DRY CLEANING

1. Exposure Data

1.1 Historical overview

Dry cleaning is believed to have originated in France in 1825: The French Federation of Dyeing and Cleaning gave an account of a servant in the household of Jean-Baptiste Jolly in Paris in 1825 who spilled the contents of a lamp on a soiled tablecloth. When the tablecloth dried, the spots had disappeared. The liquid in the lamp was probably camphene, produced from pinene, which is the main ingredient of turpentine. Camphene was initially used as a spotting agent, but it was later used for complete cleaning by hand. Use of volatile organic liquids to clean cloths became known as 'French cleaning' in Scotland and 'chemical cleaning' in Germany (Michelsen, 1957). Eventually, such processes were called 'dry cleaning' because they do not involve the use of water.

The common cleaning practice of early dyers and cleaners was to scour, using soap and water, and to add various acids and alkalis to the rinse. In the 1840s, garments were sometimes sponged inside and out with water and ox gall; dark clothes were sponged with water and logwood. A formulation for removing grease spots comprised fuller's earth, French chalk, yellow soap, pearlash and turpentine. When white fabrics became too soiled to be cleaned, they were dyed a darker colour. The early dry cleaning operation consisted of four steps: dusting (with rattan whips and brushes), hand brushing, solvent washing and drying (Michelsen, 1957).

Camphene was later replaced by benzene soap (1 lb soap for 2 gallons of benzene [60 g/L]), benzene (see IARC, 1987a), benzine (light petroleum naphtha), benzoline (a low-boiling subfraction of benzine), naphtha (see IARC, 1989a) and gasoline (see IARC, 1989b). The agents used early on for removing persistent spots on fabric (spotting agents) were benzine, turpentine, water, alcohol, cream of tartar, diethyl ether, chloroform (see IARC, 1987b), ox gall, egg yolks, boiling milk, honey, fuller's earth and spirits of wine. Attempts were made to provide mechanical agitation by adding sawdust, crushed marble and bran; however, use of these substances was soon discontinued because they were difficult to remove from the folds of the fabric (Michelsen, 1957).

The main hazard associated with the increasing use of volatile organic solvents in dry cleaning was fire. In 1928, W.J. Stoddard, president of the United States National Institute of Drycleaning (now the International Fabricare Institute) introduced Stoddard solvent, a petroleum-based solvent (see IARC, 1989c; Reich & Cormany, 1979) that was less inflammable and odour-free, which rapidly gained acceptance in the industry. Around 1917, many companies used 'cleaners' naphtha', which was similar to the light naphtha used in the paint industry. Subsequently, other petroleum solvents were marketed, including mineral turpentine, mineral

spirits and oleum spirits. Use of these materials in the war effort in the early 1940s greatly curtailed their availability for dry cleaning (Michelsen, 1957).

Carbon tetrachloride (see IARC, 1987c) was the first chlorinated hydrocarbon solvent used for dry cleaning. It was introduced in the United States of America and Europe as an alternative to the expensive petroleum-based solvents, and by 1940 it was estimated that 20 thousand tonnes were used annually for dry cleaning in the United States. Widespread use of carbon tetrachloride in this context was discontinued in the 1950s because of its toxicity and corrosiveness, and tetrachloroethylene (see monograph, this volume) became the most widely used solvent. Trichloroethylene (see monograph, this volume) was also used, but on only a limited basis because it caused bleeding of many acetate dyes (Reich & Cormany, 1979).

Figure 1 shows the evolution of solvent use in dry cleaning over time.

1.2 Description of the industry

Cleaning is the process of removing dirt from fabric through the use of aqueous and non-aqueous solvents. Aqueous solvents swell the hydrophilic textile fibres, so that the dimensions of the fibre change, which can cause wrinkles or shrinkage of the fabric. Nonaqueous dry cleaning solvents do not swell the fibres and can remove oily stains at low temperatures, whereas a high-temperature, colloidal suspension is needed in aqueous (laundering) processes (Reich & Cormany, 1979).

Dry cleaning is a batch process that involves washing fabrics in a solvent solution, extracting the solvent from the fabrics during a spin cycle and tumble-drying the damp fabrics with warm air. In many commercial facilities where tetrachloroethylene is used, washing and extraction are done in a single machine. The damp fabric is then transferred manually to a tumbler for drying. This is known as the 'transfer' process (Stricoff, 1983).

A more recent process, in which all three steps are carried out in one machine, is referred to as the 'dry-to-dry' process. After the wash cycle, the solvent is drained, and residual solvent is removed by centrifugal force. This method has eliminated the handling of solvent-laden fabrics. All coin-operated dry cleaning equipment is dry-to-dry, while industrial processes may be either transfer or dry-to-dry (Stricoff, 1983).

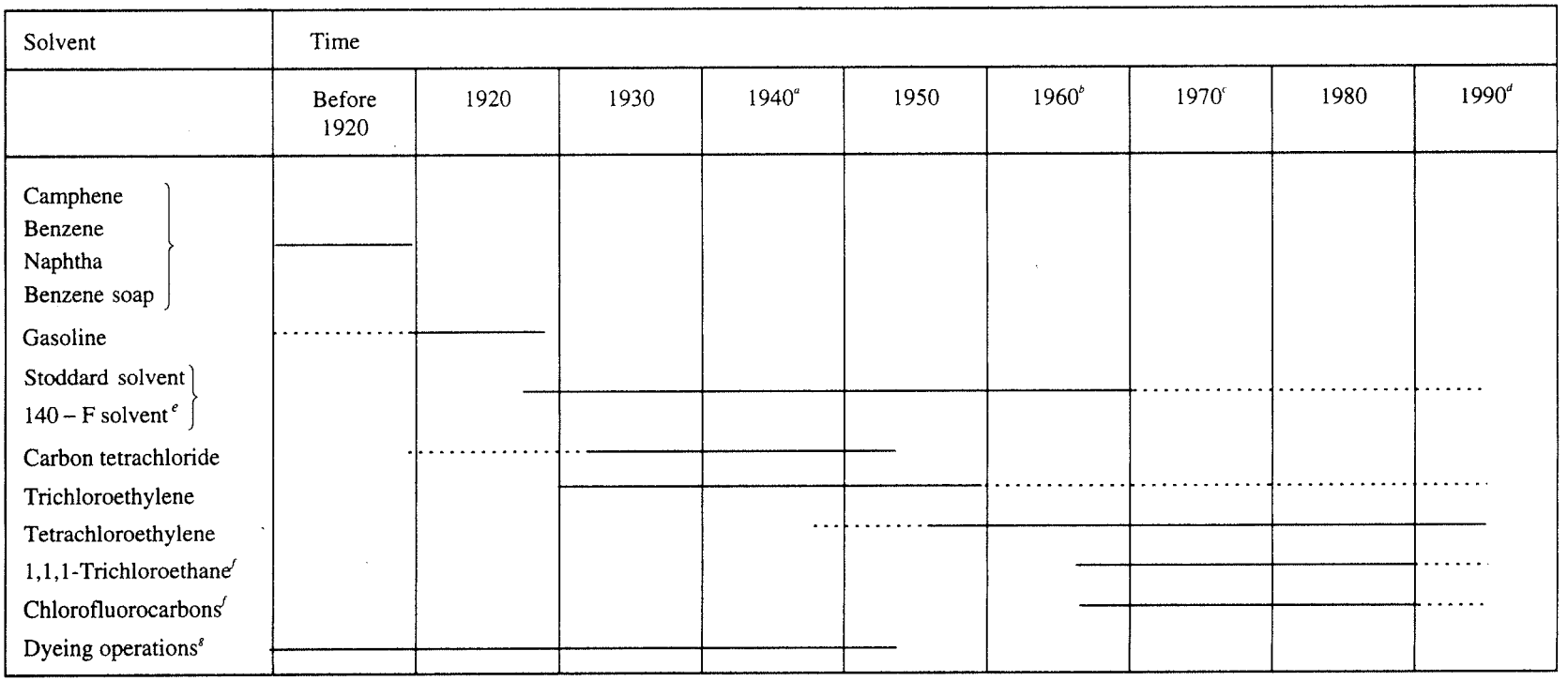
Dry cleaning involves three basic steps: washing, solvent extraction and drying. The common tetrachloroethylene-based process is described below (Reich & Cormany, 1979).

1.2.1 The wash cycle

Before the wash cycle, detergent, a small amount of water and solvent are introduced into the tank. Water and detergent are added because they increase the solubility of dirt. The optimal temperature of solvent for cleaning cloth is 75–80 °F [23–27 °C]. Clothes are normally inspected first for stains. If they are stained, they are 'spotted' with a chemical (see below); they are then weighed and placed in a drum. About 1 gallon [3.8 L] of tetrachloroethylene is added to the drum for every 2 pounds [0.91 kg] of clothing.

The wash cycle lasts about 5–10 min. While the clothes are being washed, the solvent is passed continuously through a series of wire-mesh strips coated with diatomaceous earth and

Fig. 1. Use of solvents in dry cleaning over time



From Michelsen, 1957; Blair *et al.*, 1990; Linak *et al.*, 1992. The pattern generally reflects current world use, with some exceptions:

- in Japan, 70% petroleum-based, 20% tetrachloroethylene, 5% chlorofluorocarbons, 5% 1,1,1-trichloroethane (Kubota, 1992)
- in Oklahoma (USA), 50% petroleum-based (Duh & Asal, 1984); trichloroethylene used for cleaning industrial cloths and chlorofluorocarbons for fur coats
- in Denmark, petroleum spirit was used after the Second World War until the 1950s, when tetrachloroethylene became the primary solvent, with some trichloroethylene (industrial clothing) and chlorofluorocarbons (fur)

[a] Use of chlorinated hydrocarbons greatly reduced during Second World War, with increased use of petroleum-based solvents (Michelsen, 1957)

[b] Introduction of synthetic textile fibres resulted in a reduction in the volume of clothes dry cleaned (Linak *et al.*, 1992)

[c] Environmental and engineering controls introduced (Linak *et al.*, 1992)

[d] Worldwide environmental concern and regulatory action on chlorinated hydrocarbons

[e] Petroleum distillate similar to Stoddard solvent, with a flash-point of 60 °C (Reich & Cormany, 1979)

[f] Phased out by 1996 under the Montreal Protocol on ozone-depleting substances (Rice & Weinberg, 1994)

[g] Dyeing performed in dry cleaning shops until the mid-1950s in the USA (Michelsen, 1957)

activated carbon or through disposable cartridge filters, in order to remove fugitive dyes and insoluble material. At the end of the wash cycle, the solvent is drained from the drum through a strainer that traps buttons, coins, pins and other items that could damage the pumps, and is then pumped to the still or solvent storage tank. After the solvent has been drained from the drum, some still remains in the clothes. It is estimated that 100 pounds [45 kg] of clothes will contain 11–12 gallons [42–45 L] of tetrachloroethylene at this stage. In order to remove the residual solvent, the drum spins at 350–450 revolutions per minute for 3–5 min. At the end of the extraction process, 2–3 gallons [7.6–11 L] of tetrachloroethylene still remain per 100 pounds [45 kg] of clothes.

The filter medium must be replaced periodically. When cartridge filters are used, they must be drained and discarded. When diatomaceous earth is used, the filter medium is removed from its carrier and either discarded or heated to recover solvent from the filter muck. Most dry cleaners also distil the solvent to clean it (Douglas *et al.*, 1993).

1.2.2 The drying and reclaiming process

Once the extraction step is completed, the clothes are dried. Air is blown across coils heated by steam or electrically and then into the drum, to evaporate the tetrachloroethylene that is retained in the tumbling clothes. The temperature of the air is 120–150 °F [49–65 °C]. During the drying cycle, the exhaust from the drum is directed through a lint trap to filter out fabric particles; the trap is usually cleaned twice daily. The exhaust air is directed to a water-cooled or refrigerated condenser, where the vapours are condensed. The drying cycle usually lasts 10–25 min, depending on the type of fabric. Activated carbon adsorbers may be used to recover tetrachloroethylene from washer and dryer exhaust lines (Douglas *et al.*, 1993).

The final step in the drying cycle is either aeration or cooling. In aeration, heated ambient air is blown through the drum to remove the residual tetrachloroethylene. In the cooling cycle, the air in the drum is cooled in a refrigerated condenser and recirculated to the drum. Cooler air retains less tetrachloroethylene than warm air and causes fewer wrinkles in fabrics.

1.2.3 Finishing and pressing

At the end of the drying cycle, the clothes are removed from the dryer, examined for any remaining stains and spot cleaned. They are then pressed with machines that use steam and physical pressure to remove wrinkles. In the steam process, residual tetrachloroethylene may be volatilized. After final inspection, the garments are tagged and placed on racks.

Many dry cleaning operations provide other services, such as repair, dyeing and moth- and waterproofing. Optical brighteners, antistatic agents and sizing may be added to improve the brightness and the feel of garments.

1.2.4 Spotting

The removal of stains or spots from clothing before or after dry cleaning is both an art and a science. Historically, 'spotters' used recipes and methods that were carefully guarded secrets; today, companies provide proprietary products to the dry cleaning industry. 'Spotting' involves the selective application of chemicals, steam, detergent and/or water to loosen or remove specific

stains from soiled garments. Depending on the size of the dry cleaning plant and the nature of the dry cleaning process, spotting can require a full time employee; however, this step is usually handled by the operator of a dry cleaning machine. Industrial dry cleaning plants seldom employ spotting operators.

The chemicals used typically include chlorinated solvents, amyl acetate, bleaching agents, acetic acid, aqueous ammonia, oxalic acid, hydrogen peroxide (see IARC, 1987d) and dilute hydrogen fluoride solutions. These chemicals are generally applied from plastic squeeze-bottles and are then either rubbed into the fabric with a brush, a spatula or by hand, allowed to soak into the fabric (which is subsequently handled) or flushed with steam from a steam gun. Thus, employees engaged in spotting may be exposed to toxic materials through both skin contact with liquids and inhalation of airborne vapours and mists (Stricoff, 1983).

1.3 Exposures in the workplace

1.3.1 Current practices

Today, commercial dry cleaners make up the largest segment of the industry (by number of establishments and quantity of garments cleaned). These firms handle primarily clothing and household products. Coin-operated dry cleaning machines are used directly by consumers for cleaning clothes and household furnishings. Industrial dry cleaners supply businesses, industrial plants and institutions with high-volume cleaning of uniforms, towels, linen and cleaning cloths, which are sometimes heavily soiled with industrial chemicals, oil and other materials.

In Europe, tetrachloroethylene comprises about 90% of the solvents used in dry cleaning; the main chlorofluorocarbon used is 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113) (Vieths *et al.*, 1988). There are an estimated 6500 dry cleaning establishments in the United Kingdom (Edmondson & Palin, 1993). In 1985, there were an estimated 2000 dry cleaners in Finland (Rantala *et al.*, 1992).

In 1970, there were 2886 laundries and dry cleaning shops in Denmark. White spirit (a petroleum-based solvent) was the most commonly used solvent in these establishments after the Second World War, but consumption decreased when automatic machines were introduced in the late 1950s. Tetrachloroethylene then became the most prevalent solvent, supplemented by trichloroethylene for the cleaning of work clothes and the fluorocarbons trichlorofluoromethane (CFC-11) and CFC-113 for cleaning fur coats (Lynge & Thygesen, 1990).

In Switzerland in 1991, 25% of dry cleaning shops used CFC-113 (Grob *et al.*, 1991). In France, 71 spotting agents used in dry cleaning shops were analysed. Benzene was not found; toluene (see IARC, 1989d) was found in 7% of the shops, xylenes (see IARC, 1989e) in 34%, methanol in 3% and chloroform in 1%. Chlorofluorocarbons were used in four of 30 shops studied and tetrachloroethylene in 26 (Davezies *et al.*, 1983).

In Japan, both dry cleaning and laundering are done in dry cleaning shops. Of the dry cleaning machines used, 70% (35 500) use petroleum-based solvents, 20% (10 700) use tetrachloroethylene, 5% (1900) use CFC-113 and 5% (1800) use 1,1,1-trichloroethane. In 1989, the industry consumed 7700 tonnes of petroleum solvent, 18 000 tonnes of tetrachloroethylene, 2700 tonnes of 1,1,1-trichloroethane and 4100 tonnes of CFC-113 (Kubota, 1992). In Nagoya, Japan, 50% of dry cleaning shops were reported to use petroleum solvents, 46% tetrachloro-

ethylene, 4% CFC-113 and 2% a combination of tetrachloroethylene and petroleum solvents (Takeuchi *et al.*, 1981). Almost all of the machines involving use of petroleum-based solvents are transfer types, whereas in those that use the other three types of solvents the equipment is dry-to-dry. There are relatively few coin-operated machines in operation (Kubota, 1992).

By 1991, tetrachloroethylene was used in an estimated 28 121 dry cleaning plants in the United States, including 24 947 commercial plants and 130 industrial and 3044 coin-operated establishments (United States Environmental Protection Agency, 1991a). About two-thirds had dry-to-dry machines and one-third, transfer machines. Of commercial dry cleaning establishments in the United States in 1991, 82% used tetrachloroethylene, 14% used Stoddard solvent, 3% used CFC-113 and less than 1% used 1,1,1-trichloroethane (United States Environmental Protection Agency, 1991b; Earnest *et al.*, 1994). Of industrial cleaners, about 50% used tetrachloroethylene and 50% used Stoddard solvent. Coin-operated facilities used only tetrachloroethylene (Linak *et al.*, 1992). In Oklahoma, about 50% of dry cleaning involves use of Stoddard solvent (Duh & Asal, 1984). In Canada, 90% of commercial dry cleaning is based on tetrachloroethylene (Rice & Weinberg, 1994).

In December 1991, the United States Environmental Protection Agency (1991c) began regulating tetrachloroethylene as a hazardous air pollutant under Section 112 of the Clean Air Act. Regulatory action with regard to tetrachloroethylene is also being taken on an international level (Linak *et al.*, 1992). The international dry cleaning industry has responded with increased research into alternative solvents (Kirschner, 1994) and cleaning methods: a shift from transfer machines to closed-loop dry-to-dry machines and innovations in vapour recovery equipment and other devices to reduce occupational exposures and environmental emissions. Many of the exposure problems identified during studies in the late 1970s and early 1980s still exist, however, because transfer machines continue to be used, many of the controls that have been developed are prohibitively expensive and some work practices are inadequate.

The several distinct job titles and duties involved in dry cleaning are summarized in Table 1. It is estimated that several million people are employed in dry cleaning worldwide.

1.3.2 Sources of exposure

Occupational exposure to tetrachloroethylene occurs through inhalation, skin absorption and ingestion, although most occurs by inhalation whenever tetrachloroethylene vapours escape from a dry cleaning machine in the form of process or fugitive emissions.

Process emissions are those vented during steps such as aeration, transfer of clothing and distillation. Process emissions from vented machines can account for 50% or more of the total emitted (United States Environmental Protection Agency, 1991c). From the point of view of occupational health, process emissions are not a major concern as long as they are vented outside of the work environment; however, they may then become an environmental concern. Inadequate local exhaust or general ventilation can result in exposure to process emissions. In a study conducted in the early 1980s at 67 dry cleaning facilities in the United States, 28% had non-functioning local exhaust systems and 32% of the transfer machines had inadequate local exhaust ventilation, on the basis of face velocity at the washer door (Materna, 1985).

Table 1. Job titles and duties in the dry cleaning industry

Job title	Duties
Operator	Load and retrieve garments from dry cleaning machines, apply spotters (usually solvents or detergents) to stains; may also include routine maintenance tasks, such as cleaning lint and button traps or draining the still used to recover solvent
Presser	Operate pressing machine on garments that have been dry cleaned
Clerk	Counter duties (customer service), sort and bag dirty clothing, inspect finished clothing
Managerial	Administrative duties such as bookkeeping, purchasing, supervising
Seamstress	Mend and alter garments
Other	Includes disparate categories with small numbers of individuals, including driver, wet laundry worker, leather cleaner/dryer, maintenance worker

From Solet *et al.* (1990)

Fugitive emissions are those from leaks, rather than from venting as part of the process. Fugitive emissions can result from leaky seals and fittings, residual solvent in clothing, transfer of wet clothing, solvent evaporation in storage, improper operating practices, poor maintenance and housekeeping and system malfunctions. In one study conducted by the International Fabricare Institute, 25–30% of dry cleaning machines had visible solvent leaks; however, improvements in machine design have significantly reduced this problem (Earnest *et al.*, 1994). The United States Environmental Protection Agency estimated that about 87 000 tonnes (67%) of the 130 100 tonnes of tetrachloroethylene used in the United States in 1991 were lost through emissions to the atmosphere (Cantin, 1992).

Proper equipment and operating procedures are especially important around transfer machines, which are the most readily apparent source of exposure. Transfer involves holding solvent-saturated items directly in the breathing zone and in direct contact with the skin. Premature removal of wet garments from the drying cycle can be another cause of exposure.

Maintenance is an important part of any industrial process, and dry cleaning is no exception. A number of machine components must be maintained on a regular basis, daily, weekly, monthly or less often. Some maintenance procedures can result in high exposure to tetrachloroethylene; these include changing filters, cleaning stills and removing residue, cleaning lint and button traps and maintaining water separators.

Improper storage of hazardous waste, including still residues, dirty filters, contaminants in lint and button traps and water separator run-off, can increase background levels of tetrachloroethylene if these wastes are not stored in air-tight containers. When they are stored in a shop, they contribute to occupational exposure to background levels of solvent.

Excess tetrachloroethylene may be present in a cylinder if the extraction system fails, if the vapour recovery system fails or if improper operating procedures are followed. The balance between the water temperature of refrigerated condensers and the drying air temperature is crucial: If the air is not cool enough, the solvent will not be recovered; if it is too cold, the air will not dry the garments effectively. If the carbon beds in carbon adsorbers are not properly regenerated, solvent can be discharged through vents, which may be inside the shop (Stricoff, 1983).

1.3.3 Measurements of exposure

Occupational exposure to tetrachloroethylene has been measured in the dry cleaning industry throughout the world (Table 2). Because tetrachloroethylene has been the most commonly used solvent during the last two or three decades, when most of the measurements were made, only data on that compound are included in Table 2. Data on other exposures to tetrachloroethylene, for example, in the vicinity of dry cleaning establishments and in dry cleaned clothes carried home, are included in the monograph on tetrachloroethylene (this volume).

Differences in personal exposures to tetrachloroethylene between plants and shops are often many times larger than the differences between machine operators and other staff within dry cleaning premises. Such differences between staff have decreased in time from a factor of roughly 6 in the early 1980s to a factor of 2 in the early 1990s. As can be seen from Table 2, this coincides with decreasing average exposure levels, from 50–100 ppm [339–678 mg/m^3] in the 1970s to 10–50 ppm [67.8–339 mg/m^3] in the 1980s. Applying fixed multipliers for job titles in the calculation of cumulative exposure to tetrachloroethylene will introduce severe misclassification when factors that modify exposures in specific plants and shops are not taken into account.

In a study of dry cleaners and their families in Italy, a significant correlation was observed between the concentration of tetrachloroethylene in alveolar air samples collected at the end of the work day and 8-h time-weighted average (TWA) levels in ambient air ($r = 0.758$; $p < 0.001$; $n = 49$). A similar relationship was found between tetrachloroethylene concentrations in alveolar air samples collected from dry cleaners at home ($n = 33$), about 2 h after the end of the exposure, and the 8-h TWA concentration during the work day ($r = 0.665$; $p < 0.001$). Alveolar samples collected the next day still showed a significant correlation with the 8-h TWA value of the day before ($r = 0.549$; $p < 0.001$). The concentrations of tetrachloroethylene in alveolar air in this population were 0.49–353 mg/m^3, with a geometric mean of 15.4 mg/m^3 (Aggazzotti *et al.*, 1994).

In a study in Japan, the personal TWA levels of tetrachloroethylene to which dry cleaning workers were exposed were 0.6–100.8 ppm [4.07–683 mg/m^3]. The concentrations were 0.3–87 ppm [2.03–590 mg/m^3] in expired air and 0.01–0.73 mg/L in blood; the level of total trichlorinated compounds in urine was 0.6–19.2 mg/L (Hayashi *et al.*, 1990). In another study in Japan, the average annual consumption of solvents in dry cleaning shops was estimated to be 1280 kg of petroleum solvent, 1450 kg of tetrachloroethylene and 275 kg of CFC-113. The concentration of total trichloro compounds in urine samples was 3.2 ± 2.0 mg/L in the morning and 2.6 ± 1.9 mg/L in the afternoon (Takeuchi *et al.*, 1981).

Table 2. Exposures to tetrachloroethylene in dry cleaning shops

Country (year)	No. of plants	Job/task/industry	No. of samples	Air concentration				Reference
				Mean		Range		
				ppm	mg/m^3	ppm	mg/m^3	
Belgium	6	Dry cleaning	26 subjects (P) TWA	20.8	141	8.9–37.5	60–254	Lauwerys *et al.* (1983)
Finland (1982–85)	6	Dry cleaning	10 (A) TWA	13	88	3–29	20–197	Rantala *et al.* (1992)
France	26	Dry cleaning	> 100 per shop			0–100	0–678	Davezies *et al.* (1983)
France (1989, 1990)	36	Dry cleaning operator	5–10 per shop[a]	17.5	120	NR–100	NR–678	Anon. (1991)
Germany		Dry cleaning	19 workers 55 (P)		62 (end of week) 43 (following Monday)		16–672	Pannier *et al.* (1986)
Germany		Dry cleaners	101 (P) workers TWA		205			Seeber (1989)
Germany (1987, 1989)	15	Dry cleaning	75 (A)			45% > 50 33% > 100 9% > 200	3.1–331	Gulyas & Hemmerling (1990)
Germany (1993, 1994)	21	Dry cleaning operator	100		7.4		< 0.02–27	Klein & Kurz (1994)
Italy	47	Dry cleaning	143 workers	11.3	77	1–80.8	7–548	Missere *et al.* (1988)
Italy (1992–1993)	28	Dry cleaning	60 workers[b] (P) TWA (A)		 NR 36		 2.6–221.5 0.19–308	Aggazzotti *et al.* (1994)

Table 2 (contd)

Country (year)	No. of plants	Job/task/industry	No. of samples	Air concentration				Reference
				Mean		Range		
				ppm	mg/m^3	ppm	mg/m^3	
Netherlands								
(1976)	1	Dry cleaning	48 5 workers	6.7	45	3.7–25.9	25–176	van der Tuin & Hoevers (1977a)
(1977)	1	Dry cleaning	86 10 workers	41.3	280	11–101	75–685	van der Tuin & Hoevers (1977b)
(1978)	1	Dry cleaning	80 9 workers	59.7	405	10.0–250	68–1695	van der Tuin (1979)
Switzerland	10	Dry cleaning	1 week	18.5	125			Boillat *et al.* (1986)
United Kingdom	90	Dry cleaning shops	333 (P)	74% < 30 88% < 50 97% < 100	203 339 678			Shipman & Whim (1980)
	41	Dry cleaning factories	160 (P)	53% < 30 76% < 50 93% < 100	203 339 678			
United Kingdom (1990–91)	81	Dry cleaning operator	405 (P) TWA	22.5	153	0–360	0–2441	Edmondson & Palin (1993)
Japan	3	Dry cleaning	56 workers TWA	20 g	136	3.8–94.4	26–640	Cai *et al.* (1991)
USA		Dry cleaners, commercial	19 (A) 12 workers	91.5	621	31–270	210–1831	Kerr (1972)
		Dry cleaners, coin-operated	11 (A) 4 workers	125	848	87–264	590–1790	
USA		Dry cleaning area Spotter and dry cleaners	3 (A) 4 (P)	33 62	222 420	21–48 10–171	142–325 68–1160	Eddleston & Polakoff (1974)

Table 2 (contd)

Country (year)	No. of plants	Job/task/industry	No. of samples	Air concentration				Reference
				Mean		Range		
				ppm	mg/m^3	ppm	mg/m^3	
USA (1982)	17	Transfer	(P) TWA	86.6	587	28.5–302.7	193–2052	Materna (1985)
			(P) 5-min peak	135.9	921	11.3–533.8	77–3619	
	3	Dry-to-dry	(P) TWA	28.2	192	3.0–75.9	20–515	
USA (1984)	1	Dry cleaning (transfer process)	2 (P) TWA	54.5	370	45–64	305–434	Pryor (1985)
			10 (P) 15-min ceiling	306	2075	68–597	461–3899	
USA (1985)	1	Dry cleaning (dry-to-dry process)	4 (A) TWA		119		79–135	Burr & Todd (1986)
USA (1980s)		Transfer						International Fabricare Institute (1987)
	471	Machine operator	TWA	49.8	338			
	43	Counter person, etc.		16.7	113			
	57	Spotter, finisher		18.1	123			
		Dry-to-dry						
	157	Machine operator		23.2	157			
	16	Counter person, etc		10.8	73			
	24	Spotter, finisher		12.1	82			
USA		Dry cleaning	34 workers (P)		7.9		0.002–55	Eskenazi *et al.* (1991a)
USA	10	Operator/presser in dry cleaning (transfer and dry-to-dry)	60 (P) 13 workers	10	68	0.17–44.1	1.2–300	Petreas *et al.* (1992)

P, personal air sample; A, area air sample; NR, not reported; TWA, time-weighted average
[a] Worst-case sampling (highest exposed worker)
[b] Six to eight spot samples taken at each plant
[c] Arithmetic mean
[d] Geometric mean

Table 2 (contd)

Country (year)	No. of plants	Job/task/industry	No. of samples	Air concentration				Reference
				Mean		Range		
				ppm	mg/m^3	ppm	mg/m^3	
USA		Dry cleaners	96 (P)	41	278	5–125	34–848	Center for Chemical Hazard Assessment (1985)
USA (1975)		5 machine operators	(A)	37.2	252	12.2–62.2	83–422	Tuttle *et al.* (1977)
		2 pressers		11.4	77	4.6–18.3	31–124	
		5 counters		1.3	9	0.4–2.3	3–16	
		7 miscellaneous		3	20	0.9–5.1	6–35	
		5 machine operators	(P)	20.5	139	2.3–38.7	16–262	
		2 pressers		4.48	30	4.1–4.9	28–33	
		5 counters		0.95	6.4	0.3–1.6	2–11	
		7 miscellaneous		2	14	0–4.3	0–29	
USA (1977–79)	44	Machine operator	45 (P) TWA	31[c]	210	4.0–149	27–1010	Ludwig (1981); Ludwig *et al.* (1983)
				22[d]	149			
	35	Presser	52 (P) TWA	5.7[c]	39	0.1–37	0.7–250	
				3.3[d]	22			
	12	Seamstress	12 (P) TWA	6.6[c]	45	0.6–29	4–197	
				3[d]	20			
	31	Counter area	31 (P) TWA	5.9[c]	40	0.3–26	2–176	
				3.1[d]	21			
	39	Machine operator during transfer	134 (P) 5-min peak	76[c]	515	3.3–366	22–2482	
				44[d]	298			
	30	Machine operator during transfer	49 (P) 15-min peak	55[c]	373	1–269	7–1824	
				33[d]	224			
USA	44	Washer to dryer transfer	175 (A)	95.8	650	1.0–775	7–5255	US National Institute for Occupational Safety and Health (1981)
		Counter area	39 (A)	4.8	33	0.3–26.4	2–179	
		Dry cleaning area	36 (A)	32.8	222	0.5–177	3.4–1200	
		Washer area	25 (A)	22	169	2.0–91	14–617	
		Pressing area	26 (A)	6	41	0.2–40	1.4–271	
		Spotting area	14 (A)	12.3	83.4	0.9–35	6.1–237	

In one dry cleaning shop in Switzerland, the concentrations of tetrachloroethylene and CFC-113 were 10 mg/m^3 and 150 mg/m^3 inside the shop and 25 mg/m^3 and 1000 mg/m^3 in the machine room (Grob *et al.*, 1991).

Analysis of 138 blood samples taken from workers in 55 dry cleaning shops in Finland in 1987 showed a geometric mean tetrachloroethylene concentration of 0.75 μmol/L (range, < 0.1–14.0 μmol/L) [0.12 (0.02–2.3) mg/L]; the arithmetic mean was 1.25 μmol/L [0.21 mg/L] (Rantala *et al.*, 1992).

In a study conducted by the United States National Institute for Occupational Safety and Health in 1988, occupational exposures to tetrachloroethylene and trichloroethylene in dry cleaning and exposure to 2-butoxyethanol, hexylene glycol, *n*-butyl acetate and methyl isobutyl ketone during spotting were evaluated. The concentrations of spotting agents in air were low: 2-Butoxyethanol was not detectable (n = 10), and the mean concentrations were 1.2 ppm [5.8 mg/m^3] (range, 0–6.9 ppm [0–33 mg/m^3]; n = 17) for hexylene glycol, 0.32 ppm [1.3 mg/m^3] (range, 0–4.2 ppm [0–17.2 mg/m^3]; n = 57) for methyl isobutyl ketone and 1.2 ppm [5.7 mg/m^3] (range, 0–5.69 ppm [0–27 mg/m^3]; n = 57) for *n*-butyl acetate. Spotters were exposed to mean concentrations of 4.3 ppm [29 mg/m^3] (range, 0–38.7 ppm [0–262 mg/m^3]; n = 115) tetrachloroethylene and 1.4 ppm [7.5 mg/m^3] (range, 0–9.16 ppm [0–49 mg/m^3]; n = 115) trichloroethylene in air (Earnest, 1994).

In Japan, dry cleaned test samples of fabric were found to contain up to 13.6 mg/g tetrachloroethylene. In 53 air samples from 11 establishments where dry cleaned clothes were handled, the mean concentration was [434 μg/m^3] (range, 1–4813 μg/m^3). The mean level in alveolar air from 31 dry cleaners was [37.8 μg/m^3] (average, 36.9; range, 0–168 μg/m^3) (Kawauchi & Nishiyama, 1989).

The average concentration of tetrachloroethylene to which 22 workers were exposed in six dry cleaning shops in Belgium was 21 ppm [142 mg/m^3], with a range of 9–38 ppm [61.0–258 mg/m^3]. The mean concentration of tetrachloroethylene in alveolar air was 1.9 ppm [13 mg/m^3] before work and 5.1 ppm [35 mg/m^3] 30 min after exposure. The mean concentrations in the blood at the same time intervals were 0.4 and 1.2 mg/L, respectively. Trichloroacetic acid was not detected in any urine samples. The authors concluded that a blood concentration of < 1 mg/L tetrachloroethylene 16 h after exposure probably corresponded to an 8-h time-weighted average exposure of < 50 ppm [339 mg/m^3] (Lauwerys *et al.*, 1983).

In a study of 195 individuals in one industrial and 12 commercial dry cleaning facilities in Detroit, MI, United States, in 1986–87, the concentrations of tetrachloroethylene in 181 samples of exhaled breath and 54 personal samples were measured during use of dry-to-dry and transfer machinery. In facilities where transfer machines were used, the mean concentration in breath samples was 7.72 ppm [52.3 mg/m^3] (range, 2–14 ppm [12–95 mg/m^3]), which was over five times higher than that measured in facilities where dry-to-dry machinery was used (1.47 ppm [9.97 mg/m^3]). The mean concentration in air samples from facilities using transfer machines (29.5 ppm [200 mg/m^3]; range, 1–58 ppm [7–400 mg/m^3]) exceeded that for dry-to-dry machines (7.09 ppm [48.1 mg/m^3]) by more than four times. The mean concentrations of tetrachloroethylene in breath and air samples (ppm [mg/m^3]) for various job titles were, respectively: operator, 12.5 [84.8] and 46.5 [315]; presser, 5.88 [39.9] and 14.8 [100]; clerk, 4.52 [30.6] and 11.7 [79.3]; seamstress, 6.50 [44.1] and 19.0 [129]; managerial, 5.50 [37.3] and not reported;

other, 2.55 [17.3] and 5.00 [33.9]. Of 12 air samples taken from the breathing zone of operators, eight contained > 25 ppm [170 mg/m^3], 6 contained > 50 ppm [339 mg/m^3] and one contained > 100 ppm [678 mg/m^3]. None of the air samples from the four shops where only dry-to-dry machinery was used had concentrations > 25 ppm [170 mg/m^3] (Solet *et al.*, 1990). In the same population of dry cleaners, the ratios of total urinary protein, albumin and *n*-acetylglucosaminidase to creatinine in 192 urine samples were studied in relation to tetrachloroethylene levels in breath and estimates of chronic exposure; no consistent relationship was seen (Solet & Robins, 1991).

In a study in Croatia of 19 dry cleaners exposed to tetrachloroethylene for a mean duration of 16.6 years (range, 2–30), the concentrations of tetrachloroethylene and trichloroacetic acid in blood on a Monday before work were 2.96 (1.63–32) and 6.5 (1.65–17.1) μmol/L [0.5 (0.3–53) and 1.1 (0.3–2.8) mg/L], and those on a Thursday after work were 8.44 (4.8–80) and 8.57 (1.7–20.9) μmol/L [1.4 (0.8–13.3) and 1.4 (0.3–3.4) mg/L], respectively. The concentrations of trichloroethanol and trichloroacetic acid in urine were 0.03 (0–1.7) and 2.3 (0.5–15.8) μmol/mmol [0.04 (0–2.3) and 3 (0.7–23) mg/g] creatinine on a Monday before work, and 0.13 (0–0.95) and 2.3 (0.8–10.8) μmol/mmol [0.17 (0–1.3) and 3.3 (1.2–15.6) mg/g] creatinine on a Thursday after work (Skender *et al.*, 1986).

In a study in the United States (Petreas *et al.*, 1992), the mixed exhaled air of dry cleaning machine operators contained a mean concentration of 3.4 ppm [23.1 mg/m^3] tetrachloroethylene at the end of the work shift and 2.2 ppm [14.9 mg/m^3] the next morning; the mean concentrations for a presser were 3.3 and 1.4 ppm [22.4 and 9.49 mg/m^3], respectively. Exhaled air of operators using dry-to-dry machines contained 2.4 ppm [16.3 mg/m^3] at the end of the work shift and 1.5 ppm [10.2 mg/m^3] the next morning; the exhaled air of transfer machine operators contained 5.4 and 3.1 ppm [36.6 and 21.0 mg/m^3], respectively. The levels of tetrachloroethylene in 12 blood samples were 17–1154 μg/L, with a mean of [283 μg/L]. The mean blood:breath concentration ratio was thus 21.6, similar to that of 23 derived by Monster *et al.* (1979). Petreas *et al.* (1992) found strong correlations between tetrachloroethylene concentrations in mixed exhaled air and in blood ($r = 0.94$) and in mixed exhaled air and personal air samples collected over the entire shift ($r = 0.89$).

2. Studies of Cancer in Humans

2.1 Case reports

A man and four of his five children, all of whom worked in dry cleaning in the United States, developed chronic lymphocytic leukaemia (Blattner *et al.*, 1976).

Jalihal and Barlow (1984) reported a case of myeloid leukaemia diagnosed in a 60-year-old dry cleaner in the United Kingdom. He had had heavy exposure for many years, first to trichloroethylene and later to tetrachloroethylene.

2.2 Descriptive studies

Guralnick (1963) used death certificates to evaluate the cause-specific mortality by occupation for all men aged between 20 and 64 who had died in the United States during 1950. There were 1193 deaths among laundry or dry cleaning operatives. Nonsignificant excesses of cancer mortality were seen, both overall (standardized mortality ratio [SMR], 1.4) and for cancers at specific sites, including the stomach (1.5), intestine and rectum (1.6) and trachea, bronchus and lung (1.5).

Gallagher *et al.* (1989) used death certificates to study cause-specific mortality by occupation for all men aged 20–65 in British Columbia (Canada) for the years 1950–84. There were 165 deaths among launderers and dry cleaners, and significantly elevated proportionate mortality ratios (PMRs) were observed for cancer of the lip (PMR, 53; 95% confidence interval [CI], 6.4–100, based on two deaths) and for all tumours of the digestive organs (2.0; 1.3 –3.0; 23 deaths), especially the stomach (2.5; 1.1–4.9; eight deaths).

Milham (1992) analysed information on occupation and cause of death from the death certificates of 1652 male laundry and dry cleaning operatives who died in Washington State, United States, between 1950 and 1989. Elevated PMRs were seen for cancers of the buccal cavity and pharynx and connective tissues.

Data from death certificates and censuses for Great Britain for the years 1979–80 and 1982–83 showed that mortality among men aged 20–64 and single women aged 20–59 [data for married women were not reported] who were launderers, dry cleaners or pressers was higher than that in the general population (males: SMR, 1.3 [95% CI, 1.2–1.5]; single females: 1.4 [1.1–1.7]) (Office of Population Censuses and Surveys, 1986). There was a significant overall excess of malignant neoplasms in males (1.4 [1.1–1.7]), and excesses were reported for cancers of the oesophagus (1.7 [0.5–4.5], four deaths), stomach (2.0 [0.9–3.6], 10 deaths), trachea, bronchus and lung (1.7 [1.2–2.3], 41 deaths) and urinary bladder (2.8 [0.9–6.5], five deaths). In single women, there was no overall excess of malignant neoplasms (SMR, 1.0 [0.7–1.5]), but some excess was reported for cancers of the digestive organs (1.4 [0.8–2.9], seven deaths), rectum (3.3 [0.7–9.7], three deaths) and bladder (7.3 [1.2–36], two deaths).

A proportionate mortality study in Wisconsin, United States, was based on the death certificates of 671 female laundry and dry cleaning workers in the period 1963–77 (Katz & Jowett, 1981). Comparisons were made with all occupations as well as with lower-wage occupations obtained from a data file of 66 230 deaths in the State among white women who had ever been employed. The PMRs given below are those obtained from comparisons with lower-wage occupations. Elevated risks were found for some cancers and for diabetes mellitus. For cancer of the kidney, the PMR was 2.5 [95% CI, 1.0–5.2], based on seven deaths; types of cancer associated with nonsignificantly increased PMRs included cancer of the skin (2.6 [0.73–6.8], four deaths), lymphosarcoma (1.8 [0.65–3.8], six deaths), urinary bladder cancer (1.9 [0.62–4.5], five deaths), cervical cancer (1.4 [0.68–2.6], 10 deaths) and rectal cancer (1.3 [0.45–2.7], six deaths). There was no overall excess of neoplasms.

The causes of death of 440 laundry and dry cleaning workers in Oklahoma, United States, were investigated in a study which covered the years 1975–81 (Duh & Asal, 1984). Petroleum solvents accounted for > 50% of the solvents used in the State. The distribution of deaths in the

United States in 1978 by age, sex, race and cause was used as the standard of comparison. Some SMRs were decreased, most notably that for ischaemic heart disease (0.8; 95% CI, 0.7–1.0), based on 134 deaths. For cancers at all sites, the standardized mortality odds ratio was 0.9 (0.7–1.2), based on 97 deaths. Cancer of the respiratory system was the cause of death for 39 persons (standardized mortality odds ratio, 1.8; 95% CI, 1.3–2.5), of whom 37 died of lung cancer (1.7; 1.2–2.5). For renal cancer, the standardized mortality odds ratio was 3.8 (1.9–7.6), based on seven deaths. There were two deaths from cervical cancer (1.3; 0.3–5.3), five from cancer of the ovary (1.5; 0.6–3.6), one from urinary bladder cancer (0.4) and one from breast cancer (0.1).

A further report on the Oklahoma dry cleaners was published as an abstract (Petrone, 1988). PMRs were based on the mortality of 474 white male dry cleaners whose exposure histories were obtained from plant records. The men had been exposed to petroleum solvents for an average of 10.5 years and had had no known exposure to 'synthetic solvents'. For all malignant neoplasms, the PMR was 1.0 (95% CI, 0.83–1.3), based on 84 deaths. For respiratory cancer, the PMR was 1.5 (1.0–2.1), based on 35 deaths; no relationship was seen with latency or degree of exposure. A PMR of 2.0 (0.89–3.7) was obtained for pancreatic cancer. The PMR for renal cancer was 2.0 (0.66–4.7), based on five deaths; when only men exposed to petroleum solvents were analysed, the PMR was 1.1 (0.13–3.9), based on two deaths. [The degree of overlap between this study and that of Duh & Asal (1984) is unknown.]

Nakamura (1985) conducted a proportionate mortality study of members of the All-Japan Laundry and Dry-cleaning Association. Trichloroethylene was reported to be the solvent used most commonly for dry cleaning in Japan between 1903 and 1940; more recently, 30% of dry cleaning was stated to be done using tetrachloroethylene and 65% with petroleum solvents. Death certificates were obtained for 1711 members who had died between 1971 and 1980, and expected numbers of deaths were calculated from mortality rates for Japanese males and females in 1975. When the results for men and women were combined, there was an increased risk for cancer of the bone ([PMR, 2.9; 95% CI, 0.9–6.9]; five deaths).

2.3 Cohort studies

A union of dry cleaning workers in Missouri, United States, had 11 062 members between 1945 and 1978, of whom 5790 had held membership for one year or more. After exclusion of 425 members for whom information on race, sex or date of birth was unavailable, the analysis was restricted to 5365 members (Blair *et al.*, 1986, abstract; Blair *et al.*, 1990). The members were followed-up from entry to the Union or 1 January 1948 (whichever came later) until 1 January 1979: follow-up was 88% successful, with slight variations for men and women and for race. The cohort contributed 98 818 person-years, and the expected numbers of deaths were calculated from national rates. The mortality rate was slightly lower than expected for all causes combined (SMR, 0.9; 95% CI, 0.9–1.0; 1129 deaths) but slightly raised for cancer (1.2; 1.0–1.3; 294 deaths). Excesses were found for cancers of the oesophagus (SMR, 2.1; 1.1–3.6; 13 deaths), larynx (1.6; 0.3–4.7; three deaths), lung (1.3; 0.9–1.7; 47 deaths), cervix uteri (1.7; 1.0–2.0; 21 deaths), bladder (1.7; 0.7–3.3; eight deaths) and thyroid (3.3; 0.7–9.8; three deaths) and for lymphosarcoma and reticulosarcoma (1.7; 0.7–3.4; seven deaths) and Hodgkin's disease (2.1; 0.6–5.3; four deaths). There was no excess of cancer of the liver or of the kidney. The excess risk

for cancer of the oesophagus was restricted to black men (SMR, 3.5; 11 deaths). The relative risk for cancer at this site for all cohort members was related to estimated cumulative exposure to dry cleaning solvents and was 2.8 for those in the highest category of exposure. For deaths from causes other than cancer, an SMR of 2.0 (95% CI, 1.1–3.4) for emphysema was the most relevant finding. With the highest level of exposure to dry cleaning solvents, there were five deaths from lymphatic and haematopoietic malignancies, whereas 1.3 were expected (SMR, 4.0 [1.2–90]). The authors stated that the relative risks were similar for workers first employed before 1960 and those employed after that date, when use of tetrachloroethylene became predominant, but no details were provided.

Proportionate mortality among the same workers, reported in a previous study (Blair *et al.*, 1979), showed excess numbers of deaths from cancers of the liver, cervix and skin.

An updating of an earlier cohort mortality study in the United States (Kaplan, 1980; Brown & Kaplan, 1987) from California, Illinois, Michigan and New York, included 1701 dry cleaning workers in four labour unions (Ruder *et al.*, 1994). The inclusion criteria were employment for at least one year before 1960 in a shop where tetrachloroethylene was the primary solvent used and there was no known exposure to carbon tetrachloride. A survey in 1977–79 (Brown & Kaplan, 1987) showed geometric mean, time-weighted average concentrations of tetrachloroethylene in the range of 3–22 ppm [20.3–149 mg/m^3]; other solvents used for spot cleaning were not detected in the samples. In the analyses, two subcohorts were defined: people employed only in shops where tetrachloroethylene was the primary solvent, and people whose work also involved exposure to other solvents. The mean duration of employment in dry cleaning through 31 December 1990 was 6.4 years for those exposed only to tetrachloroethylene and 11.4 years for those also exposed to other solvents; the latter group had a mean duration of 6.0 years' exposure to tetrachloroethylene. Expected numbers of deaths were calculated from the national death rates. The follow-up reached 94% of the women and 96% of the men, contributing 47 273 person-years. There were 769 deaths (SMR, 1.0; 95% CI, 0.94–1.1) and 209 cancer deaths (1.2; 1.1–1.4). The SMR for urinary bladder cancer was significantly increased (2.5; 1.2–4.8; nine deaths), as were those for oesophageal cancer (2.1; 1.0–3.9; 10 deaths) and cancers of the colon and small intestine (1.6; 1.0–2.3; 26 deaths). Some excess of pancreatic cancer was noted (1.7; 0.93–2.8; 15 deaths). When the analysis was restricted to workers with a 20-year latency since first employment and with a length of employment ≥ 5 years, the SMRs were increased for cancers at all sites combined (1.5; 1.2–1.9; 83 deaths) and, notably, for cancers of the oesophagus (5.4; 2.3–11; eight deaths) and the urinary bladder (6.5; 2.8–13; eight deaths). Some overall excess was also seen for cervical cancer (1.8; 0.86–3.3; 10 deaths) and for renal cancer (1.5; 0.40–3.7; four deaths), but there was no association with time since first employment or length of employment. There were also three cancers of the tongue (3.5; 0.73–10). Only one death from cancer of the liver and biliary tract was found [with 4.8 expected].

A Danish cohort of 8567 women and 2033 men aged 20–64 years and employed in laundry and dry cleaning in 1970 was followed-up for 10 years (Lynge & Thygesen, 1990). One-fourth of the cohort was estimated to work in dry cleaning, but at the individual level there was no way of distinguishing those who worked in dry cleaning from those who worked in laundries. The dry cleaners in the cohort were mainly exposed to tetrachloroethylene after the late 1950s, but had also been exposed to trichloroethylene and chlorofluorocarbons CFC-11 and CFC-113. In

measurements taken in 1979–80, the concentrations of tetrachloroethylene in clothes being taken out of the machines were 1000–7000 ppm [mg/kg] in some samples but were usually less than 100 ppm. The expected numbers of cases were calculated on the basis of the rates for the economically active proportion of the general population. A total of 510 cancer cases were observed [standardized incidence ratio (SIR), 1.0; 95% CI, 0.9–1.1]. For colon cancer, the SIR was [1.0] ([0.70–1.4]; 35 observed); for lung cancer, the SIR was [1.2] ([0.9–1.6]; 60 observed). Seven cases of liver cancer were observed [SIR, 2.2; 95% CI, 0.9–4.5], and there were 22 cases of pancreatic cancer (1.7; 1.1–2.6).

When the study was updated for the period 1981–87, a total of 10 additional cases of liver cancer were observed (4.5 expected) (Lynge, 1994).

The Swedish population at the time of the 1960 census was followed-up for cancer incidence, first for 1961–73 (Malker & Weiner, 1984) and later for 1961–79 (McLaughlin *et al.*, 1987). In the first follow-up, data on the following cancers were reported for laundry and dry cleaning workers: all cancers (SIR, 1.0 [95% CI, 0.9–1.1]; 646 observed) and cancers of the buccal cavity and nasopharynx ([2.9; 1.7–4.7]; 16 observed), liver and biliary passages (1.2 [0.7–1.8]; 17 observed), lung (1.2 [0.9–1.7]; 34 observed) and breast (0.8 [0.7–1.0]; 113 observed). In the second follow-up, the only site for which data were reported for this occupational group was the kidney: the SIR was 0.99 ([0.6–1.6] 18 observed) in men and 0.86 ([0.6–1.3] 25 observed) in women.

Table 3 gives the details of these cohort studies. Results are shown for all cancer sites for which at least one of the cohort studies showed a significantly increased risk. In addition, results are shown for cancer sites on which a relevant case–control study was conducted (see Table 4).

2.4 Case–control studies

Dry cleaning (both in association with and independently of work in laundries) has been evaluated for possible associations with several types of cancer in case–control studies. Risks were investigated in relation to a variety of exposures and occupations and were not specifically concerned with dry cleaners. The studies addressed cancers of the colon (Fredriksson *et al.*, 1989), liver (Stemhagen *et al.*, 1983; Austin *et al.*, 1987; Suarez *et al.*, 1989), lung (Brownson *et al.*, 1993), kidney (Asal *et al.*, 1988; McCredie & Stewart, 1993; Mellemgaard *et al.*, 1994), pancreas (Mack *et al.*, 1985), oral cavity and pharynx (Huebner *et al.*, 1992) and non-Hodgkin's lymphoma (Blair *et al.*, 1992, 1993). Data from the National Bladder Cancer study of the United States National Cancer Institute conducted in 1978, in relation to dry cleaners, were used in four studies (Silverman *et al.*, 1983; Schoenberg *et al.*, 1984; Smith *et al.*, 1985; Silverman *et al.*, 1989). A study of multiple sites was reported by Siemiatycki (1991).

A record-linkage study from Denmark on parental employment at the time of conception and the risk of cancer in offspring mentions an increased risk for cancers at all sites combined among children of mothers who owned a laundry or dry cleaning establishment (odds ratio, 3.7; $p < 0.01$; 6 observed) (Olsen *et al.*, 1991).

Table 4 summarizes the results of the case–control studies. [The Working Group noted that positive results may have been reported preferentially.]

Table 3. Results of cohort studies of dry cleaners

Site of cancer	Blair *et al.* (1990) 5365 US dry cleaners followed for mortality during 1948–78			Ruder *et al.* (1994) 1701 US dry cleaners followed for mortality during 1940–90			Lynge & Thygesen (1990) 10 600 Danes employed in laundry and dry cleaning in 1970, followed for cancer incidence during 1970–80			Malker & Weiner (1984) Swedes employed in laundry and dry cleaning in 1960, followed for cancer incidence during 1961–73		
	Obs.	SMR	95% CI	Obs.	SMR	95% CI	Obs.	SIR	95% CI	Obs.	SIR	95% CI
All	294	1.2	1.0–1.3	209	1.2	1.1–1.4	510	[1.0]	[0.9–1.1]	646	1.0	[0.9–1.1]
Oesophagus	13	2.1	1.1–3.6	10	2.1	1.0–3.9	–	–	–	–	–	–
Colon	25	1.0	0.6–1.4	26	1.6	1.0–2.3	35	[1.0]	[0.7–1.4]	–	–	–
Liver and biliary passages	5	0.7	0.2–1.7	1	0.21	0.0–1.7	15	[1.9]	[1.0–3.1]	17	1.2	[0.7–1.8]
Liver	–	–	–	–	–	–	7	[2.2]	[0.9–4.5]	–	–	–
Gall-bladder	–	–	–	–	–	–	8	[1.6]	[0.7–3.2]	–	–	–
Pancreas	15	1.2	0.7–1.9	15	1.7	0.93–2.8	22	1.7	1.1–2.6	–	–	–
Lung	47	1.3	0.9–1.7	43	1.2	0.85–1.6	60	[1.2]	[0.9–1.6]	34	1.2	[0.9–1.7]
Cervix	21	1.7	1.0–2.0	10	1.8	0.86–3.3	34	[0.8]	[0.6–1.2]	–	–	–
Kidney	2	0.5	0.1–1.8	4	1.5	0.40–3.7	11	[0.9]	[0.4–1.6]	43[a]	[0.9][a]	[0.7–1.2]
Urinary bladder	8	1.7	0.7–3.3	9	2.5	1.2–4.8	14	[0.7]	[0.4–1.2]	–	–	–
Non-Hodgkin's lymphoma	7[b]	1.7	0.7–3.4	2[b]	0.99	0.12–3.6	8[c]	[1.0]	[0.4–2.0]	–	–	–

Obs, observed; SMR, standardized mortality ratio; CI, confidence interval
[a] Follow-up for 1961–79 (McLaughlin *et al.*, 1987)
[b] ICD 200
[c] ICD 200 and 202

Table 4. Risks for cancer associated with dry cleaning work in case–control studies of people with a variety of exposures and occupations

Reference (country)	Study design	Exposure	Sex	Numbers of cases/controls		Odds ratio	95% CI	Comments
				Total	Exposed			
Colon cancer								
Fredriksson *et al.* (1989) (Sweden)	Population-based; response rates: 95% of cases and controls	Employment as dry cleaner	F	156/317	5/5	2.0	0.5–7.1	Adjusted for age and physical activity
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment as launderer or dry cleaner:	M	497/2056				Adjusted for age, race, income, smoking and beer consumption
		Any[b]			5/NR	0.6	[0.3–1.4]	
		'Substantial'[c]			1/NR	0.2	[0.0–1.5]	
Oesophageal cancer								
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment as launderer or dry cleaner:	M	99/2546				
		Any[b]			0/NR	0.0		
		'Substantial'[c]			0/NR	0.0		
Liver cancer								
Stemhagen *et al.* (1983) (USA)	Population-based; response rates, 79% for cases and 77% for controls	Employed for ≥ 6 months in laundry, dry cleaning and garment services	M	178/356	10/8	2.5	1.0–6.1	All primary liver cancer
					8/7	2.3	0.85–6.1	Hepatocellular carcinoma
								Matched on age, race, county and vital status
Austin *et al.* (1987) (USA)	Hospital-based; response rates: 93% for cases and 91% for controls	Employment for ≥ 6 months in laundry and cleaning	M/F	80/146	0/4	–		Matched on sex, age, race and study centre
Suarez *et al.* (1989) (USA)	Based on death certificates	Usual occupation:	M	1742/1742				Adjusted for age and race
		in dry cleaning services			11/12	0.98	0.44–2.2	
		as dry cleaning operator			4/8	0.55	0.17–1.8	

Table 4 (contd)

Reference (country)	Study design	Exposure	Sex	Numbers of cases/controls		Odds ratio	95% CI	Comments
				Total	Exposed			
Lung cancer								
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment as launderer or dry cleaner:	M	857/1360				Adjusted for age, race, income, smoking and alcohol consumption
		Any[b]			12/NR	0.8	[0.4–1.5]	
		'Substantial'[c]			5/NR	0.6	[0.2–1.9]	
Brownson *et al.* (1993) (USA)	Population-based; response rates: 66% for cases, 67% for controls	Any employment in dry cleaning	F	429/1021	30/39	1.8	1.1–3.0	Never and ex-smokers
						2.9	1.5–5.4	Employed for > 1.125 years
					23/31	2.1	1.2–3.7	Never smokers Adjusted for age
Prostate cancer								
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment as launderer or dry cleaner:	M	449/1550				Adjusted for age, race, income, smoking and body-mass index
		Any[b]			9/NR	1.5	[0.7–3.3]	
		'Substantial'[c]			6/NR	2.1	[0.7–6.0]	
Kidney cancer								
Asal *et al.* (1988) (USA)	Population-based	Employed predominantly in dry cleaning		315/336				Adjusted for age, weight and smoking
			M		3/6	0.7	0.2–2.3	
			F		8/1	2.8	0.8–9.8	
						8.7	0.9–81	From regression analysis
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment in laundry or dry cleaning:	M	177/2481				Adjusted for age, race, income and smoking
		Any[b]			5/NR	2.0	[0.8–5.1]	
		'Substantial'[c]			2/NR	2.1	[0.5–9.2]	

Table 4 (contd)

Reference (country)	Study design	Exposure	Sex	Numbers of cases/controls		Odds ratio	95% CI	Comments
				Total	Exposed			
Kidney cancer (contd)								
McCredie & Stewart (1993) (USA)	Population-based; response rates: 68% for renal cases, 75% for pelvic cases, 74% for controls	Any employment in dry cleaning	F	179/292	MF 16/7	2.7	1.1–6.7	Renal-cell cancer: adjusted for age and sex; also adjusted for smoking
			M	310/231		2.5	0.97–6.4	
			F	89/292	MF 8/7	6.1	2.0–19	Renal pelvic cancer: adjusted for age, sex and education; also adjusted for smoking
			M	58/231		4.7	1.3–17	
Mellemgaard *et al.* (1994) (Denmark)	Population-based; response rates: 76% for cases, 88% for controls	Any employment ≥ 10 years before interview	M	226/237	2/1	2.3	0.2–27	Adjusted for age, body-mass index and smoking
			F	142/159	2/1	2.9	0.3–33	
Bladder cancer[d]								
Silverman *et al.* (1983) (USA)	Response rates: 81% for cases, 84% for controls	Employed ≥ 6 months in laundry and dry cleaning	M	303/296	12/5	2.4	0.8–6.9	Detroit area, whites only
Schoenberg *et al.* (1984) (USA)	Response rates: 90% for cases, 87% for controls	Employed ≥ 6 months in dry cleaning	M	658/1258	7/10	1.3	0.50–3.6	New Jersey area, whites only; adjusted for age and smoking
Smith *et al.* (1985) (USA)		Employed ≥ 6 months in laundry and dry cleaning	M	NR	NR	1.3	0.85–2.0	All study areas, nonsmokers only
Silverman *et al.* (1989) (USA)		Employed ≥ 6 months as dry cleaner, ironer or presser	M	126/383	11/12	2.8	1.1–7.4	All study areas, non-whites only; adjusted for smoking

Table 4 (contd)

Reference (country)	Study design	Exposure	Sex	Numbers of cases/controls		Odds ratio	95% CI	Comments
				Total	Exposed			
Bladder cancer (contd)								
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment as launderer or dry cleaner:	M	484/1879				Adjusted for age, income, smoking and coffee consumption
		Any[b]			10/NR	1.6	[0.8–3.3]	
		'Substantial'[c]			7/NR	1.9	[0.8–4.8]	
Pancreas cancer								
Mack *et al.* (1985) (USA)	Population-based; response rate: 67% for cases	Employment ≥ 6 months in laundry and dry cleaning > 10 years before diagnosis	M/F	490/490	23/36	[0.6]	[0.4–1.1]	Crude odds ratio
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate: 82%	Employment as launderer or dry cleaner:	M	116/2454				
		Any[b]			0/NR	0.0		
		'Substantial'[c]			0/NR	0.0		
Oral and pharyngeal cancer								
Huebner *et al.* (1992) (USA)	Population-based; response rates: 75% for cases, 76% for controls	Employed for ≥ 6 months:	M	762/837				Adjusted for age, race, smoking, alcohol and study location
		as laundry or dry cleaning worker			14/22	0.39	0.17–0.88	
		in laundry or dry cleaning industry			18/26	0.64	0.32–1.3	
Non-Hodgkin's lymphoma								
Siemiatycki (1991) (Canada)	Population-based (case–case)[a]; response rate, 82%	Employment as launderer or dry cleaner:	M	215/2357				Adjusted for age, income and smoking
		Any[b]			3/NR	0.9	[0.3–3.1]	
		'Substantial'[c]			0/NR	0.0		

Table 4 (contd)

Reference (country)	Study design	Exposure	Sex	Numbers of cases/controls		Odds ratio	95% CI	Comments
				Total	Exposed			
Non-Hodgkin's lymphoma (contd)								
Blair *et al.* (1992, 1993) (USA)	Population-based; response rates: 87% for cases, 77–79% for controls	Employed for ≥ 1 year in laundry and dry cleaning	M	622/1245	16/14	2.0	0.97–4.3	Adjusted for smoking
Childhood cancer								
Olsen *et al.* (1991) (Denmark)	Population-based	Laundry and dry cleaner owners	M/F	1721/8340	6/8	3.7	[1.1–12]	Data relate to mothers' exposure

CI, confidence interval; NR, not reported; M, male; F, female

[a]Siemiatycki (1991) studied 21 cancer sites; for each site, patients with other cancers served as controls

[b]≥ 5 years before disease onset

[c]≥ 10 years employment, ≥ 5 years before disease onset

[d]The first four studies involved cases and population controls from the National Bladder Cancer study of the United States National Cancer Institute. There was some overlap between the studies, which had different inclusion criteria, as noted.

3. Other Data Relevant to an Evaluation of Carcinogenicity and its Mechanisms

3.1 Absorption, distribution, metabolism and excretion in humans

Studies of the toxicokinetics of tetrachloroethylene are described in the relevant monograph (this volume).

3.2 Toxic effects in humans

Slight renal changes have been reported in workers exposed to tetrachloroethylene in dry cleaning shops in several studies. In a multi-centre cross-sectional investigation in several European countries, of nine men and 41 women (mean age, 41 years; range, 17–65) who had an average of 10 years of exposure to tetrachloroethylene (median air concentration, 15 ppm [102 mg/m^3]), high-relative-molecular-mass proteinuria and increased release of laminin fragments, fibronectin and glycosaminoglycans indicated slight nephrotoxicity. In addition, shedding of epithelial membrane components from tubular cells into the urine was observed. No such renal changes were observed in 50 blood donors matched by sex, age, smoking habits, alcohol consumption and use of medication. The presence of several other possible markers of renal damage, including urinary retinol-binding protein and β_2-microglobulin, was not increased (Mutti *et al.*, 1992). [The Working Group noted that the period of employment was not taken into consideration.]

Biochemical markers of kidney damage were studied in 16 female dry cleaning workers in the former Czechoslovakia who were chronically exposed to tetrachloroethylene and compared with those in 13 women with only administrative functions and no known exposure to organic solvents. The concentration of tetrachloroethylene in the breathing zone of the dry cleaning workers was 157 mg/m^3 (time-weighted average exposure; range, 9–799 mg/m^3). Urinary excretion of lysozyme was 0.15 mg/g creatinine (range, 0–1.49) in the controls and 0.56 mg/g creatinine (range, 0–4.16) in the 16 exposed subjects, whereas there were no differences in the urinary excretion of albumin, β_2-microglobulin, lactate dehydrogenase, total protein or glucose. Moreover, no correlation was observed between the level of tetrachloroethylene in air and biochemical parameters of renal function (Vyskocil *et al.*, 1990).

In contrast, several other studies found no relationship between exposure to tetrachloroethylene in dry cleaning and renal damage. Solet and Robins (1991) obtained histories of exposure and medical conditions and samples of urine and breath from 192 dry cleaning workers in the United States. No association was found between exposure and parameters indicative of renal damage. In a study of 22 subjects exposed to tetrachloroethylene in six dry cleaning shops in Belgium (Lauwerys *et al.*, 1983), exposure was assessed by monitoring air in the breathing zone, by urinary analysis for trichloroacetic acid and by analysis of expired air and venous blood for tetrachloroethylene. The results were compared with those for 33 subjects who were not occupationally exposed to organic solvents. The time-weighted average exposure to tetrachloro-

ethylene was 21 ppm [142 mg/m^3] (range, 9–38 ppm [61.0–258 mg/m^3]). The urinary concentrations of albumin, β_2-microglobulin and retinol-binding protein were similar in the exposed and control workers.

3.3 Reproductive and prenatal effects in humans

3.3.1 Endocrine and gonadal effects

In a small study on the association between dry cleaning work and menstrual disorders, 592 women involved in dry cleaning or laundry work in the Netherlands received a postal questionnaire; 471 (80%) responded, of whom 72 were excluded because of current pregnancy or lactation, chronic illness or gynaecological surgery. Of the remaining 399, 193 were potentially exposed to tetrachloroethylene and 206 were unexposed. Only the 68 exposed and 76 unexposed women who did not use oral contraceptives were included in the analysis. The mean length of the cycle was the same in the two groups, but virtually all of the menstrual disorders seen in exposed women occurred more frequently than in the reference group, the increase being significant for premenstrual syndrome (odds ratio, 3.6 [95% CI, 1.3–10]), menorrhagia (3.0 [1.4–6.3]) and dysmenorrhea (1.9 [1.0–3.8]) (Zielhuis *et al.*, 1989). [The main drawbacks of this study are its small sample size, the use of a postal questionnaire and the lack of exposure measurements; however, the two groups were investigated in the same way and had similar working conditions, except for potential exposure to tetrachloroethylene.]

The semen quality of 34 dry cleaners was compared with that of 48 laundry workers who were members of the Laundry and Dry Cleaners Union in the San Francisco Bay area and Greater Los Angeles, CA, United States (Eskenazi *et al.*, 1991a). Sperm concentrations and the overall percentage of abnormal forms were similar in the two groups. Sperm heads of dry cleaners had significantly more round forms, fewer narrow forms and showed greater amplitude of lateral head displacement and less linearity in the sperm swimming paths. These subtle effects on sperm quality were related to measures of exposure to tetrachloroethylene; it was not established whether these changes affected fertility.

3.3.2 Fertility

In a study of the effects of occupational exposures on fertility, 1069 infertile couples treated in hospital and resident on the island of Funen, Denmark, were compared with 4305 fertile couples. Occupational exposures, sociodemographic data and medical histories were obtained by postal questionnaires from 927 case and 3728 control couples (about 87% of the original sample), and associations with exposure to 18 groups of agents were tested. A significant association was reported between exposure to 'dry cleaning chemicals' and the risk for idiopathic infertility among women (odds ratio, 2.7; 95% CI, 1.0–7.1; adjusted for woman's age, education, residence and parity). Significant associations were also reported (but not quantified) between work as a dry cleaner and sperm abnormalities, hormonal disturbance in women and delay of conception for more than one year (Rachootin & Olsen, 1983).

The reproductive outcomes of the wives of 17 men working in dry cleaning were compared with those of the wives of 32 laundry workers who were not exposed to dry cleaning fluids. The mean number of pregnancies was 2.1 in both groups, and the rates of spontaneous abortion were

not significantly different (11.1% for dry cleaners' wives and 15.2% for laundry workers' wives). The wives of dry cleaners were more than twice as likely to have a history of delayed conception for more than 12 months or to have sought care for an infertility problem. The ratio of the pregnancy rate per cycle for wives of dry cleaning workers to that for the comparison group was 0.54 (95% CI, 0.23–1.27) (Eskenazi *et al.*, 1991a,b). [The power of this study is obviously limited.]

3.3.3 Pregnancy

(a) Spontaneous abortion

In a survey in Finland, hospital discharge records were used to analyse the effects of parental occupations and exposures, obtained from census data, on the prevalence of spontaneous abortion. A total of 294 309 pregnancies were considered between 1973 and 1976; 416 occurred among dry cleaning and laundry workers. This group was found to have a higher rate of spontaneous abortions than other service workers (odds ratio, 1.5; 95% CI, 1.1–2.0; adjusted for age, place of residence and parity) (Lindbohm *et al.*, 1984).

A nested case–control study was conducted in Finland within a cohort of 5700 women who had been identified from union files and employers as dry cleaning or laundry workers between 1973 and 1983. They had experienced a total of 3279 pregnancies. One pregnancy per woman was randomly selected for analysis, and 243 cases of spontaneous abortion were identified from hospital discharge data; 680 age-matched controls were selected. A questionnaire was mailed to all subjects; the response rate was 68.3% for cases and 80.4% for controls. A total of 130 women who had had a spontaneous abortion and 289 controls reported the pregnancy under study, and the corresponding exposures were included in the analysis. Dry cleaning was associated with an increased risk for spontaneous abortion (odds ratio, 4.9; 95% CI, 1.3–20) and appeared to be closely related to exposure to tetrachloroethylene (Kyyrönen *et al.*, 1989).

In the Nordic countries (Denmark, Finland, Norway and Sweden), a common protocol was used in order to study reproductive outcomes among dry cleaning workers (Olsen *et al.* 1990). More than 18 000 women who had worked for at least one month between 1973 and 1983 in a laundry or dry cleaning establishment were enrolled in the cohort. All data related to their pregnancies were obtained from hospital registries, and exposure histories were collected by interview or postal questionnaire or from employers, depending on the country. The analysis of spontaneous abortions did not include data from Norway. Data on 159 women who had had a spontaneous abortion were compared with those on 436 controls within the cohort, matched for mother's age, year of pregnancy and parity (except in the Finnish study). The combined odds ratio for spontaneous abortion, adjusted for parity, smoking and drinking habits, was 1.2 (95% CI, 0.74–1.9) in the group considered to have had low exposure and 2.9 (95% CI, 0.98–8.4) in the group with high exposure (dry cleaning or spot removal for at least 1 h per day during the first trimester of pregnancy). [The Working Group noted that 118 of the 159 spontaneous abortions included in the combined study occurred in Finland. The results of the Finnish study are those reported by Kyyrönen *et al.* (1989).]

In Montréal (Québec, Canada), 56 012 women were interviewed in 11 obstetrical units over two years, after delivery (51 885) or after a spontaneous abortion (4127). Associations between

spontaneous abortion (at the time of interview or previously) and occupations during pregnancy were studied in relation to 100 current and 123 previous pregnancies among women who had worked in laundries and dry cleaning shops. After adjustment for maternal age, parity, history of previous abortion, smoking habits and highest educational level reached, the odds ratios for spontaneous abortion were 1.2 (eight observed) for current pregnancies and 1.0 (31 observed) for previous pregnancies (McDonald *et al.*, 1986).

All 67 women working in 53 dry cleaning shops in two large neighbourhoods in Rome, Italy, were interviewed about their work and obstetrical history. Exposure to dry cleaning solvents (mostly tetrachloroethylene) was evaluated by the presence of trichloroacetic acid in 24-h urine samples. Of the 56 pregnancies that occurred during employment in dry cleaning, five ended in spontaneous abortion, whereas of the 46 pregnancies of women who were not working outside the home, one ended in spontaneous abortion (χ^2, 3.05; $p < 0.10$) (Bosco *et al.*, 1987).

(b) Stillbirths, congenital malformations, low birth weight

In the study in Montréal described above (McDonald *et al.*, 1987), three stillbirths (observed/expected, 1.86), nine cases of congenital defects (observed/expected, 1.41) and 15 infants with low birth weight (≤ 2500 g) (observed/expected, 1.7) were seen. None of the results was significant.

In the study of Kyyrönen *et al.* (1989), described above, 24 cases of malformations in infants of dry cleaning and laundry workers were compared with 93 cases in controls. Dry cleaning was not associated with an excess of congenital malformations.

In the Nordic study described above (Olsen *et al.*, 1990), there were 13 stillbirths, 38 cases of congenital malformations and 13 infants with low birth weights (< 1500 g). The odds ratio for these three outcomes combined was 1.7 (95% CI, 0.40–7.1) in association with low exposure and 0.87 (95% CI, 0.20–3.7) for high exposure.

[Most of the studies on outcomes other than spontaneous abortions are obviously limited by small numbers.]

3.4 Genetic and related effects in humans

3.4.1 Alkaline-labile sites/DNA single-strand breaks

No differences in DNA alkaline elution rates (indicating alkali-labile sites/single-strand breaks in DNA) were seen in peripheral lymphocytes from 16 female dry cleaners and from 18 control women in Germany; both groups were smokers. The dry cleaners were reported to have been exposed mainly to tetrachloroethylene, and in some of the facilities the workers were exposed to 'high levels of tetrachloroethylene as evidenced by the smell in the rooms where they worked with no visible signs of protection'. No data on exposure were available (Doerjer *et al.*, 1988).

3.4.2 Urinary mutagenicity

The microfluctuation assay with *Salmonella typhimurium* TA98 and exogenous metabolic activation was used to study the mutagenicity of the urine of 35 dry cleaners (number of

nonsmokers not reported) and eight controls. Concentrations of 1–1518 μg/L tetrachloroethylene and 181–320 μg/L fluorohydrocarbons were measured in blood (Kouros *et al.*, 1989). [No evaluation was possible, owing to the limited reporting of the study.]

A significant correlation ($r = 0.84$) was found between the tetrachloroethylene content of air and urinary mutagenicity (assayed in *Salmonella typhimurium* TA100 and TA98) in 24 Estonian dry cleaners (Pruul, 1992). [No evaluation was possible, owing to the limited reporting of the study, including the absence of information on smoking.]

3.4.3 Cytogenetic damage in lymphocytes

Sister chromatid exchange was studied in peripheral lymphocytes from 14 male and 13 female dry cleaners, 12 male and 14 female clerks and an expanded control group of 21 men and 23 women in Japan. The workers had been exposed to a geometric mean, 8-h time-weighted average concentration of tetrachloroethylene of 10 ppm [67.8 mg/m^3] (75th percentile, 27 ppm [183 mg/m^3]; maximum, 179 ppm [1214 mg/m^3]). An effect of exposure to tetrachloroethylene was reported in smoking men but not in nonsmoking women. This conclusion was based on a significant ($p < 0.05$) difference in the mean number of sister chromatid exchanges per cell in 12 exposed male smokers (5.91) from that in three control male nonsmokers (5.01). No difference was seen in comparison with nine nonsmoking men in the expanded control group (5.48) or with men in each control group (5.60; 5.70). No effect was seen in nonsmoking women (Seiji *et al.*, 1990). [The possible confounding effect of smoking was not accounted for.]

4. Summary and Evaluation

4.1 Exposure data

The process of cleaning fabrics with nonaqueous liquids is believed to have begun in France in 1825. The process has evolved into an industry called 'dry cleaning'. 'Camphene' (turpentine) was used initially; in the late 1800s, benzene, benzene soap, naphtha and gasoline began to be used. In the 1920s, Stoddard solvent (mineral spirits or white spirits) was introduced in the United States in order to minimize the fire hazards associated with use of the more volatile hydrocarbon-based solvents. Carbon tetrachloride, the first chlorinated solvent used for dry cleaning, was introduced because of the high cost of petroleum solvents and was widely used until the 1950s. Its use was discontinued because of its toxicity and corrosiveness. Trichloroethylene was introduced in the 1930s. It is still used to a limited extent in Europe and in industrial cleaning plants throughout the world, but it has had a limited market in dry cleaning in the United States because of its incompatibility with acetate dyes.

Use of tetrachloroethylene began to increase in the 1940s, and by the late 1950s it had virtually replaced carbon tetrachloride and trichloroethylene in commercial dry cleaning. Tetrachloroethylene is currently the solvent of choice in most of the world, except in regions, such as Japan, where petroleum-based solvents have remained important in the dry cleaning industry. In 1990, about 53% of the world demand for tetrachloroethylene was for dry cleaning,

and about 75% of all dry cleaners used it to clean garments. Chlorofluorocarbon solvents (especially CFC-113) were introduced for use in dry cleaning in the 1970s; however, because of environmental concerns, their use is declining rapidly.

It is estimated that several million people are employed in dry cleaning worldwide. The predominant route of exposure to the solvents used in dry cleaning is by inhalation, although skin absorption and ingestion may also occur. In addition, a wide range of chemicals are used in 'spotting' (treatment of spots); they include chlorinated solvents, amyl acetate, bleaching agents, acetic acid, aqueous ammonia, oxalic acid, hydrogen peroxide and dilute hydrogen fluoride solutions.

Improvements in equipment, solvent reclamation and engineering controls in the dry cleaning industry are resulting in decreasing occupational exposures to chlorinated solvents. The trend to use of 'dry-to-dry' machines, as opposed to the transfer process, has also resulted in reduced emissions and exposures. Typical average exposures to tetrachloroethylene in dry cleaning declined from about 350–700 mg/m^3 in the 1970s to 70–350 mg/m^3 in the late 1980s. The differences in airborne concentrations between dry cleaning shops are often many times greater than the differences in the exposures of machine operators and other staff within a shop.

4.2 Human carcinogenicity data

The relationship between employment in dry cleaning and the occurrence of cancer has been assessed in proportionate mortality studies, case–control studies and four cohort studies. Two cohort studies restricted to dry-cleaning workers in the United States were given greater weight in the evaluation than were the results of cohort studies of laundry and dry-cleaning workers (from Denmark and Sweden).

The relative risks for mortality from urinary bladder cancer were elevated in both United States cohorts (relative risks of 1.7 and 2.5, total of 17 deaths), with evidence in one of the studies of an increasing risk with increasing duration of employment. These results are consistent with those from case–control studies in the United States and in Canada and with the findings of a proportionate mortality study in the United States (although the Danish cohort study found no elevated incidence of bladder cancer) and do not appear to be due to confounding by cigarette smoking.

The relative risk for mortality from oesophageal cancer was elevated by a factor of two in both United States cohorts (23 observed deaths in the two studies combined) and increased with increasing duration and/or intensity of employment. This cancer also occurred in slight excess in a proportionate mortality study in the United Kingdom with respect to launderers, dry cleaners and pressers. Risk estimates for oesophageal cancer were not provided in either of the two Nordic studies of laundry and dry cleaning workers. While in a case–control study of oesophageal cancer in Montréal, Canada, none of the case subjects had worked in dry cleaning, the study was relatively small. The relative incidence of oesophageal cancer is increased by consumption of alcohol drinking and cigarette smoking, but potential confounding by these exposures could not be explored directly in these studies.

The relative risk for mortality from cancer of the pancreas was modestly increased in both United States cohort studies; however, this result was not confirmed in two North American case–control studies.

The occurrence of lung cancer was increased slightly in each of the four cohort studies. The mortality rate from lung cancer in the subgroup with long duration of employment and a long interval since first employment (in the one study that evaluated these characteristics) was not elevated. Two case–control studies in North America gave conflicting results.

The relative risk for mortality from cervical cancer was increased by 70–80% in the two United States cohort studies but not at all among Danish dry cleaning and laundry workers. Socioeconomic characteristics were not adjusted for in these studies.

While in a Swedish case–control study and in one of the United States cohort studies moderate increases were found in the relative risk for cancer of the colon in association with employment in dry cleaning, there was no suggestion of an increase in the risk for this form of cancer in the other relevant studies. Furthermore, in the United States cohort study, there was no particular accentuation of the increased risk in relation to increasing duration of employment.

The Danish cohort study of dry cleaning and laundry workers showed some increase in the incidence of cancers of both the liver and the gall-bladder; however, this result was not confirmed in the two United States cohort studies. The results of the case–control studies of liver cancer in the United States are conflicting.

There was a suggestion of an increased risk for non-Hodgkin's lymphoma in one of the two United States cohort studies (relative risk, 1.7, based on seven deaths) and in a large case–control study in the United States; however, no increase in risk for non-Hodgkin's lymphoma was observed in the other United States cohort study, in the Danish cohort study or in a case–control study from Montréal, Canada.

The results of the four cohort studies do not suggest an increase in the risk for cancer of the kidney, while the results of proportionate mortality studies in Wisconsin and Oklahoma and of the case–control studies from Canada, Denmark and the United States indicate an increase in risk associated with a history of work as a dry cleaner. It may be noteworthy that the petroleum solvents used for dry cleaning in Oklahoma are not typical of those used in much of the rest of the world.

Variation within individual studies of dry cleaners may depend on the nature and level of exposure, which varies from shop to shop and across studies of dry cleaning workers. There is also variation in the types of solvents used over time and across geographic regions. These limitations notwithstanding, the epidemiological studies on dry cleaning indicate that the risks for cancers at two sites, urinary bladder and oesophagus, may be increased by employment in dry cleaning.

4.3 Other relevant data

Inconsistent evidence of slight renal damage among workers exposed to tetrachloroethylene in dry cleaning shops was found in two studies, whereas two other studies in which exposure to tetrachloroethylene was at least as high did not find such an association.

Disturbances of sperm quality and fertility have been observed among dry cleaning workers in a few studies of limited size. Several studies performed in Nordic countries have shown a consistent increase in the risk for spontaneous abortion among dry cleaners, but the studies are not entirely independent of each other. No effect has been observed on other reproductive outcomes, such as stillbirth, congenital malformation or low birth weight, but the power of the studies was limited.

In single studies, lymphocytes from dry cleaning workers showed no increase in the frequency of alkaline-labile sites/DNA single-strand breaks. There was inadequate information to evaluate the genetic effects in humans of exposures in dry cleaning.

4.4 Evaluation[1]

There is *limited evidence* in humans for the carcinogenicity of occupational exposures in dry cleaning.

Overall evaluation

Dry cleaning entails exposures that *are possibly carcinogenic to humans (Group 2B).*

6. References

Aggazzotti, G., Fantuzzi, G., Righi, E., Predieri, G., Gobba, F.M., Paltrinieri, M. & Cavalleri, A. (1994) Occupational and environmental exposure to perchloroethylene (PCE) in dry cleaners and their family members. *Arch. environ. Health*, **49**, 487–493

Anon. (1991) A close look at dry cleaning shops. *Manuel tech. Nettoyeur Sec*, **111**, 4–11 (in French)

Asal, N.R., Geyer, J.R., Risser, D.R., Lee, E.T., Kadamani, S. & Cherng, N. (1988) Risk factors in renal cell carcinoma. II. Medical history, occupation, multivariate analysis, and conclusions. *Cancer Detect. Prevent.*, **13**, 263–279

Austin, H., Delzell, E., Grufferman, S., Levine, R., Morrison, A.S., Stolley, P.D. & Cole, P. (1987) Case–control study of hepatocellular carcinoma, occupation, and chemical exposures. *J. occup. Med.*, **29**, 665–669

Blair, A., Decoufle, P. & Grauman, D. (1979) Causes of death among laundry and dry cleaning workers. *Am. J. public Health*, **69**, 508–511

Blair, A., Tolbert, P., Thomas, T. & Grauman, D. (1986) Mortality among dry cleaners (Abstract). *Med. Lav.*, **77**, 82–83

Blair, A., Stewart, P.A., Tolbert, P.E., Grauman, D., Moran, F.X., Vaught, J. & Rayner, J. (1990) Cancer and other causes of death among a cohort of dry cleaners. *Br. J. ind. Med.*, **47**, 162–168

[1]For definitions of the italicized terms, see pp. 22–26. For separate evaluations of the carcinogenic risk to humans of some of the solvents used in dry cleaning, see this volume, pp. 75 and 159 and IARC (1987a–e, 1989).

Blair, A., Linos, A., Stewart, P.A., Burmeister, L.F., Gibson, R., Everett, G., Schuman, L. & Cantor, K.P. (1992) Comments on occupational and environmental factors in the origin of non-Hodgkin's lymphoma. *Cancer Res.*, **52** (Suppl.), 5501s–5502s

Blair, A., Linos, A., Stewart, P.A., Burmeister, L.F., Gibson, R., Everett, G., Schuman, L. & Cantor, K.P. (1993) Evaluation of risks for non-Hodgkin's lymphoma by occupation and industry exposures from a case–control study. *Am. J. ind. Med.*, **23**, 301–312

Blattner, W.A., Strober, W., Muchmore, A.V., Blaese, R.M., Broder, S. & Fraumeni, J.F., Jr (1976) Familial chronic lymphocytic leukemia. Immunologic and cellular characterization. *Ann. intern. Med.*, **84**, 554–557

Boillat, M.-A., Berode, M. & Droz, P.-O. (1986) Surveillance of workers exposed to tetrachloroethylene or styrene. *Soz. Präventivmed.*, **31**, 260–262 (in French)

Bosco, M.G., Figà-Talamanca, I. & Salerno, S. (1987) Health and reproductive status of female workers in dry-cleaning shops. *Int. Arch. occup. environ. Health*, **59**, 295–301

Brown, D.P. & Kaplan, S.D. (1987) Retrospective cohort mortality study of dry cleaner workers using perchloroethylene. *J. occup. Med.*, **29**, 535–541

Brownson, R.C., Alavanja, M.C.R. & Chang, J.C. (1993) Occupational risk factors for lung cancer among nonsmoking women: a case–control study in Missouri (United States). *Cancer Causes Control*, **4**, 449–454

Burr, G.A. & Todd, W. (1986) *Dutch Girl Cleaners, Springdale, OH* (HETA 86-005-1679), Cincinnati, OH, United States National Institute for Occupational Safety and Health

Cai, S.-X., Huang, M.-Y., Chen, Z., Liu, Y.-T., Jin, C., Watanabe, T., Nakatsuka, H., Seiji, K., Inoue, O. & Ikeda, M. (1991) Subjective symptom increase among dry-cleaning workers exposed to tetrachloroethylene vapor. *Ind. Health*, **29**, 111–121

Cantin, J. (1992) Overview of exposure pathways. In: *Proceedings, International Roundtable on Pollution Prevention and Control in the Drycleaning Industry, May 27–28, 1992, Falls Church, VA* (EPA/774R-92/002), Springfield, VA, National Technical Information Service, pp. 5–11

Center for Chemical Hazard Assessment (1985) *Monographs on Human Exposure to Chemicals in the Workplace: Tetrachloroethylene* (NIOSH Report No. 00167179); SCR TR 84-629), Bethesda, MD, United States National Cancer Institute

Davezies, P., Briant, V., Bergeret, A., Eglizeau, M. & Prost, G. (1983) Study of working conditions in the dry-cleaning business. *Arch. Mal. prof.*, **44**, 159–165 (in French)

Doerjer, G., Buchholz, U., Kreuzer, K. & Oesch, F. (1988) Biomonitoring of DNA damage by alkaline filter elution. *Int. Arch. occup. environ. Health*, **60**, 169–174

Douglas, V., Eli, A., Kemena, R., Marvin, C., McLaughlin, C., Vincent, R. & Woodhouse, L. (1993) *Proposed Airborne Toxic Control Measure and Proposed Environmental Training Program for Perchloroethylene Dry Cleaning Operations*, Sacramento, CA, California Environment Protection Agency

Duh, R.-W. & Asal, N.R. (1984) Mortality among laundry and dry cleaning workers in Oklahoma. *Am. J. public Health*, **74**, 1278–1280

Earnest, G.S. (1994) *Widmers Dry Cleaners, Cincinnati, OH (Health Hazard Evaluation Report)*, Cincinnati, OH, United States National Institute for Occupational Safety and Health

Earnest, G.S., Smith, S.S. & Song, R. (1994) *Control of Chemical Exposures and Ergonomic Risk Factors in Commercial Dry Cleaners* (Report No. ECTB 201-03), Cincinnati, OH, United States National Institute for Occupational Safety and Health

Eddleston, M.T. & Polakoff, P.L. (1974) *Swiss Cleansing Co., Providence, RI* (HHE Report No. 73-86-114; NTIS PB, 232-742), Cincinnati, OH, United States National Institute for Occupational Safety and Health

Edmondson, G.K. & Palin, M.J. (1993) *Occupational Exposure to Perchloroethylene in the UK Drycleaning Industry*, Harrogate, North Yorkshire, Fabric Care Research Association

Eskenazi, B., Wyrobek, A.J., Fenster, L., Katz, D.F., Sadler, M., Lee, J., Hudes, M. & Rempel, D.M. (1991a) A study of the effect of perchloroethylene exposure on semen quality in dry-cleaning workers. *Am. J. ind. Med.*, **20**, 575–591

Eskenazi, B., Fenster, L., Hudes, M., Wyrobek, A.J., Katz, D.F., Gerson, J. & Rempel, D.M. (1991b) A study of the effect of perchloroethylene exposure on the reproductive outcomes of wives of dry-cleaning workers. *Am. J. ind. Med.*, **20**, 593–600

Fredriksson, M., Bengtsson, N.-O., Hardell, L. & Axelson, O. (1989) Colon cancer, physical activity, and occupational exposures. A case–control study. *Cancer*, **63**, 1838–1842

Gallagher, R.P., Threlfall, W.J., Band, P.R. & Spinelli, J.J. (1989) *Occupational Mortality in British Columbia 1950–1984*, Vancouver, Cancer Control Agency of British Columbia

Grob, K., Artho, A. & Egli, J. (1991) Food contamination by perchloroethylene from the air: limits for the air rather than for foods! *Mitt. Geb. Lebensm. Hyg.*, **82**, 56–65 (in German)

Gulyas, H. & Hemmerling, L. (1990) Tetrachloroethylene air pollution originating from coin-operated dry cleaning establishments. *Environ. Res.*, **53**, 90–99

Guralnick, L. (1963) *Mortality by Occupation and Cause of Death among Men 20 to 64 Years of Age: United States 1950. Vital Statistics* (Special Reports 53, No. 3), Washington DC, United States Department of Health, Education, and Welfare

Hayashi, M., Kitazume, M., Yazawa, A., Sato, Y. & Kawamura, T. (1990) Investigation of the health effects associated with solvents used in dry cleaning workplace. Report 2: Personal exposure to tetrachloroethylene (TCE) and TCE levels in man. *Nippon Koshu Eisei Zasshi*, **37**, 177–185 (in Japanese)

Huebner, W.W., Schoenberg, J.B., Kelsey, J.L., Wilcox, H.B., McLaughlin, J.K., Greenberg, R.S., Preston-Martin, S., Austin, D.F., Stemhagen, A., Blot, W.J., Winn, D.M. & Fraumeni, J.F., Jr (1992) Oral and pharyngeal cancer and occupation: a case–control study. *Epidemiology*, **3**, 300–309

IARC (1987a) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Suppl. 7, *Overall Evaluations of Carcinogenicity: An Updating of* IARC Monographs *Volumes 1–42*, Lyon, pp. 120–122

IARC (1987b) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Suppl. 7, *Overall Evaluations of Carcinogenicity: An Updating of* IARC Monographs *Volumes 1–42*, Lyon, pp. 152–154

IARC (1987c) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Suppl. 7, *Overall Evaluations of Carcinogenicity: An Updating of* IARC Monographs *Volumes 1–42*, Lyon, pp. 143–144

IARC (1987d) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Suppl. 7, *Overall Evaluations of Carcinogenicity: An Updating of* IARC Monographs *Volumes 1–42*, Lyon, p. 64

IARC (1987e) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Suppl. 7, *Overall Evaluations of Carcinogenicity: An Updating of* IARC Monographs *Volumes 1-42*, Lyon, p. 73

IARC (1989a) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Vol. 45, *Occupational Exposures in Petroleum Refining; Crude Oil and Major Petroleum Fuels*, Lyon, pp. 39–117

IARC (1989b) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Vol. 45, *Occupational Exposures in Petroleum Refining; Crude Oil and Major Petroleum Fuels*, Lyon, pp. 159–201

IARC (1989c) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Vol. 47, *Some Organic Solvents, Resin Monomers and Related Compounds, Pigments and Occupational Exposures in Paint Manufacture and Painting*, Lyon, pp. 43–77

IARC (1989d) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Vol. 47, *Some Organic Solvents, Resin Monomers and Related Compounds, Pigments and Occupational Exposures in Paint Manufacture and Painting*, Lyon, pp. 79–123

IARC (1989e) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, Vol. 47, *Some Organic Solvents, Resin Monomers and Related Compounds, Pigments and Occupational Exposures in Paint Manufacture and Painting*, Lyon, pp. 125–156

International Fabricare Institute (1987) Perchloroethylene vapor in dry cleaning plants. *Focus Dry Cleaning*, **11**, 1–17

Jalihal, S.S. & Barlow, A.M. (1984) Leukaemia in drycleaners (Letter to the Editor). *J. R. Soc. Health*, **104**, 42

Kaplan, S.D. (1980) *Dry Cleaners Workers Exposed to Perchloroethylene—A Retrospective Cohort Mortality Study* (PB81–231367), Springfield, VA, National Technical Information Service

Katz, R.M. & Jowett, D. (1981) Female laundry and dry cleaning workers in Wisconsin: a mortality analysis. *Am. J. public Health*, **71**, 305–307

Kawauchi, T. & Nishiyama, K. (1989) Residual tetrachloroethylene in dry-cleaned clothes. *Environ. Res.*, **48**, 296–301

Kerr, R.E. (1972) *Environmental Exposures to Tetrachloroethylene in the Dry-cleaning Industry*, M.S. Thesis, Cincinnati, OH, University of Cincinnati

Kirschner, E.M. (1994) Environment, health concerns force shift in use of organic solvents. *C&EN*, **20 June**, 13–20

Klein, P. & Kurz, J. (1994) *Untersuchung von Massnahmen zur Reduzierung der Lösemittelkonzentration in der Nachbarschaft von Textilreinigungen* [Study on preventive measures to reduce the concentration of solvents in the vicinity of textile cleaning shops], Bönnigheim, Hohenstein e.V. Physiological Institute on Clothing

Kouros, B.M., Böttger, A. & Dehnen, W. (1989) Investigations on correlation between thioether excretion and urinary mutagenicity in industrially exposed workers. *Zbl. Hyg.*, **189**, 125–134 (in German)

Kubota, J. (1992) Dry cleaning in Japan: current conditions and regulations. In: *Proceedings, International Roundtable on Pollution Prevention and Control in the Dry Cleaning Industry, May 27–28, 1992, Falls Church, VA* (EPA/774 R-92/002), Springfield, VA, United States National Technical Information Service, pp. 40–43

Kyyrönen, P., Taskinen, H., Lindbohm, M.-L., Hemminki, K. & Heinonen, O.P. (1989) Spontaneous abortions and congenital malformations among women exposed to tetrachloroethylene in dry-cleaning. *J. Epidemiol. Community Health*, **43**, 346–351

Lauwerys, R., Herbrand, J., Buchet, J.P., Bernard, A. & Gaussin, J. (1983) Health surveillance of workers exposed to tetrachloroethylene in dry-cleaning shops. *Int. Arch. occup. environ. Health*, **52**, 69–77

Linak, E., Leder, A. & Yoshida, Y. (1992) C_2 Chlorinated solvents. In: *Chemical Economics Handbook*, Menlo Park, CA, SRI International, pp. 632.3000–632.3002

Lindbohm, M.-L., Hemminki, K. & Kyyrönen, P. (1984) Parental occupational exposure and spontaneous abortions in Finland. *Am. J. Epidemiol.*, **120**, 370–378

Ludwig, H.R. (1981) *Occupational Exposure to Perchloroethylene in the Dry Cleaning Industry*, Cincinnati, OH, United States National Institute for Occupational Safety and Health

Ludwig, H.R., Meister, M.V., Roberts, D.R. & Cox, C. (1983) Worker exposure to perchloroethylene in the commercial dry cleaning industry. *Am. ind. Hyg. Assoc. J.*, **44**, 600–605

Lynge, E. (1994) Danish Cancer Registry as a resource for occupational research. *J. occup. Med.*, **36**, 1169–1173

Lynge, E. & Thygesen, L. (1990) Primary liver cancer among women in laundry and dry-cleaning work in Denmark. *Scand. J. Work Environ. Health*, **16**, 108–112

Mack, T.M., Peters, J.M., Yu, M.C., Hanisch, R., Wright, W.E. & Henderson, B.E. (1985) Pancreas cancer is unrelated to the workplace in Los Angeles. *Am. J. ind. Med.*, **7**, 253–266

Malker, H. & Weiner, J. (1984) Cancer environment register. Examples of use of register-based epidemiology in occupational health. *Arbete Hälsa*, **9**, 1–107 (in Swedish)

Materna, B.L. (1985) Occupational exposure to perchloroethylene in the dry cleaning industry. *Am. ind. Hyg. Assoc. J.*, **46**, 268–273

McCredie, M. & Stewart, J.H. (1993) Risk factors for kidney cancer in New South Wales. IV. Occupation. *Br. J. ind. Med.*, **50**, 349–354

McDonald, A.D., Armstrong, B., Cherry, N.M., Delorme, C., Diodati-Nolin, A., McDonald, J.C. & Robert, D. (1986) Spontaneous abortion and occupation. *J. occup. Med.*, **28**, 1232–1238

McDonald, A.D., McDonald, J.C., Armstrong, B., Cherry, N., Delorme, C., Nolin, A.D. & Robert, D. (1987) Occupation and pregnancy outcome. *Br. J. ind. Med.*, **44**, 521–526

McLaughlin, J.K., Malker, H.S.R., Stone, B.J., Weiner, J.A., Malker, B.K., Ericsson, J.L.E., Blot, W.J. & Fraumeni, J.F., Jr (1987) Occupational risks for renal cancer in Sweden. *Br. J. ind. Med.*, **44**, 119–123

Mellemgaard, A., Engholm, G., McLaughlin, J.K. & Olsen, J.H. (1994) Occupational risk factors for renal-cell carcinoma in Denmark. *Scand. J. Work Environ. Health*, **20**, 160–165

Michelsen, E.M. (1957) *Remembering the Years 1907–1957*, Silver Spring, MD, National Institute of Drycleaning

Milham, S., Jr (1992) *Occupational Mortality in Washington State 1950–1989*, Seattle, Washington State Department of Health

Missere, M., Giacomini, C., Gennari, P., Violante, F., Dallolio, L., Failla, G., Lodi, V. & Raffi, G. (1988) Evaluation of exposure to tetrachloroethylene in dry cleaning shops. *Med. Lav.*, **10**, 261–267 (in Italian)

Monster, A.C., Boersma, G. & Steenweg, H. (1979) Kinetics of tetrachloroethylene in volunteers; influence of exposure concentration and work load. *Int. Arch. occup. environ. Health*, **42**, 303–309

Mutti, A., Alinovi, R., Bergamaschi, E., Biagini, C., Cavazzini, S., Franchini, I., Lauwerys, R.R., Bernard, A.M., Roels, H., Gelpi, E., Rosello, J., Ramis, I., Price, R.G., Taylor, S.A., De Broe, M., Nuyts, G.D., Stolte, H., Fels, L.M. & Herbort, C. (1992) Nephropathies and exposure to perchloroethylene in dry-cleaners. *Lancet*, **340**, 189–193

Nakamura, K. (1985) Mortality patterns among cleaning workers. *Jpn. J. ind. Health*, **27**, 24–37

Office of Population Censuses and Surveys (1986) *Occupational Mortality—Decennial Supplement. 1979–80, 1982–83* (Series DS No.6), London, Her Majesty's Stationery Office

Olsen, J., Hemminki, K., Ahlborg, G., Bjerkedal, T., Kyyrönen, P., Taskinen, H., Lindbohm, M.-L., Heinonen, O.P., Brandt, L., Kolstad, H., Halvorsen, B.A. & Egenaes, J. (1990) Low birthweight, congenital malformations, and spontaneous abortions among dry-cleaning workers in Scandinavia. *Scand. J. Work Environ. Health*, **16**, 163–168

Olsen, J.H., de Nully Brown, P., Schulgen, G. & Møller Jensen, O. (1991) Parental employment at time of conception and risk of cancer in offspring. *Eur. J. Cancer*, **27**, 958–965

Pannier, R., Hübner, G. & Schulz, G. (1986) Results of biological exposure tests in connection with passive dosimetric measurements of ambient air concentrations in occupational exposure to tetrachloroethylene in dry-cleaning shops. *Z. ges. Hyg.*, **32**, 297–300 (in German)

Petreas, M.X., Rappaport, S.M., Materna, B.L. & Rempel, D.M. (1992) Mixed-exhaled air measurements to assess exposure to tetrachloroethylene in dry cleaners. *J. Exposure Anal. environ. Epidemiol.*, **Suppl. 1**, 25–39

Petrone, R.L. (1988) Cancer mortality among petroleum solvent exposed Oklahoma dry cleaners (Abstract). *Diss. Abstr. int.*, **48**, 1955-B

Pruul, R.K. (1992) The role of tetrachloroethylene on genetic system of dry-cleaning workers. *Gig. Sanit.*, **31**, 23–24 (in Russian)

Pryor, P. (1985) *Denver Laundry and Dry Cleaning, Denver, CO* (Health Hazard Evaluation Report No. 84-340-1606), Cincinnati, OH, United States National Institute for Occupational Safety and Health

Rachootin, P. & Olsen, J. (1983) The risk of infertility and delayed conception associated with exposures in the Danish workplace. *J. occup. Med.*, **25**, 394–402

Rantala, K., Riipinen, H. & Anttila, A. (1992) *Altisteet Työssä. 22. Halogeeni-hiilivedyt (Exposure at work. 22. Halogenated hydrocarbons)*, Helsinki, Finnish Institute of Occupational Health, Finnish Work Environment Fund

Reich, D.A. & Cormany, C.L. (1979) Dry cleaning. In: Mark, H.F., Othmer, D.F., Overberger, C.G., Seaborg, G.T. & Grayson, M., eds, *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd Ed., Vol. 8, New York, John Wiley & Sons, pp. 50–68

Rice, B. & Weinberg, J. (1994) *Dressed to Kill. The Dangers of Dry Cleaning and the Case for Chlorine-free Alternatives*, Washington DC, Greenpeace Pollution Probe

Ruder, A.M., Ward, E.M. & Brown, D.P. (1994) Cancer mortality in female and male dry-cleaning workers. *J. occup. Med.*, **36**, 867–874

Schoenberg, J.B., Stemhagen, A., Mogielnicki, A.P., Altman, R., Abe, T. & Mason, T.J. (1984) Case–control study of bladder cancer in New Jersey. I. Occupational exposures in white males. *J. natl Cancer Inst.*, **72**, 973–981

Seeber, A. (1989) Neurobehavioral toxicity of long-term exposure to tetrachloroethylene. *Neurotoxicol. Teratol.*, **11**, 579–583

Seiji, K., Jin, C., Watanabe, T., Nakatsuka, H. & Ikeda, M. (1990) Sister chromatid exchanges in peripheral lymphocytes of workers exposed to benzene, trichloroethylene, or tetrachloroethylene, with reference to smoking habits. *Int. Arch. occup. environ. Health*, **62**, 171–176

Shipman, A.J. & Whim, B.P. (1980) Occupational exposure to trichloroethylene in metal cleaning processes and to tetrachloroethylene in the dry cleaning industry in the UK. *Ann. occup. Hyg.*, **23**, 197–204

Siemiatycki, J. (1991) *Risk Factors for Cancer in the Workplace*, Boca Raton, FL, CRC Press

Silverman, D.T., Hoover, R.N., Albert, S. & Graff, K.M. (1983) Occupation and cancer of the lower urinary tract in Detroit. *J. natl Cancer Inst.*, **70**, 237–245

Silverman, D.T., Levin, L.I. & Hoover, R.N. (1989) Occupational risks of bladder cancer in the United States: II. Nonwhite men. *J. natl Cancer Inst.*, **81**, 1480–1483

Skender, L., Karacic, V., Prpic-Majic, D. & Kezic, S. (1986) Occupational exposure indicators to tetrachloroethylene in a dry-cleaning shop. In: Foa, V., Emmet, E.A., Maroni, M. & Colombi, A., eds, *Occupational and Environmental Chemical Hazards*, Chichester, Ellis Horwood, pp. 192–196

Smith, E.M., Miller, E.R., Woolson, R.F. & Brown, C.K. (1985) Bladder cancer risk among laundry workers, dry cleaners, and others in chemically-related occupations. *J. occup. Med.*, **27**, 295–297

Solet, D. & Robins, T.G. (1991) Renal function in dry cleaning workers exposed to perchloroethylene. *Am. J. ind. Med.*, **20**, 601–614

Solet, D., Robins, T.G. & Sampaio, C. (1990) Perchloroethylene exposure assessment among dry cleaning workers. *Am. ind. Hyg. Assoc. J.*, **51**, 566–574

Stemhagen, A., Slade, J., Altman, R. & Bill, J. (1983) Occupational risk factors and liver cancer. A retrospective case–control study of primary liver cancer in New Jersey. *Am. J. Epidemiol.*, **117**, 443–454

Stricoff, R.S. (1983) *Control of Occupational Health Hazards in the Dry Cleaning Industry. Instructor's Guide* (DHHS (NIOSH) Publ. No. 82-1876), Cincinnati, OH, United States National Institute for Occupational Safety and Health

Suarez, L., Weiss, N.S. & Martin, J. (1989) Primary liver cancer death and occupation in Texas. *Am. J. ind. Med.*, **15**, 167–175

Takeuchi, Y., Hisanaga, N., Ono, Y., Iwata, M., Oguri, S., Tauchi, T. & Tanaka, T. (1981) An occupational health survey on dry cleaning workers. *Jpn. J. ind. Health*, **23**, 407–418 (in Japanese)

van der Tuin, J. (1979) *Perchloroethylene in a Dry Cleaning Service* (Report F1647), Rijswyk, Institute of Environmental Hygiene and Health Engineering/Dutch Organization for Applied Research (in Dutch)

van der Tuin, J. & Hoevers, W. (1977a) *Perchloroethylene in a Dry Cleaning Service* (Report F1560), Rijswyk, Institute of Environmental Hygiene and Health Engineering/Dutch Organization for Applied Research (in Dutch)

van der Tuin, J. & Hoevers, W. (1977b) *Perchloroethylene in a Dry Cleaning Service* (Report F1590), Rijswyk, Netherlands, Institute of Environmental Hygiene and Health Engineering/Dutch Organization for Applied Research (in Dutch)

Tuttle, T.C., Wood, G.D. & Grether, C.B. (1977) *A Behavioral and Neurological Evaluation of Dry Cleaners Exposed to Perchloroethylene* (DHEW (NIOSH) Publ. No. 77-214), Cincinnati, OH, United States National Institute for Occupational Safety and Health

United States Environmental Protection Agency (1991a) *Economic Impact Analysis of Regulatory Controls in the Dry Cleaning Industry* (EPA 450/3-91-021; PB 92-126770), Research Triangle Park, NC, Office of Air Quality Planning and Standards

United States Environmental Protection Agency (1991b) *Dry Cleaning Facilities—Background Information for Proposed Standards* (EPA 450/3-91-020a), Research Triangle Park, NC, Office of Air Quality Planning and Standards

United States Environmental Protection Agency (1991c) National emission standards for hazardous air pollutants for source categories: perchloroethylene emissions from dry cleaning facilities. Proposed rule and notice of public hearing. *Fed. Reg.*, **56**, 64382–64402

United States National Institute for Occupational Safety and Health (1981) *NIOSH National Occupational Health Survey: Written Communication* (IWSB-071.25-0.71.54), Cincinnati, OH, US Department of Health and Human Services, Public Health Service, Centers for Disease Control

Vieths, S., Blaas, W., Fischer, M., Krause, C., Matissek, R., Mehlitz, I. & Weber, R. (1988) Contamination of foodstuffs by emissions from dry cleaning units. *Z. Lebensm. Unters.-Forsch.*, **186**, 393–397 (in German)

Vyskocil, A., Emminger, S., Tejral, J., Fiala, Z., Ettlerova, E. & Cermanová, A. (1990) Study on kidney function in female workers exposed to perchloroethylene. *Hum. exp. Toxicol.*, **9**, 377–380

Zielhuis, G.A., Gijsen, R. & van der Gulden, J.W.J. (1989) Menstrual disorders among dry-cleaning workers (Letter to the Editor). *Scand. J. Work Environ. Health*, **15**, 238