ) in the 1970s to 92 ppm (range: 58–153,  $n = 8$ ) in the 1990s. Personal measurements of dry-to-dry operators fell from 41 ppm (range: 4–257,  $n = 32$ ) in the 1970s to 11 ppm (no range given,  $n = 23$ ) in the 1980s. GSDs for both types of operators fell from a range of 1.5–3.4 in the 1970s to 1.2–2.6 in the 1990s. We found almost no change over time, however, in longer term measurements for operators. Mean PCE measurements in jobs other than operators changed little in each decade, regardless of the duration category, but the GSDs of non-operator measurements decreased over time.

## PCE Use in Degreasing

### Process

After dry cleaning, the most common use of PCE is degreasing of metal and solvent-resistant plastic parts. Often these parts are shipped with a temporary protective oil coating, they become oily during machining, or they are soiled in

operations such as polishing and buffing.<sup>(30)</sup> Degreasing must be done before painting, enameling, lacquering, electroplating, assembly, packing, or other processing.<sup>(31,32)</sup> Although trichloroethylene (TCE) historically has been preferable to PCE for most degreasing,<sup>(33)</sup> PCE is more useful for removal of waxes with high melting points because it has a higher boiling point than TCE. This characteristic enables PCE to condense on items longer than solvents with lower boiling points, allowing a longer cleaning cycle.<sup>(34)</sup>

Following degreasing, PCE leaves no residue or film on metal surfaces, making it ideal for items requiring spot-free finishes such as medical devices, disk drives, and parts used in the aerospace industry.<sup>(33)</sup> PCE is useful for removing water when drying metal parts and for cleaning spot-welded seams or small orifices.<sup>(35)</sup> PCE can also clean coils and components for electric motors, since it does not damage wire coating or sealing agents.<sup>(36)</sup> The mean air concentration of PCE used for degreasing in personal and area measurements was 72 ppm (range: 0–1800,  $n = 331$ ) for all sample durations (Table III).

PCE is used in two types of degreasing processes: cold cleaning and vapor. These have been described in detail by Bakke et al.,<sup>(37)</sup> but a brief description is provided.

### Cold Degreasing

Cold degreasing includes spraying, flushing, brushing, wiping, and immersion of an item in a solvent at room temperature. Because the solvent cannot generally be recovered and PCE is relatively expensive, it has never been widely used for cold degreasing. As of the 1970s, PCE accounted for only about 2% of the total volume of solvents used for cold degreasing.<sup>(38)</sup> We identified only three cold degreasing PCE measurements. One was a report of an accidental overexposure of almost 400 ppm by a man cleaning stairs with a cloth in 1960.<sup>(39)</sup> The other two were measurements taken for 1–6 hr in the breathing zone of a degreasing foreman and an assistant cleaning parts in the special industrial machinery industry (SIC 3559) (AM = 0.2 ppm [range: 0.1–0.2]).<sup>(40)</sup>

### Vapor Degreasing

Vapor degreasing consists of heating the solvent to a boil and placing the parts in the vapor zone above a tank, where they are flushed with the solvent condensate. As of the 1970s, about 12–20% of vapor degreasing used PCE.<sup>(20,41)</sup> The AM for all sample durations of vapor degreasing personal and area measurements was 82 ppm (range: 0.04–1800,  $n = 278$ ) (Table III). The AM for personal vapor degreasing measurements of all durations was 110 ppm (range: 0.04–1800,  $n = 171$ ). Like dry cleaning, the highest personal measurements seen in vapor degreasing were <1 hr (AM = 23 ppm [range: 0.1–185,  $n = 25$ ]), compared with the AM for measurements taken in 1–6 hr (5.7 ppm [range: 0.04–84,  $n = 33$ ]) and >6 hr (3.2 ppm [range: 0.1–82,  $n = 57$ ]) (note that 55 personal measurements from the 1940s with an AM of 324 ppm were excluded from these because they did not include the duration of the measurement) (Table III).

Peer reviewed publications had a weighted personal AM of all sample durations of 324 ppm (range: 20–1800, n = 55), but this included only one study done in the 1940s that did not provide sample durations (not shown). The AM of personal PCE measurements of all durations found in NIOSH reports was 8.2 ppm (range: 0.1–185, n = 116). Other studies describing degreasing operations without identifying the type of degreasing are presented in the table for completeness.

### *Determinants of Exposure*

Determinants of TCE exposure in degreasing tasks have been described previously<sup>(37)</sup> and are similar to those for PCE. Briefly, these include local ventilation practices, the length of time that degreased parts are dried above the tank, and the shape of the parts.<sup>(42)</sup> Poor work practices such as overloading degreasing machines and introducing soiled items too rapidly into the solvent bath are sources of high air concentrations.<sup>(43,44)</sup>

In addition, lack of covers for tanks, inappropriately located tanks, and improper cleaning procedures were common as late as the 1990s in the U.K.<sup>(45)</sup> Drafts were shown to increase air concentrations of PCE from 30–40 ppm to 170–230 ppm.<sup>(44)</sup> Particularly high exposures can also occur when degreasing tanks are cleaned and filled with solvent.

We found that exposure to PCE from degreasing decreased dramatically over time. The earliest measurements taken in the 1940s (duration of sample measurement was not given) and another in the 1960s (1–6 hr) showed personal exposures to PCE >300 ppm (Table III). However, mean personal measurements of >6 hr fell in every subsequent decade from 18 ppm (range: 7–29, n = 2) in the 1970s, 4.7 ppm (range: 0.1–82, n = 41) in the 1980s, 1.6 ppm (no range given, n = 4) in the 1990s, and 1.1 ppm (range: 0.1–16, n = 21) in the 2000s. GSDs ranged from 1 to less than 4 and were fairly consistent, regardless of the durations of the measurements or the decades that the measurements were taken.

### *Industries and Jobs*

Overall, degreasing with solvents is primarily done in metal industries, although it can be used in many other industries. As of the 1970s, about 65% of metalworking jobs involved metal cleaning and 40–65% of this cleaning used solvent systems.<sup>(41)</sup> About half of the metal cleaning used cold cleaning, 25% used vapor degreasing, and 20% used both.<sup>(37)</sup>

Degreasing with PCE is primarily done in the metal fabrication industries, particularly blast furnace and blast steel products (SIC 3310), iron foundries (SIC 3320),<sup>(46)</sup> nonferrous foundries (SIC 3360), miscellaneous primary metal products (SIC 3390), cutlery, hand tools, and hardware (SIC 3420), plumbing and heating products (SIC 3430), fabricated structural metal products (SIC 3440), screw machine products and bolts (SIC 3450), metal services (SIC 3470), miscellaneous fabricated metal products (SIC 3490), farm and garden machinery (SIC 3520), specialized industrial machinery (SIC 3559),<sup>(31)</sup> pumps and pumping equipment (SIC 3561),<sup>(47)</sup> electric distributing equipment (SIC 3610), electrical industrial

apparatus (SIC 3620), household appliances (SIC 3630),<sup>(48,49)</sup> electric lighting and wiring equipment (SIC 3640), communication equipment (SIC 3660), electronic components and accessories (SIC 3670), photographic equipment and supplies (SIC 3681),<sup>(50)</sup> motor vehicles and equipment (SIC 3710), aircraft and parts (SIC 3720),<sup>(20)</sup> tanks and tank components (SIC 3795),<sup>(51)</sup> and medical instruments and supplies (SIC 3840)<sup>(52)</sup> industries. The AM for personal PCE measurements of all durations for degreasing in metal manufacturing industries (SIC 33–38) was 94 ppm (range: 0.04–1800, n = 205) (not shown), and we noted little difference in levels among these industries, although numbers were generally small.

Additional industries that have been reported to use PCE for degreasing are the railroad (SIC 4000), local and interurban passenger transportation (SIC 4100), trucking and warehousing (SIC 4200), and transportation by air (SIC 4500) industries. The automobile dealer (SIC 5500) and service station (SIC 7500) industries have also reported using PCE for degreasing and were more likely to use it for cold cleaning than for vapor degreasing.<sup>(31)</sup>

Few measurements for vapor degreaser operators were found and personal measurements of >1 hr, primarily from the 2000s, were low (AM = 1.1 ppm [range: 0.1–13, n = 21]). The JT “reflow operator” in the metal plating and polishing industry (SIC 3471), who was exposed to PCE when metal parts were dipped in a vat of the solvent to remove residual oil following electroplating, had the highest <1-hr measurements in papers that identified JTs (AM = 153 ppm [range: 120–185, n = 2]). The average measurements taken >1 hr for reflow operators was 83 ppm (range: 82–84, n = 2). Electroplaters had a mean exposure of 26 ppm (range: 1.9–66, n = 9) for measurements taken in <1 hr in the 1980s. Other jobs generally were associated with AMs of ≤10 ppm (range of AMs 0.1–10, n = 97) (Table III).

We also identified measurements in specific JTs for unspecified types of degreasing. Air filter assemblers in the motor vehicle parts and accessories industry (SIC 3714) had average <1 hr measurements of 63 ppm (range: 14–103, n = 4). (A single 3 hr measurement for this JT was 13 ppm.) Jobs with cleanup in their title had an average exposure for samples of 1–6 hr of 40 ppm (range: 23–76, n = 3) (Table III). Other JTs that did not specify the type of degreasing had AMs ranging from 0.3–10 ppm (n = 9) (Table III).

## **OTHER USES AND OCCURRENCES OF PCE**

### **Apparel and Other Textile Products Manufacturing (SIC 230)**

Beginning in the late 1970s, solvents, including PCE, were used in the knit fabric sector of the textile industry for scouring, which removes wax, pectin, dirt, lubricants, and other foreign substances from textiles.<sup>(38)</sup> In addition, PCE was used in the textile industry as an aerosol solvent for waterproofing clothes<sup>(10,53)</sup> and to remove spots on finished clothing.<sup>(54)</sup> We found an AM of 0.2 ppm (range: 0.03–0.3, n = 3) for >6 hr

personal measurements of workers using spot removers in the textile industry (Table IV).

### **Paper and Pulp Plant Workers (SIC 261)**

PCE was used in the production and recycling of paper and paper products in an international survey of paper plants conducted from 1992 to 1995. Although PCE was found in relatively few of the measurements in this survey ( $n = 61$  out of 31,500), 30% of these were in excess of the permissible exposure limits (PEL) of an 8-hr time-weighted average (TWA8) of 100 ppm set by the Occupational Safety and Health Administration (OSHA) (not shown).<sup>(55)</sup> The highest exposures to PCE occurred in the calendaring area and during coating of paper.<sup>(56)</sup> Another study on this industry reported trace amounts ( $<0.001$  ppm,  $n = 61$ ) (Appendix) of PCE in a softwood and hardwood pulp mill in Finland, where it was used for the treatment of spent liquors.<sup>(57)</sup>

### **Printing and Publishing (SIC 270)**

PCE was used as early as the 1930s as a fat solvent for duplicator operators in the printing industry.<sup>(58)</sup> Workers also used PCE to clean inked images off rubber blankets of duplicating machines in the 1960s.<sup>(59)</sup> From 1972 to 1995, PCE was used in this industry to clean printing presses. This use was probably more common in low volume shops that used smaller presses requiring manual cleaning.<sup>(60)</sup> Office workers who used photocopiers in the early 1980s were exposed to trace amounts of PCE.<sup>(61)</sup> PCE has also been used in printing ink.<sup>(62)</sup>

During platemaking for lithographic printing, PCE was used to clean unreacted monomer off the plate after the film negative had been imprinted on it. In one case, the plate was placed in a revolving drum for about 6 min and cleaned with a solution that was 75% PCE and 25% n-butanol.<sup>(63)</sup> Use of PCE has also been reported in printing for the greeting card industry (SIC 2770)<sup>(64)</sup> and rotogravure printing (SIC 2754).<sup>(65)</sup>

Exposures to PCE in the printing industry were low, with an AM of 6 ppm (range: 1.9–16,  $n = 22$ ) for personal measurements of all durations from workers cleaning printing plates (Table IV). Exposure to PCE was also reported from printing ink (personal AM = 2 ppm for all sample durations [range: 0.001–22,  $n = 58$ ]).

### **Chemicals and Allied Products (280)**

Several industries related to chemical manufacturing have used PCE. Beginning in the 1970s, one of the major uses of PCE was as a chemical intermediate for the production of CFC and HFC.<sup>(1)</sup> PCE was also used as a chemical intermediate in the 1960s to synthesize trichloroacetic acid for the production of pest control agents.<sup>(66)</sup> PCE was a solvent in many pesticides registered with the EPA from 1969–1989, including the widely used insecticide diazinon and several fungicides. PCE was also a component of gaseous fumigants in the 1970s.<sup>(62)</sup>

After 1989, no pesticides containing PCE were registered with the EPA in the United States, but at least one study reported it in pesticides in Italy as recently as 1993.<sup>(67)</sup> PCE was also

used in the 1960s to extract sulfur from iron oxide pellets used in the purification of coke oven gases.<sup>(66)</sup> In addition, the use of PCE in pharmaceutical manufacturing was noted.<sup>(68)</sup>

We found only one report that identified PCE measurements in the U.S. chemical production industry. In a plant synthesizing PCE, the AM was 0.01 ppm (range not given,  $n = 17$ ) in  $>6$  hr personal measurements (Table IV).

Small amounts of PCE have been used in rubber production (SIC 2822) as a rubber solvent, for degreasing,<sup>(68,69)</sup> and as a fire extinguishing chemical.<sup>(70)</sup> Trace amounts of PCE were found at a butyl rubber plant.<sup>(71)</sup> Further information on these uses was not provided.

PCE was occasionally used in the manufacture of surface coatings (paints, varnishes, lacquers, enamels, and allied products) (SIC 2850) and in solvent-based architectural (i.e., residential, commercial, institutional, and industrial structures) coatings as of 1984.<sup>(72)</sup> A review of components in water-based paints in Denmark did not find any evidence of PCE.<sup>(73)</sup> PCE was occasionally used as a paint remover in the 1960s but not extensively.<sup>(62,66)</sup> We found two reports of 1- to 6 hr personal measurements of PCE from paints (AM = 4.3 ppm [range: 0.001–25,  $n = 10$ ]).<sup>(74,75)</sup>

### **Leather and Leather Products (SIC 31)**

Small amounts of PCE were detected in surveys of shoe manufacturing (SIC 3130) facilities in Portugal<sup>(76)</sup> and in Italy<sup>(77)</sup> in the early 1990s. Most likely, the source of PCE was from adhesives applied to the shoes. The AM for personal samples taken in Portugal from 1–6 hr was 15 ppm (range not given,  $n = 71$ ) (Appendix). No measurements were provided in the report from Italy.

### **Electronic Components and Accessories (SIC 367)**

PCE has been used to manufacture semiconductors and printed circuit boards. Beginning in the 1970s, PCE was used to strip developed negative photoresist coatings from wafers during the manufacture of semiconductors. However, PCE use in this industry has never been large or widespread.<sup>(78–80)</sup> In printed circuit board manufacture, PCE was used to remove flux after soldering and for vapor degreasing.

After the 1970s, PCE was also used in limited amounts in electrical transformer insulating fluids and cooling gases as a substitute for polychlorinated biphenyls (PCBs).<sup>(10)</sup> We found one report of PCE measurements for an etching technician degreasing in this industry (AM = 1.6 ppm [range not given,  $n = 4$ ] in a  $>6$  hr sample) (Table III).<sup>(81)</sup>

### **Aircraft and Parts Manufacturing (SIC 372)**

In one study that reviewed chlorinated solvent use in an aircraft manufacturing plant from the 1960s to the 1990s, JTs involving regular use of PCE included painter (14% were exposed), electroplater (56%), process equipment operator (73%), plastics fabricator (21%), welder (14%), metal bonder (74%), final assembler (15%), and fabrication and structural development mechanic (77%).<sup>(82)</sup> PCE was the primary

degreaser used in that facility after 1966, following the passage of legislation to decrease air pollution from TCE.<sup>(82)</sup>

Another study conducted in Utah found that 6% of the aircraft maintenance workers in that study were exposed to PCE, primarily those who used it to clean fabric in the parachute shop.<sup>(82)</sup> PCE was also used in relatively small amounts as a replacement for 1,1,1-trichloroacetic acid in aerosol brake and engine cleaners.<sup>(10)</sup> The AM for personal measurements for degreasing jobs in the aircraft and parts industry was 13 ppm for <1 hr samples (range: 0.1–66, n = 19) and 1.4 ppm (range: 0.1–16, n = 62) for >1 hr samples.

### Sanitary Services (SIC 495)

Exposure to PCE has been reported in the wastewater treatment industry (SIC 4952). In one case, exposure was traced to a sewage spill from a pigment plant,<sup>(83)</sup> but exposures were reported at other facilities without an identified source.<sup>(84,85)</sup> The AM for PCE area samples taken in <1 hr and 1- to 6 hr samples in wastewater facilities was 0.4 ppm (range: 0–1.6, n = 12) (Table IV). Also, PCE was detected at a landfill in New York City in personal and area >6-hr samples (AM = 0.06 ppm [range: 0.02–1.1, n = 55])<sup>(86)</sup> (Table IV).

### Health Services (SIC 800)

Thymol-stabilized PCE was used as an anthelmintic (a deworming medication) from about the 1920s to the 1950s in humans as well as in dogs and livestock.<sup>(66,87,88)</sup> Use of PCE as a portable, nonflammable anesthetic was explored during World War II, but it never achieved widespread use for this purpose.<sup>(89)</sup>

### Miscellaneous Industries That Use PCE

We found several reports of PCE used in mining industries for cleaning equipment in personal 1- to 6-hr samples (AM = 245 ppm [range: 0–960, n = 4])<sup>(90)</sup> (Table IV). The presence of PCE was also reported in two studies on float and sink testing coal that involved immersing coal to determine its ash content and other characteristics.<sup>(91)</sup> The AM for 1- to 6 hr personal measurements was 149 ppm (range: 110–194, n = 3) and for <1 hour was 0.1 ppm (range: 0.08–0.12, n = 7).<sup>(91,92)</sup> The former study, conducted in 1980, reported that only respirators were used to reduce exposure to solvent vapors and recommended that a local exhaust ventilation system be implemented. The latter study, done in 1989, reported that a wall exhaust fan was adequately controlling solvent vapor generation.

We identified two studies that reported long-term (>1 hr) area measurements of PCE from adhesives (AM = 0.3 ppm [range: 0.001–0.6, n = 2])<sup>(3,93)</sup> (Table IV). PCE has also been used in taxidermy shops (SIC 7699) for degreasing animal fur and in paints. A NIOSH report examining five taxidermy shops in 1983 did not find any that used PCE<sup>(94)</sup> but another document reported PCE in one shop (personal AM = 164 ppm in <1- to 6-hr samples for the fur coat cleaner [range: 113–228, n = 3] and an AM = 7.2 ppm [range: 0–25, n = 6] in a 1- to 6 hr

sample for a head finisher exposed to PCE from paints) (Table IV).<sup>(75)</sup>

Isolated reports of PCE use were found in several industries, including plastic container manufacture (SIC 3089) where it was used to clean the insides of metal molds.<sup>(95)</sup> PCE was also used in this industry for solvent-welding for softening the surfaces of polystyrene products to be joined.<sup>(96)</sup> PCE was used as a carrier solvent for silicones in the preparation of silicone wax mold release agents for plastic patterns in investment casting, which is used to make parts used in the aerospace, military, automotive, and power generation industries.<sup>(10,97,98)</sup> We found two studies<sup>(4,46)</sup> that reported personal measurements taken during cleaning of molds or use of mold release agents; all were <1 ppm (n = 5) (Table IV).

Cleaning and duplicating film was associated with AMs of 38 (0.8–236, n = 40) and 22 ppm (0.4–236, n = 63) for personal measurements taken <1 hr and 1–6 hr, respectively<sup>(50,99)</sup> (Table IV). Firefighters (SIC 9224) were exposed to PCE during training exercises with smoke bombs (no source identified) (no AM [range of area measurements: 0.1–88 ppm, n~50])<sup>(100,101)</sup> (Table IV). We found one report of PCE used in a lacquer mixture applied to jewelry as a protective coating after electroplating, in the jewelry industry (SIC 3911) (no AM [range: 0.001–2 ppm, n = 9] for personal and area samples taken 1–6 hr)<sup>(102)</sup> (Table IV).

Other operations that reported using PCE were watchmaking (for ultrasonic degreasing of instruments),<sup>(36,103)</sup> silk-screening (no PCE source identified),<sup>(104,105)</sup> uranium enrichment (in the gaseous centrifuge processes),<sup>(106)</sup> and during application of an asphalt roofing system (no PCE source identified).<sup>(107)</sup> PCE has also been reported as an additive to heat transfer fluids<sup>(68)</sup> and as an ingredient in solvent soaps.<sup>(66,108)</sup>

## DISCUSSION

Several entities, including the EPA,<sup>(109)</sup> IARC,<sup>(110)</sup> and the state of California,<sup>(10)</sup> have classified PCE as a possible or probable carcinogen. Occupational exposures are by far the source of the highest exposures to PCE. About 5% of the AMs that we identified in our database exceeded the PEL set by OSHA of a TWA8 of 100 ppm or a maximum exposure level of 200 ppm, indicating that overexposure to this chemical has occurred with some regularity. Exposure to PCE occurred most often in the dry cleaning industry, but substantial exposures also took place in metal manufacturing industries through degreasing processes, as well as from a variety of uses in several other industries.

Production and quantities of PCE used for dry cleaning peaked in the late 1970s and early 1980s, but PCE remains the main solvent used in this industry. Exposure to PCE varied widely depending on whether the dry cleaning machine involved transferring wet clothes to a dryer. In addition, characteristics of dry cleaning shops such as ventilation, the degree of maintenance of equipment, and work practices influenced PCE exposures. We identified 71 short-term measurements in

this industry that exceeded 200 ppm, and 12 measurements that exceeded the PEL of 100 ppm; 7 of these were operators of wet-transfer machines in the 1970s and 1980s. This data are likely to underestimate the prevalence of overexposures, since some of the papers we reviewed did not provide individual measurement results.

We identified 36 measurements of PCE taken during vapor degreasing in 1944 that exceeded the PEL, but the durations of these measurements were not specified.<sup>(111)</sup> Other operations with measurements in excess of the PEL were cold degreasing (one measurement),<sup>(39)</sup> tasks in the mining industry (two measurements),<sup>(90,91)</sup> and degreasing animal coats for taxidermy (two measurements).<sup>(75)</sup> Measurements exceeding the short-term maximum exposure were found in an unspecified type of degreasing (one measurement) and among workers cleaning and duplicating film in the photographic equipment and supplies industry (three measurements).<sup>(99)</sup> These measurements indicate that substantial exposures to PCE have occurred in a variety of industries.

A limitation of this article is that we may not have identified all of the published data of PCE measurements, so we cannot be certain that industries not included in this report did not entail exposure to PCE. However, we searched four databases for information on chlorinated solvents in general and PCE specifically, identifying 258 relevant articles.

Another limitation is that many (75%) of the papers that reported measurement data were NIOSH reports conducted by request from a union or worker as a result of health concerns. Measurements from the NIOSH reports were not subject to a rigorous peer review process and may represent less reliable data than those published in the journals.

However, since our aim was to include as many PCE measurements as possible, we included these. We also cannot be certain that the measurement data in this review is representative of the true PCE exposure levels in these industries, and no similar database of U.S. measurements exists to compare this data. It is possible that jobs were measured because they had the highest hypothesized exposure levels in many of the industries, but this practice does not necessarily bias the measurements for these jobs.

Another limitation is that this review reported averages from many sources and studies with different purposes, types of measurements (personal vs. area), durations, and sampling and analytic methods into a comprehensive summary of PCE use over time. Although exposure assessment methods ideally should be standardized for these variables, this is impossible for case-control studies in which the relevant exposures occurred in the past and over multiple decades. Many studies included in this review did not identify important information that would have been useful for exposure assessment, such as JT, length of time the samples were taken, the source of the PCE exposure, or other important determinants, such as type of degreasing. Because of this limited information, we were limited in our ability to interpret some of the exposure scenarios.

Although we identified a few studies from other countries, the measurements and uses described in this review predomi-

nantly concerned PCE as it has been used in the United States. These trends are likely similar to those seen in other countries, but our data is best suited to summarize U.S. trends.

## CONCLUSIONS

Exposure assessment in population-based, case-control studies is a complex process requiring substantial resources. This article provides a comprehensive reference that will allow for more accurate and consistent exposure assessment by industrial hygienists who are investigating disease risk associated with PCE in case-control studies. Historically, investigators have used subjective methods to assess exposures and have not provided the detailed methods of their assessments which has likely resulted in unreliable evaluations.<sup>(112)</sup>

Our review will be especially useful for situations in which measurements of PCE exposure are impossible to obtain since, for many chronic diseases such as cancer, the relevant exposure period was usually 20 or more years in the past, and exposures that conceivably could have led to disease are impossible to measure.

Similar reviews have examined historical exposures to and uses of TCE and benzene.<sup>(37,113)</sup> Our database was also compiled to reduce the amount of time other investigators would have to expend when assessing exposure to PCE. This review, however, is just the first step of the assessment process. The next step is using this information for assessing exposures of the study subjects, based on rules followed consistently across all industries, jobs, and time periods. Although some error may still exist, it will likely be reduced because the assessments will be based on more comprehensive and consistent information than presumably has been used in the past.

This extensive review summarized PCE uses and measurements in different industries for the specific purpose of assessing occupational exposures in case control studies. The dry cleaning industry was the most common industry sampled, followed by various industries that used PCE for degreasing, reflecting the two major uses of PCE.

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## APPENDIX

The following table summarizes our database of PCE measurements.

**TABLE AI. Database of PCE Measurements, Including Countries Outside the United States**

SIC	Source of Exposure	Country	Year(s)		Sample Type	Sample Duration (hrs)	N	AM (ppm) <sup>A</sup>	Min (ppm)	Max (ppm)	GM (ppm)	GSD <sup>A</sup>	Job Title and Other Comments	Reference
			Measurement	of Measurement										
2321	Dry cleaning	USA	1988-89		P	>6	5	0.9	<0.4 <sup>B</sup>	2.2	0.7	1.9	No JT	54 <sup>C</sup>
2321	Dry cleaning	USA	1988-89		A	>6	9	0.4	<0.4 <sup>B</sup>	0.6	0.4	1.1	No JT	54 <sup>C</sup>
3840	Dry cleaning	USA	1979		A	>6	1	11					No JT	52 <sup>C</sup>
7215	Dry cleaning	USA	1974-75		P	1-6	5	5.8	1	16	2.8	3.5	Operator (coin-operated)	119
7216	Dry cleaning	USA	1936 <sup>D</sup>		P	<1	2	155		4636			No JT	120
7216	Dry cleaning	USA	1936 <sup>D</sup>		P	<1	1	47		2960			Operator. Max measurement when operator repaired door	120
7216	Dry cleaning	USA	1952-63		P	<1	16	205	15	315			Operator (transfer); during transfer	21
7216	Dry cleaning	USA	1952-63		A	<1	17	50	6	139	35		No JT	21
7216	Dry cleaning	USA	1956-73		A	<1	16	27	2.7	100	15		No JT	21
7216	Dry cleaning	USA	1956-73		P	<1	9	198	24	690			Operator (transfer); during transfer	21
7216	Dry cleaning	USA	1963		P	<1	30	150	10	300			Operator (transfer); during transfer	21
7216	Dry cleaning	USA	1963		A	<1	34	50	0	200	21		No JT	21
7216	Dry cleaning	USA	1964-1976		A	<1	11	52	5	117	35		No JT	21
7216	Dry cleaning	USA	1968		P	<1	43	244	3	350			Operator (transfer); during transfer	21
7216	Dry cleaning	USA	1968		A	<1	65	29	3	300	16		No JT	21
7216	Dry cleaning	USA	1968-1969		A	<1	100	37	0	200	23		No JT	21
7216	Dry cleaning	USA	1971		A	>6	12	94	34	239	80		No JT	121
7216	Dry cleaning	USA	1974		P	1-6	38	36	5.2	211	24		No JT	122
7216	Dry cleaning	USA	1974-5		P	1-6	29	41	8.2	211	28	2.3	Operator (transfer)	119
7216	Dry cleaning	USA	1974-5		P	1-6	9	21	5.2	69	15	2.1	Operator (dry-to-dry)	119
7216	Dry cleaning	USA	1974-5		P	<1	22	935	250	1000	889	1.5	Operator (transfer)	119
7216	Dry cleaning	USA	1974-5		A	1-6	30	24	<10	100	18	2	Area of transfer machine	119
7216	Dry cleaning	USA	1974-5		A	1-6	8	12	<10	20	8.8	1.6	Area of dry-to-dry machine	119
7216	Dry cleaning	USA	1974-1976		A	<1	4	39	5.5	61	29		No JT	21
7216	Dry cleaning	USA	1976 <sup>D</sup>		P	>6	5	21		215			Operator	123

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**TABLE AI. Database of PCE Measurements, Including Countries Outside the United States (Continued)**

SIC	Source of Exposure	Country	Year(s) of Measurement	Sample Type	Sample Duration (hrs)	N	AM (ppm) <sup>A</sup>	Min (ppm)	Max (ppm)	GM (ppm)	GSD <sup>A</sup>	Job Title and Other Comments	Reference
7216	Dry cleaning	USA	1976 <sup>D</sup>	P	>6	2	4.5		52			Presser	123
7216	Dry cleaning	USA	1976 <sup>D</sup>	P	>6	5	1.0		2.6			Counter clerk	123
7216	Dry cleaning	USA	1976 <sup>D</sup>	P	>6	7	2.0		27			No JT	123
7216	Dry cleaning	USA	1977	P	<1	16	90	0	299			Operator (transfer); during transfer	21
7216	Dry cleaning	USA	1977	A	1-6	16	33	4	114	22		No JT	21
7216	Dry cleaning	USA	1977-79	A	1-6	10	5.7	0.4	17	3.3		No JT	21
7216	Dry cleaning	USA	1977-79	A	>6	13	5.8	0.3	22	2.8		No JT	21
7216	Dry cleaning	USA	1977-79	P	<1	6	73.3	29	139	63		Operator	21
7216	Dry cleaning	USA	1977-79	P	<1	145	103	1	775	53		Operator (transfer)	21
7216	Dry cleaning	USA	1977-79	P	<1	32	41	4	257	20		Operator (dry-to-dry)	21
7216	Dry cleaning	USA	1977-79	P	1-6	13	26	5	67	21		Operator (transfer)	21
7216	Dry cleaning	USA	1977-79	P	1-6	6	41	11	74	33		Operator (dry-to-dry)	21
7216	Dry cleaning	USA	1977-79	P	>6	1	65					Operator	21
7216	Dry cleaning	USA	1977-79	P	>6	22	35	4	149	22		Operator (transfer)	21
7216	Dry cleaning	USA	1977-79	P	>6	3	8.7	5	14	8		Operator (dry-to-dry)	21
7216	Dry cleaning	USA	1977-79	P	1-6	3	11	4	15	9.2		Presser (dry-to-dry)	21
7216	Dry cleaning	USA	1977-79	P	1-6	8	5.5	0.5	12	3.4		Presser (transfer)	21
7216	Dry cleaning	USA	1977-79	P	1-6	3	7.6	0.9	21	2.7		Seamstress (transfer)	21
7216	Dry cleaning	USA	1977-79	P	>6	2	33	29	37	33		Presser	21
7216	Dry cleaning	USA	1977-79	P	>6	8	5.7	0.6	27	3		Presser (dry-to-dry)	21
7216	Dry cleaning	USA	1977-79	P	>6	28	4.8	0.1	17	2.7		Presser (transfer)	21
7216	Dry cleaning	USA	1977-79	P	>6	7	3.9	1	8	2.9		Seamstress (transfer)	21
7216	Dry cleaning	USA	1978-79	P	<1	15	46	17	114			Operator (transfer); during transfer	21
7216	Dry cleaning	USA	1978-79	P	1-6	328	23	4.6	60	19		No JT	124
7216	Dry cleaning	UK	1979 <sup>D</sup>	P	>6	333	28	5	450			No JT	125
7216	Dry cleaning	The Netherlands	1982 <sup>D</sup>	P	1-6	23	41	4.7	1601			Operator	126
7216	Dry cleaning	Belgium	1982 <sup>D</sup>	P	>6	26	21	9	38			No JT	127
7216	Dry cleaning	Italy	1982 <sup>D</sup>	P	NA	57	10					No JT	128
7216	Dry cleaning	USA	1982	P	>6	14	88	31	303			Operator (transfer). Inadequate local exhaust	22

7216	Dry cleaning	USA	1982	P	<1	14	160	25	534	Operator (transfer). Inadequate local exhaust	22
7216	Dry cleaning	USA	1982	P	>6	3	81	29	184	Operator (transfer). Adequate local exhaust	22
7216	Dry cleaning	USA	1982	P	<1	3	25	11	43	Operator (transfer). Adequate local exhaust	22
7216	Dry cleaning	USA	1982	P	>6	3	28	3	76	Operator (dry-to-dry). Adequate local exhaust	22
7216	Dry cleaning	USA	1984	A	<1	10	306	68	597	No JT	129 <sup>C</sup>
7216	Dry cleaning	USA	1984	P	>6	2	55	45	64	No JT	129 <sup>C</sup>
7216	Dry cleaning	USA	1985	A	>6	4	17	12	20	No JT	130 <sup>C</sup>
7216	Dry cleaning	USA	1986-87	P	>6	9	58			Operator (transfer)	24
7216	Dry cleaning	USA	1986-87	P	>6	3	11			Operator (dry-to-dry)	24
7216	Dry cleaning	USA	1986-87	P	>6	19	16			Non-operator (transfer)	24
7216	Dry cleaning	USA	1986-87	P	>6	8	6			Nonoperator (dry-to-dry)	24
7216	Dry cleaning	USA	1986-87	P	>6	12	15		10	Presser	24
7216	Dry cleaning	USA	1986-87	P	>6	12	12		8.1	Counter clerk	24
7216	Dry cleaning	USA	1986-87	P	>6	1	19		19	Seamstress	24
7216	Dry cleaning	USA	1986-87	P	>6	2	5		3.3	No JT	24
7216	Dry cleaning	USA	1986-87	P	<1	24	0			Counter clerk (dry-to-dry)	131
7216	Dry cleaning	USA	1986-87	P	<1	18	4.3			Presser (dry-to-dry)	131
7216	Dry cleaning	USA	1986-87	P	<1	23	11			Operator (dry-to-dry)	131
7216	Dry cleaning	USA	1986-87	P	<1	24	0.6			Counter clerk (transfer)	131
7216	Dry cleaning	USA	1986-87	P	<1	18	12			Presser (transfer)	131
7216	Dry cleaning	USA	1986-87	P	<1	23	42			Operator (transfer)	131
7216	Dry cleaning	Finland	1987	P	NA	NA		0.03	0.2	Fur washers	132
7216	Dry cleaning	Finland	1987	P	NA	NA		0	0.3	No JT	132
7216	Dry cleaning	Italy	1987 <sup>D</sup>	P	1-6	131			10	No JT	133
7216	Dry cleaning	Czechoslovakia	1989 <sup>D</sup>	P	>6	80	28	1.3	118	No JT	134
7216	Dry cleaning	Japan	1989 <sup>D</sup>	A	>6	27	34		13	No JT	135,136
7216	Dry cleaning	Yugoslavia	1990 <sup>D</sup>	P	>6	18		33	53	No JT	137

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**TABLE AI. Database of PCE Measurements, Including Countries Outside the United States (Continued)**

SIC	Source of Exposure	Country	Year(s) of Measurement	Sample Type	Sample Duration (hrs)	N	AM (ppm) <sup>A</sup>	Min (ppm)	Max (ppm)	GM (ppm)	GSD <sup>A</sup>	Job Title and Other Comments		Reference
7216	Dry cleaning	Japan	1990 <sup>D</sup>	P	NA	21		3.8	94	20		No JT		138
7216	Dry cleaning	Europe	1991 <sup>D</sup>	P	1-6	39		<0.1 <sup>B</sup>	85	15		No JT		139
7216	Dry cleaning	USA	1991-92	P	>6	19	16	0.4	83			Operator (dry-to-dry)		140
7216	Dry cleaning	Italy	1992-93	A	>6	~200	3.2	0.03	46			No JT		141
7216	Dry cleaning	USA	1994 <sup>D</sup>	P	>6	60	6.4	0.01	39			Spotter		142
7216	Dry cleaning	USA	1994 <sup>D</sup>	P	>6	7	6.1	<0.01 <sup>B</sup>	14			Tagger		142
7216	Dry cleaning	USA	1994 <sup>D</sup>	A	>6	40	7.7	2.7	25			No JT		142
7216	Dry cleaning	USA	1994	P	<1	2	58					Operator (transfer). Taken during transfer		143
7216	Dry cleaning	USA	1994	P	<1	1	120					Operator (transfer). Taken during filter change		143
7216	Dry cleaning	USA	1994	P	>6	4	20					Operator (transfer)		143
7216	Dry cleaning	USA	1994	P	>6	8	3.6					Presser		143
7216	Dry cleaning	USA	1994	P	1-6	3	15	13	19	15	1.2	Operator (transfer)		26
7216	Dry cleaning	USA	1994	P	1-6	6	3.4	1.4	6.5	3	1.7	Presser		26
7216	Dry cleaning	USA	1994	P	<1	5	100	82	153	103	1.2	Operator (transfer). Taken during waterproofing		26
7216	Dry cleaning	USA	1995	P	>6	11	8.4	5.5	12	7.9	1.4	Spotter		144
7216	Dry cleaning	USA	1995	P	>6	15	22	11	31	20	1.5	Operator		144
7216	Dry cleaning	USA	1995	P	>6	12	8.1	1.4	15	5.5	2.7	Manager		144
7216	Dry cleaning	USA	1995	P	>6	11	7.2	5.1	10	7	1.3	No JT		144
7216	Dry cleaning	USA	1995 <sup>D</sup>	P	>6	7	16	13	19	15	1.5	Operator (dry-to-dry)		145
7216	Dry cleaning	USA	1995 <sup>D</sup>	P	1-6	14	3.7	1.4	6.5	3	1.9	Presser		145
7216	Dry cleaning	USA	1995 <sup>D</sup>	A	1-6	28	6.9	1.9	23	5.9	1.8	No JT		145
7216	Dry cleaning	Czech Republic	1996 <sup>D</sup>	P	>6	160	19	1.6	111			No JT		146
7216	Dry cleaning	Italy	1997 <sup>D</sup>	P	1-6	66		0.01	23	2.5		No JT		147
7216	Dry cleaning	USA	1998	P	>6	1	0.2					Spotter		28 <sup>C</sup>
7216	Dry cleaning	USA	1998	P	>6	3	0.9	0.2	1.8	0.6	2.3	Presser		28 <sup>C</sup>
7216	Dry cleaning	USA	1998	P	>6	1	5.8					Operator (dry-to-dry)		28 <sup>C</sup>
7216	Dry cleaning	USA	1998	A	>6	2	6.5	5.6	7.4	6.4	1.1	No JT		28 <sup>C</sup>

7216	Dry cleaning	USA	1998	A	<1	5	974	377	1648	814	1.9	Cleaning up spill	28 <sup>C</sup>
7216	Dry cleaning	USA	1998	A	<1	8	677	306	1204	605	1.6	Adding and removing items from machine	28 <sup>C</sup>
7216	Dry cleaning	USA	1998	P	1-6	11	0.5	0.2	0.9	0.4	1.6	Presser (dry-to-dry).	29
7216	Dry cleaning	USA	1998	P	1-6	4	0.7	0.3	1.5	0.5	2.0	No local exhaust	29
7216	Dry cleaning	USA	1998	P	1-6	14	6.8	2.5	22	5.1	2	Clothes bagger (dry-to-dry). No local exhaust	29
7216	Dry cleaning	USA	1998	P	1-6	12	1.8	0.3	8	0.9	2.7	Operator (dry-to-dry). Local exhaust	29
7216	Dry cleaning	USA	1998	P	1-6	4	0.9	0.4	1.6	0.8	1.6	Presser (dry-to-dry). Local exhaust	29
7216	Dry cleaning	USA	1998	A	1-6	28	3.6	0.1	20	2	3.1	Clothes bagger (dry-to-dry). Local exhaust	29
7216	Dry cleaning	USA	1998	A	>6	20	4.3	0.5	22	2.9	2.3	No JT (dry-to-dry); no local exhaust	29
7216	Dry cleaning	USA	1998-99	P	1-6	14	8.7	2.4	20	7.5	1.7	No JT (dry-to-dry); no local exhaust	29
7216	Dry cleaning	Korea	1999	A	1-6	8	0.6					Operator (dry-to-dry). No local exhaust	148
7216	Dry cleaning	Finland	2000 <sup>D</sup>	P	>6	17	4.1					No JT	149
7216	Dry cleaning	Finland	2000 <sup>D</sup>	P	>6	19	1.1					Operator (dry-to-dry)	149
7216	Dry cleaning	Finland	2000 <sup>D</sup>	P	>6	6	0.1					Presser	149
7216	Dry cleaning	USA	2001 <sup>D</sup>	P	>6	15	1.6	0.3	4.9	0.9	2.6	Counter clerk	150
7216	Dry cleaning	USA	2001 <sup>D</sup>	P	>6	15	<0.08 <sup>B</sup>					Operator (dry-to-dry)	150
7216	Dry cleaning	USA	2002 <sup>D</sup>	P	>6	36	3.1					Presser	151
7216	Dry cleaning	Italy	2002 <sup>D</sup>	P	>6	26	6.5	0.8	33			Operators and pressers	152
7218	Dry cleaning	U.K.	1979	P	>6	160	49	5	550			No JT	125
7218	Dry cleaning	USA	1996 <sup>D</sup>	P	<1	1	334					Maintenance worker; changing filter	25
7218	Dry cleaning	USA	1996 <sup>D</sup>	P	>6	2	11					Maintenance workers	25

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**TABLE AI. Database of PCE Measurements, Including Countries Outside the United States (Continued)**

SIC	Source of Exposure	Country	Year(s) of Measurement	Sample Type	Sample Duration (hrs)	Sample			Job Title and Other Comments	Reference
						N	AM (ppm) <sup>A</sup>	GM (ppm)		
7218	Dry cleaning	Finland	2000	P	>6	15	3.6		Operator (dry-to-dry)	149
7218	Dry cleaning	Finland	2000	P	>6	12	0.5		Presser	149
2754	Degreasing	South Korea	1992 <sup>D</sup>	P	>6	13	22	0	No JT; rotogravure printing	65
2800	Cold degreasing	USA	1960 <sup>D</sup>	P	1-6	1	393		No JT; cleaning tank	39
3353	Degreasing	USA	1980	P	>6	1	5		Entry end shear	153 <sup>C</sup>
3353	Degreasing	USA	1980	P	>6	1	10		Shear operator	153 <sup>C</sup>
3353	Degreasing	USA	1980	P	>6	1	10		Flat sheet stacker	153 <sup>C</sup>
3353	Degreasing	USA	1980	P	>6	1	10		Crane relief	153 <sup>C</sup>
3353	Degreasing	USA	1980	P	>6	1	10		Supervisor	153 <sup>C</sup>
3353	Degreasing	USA	1980	A	>6	1	9		No JT	153 <sup>C</sup>
3400	Vapor degreasing	USA	1944 <sup>D</sup>	P	NA	14	179	25	No JT; parts being placed in degreaser	111
3400	Vapor degreasing	USA	1944 <sup>D</sup>	P	NA	24	557	80	No JT; parts being taken out of degreaser	111
3400	Vapor degreasing	USA	1944 <sup>D</sup>	P	NA	9	55	20	No JT; cover on	111
3400	Vapor degreasing	USA	1944 <sup>D</sup>	P	NA	8	181	25	No JT; cover off	111
3471	Vapor degreasing	USA	1985	P	<1	2	153	120	Reflow operator	154 <sup>C</sup>
3471	Vapor degreasing	USA	1985	P	1-6	2	83	82	Reflow operator	154 <sup>C</sup>
3471	Vapor degreasing	USA	1985	P	>6	1	82		Reflow operator	154 <sup>C</sup>
3479	Vapor degreasing	USA	1984	P	<1	1	0.5		No JT	155
3479	Vapor degreasing	USA	1984	P	1-6	11	0.4	<0.07 <sup>B</sup>	No JT	155 <sup>C</sup>
3479	Vapor degreasing	USA	1984	P	>6	2	0.1	<0.07 <sup>B</sup>	No JT	155 <sup>C</sup>
3479	Vapor degreasing	USA	1984	A	1-6	2	0.1	<0.07 <sup>B</sup>	No JT	155 <sup>C</sup>

3559	Vapor degreasing	USA	2001	P	1-6	1	0.04							Degreaser foreman	40
3559	Vapor degreasing	USA	2001	P	>6	2	0.1	0.05	0.07	0.1	1.2			Degreaser foreman	40
3559	Cold degreasing	USA	2001	P	1-6	1	0.1							Degreaser foreman	40
3559	Vapor degreasing	USA	2001	P	1-6	1	0.1							Degreaser assistant	40
3559	Cold degreasing	USA	2001	P	1-6	1	0.2							Degreaser assistant	40
3559	Vapor degreasing	USA	2001	P	>6	2	0.1	0.09	0.1	0.1	1.1			Degreaser assistant	40
3559	Vapor degreasing	USA	2001	P	1-6	1	0.05							Lab tech	40
3559	Vapor degreasing	USA	2001	P	>6	1	0.1							Lab tech	40
3559	Vapor degreasing	USA	2001	A	<1	1	0.1							No JT	40
3561	Degreasing	USA	1950	A	<1	NA		232	385					No JT	47
3600	Degreasing	USA	1978-85	P	NA	8	0.8	<0.3 <sup>B</sup>	3					No JT	156 <sup>C</sup>
3600	Degreasing	USA	1978-85	A	NA	10	0.4	<0.3 <sup>B</sup>	1					No JT	156 <sup>C</sup>
3613	Degreasing	USA	1990	A	1-6	2	3.6	3.6	3.6	3.6	1			No JT	157 <sup>C</sup>
3630	Vapor degreasing	USA	1982	P	>6	3	6.7	5.5	7.4	6.6	1.1			Racker at vacuum manufacturing plant.	48 <sup>C</sup>
3630	Vapor degreasing	USA	1982	P	>6	4	1.6	1.2	2.1	1.5	1.2			Paint stripper, spray painter, and paint mixer	48 <sup>C</sup>
3630	Vapor degreasing	USA	1982	A	>6	1	0.6							Pace line	48 <sup>C</sup>
3630	Vapor degreasing	USA	1982	P	>6	1	1.5							Group leader	48 <sup>C</sup>
3630	Vapor degreasing	USA	1983	P	NA	1	13							Degreaser operator	49 <sup>C</sup>
3630	Vapor degreasing	USA	1983	A	NA	3	19	6.1	37	15	2.1			No JT	49 <sup>C</sup>
3670	Degreasing	USA	1993	P	>6	4	1.6							Etching technicians	81 <sup>C</sup>
3670	Degreasing	USA	1993	A	>6	4	0.3							No JT, Etch area.	81 <sup>C</sup>
3714	Degreasing	USA	1982	P	<1	4	63	14	103	50	2.1			Air filter assembler	158 <sup>C</sup>
3714	Degreasing	USA	1982	P	1-6	1	13							Air filter assembler	158 <sup>C</sup>
3714	Degreasing	USA	1982	P	1-6	1	22							Cleanup and trim	158 <sup>C</sup>

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**TABLE AI. Database of PCE Measurements, Including Countries Outside the United States (Continued)**

SIC	Source of Exposure	Country	Year(s) of Measurement		Sample Type	Sample Duration (hrs)	N	AM (ppm) <sup>A</sup>	Min (ppm)	Max (ppm)	GM (ppm)	GSD <sup>A</sup>	Job Title and Other Comments	Reference
			Measurement	Year(s)										
3714	Degreasing	USA	1982		P	1-6	1	76					Gasket and cleanup	158 <sup>C</sup>
3714	Degreasing	USA	1982		P	1-6	1	23					Cleanup	158 <sup>C</sup>
3720	Vapor degreasing	USA	1978-88		B	<1	70	56	1.7	150			No JT	82
3720	Vapor degreasing	USA	1987-88		B	>6	6	9.5	0.1	27			No JT	82
3720	Vapor degreasing	USA	2000		P	1-6	11	0.7	0.1	0.8	0.4	3.0	Degreaser operator	31
3720	Vapor degreasing	USA	2000		A	1-6	5	1.0	0.2	1.5	0.8	2.3	No JT	31
3720	Vapor degreasing	USA	2000		P	<1	2	1.3	0.1	2.5	0.4	6.5	Maintenance worker	31
3720	Vapor degreasing	USA	2000		A	>6	5	2.0	0.2	8.0	0.7	3.6	No JT	31
3720	Vapor degreasing	USA	2000		P	>6	9	0.4	0.2	0.9	0.3	2.0	Degreaser operator	31
3720	Vapor degreasing	USA	2001		P	<1	1	17					Electroplater.	159
3720	Vapor degreasing	USA	2001		P	1-6	5	1.5	0.2	5.7	0.6	3.5	Open-top degreaser in use	159
3720	Vapor degreasing	USA	2001		P	>6	7	2.7	0.1	16	0.7	3.9	Electroplater.	159
3720	Vapor degreasing	USA	2001		A	1-6	1	0.3					Open-top degreaser in use	159
3720	Vapor degreasing	USA	2001		A	>6	1	1.9					No JT	159
3721	Degreasing	USA	1984		P	1-6	1	2.8					Solvent sprayer	160 <sup>C</sup>
3721	Degreasing	USA	1984		P	1-6	2	0.4	0.2	0.5	0.3	1.6	Inspector	160 <sup>C</sup>
3721	Degreasing	USA	1984		P	1-6	1	0.3					Structural repairman	160 <sup>C</sup>
3721	Degreasing	USA	1984		A	1-6	1	0.4					No JT	160 <sup>C</sup>
3721	Degreasing	USA	1984		P	1-6	1	0.6					Core cutter	160 <sup>C</sup>
3722	Vapor degreasing	USA	1982		P	>6	11	3.4	0.4	7.2	2.6	2	mechanic	161 <sup>C</sup>
													Electroplater	

3722	Vapor degreasing	USA	1982	P	<1	9	26	1.9	66	15	3.2	Electroplater	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	2	0.9	0.6	1.1	0.8	1.4	Sheet metal worker	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	4	0.4	0.4	0.4	0.4	1	Tube bender	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	2	1.5	0.7	2.2	1.2	1.8	Mechanic	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	A	>6	8	0.8	0.3	2.3	0.6	2.2	No JT	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	<1	2	0.6	<0.2 <sup>B</sup>	0.9	0.4	2.1	Sheet metal worker	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	1	0.6					Broach operator	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	1	0.5					Inspector	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	1	0.5					Cleaning processor	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	<1	1	0.7					Cleaning processor	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	<1	3	0.6	0.2	1.1	0.5	2	Assembler	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	>6	3	0.5	0.5	0.5	0.5	1	Assembler	161 <sup>C</sup>
3722	Vapor degreasing	USA	1982	P	<1	4	0.2	<0.2 <sup>B</sup>	0.2	0.2	1	Tube bender	161 <sup>C</sup>
3795	Degreasing	The Netherlands	1982	P	1-6	9	2.1	1.6	3.1			Metal cleaner	126
3795	Degreasing	Sweden	1985	P	<1	1	516					Railway tank cleaner	51
3840	Degreasing	USA	1979	P	>6	2	18	7	29			Degreaser operator	52 <sup>C</sup>
3841	Vapor degreasing	USA	1982	P	1-6	1	3.5					Electropolisher	162 <sup>C</sup>
3841	Vapor degreasing	USA	1982	A	1-6	4	2.9	0.1	7.4	1.3	4.2	No JT	162 <sup>C</sup>
3911	Degreasing	USA	1988	B	1-6	9		<0.001 <sup>B</sup>	2			No JT	102 <sup>C</sup>
NA	Degreasing	Germany	1985	A	NA	NA		13	20			No JT	163
NA	Degreasing	Germany	1985	P	NA	NA	8.4					No JT	163
NA	Degreasing	Germany	1988	A	NA	NA		7.2	10			No JT	163
NA	Degreasing	Germany	1991	A	NA	NA		1.3	6.2			No JT	163
NA	Degreasing	Germany	1991	P	NA	NA		1.4	2			No JT	163

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TABLE AI. Database of PCE Measurements, Including Countries Outside the United States (Continued)

SIC	Source of Exposure	Country	Year(s) of Measurement	Sample Type	Sample Duration (hrs)	N	AM (ppm) <sup>A</sup>	Min (ppm)	Max (ppm)	GM (ppm)	GSD <sup>A</sup>	Job Title and Other Comments	Reference
NA	Degreasing	Germany	1993	A	NA	NA		<0.5 <sup>B</sup>				No JT. Closed-loop degreasing machines	163
NA	Degreasing	Germany	1993	P	NA	NA	2.8					No JT. Closed-loop degreasing machines	163
NA	Degreasing	Finland	1982–1985	A	NA	NA	3	1.8	5			No JT	163,164
NA	Vapor degreasing	Japan	1979 <sup>D</sup>	A	NA	25		30	220	92		Degreasing operator	165
NA	Vapor degreasing	Japan	1979 <sup>D</sup>	A	NA	NA		10	80			No JT	165
NA	Degreasing	Finland	1996	A	NA	NA	5.2	1	10			No JT	163,166
NA	Degreasing	Finland	1996	A	NA	NA	10	3.8	16			No JT	163,166
NA	Mostly vapor degreasing	Japan	1996	A	NA	38			30			No JT; various industries	167
1094	Cleaning mining equipment	USA	1980	P	1–6	2	490	27	960	162	6	Mine electrician	90 <sup>C</sup>
1094	Cleaning mining equipment	USA	1980	P	1–6	1	<0.001 <sup>B</sup>					Lab technician	90 <sup>C</sup>
1094	Cleaning mining equipment	USA	1980	P	1–6	1	1.2					Mine mechanic	90 <sup>C</sup>
1094	Cleaning mining equipment	USA	1980	A	1–6	3	2	<0.001 <sup>B</sup>	5	0.2	40	No JT	90 <sup>C</sup>
1200	Float-sink testing coal	USA	1980	A	1–6	~3	149	110	194			No JT; near mine technician	91 <sup>C</sup>
1200	Float-sink testing coal	USA	1989	P	<1	7	<0.08 <sup>B</sup>	<0.08 <sup>B</sup>	0.1			Coal density tester	92 <sup>C</sup>
1211	NA	USA	1989	P	>6	1	0.04					tipple operator	168 <sup>C</sup>
1629	Paints	USA	1981	P	1–6	4	0.06	<0.001 <sup>B</sup>	0.1	0.02	11	Welder	74 <sup>C</sup>
												Paint sprayer and trowler	



TABLE AI. Database of PCE Measurements, Including Countries Outside the United States (Continued)

SIC	Source of Exposure	Country	Year of Measurement	Sample Type	Sample Duration (hrs)	N	AM (ppm) <sup>A</sup>	Min (ppm)	Max (ppm)	GM (ppm)	GSD <sup>A</sup>	Job Title and Other Comments		Reference
												Job Title	Other Comments	
2795	Cleaning plates USAed in lithographic printing	USA	1979	P	>6	11	5.1	2.8	10	4.7	1.5	No JT		175
2800	Chemical production	USA	1980	P	>6	17	0.01	0.01	0.01	0.01	1.0	Chemical plant operator		12
2860	Chemical production	Japan	1989 <sup>D</sup>	P	>6	19			567	17		PCE synthesis workers		136
3061	Adhesives	USA	1994	A	1-6	1	0.6					No JT		93 <sup>C</sup>
3079	Cleaning plastic molds	USA	1984	P	1-6	4	<0.03 <sup>B</sup>					Plastic molding machine operator		4 <sup>C</sup>
3079	Cleaning plastic molds	USA	1984	P	>6	1	<0.03 <sup>B</sup>					Plastic molding machine operator		4 <sup>C</sup>
3089	Unknown	USA	1990	A	NA	10		0.03	0.2			No JT; silkscreen room		105 <sup>C</sup>
3130	Adhesives	Portugal	1994	P	1-6	71	15					No JT		76
3321	Mold release agent	USA	1983	A	>6	4	0.1	0.01	0.2	0.07	3.1	No JT; welding shop		46 <sup>C</sup>
3321	Paints	USA	1986	A	>6	2	0.6	0.3	0.9	0.5	1.7	No JT		176 <sup>C</sup>
3444	Unknown	USA	1983	A	1-6	3	0.2	0.06	0.4	0.2	2.2	No JT; application of Koppers roofing system		107 <sup>C</sup>
3452	Unknown	USA	1982	A	1-6	3	0.2	<0.1 <sup>B</sup>	0.2			No JT		177 <sup>C</sup>
3681	Cleaning film	USA	1979	P	1-6	61	22	0.4	236	9	4.2	Cameraman/film cleaner		99 <sup>C</sup>
3681	Cleaning film	USA	1979	P	<1	40	38	0.8	236	17	4	Cameraman/film cleaner		99 <sup>C</sup>
3681	Cleaning film	USA	1979	A	<1	2	14	4	23	9.8	2.4	No JT		99
3681	Cleaning film	USA	1979	A	1-6	16	27	0.7	142	10	4.2	No JT		99 <sup>C</sup>
3681	Cleaning film	USA	1979	A	>6	22	11	0.3	32	5.3	4	No JT		99 <sup>C</sup>
3681	Cleaning film	USA	1980	P	1-6	1	1.4	4	23	9.8	2.4	Cleaning machine operator		50 <sup>C</sup>

3681	Cleaning film	USA	1980	A	>6	1	129				No JT; film cleaning machine	50 <sup>C</sup>
3681	Duplicating film	USA	1980	P	1-6	1	8				Duplicator operator	50 <sup>C</sup>
4171	Paints	USA	1981	A	>6	2	<0.01 <sup>B</sup>				No JT; in paint shop	5 <sup>C</sup>
4950	Wastewater	USA	1986 <sup>D</sup>	A	NA	NA	0.002				No JT; influent wastewater	84
4950	Wastewater	USA	1986 <sup>D</sup>	A	NA	NA	0.0003				No JT; effluent wastewater	84
4952	Wastewater	USA	1981	A	<1	5	0.7	<0.1 <sup>B</sup>	1.6	0.5	No JT; sewage spill from a pigment plant	83 <sup>C</sup>
4952	Wastewater	USA	1981	A	1-6	2	0.3	0.2	0.4	0.3	No JT	178 <sup>C</sup>
4952	Wastewater	USA	1982 <sup>D</sup>	A	1-6	5	0.03	0.0002	0.007	0.001	No JT	85
4953	Landfill	USA	1982	B	>6	55	0.06	0.02	1.1	0.1	No JT	86
7399	Printing ink	USA	1983	P	>6	2	4.1	3.1	5	3.9	Silk screener	104 <sup>C</sup>
7399	Printing ink	USA	1983	A	>6	2	3.4	3.2	3.5	3.3	No JT	104 <sup>C</sup>
7699	Paints	USA	1978	P	1-6	6	7.2	<0.001 <sup>B</sup>	25	0.03	Head finisher	75 <sup>C</sup>
7699	Cleaning animal coats	USA	1978	P	<1	1	228				Cleaner (fur coats)	75 <sup>C</sup>
7699	Cleaning animal coats	USA	1978	P	1-6	2	132	113	151	131	Cleaner (fur coats)	75 <sup>C</sup>
8220	NA	USA	1982	P	1-6	4		0.3	0.4		Students doing lithography at art school	179 <sup>C</sup>
8220	NA	USA	1982	P	1-6	7		0.2	0.4		Students doing photography at art school	179 <sup>C</sup>
8399	Printing ink	USA	1993	P	1-6	1	1.7				No JT	180 <sup>C</sup>
8399	Printing ink	USA	1993	A	1-6	1	0.6				No JT; print shop	180 <sup>C</sup>
9224	Smoke bomb	USA	1986	A	<1	~40		2.1	88		No JT	100 <sup>C</sup>
9224	Smoke bomb	USA	1987	A	<1	~11		<0.1 <sup>B</sup>	9.2		No JT; samples taken where firefighters were during training	101 <sup>C</sup>

<sup>A</sup>AM and GSD may have been reported in publication or may have been calculated.

<sup>B</sup>Measurement was less than LOD.

<sup>C</sup>Measurements taken at the request of employees or union because of health concerns.

<sup>D</sup>Year of measurement estimated as 1 year prior to publication.