OCCUPATIONAL EXPOSURE AS A PAINTER

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1. Exposure Data

1.1 Description of paint products

1.1.1 *Introduction*

The term *organic coating* encompasses conventional paints, varnishes, enamels, lacquers, water-emulsion and solution finishes, nonaqueous dispersions (organosols), plastisols, and powder coatings. The following definitions have been used commonly, although not always in a consistant manner (IARC, 1989a; Stoye & Freitag, 1998; Brock *et al.*, 2000; Goldschmidt & Streitberger, 2002). Glossaries for short explanations of paint and painting terms are available on the internet (e.g. www.occa.org.za/paintopedia/glossary.htm # Sect. S).

Paint is a suspension of finely divided pigment particles in a liquid composed of a binder (resin) and a volatile solvent or water, normally with additives to impart special characteristics. The volatile components evaporate from the drying film after application, while the binder holds the pigment in the dry film, causing it to adhere to the substrate. Some high quality, hard gloss paints are referred to as enamels.

Lacquer is defined as a coating that dries primarily by evaporation rather than by oxidation or polymerization. Because the solvents or water used in lacquers are relatively volatile and no chemical change is required for formation of the film, lacquers dry very rapidly.

Varnish is defined as a homogeneous, transparent or translucent liquid that is converted to a solid transparent film after being applied as a thin layer.

The basic components of paints vary widely in terms of chemical composition, depending on the colour, durability, and other properties required from the paint. Table 1.1 lists the main substances and classes of substances present in paints and to which workers may be exposed in the painting trades.

At the time of writing, solvent-borne paints contain much less solvent (high-solids paints) and less hazardous solvents than a decade ago. Sometimes, the solvent content is reduced to such an extent that volatile organic compounds (VOCs) emission levels are similar to those of waterborne paints.

Waterborne paints are used for private end consumers, as well as in several industries, including:

- the construction industry, for interior and exterior decoration
- the metal industry,
- the wood industry, including the furniture-making industry,
- the car industry, and
- the plastics industry.

Research and development for higher performance focuses on faster drying, and decrease of the residual solvents used in formulation. In countries where the ambiant air temperature is high together with elevated air humidity, waterborne paints are less convenient because of their very slow drying time. In these environments, high-solids paints or powder coatings are preferred.

The quality of powder coatings has much improved since their introduction, and now often reaches that of conventional paints. Future developments will allow their application onto heat-sensitive substrates such as wood-fibre plates or plastics.

1.1.2 *Pigments and extenders (fillers)*

Pigments can be classified as (i) inorganic, and (ii) organic pigments (Bentley & Turner, 1998; Stoye & Freitag, 1998; Brock *et al.*, 2000; Smith, 2002). They can also be classified into whites, colours, and effect pigments. Pigments are generally added in considerable proportion (3–60% by weight) to paint formulations and are used to provide colour, opacity, and sheen. They also affect the viscosity, flow, toughness, durability, and other physical or chemical properties of the coating, such as corrosion protection. The physical properties of pigments (particle shape and size) vary; the diameter of pigment particles is mostly <3 μm, and for special performance up to 15 or 20 μm. The particles in dry pigment powders are 0.5–10 μm in diameter (Oyarzún, 2000).

Dyes (soluble in paint medium, unlike pigments) are used only in very few instances or products because they provide much less long-term stability against light and other influences. Examples of use are the extremely transparent wood stains (see 1.3.2) (Zollinger & Iqbal, 2003), and the limited use of transparent colorants in automotive clear coats for special effects in Japan (Streitberger & Dössel, 2008).

Hazardous pigments and fillers, especially chromate- or lead-based products, are being increasingly replaced even though many of the new products possess lower performance in coloristics, corrosion protection or mechanical properties of paint layers. The speed and type of changes depends mainly on local legislation, costs, suitability and simplicity of substituting for the newer products. Many paint systems for industrial or individual use are

free of lead and chromate, especially in western Europe, but the situation is extremely heterogeneous across countries worldwide.

Besides nanoparticle-based pigments (see below), new colour-effect pigments are being developed, such as interfering mica pigments, liquid-crystal pigments, inorganic or organic pigments with better performance in colour or stability, and corrosion-protection pigments with better corrosion effects for chromate substitution. New fillers with better mechanical properties are also being formulated and produced.

(a) Inorganic pigments and fillers

Inorganic pigments are an integral part of numerous decorative, protective and functional coating systems, as found in automobile finishes, marine paints, industrial coatings, traffic paints, maintenance paints, and exterior and interior oil, alkyd and latex house paints. Inorganic pigments belong to several different chemical classes, i.e. primary elements, oxides, carbonates, chromates, phosphates, sulfides and silicates (Brock *et al.*, 2000; Smith, 2002; Buxbaum & Pfaff, 2005).

Many forms of lead have been used for over 200 years in pigments including: carbonate (white lead), oxides (litharge, red lead), sulfate, oxychloride (Turner's yellow), acetate, borate, and chromates (IARC, 2006a). During the last few decades, they have been substituted to a large extent by organic pigments or lead-free inorganic pigments. Alternatives to lead are the very resistant and insoluble mixed-phase oxide pigments such as nickel (or chromium) titanium yellow ($NiO.Sb_2O_5.20TiO_2$), and bismuth vanadate (BiO_4V^{-5}). New oxide pigments include the spinel-structured cobalt blue $Co(Al,Cr)_2O_4$ and cobalt green $(Co,Ni,Zn)_2(Ti,Al)O_4$ (Winkler, 2003; Buxbaum & Pfaff, 2005).

Zinc chromate was widely employed to protect against rust formation on all sorts of equipment until recently (Buxbaum & Pfaff, 2005). Currently, its use is restricted to a few applications such as in primer formulations for airplanes. Other chromium pigments that had been used in paint for many years included lead chromates, barium chromate and chromium oxide (see IARC, 1990). Cadmium sulfide, cadmium sulfoselenide and antimony trioxide are now substituted with various grades of naturally occurring, or synthetic, ferric oxide which provide yellow, red and brown pigments (Buxbaum & Pfaff, 2005).

Today, the most common pigment employed in paint is the white pigment titanium dioxide, TiO_2 (IARC, 2010a), produced in two different crystal forms – rutile and anatase – with distinct colour properties. The rutile crystal structure has an almost 25% greater opacity than the anatase form. Because of its chemical inertness, extreme whiteness, excellent covering power and lack of toxicity compared to white lead, titanium dioxide is the dominant component in the manufacture of white paint, and represents 90% of all pigments on the market worldwide. Lithopone, a coprecipitate of 28–30% zinc sulfide and 70–72% barium sulfate (Buxbaum & Pfaff, 2005) introduced before the First World War, is hardly ever used any more.

Table 1.1 Main substances (and classes of substances) which workers may be exposed to in the painting trades[a]

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Acrylates (e.g., ethyl acrylate, methyl methacrylate)	Acrylic resins, ultraviolet curing paints	Ethyl acrylate Acrylic acid Methyl acrylate Methyl methacrylate	IARC (1999a) IARC (1999a) IARC (1999a) IARC (1999a)	2B 3 3 3
Acrylic resins	Binders	As above		
Alcohols, aliphatic (e.g., methanol, isopropanol, *n*-butanol)	Solvents (lacquers), paint removers	Methanol Ethanol Isopropanol *n*-Butanol	– – IARC (1999a) –	– – 3 –
Alkalis (e.g., sodium hydroxide, potassium hydroxide)	Paint removers	–	–	–
Alkyd resins	Binders	–	–	–
Aluminium, powder	Pigment	–	–	–
Amides, aliphatic (e.g., dimethylformamide)	Solvents	Dimethylformamide	IARC (1999a)	2A
Amines (mono), aliphatic (e.g., diethylamine) and alkanolamines (e.g., 2-amino-2-methyl-1-propanol)	Water-based paints	Triethanolamine	IARC (2000)	3
Amines (poly), aliphatic (e.g., diethylenetriamine)	Curing agents (epoxy resins)	–	–	–
Amines, aromatic (e.g., *meta*-phenylenediamine, 4,4-methylenedianiline)	Curing agents (epoxy resins)	*meta*-Phenylenediamine 4,4-Methylenedianiline	IARC (1987) IARC (1987)	3 2B
Amino resins (e.g., urea-formaldehyde resins, melamine-formaldehyde resins)	Binders	See Formaldehyde		

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Ammonia	Water-based paints	–	–	–
Anhydrides, organic (e.g., maleic anhydride, phthalic anhydride, trimellitic anhydride)	Alkyd resin synthesis, curing agents (epoxy resins)	Succinic anhydride	IARC (1987)	3
Antimony compounds (e.g., antimony trioxide)	Pigments, fire retardant pigments	Antimony trioxide Antimony trisulfide	IARC (1989a) IARC (1989a)	2B 3
Arsenic compounds (e.g., copper aceto-arsenate)	Antifouling agents	–	IARC (1987)	1
Asbestos	Filler, spackling and taping compounds, talc	Asbestos	IARC (1987)	1
Barium compounds (e.g., barium sulfate, barium carbonate)	Pigments	–	–	–
Benzoyl peroxide	Catalyst	Benzoyl peroxide	IARC (1999a)	3
Bisphenol A	Epoxy resins		IARC (1999a)	3
Cadmium compounds (e.g., cadmium sulfide, cadmium sulfoselenide)	Pigments	Cadmium and Cadmium compounds	IARC (1993)	1
Calcium compounds (e.g., calcium sulfate, calcium carbonate)	Fillers	–	–	–
Camphor	Plasticizer	–	–	–
Carbon black	Pigment	Carbon black	IARC (2010a)	2B
Cellulose ester resins (e.g., cellulose nitrate, cellulose acetate)	Binders	–	–	–
Chloracetamide	Fungicide (water-based paints)	–	–	–

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Chlorofluorocarbons	Spray-can paint propellants	Chlorofluoromethane	IARC (1999a)	3
Chromium and chromium compounds (e.g., chromic oxide, chromates)	Pigments	Chromium (III) compounds	IARC (1990)	3
		Chromium (VI) compounds	IARC (1990)	1
		Chromium, metallic	IARC (1990)	3
Clays (e.g., bentonite)	Fillers	–	–	–
Coal-tar and asphalt	Special waterproof coatings (ships, tanks, pipes)	Coal tar	IARC (1987)	1
		Coal-tar pitches	IARC (1987)	1
		Bitumen extracts	IARC (1987)	2B
		Bitumen refined	IARC (1987)	3
Cobalt compounds	Pigments, driers	Cobalt and cobalt compounds	IARC (1991a)	2B
		Cobalt, metallic	IARC (2006a)	2B
Copper and copper compounds (e.g., bronze powder, cuprous oxide)	Pigments, antifouling agents	–	–	–
Dyes and pigments, organic (e.g., aromatic azo dyes, phthalocyanines, rhodamine)	Pigments	CI Basic Red 9		2B
		Magenta production		1
		2-naphthylamine	IARC (1982)	1
		4-aminobiphenyl	IARC (2010b)	1
		Auramine production		1
		Benzidine		1
		Benzidine-based dyes		1
Epichlorohydrin	Epoxy resins	Epichlorohydrin	IARC (1999a)	2A
Epoxy resin	Binders	–	IARC (1976)	–
Esters, aliphatic (e.g., ethyl acetate, isopropyl acetate)	Solvents	–	–	–

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Ethers, aliphatic (e.g., isopropyl ether, tetrahydrofuran) and glycol ethers (e.g., methyl cellosolve)	Solvents	2-Butoxyethanol 1-*tert*-Butoxypropan-2-ol	IARC (2006b) IARC (2006b)	3 3
Formaldehyde	Amino resin varnishes, biocide (water-based paints)	Formaldehyde	IARC (2006b)	1
Gasoline	Solvent	Gasoline	IARC (1989b)	2B
Glycidyl ethers (e.g., *n*-butyl glycidyl ether and bisphenol A diglycidyl ether)	Epoxy resin diluents and constituents	Phenylglycidyl ether Triethylene glycol diglycidyl ether Bisphenol A diglycidyl ether	IARC (1999a) IARC (1999a) IARC (1999a)	2B 3 3
Glycols (e.g., ethylene glycol)	Polyester resins, water-based paints	–	–	–
Hydrocarbons, aliphatic (e.g., hexanes, heptanes)	Solvents (naphthas, white spirits)	–	–	–
Hydrocarbons, aromatic (e.g., benzene, toluene, xylenes, trimethylbenzene)	Solvents (naphthas, white spirits), paint removers	Benzene Toluene Xylene Ethylbenzene	IARC (1987) IARC (1999a) IARC (1999a) IARC (2000)	1 3 3 2B
Hydrocarbons, chlorinated (e.g., dichloromethane, 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene)	Solvents, paint removers, metal degreasers	Dichloromethane 1,1,1-Trichloroethane Carbon tetrachloride Trichloroethylene	IARC (1999a) IARC (1999a) IARC (1999a) IARC (1995)	2B 3 2B 2A
Hydrochloric acid (hydrogen chloride)	Catalyst (amino resins)	–	IARC (1992)	3
Iron compounds (e.g., iron oxides, ferric ferrocyanide)	Pigments	Ferric oxide	IARC (1987)	3

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Isocyanates (e.g., 1,6-hexamethylene diisocyanate, toluene diisocyanate)	Two-component polyurethane resins	Toluene diisocyanate	IARC (1999a)	2B
Isothiazolones (e.g., 1,2-benzisothiazolin-3-one)	Biocides in tinned foods	–	–	–
Kerosene	Solvent	Jet fuel	IARC (1989c)	3
Ketones, aliphatic (e.g., acetone, methyl ethyl ketone, cyclohexanone, isophorone, diacetone alcohol)	Solvents, lacquers, paint removers	Cyclohexanone	IARC (1999a)	3
Lead compounds (e.g., lead chromate, lead oxides, basic lead carbonate, lead naphthenate)	Primers, pigments, driers	Lead Lead compounds, inorganic	IARC (1987) IARC (2006c)	2B 2A
Magnesium compounds (e.g., magnesium carbonate)	Fillers	–	–	–
Manganese naphthenate	Drier	–	–	–
Mercury compounds (e.g., mercuric oxide, phenyl mercuric acetate)	Fungicides (water-based paints)	Mercury and inorganic mercury compounds	IARC (1993)	3
Methyl cellulose	Thickener (water-based paints)	–	–	–
Mica	Filler	–	–	–
Molybdenum compounds (e.g., lead molybdate)	Pigments	–	–	–
Nickel, metal powder	Pigment	Nickel compounds Nickel, metallic and alloys	IARC (1990) IARC (1990)	1 2B 2B
Nitroparaffins (e.g., nitroethane, 2-nitropropane)	Solvents	2-Nitropropane	IARC (1999a)	2B
Oils, vegetable (e.g., linseed oil, tung oil)	Binders	–	–	–

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Oximes (e.g., methyl ethyl ketoxime)	Anti-oxidants, anti-skinning agents	–	–	–
Petroleum solvents (e.g., Stoddard solvent, VM & P naphtha)	Solvents, paint removers	Petroleum solvents	IARC (1989a)	3
Phenol	Phenol-formaldehyde resins, paint remover (formerly)	Phenol	IARC (1999a)	3
Phenol-formaldehyde resins	Binders	See Phenol, and Formaldehyde		
Phenols, chlorinated (e.g., pentachlorophenol)	Fungicides (water-based paints)	Polychlorophenols and their sodium salts	IARC (1999a)	2B
		Pentachlorophenol	IARC (1991b)	2B
Phosphates, organic (e.g., tricresyl-*ortho*-phosphate, tributyl phosphate)	Plasticizers	–	–	–
Phthalate esters (e.g., dibutyl phthalate, dioctyl phthalate	Plasticizers	Di(2-ethylhexyl)phthalate	IARC (2000)	3
		Butyl benzyl phthalate	IARC (1999b)	3
Polychlorinated biphenyls	Plasticizers	Polychlorinated biphenyls	IARC (1987)	2A
Polycyclic aromatic hydrocarbons	Special waterproof coatings (ships, tanks, pipes)	Selected polycyclic aromatic hydrocarbons	IARC (2010c)	–[b]
Polyester resins	Binders	–	–	–
Polyurethane resins	Binders	Polyurethane foams	IARC (1987)	3
Polyvinylacetate resins	Binders	Polyvinyl acetate	IARC (1987)	3

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Pyrolysis fumes	Removal of paint by burning; heat-curing operations	–	–	–
Rosin	Binder	–	–	–
Rubber, synthetic (e.g., butyl rubber, styrene-butadiene rubber)	Binders (special paints, water-based paints)	Rubber industry	IARC (1987)	1
Shellac resin	Binder	–	–	–
Silica, amorphous (e.g., diatomaceous earth)	Filler	Silica, amorphous	IARC (1997)	3
Silica, crystalline (e.g., quartz)	Filler, sand-blasting operation	Silica, crystalline	IARC (1997)	1
Silicates (e.g., sodium silicate, aluminium silicate)	Fillers	–	–	–
Stearates (e.g., aluminium stearates, zinc stearates)	Soaps, flattening agents	–	–	–
Strontium compounds (e.g., strontium chromate, strontium sulfide)	Pigments	Strontium chromate see Chromium and chromium compounds		
Styrene	Polyester resins	Styrene	IARC (2002)	2B
Styrene oxide	Diluent (epoxy resins)	Styrene-7,8-oxide	IARC (1994)	2A
Sulfuric acid	Metal cleaner	–	–	–

Table 1.1 (Contd)

Material	Principal uses or sources of emissions	Agent evaluated	*IARC Monographs*	Evaluation
Talc	Filler	Talc containing asbestiform fibres	IARC (1987)	1
		Talc, not containing asbestiform fibres	IARC (2010a)	3
Tin, metal powder	Lacquers (tinplate containers)	–	–	–
Tin, organic compounds (e.g., tri-*n*-butyltin oxide, dibutyltin laurate)	Antifouling agents, catalysts	–	–	–
Titanium dioxide	Pigment	Titanium dioxide	IARC (2010a)	2B
para-Toluenesulfonic acid	Catalyst (amino resins)	–	–	–
Turpentine	Solvent	–	–	–
Vinyl acetate	Polyvinylacetate resins	Vinyl acetate	IARC (1995)	2B
		Vinyl chloride – vinyl acetate copolymers	IARC (1987)	3
Zinc and compounds (e.g., zinc metal powder, zinc oxide, zinc chromate)	Pigments, catalysts, bodying agents	Zinc chromate see Chromium and chromium compounds		

[a] Updated from IARC (1989); –, not evaluated by IARC
[b] Groups 1–3, see *IARC Monographs* Volume 92 for details

The use of iron-blue pigments $M^{I}[Fe^{II}Fe^{III}(CN)_6]$ (Milori blue, Vossen blue, Berlin blue, Prussian or Turnbull´s blue) is in decline as they are too sensitive to chemicals and alkaline water.

The term *earth pigments* is obsolete, as these iron or chromium(III) oxide pigments (Fe_2O_3, Fe(O)OH, Cr_2O_3) are now produced synthetically from ores in a similar manner to titanium dioxide, the most widely used of the coloured pigments derived from natural sources (Buxbaum & Pfaff, 2005). Natural iron oxides are processed from several different ores, including haematite (see IARC, 1987), limonite, siderite and magnetite, and provide a range of reds, yellows, purples, browns and blacks. Iron oxide particles of around 10 nm are highly transparent and additionally, offer good ultraviolet (UV) protection of wood.

Bismuth vanadate pigments are a relatively new class of pigments that have steadily gained importance over the last three decades. Formulations range from BiO_4V^{-5} to the mixed pigment $4BiVO_4x3Bi_2MoO_6$. The pigments are lead- and chromate-free inorganic yellow pigments used to manufacture high-peformance brillant yellow, orange, red, and green shades. Bismuth vanadate has become an increasingly important substitute for lead chromate in the last 10–20 years. Nevertheless, lead chromate and lead wolframate are still used in some countries (Smith, 2002).

Traditionally, the most important black pigment, carbon black (microcrystalline carbon, graphite-similar), belongs to inorganic pigments (Buxbaum & Pfaff, 2005). The small particles (10–40 nm) can have surface areas as large as 1000 m^2/g.

Nanoparticles, mostly inorganic, are chemically similar to pigments and fillers, but they are discussed together with additives because of their special additive-like functions, and the low contents at which they are used in formulations.

(i) *Lustre pigments (effect pigments)*

This group includes metallic, pearlescent and iridescent pigments. The most common metallic dusts and powders used in paint are aluminium powder or fine flakes and bronze powders, which consist of metals in a finely divided state; e.g. gold bronzes are alloys of copper with varying proportions of zinc or aluminium (Glausch *et al.*, 1998; Wissling, 2006).

Additional effect pigments developed for new optical effects include mica plates, which have been increasingly used over the last 20 years (often inorganically coated with silicium dioxide, iron(III)oxide, chromium(III)oxide or aluminium oxide). The thickness and the kind of metal oxide used has an impact on the optical effect, especially the colour and the interference effect [where the angle of watching determines the colour]. Other plate-like effect pigments are based on silicium dioxide, thin polymer flakes or haematite (Wissling, 2006).

(ii) *Fillers*

Materials used as fillers (extenders) are not pigments as they do not contribute to the coloristic or functional properties of the coating (Stoye & Freitag, 1998; Brock *et al.*, 2000;

Nanetti, 2000). Typical fillers are barium sulfate (barytes), calcium carbonate (ground limestone and chalk), silica (diatomaceous or amorphous, pyrogenic or precipitated; see IARC, 1997), clays (hydrated aluminium silicate), talcum (hydrated magnesium silicate; see IARC, 1987) and mica (hydrated potassium aluminium silicate). Fillers are often added to paint to reduce cost, improve physical characteristics, and increase resistance to wear; their effects are largely governed by their average particle size. This size is normally about 1–10 μm, and under 0.1 μm for special performances.

(b) Organic pigments

Hundreds of organic pigments, comprising a broad spectrum of structural classes, are used in the paint industry (Brock *et al.*, 2000; Smith, 2002; Zollinger & Iqbal, 2003). The most important and established uses for organic pigments include the coloration of coating compositions for interior, exterior, trade and automotive applications, including oil and water emulsion paints and lacquers. Azo pigments are formed by successive diazotization of a primary amine and coupling.

After the discovery of Perkins' mauve in 1856, the development of synthetic colouring materials continued with the discovery of fuchsin in 1858 and of other triphenylmethane dyes, such as alkali blue, methyl violet, and malachite green. Large amounts of these dyes were used as the first synthetic organic pigments. The largest single advance in pigment technology after the First World War was the discovery in the 1930s of phthalocyanine blue and, later, its halogenated green derivatives, which are still widely used in automotive finishes. Other main categories of organic pigments used in paints and related products include quinacridones, thioindigos, perinones, perylenes, diketo-pyrrolopyrroles and anthraquinone.

Organic effect pigments have reached some commercial significance. In particular, liquid crystals (spiro compounds), fixed in the binder matrix by polymerization, permit extreme colour changes depending on the viewing angle.

In the 1960s, there were probably more than 200 different organic pigments used in paints. At the time, azo pigments such as Benzidine Yellow were considered to have relatively low toxicity, and were widely used. These pigments are of relatively low solubility, and although they are based on the aromatic amine 3,3′-dichlorobenzidine, the free amine is not bioavailable. IARC (1982) identified eight pigments based on 3,3′-dichlorobenzidine. Three 3,3′-dichlorobenzidine-based paint pigments were commonly used in architectural finishes in the mid-to-late 1960s. Benzidine was used as the basis for the paint pigment pyrazolone maroon (see IARC, 2010b).

Free aromatic amines used in the synthesis of azo pigments can be found in trace amounts as impurities. The aromatic amines 4-aminobiphenyl, benzidine, 2-naphthylamine and 2-methyl-4-chloroaniline [4-chloro-*ortho*-toluidine] have been found in azo pigments (see IARC, 2010b).

1.1.3 *Binders (resins)*

The 'vehicle' part of paints contains components collectively termed 'binders' or film formers. Binders protect the substrate and hold the pigment in the dry film when required, and cause it to adhere to the surface to be painted. Almost all binders in modern paint films are composed of polymer materials such as resins and drying oils, whose main functions are to provide film hardness, gloss, surface adhesion, and resistance of the film to the weather, atmospherilics, acids, alkalis, and other agents (Stoye & Freitag, 1998; Brock *et al.*, 2000; Müller & Poth, 2006). A large variety of both natural and mainly synthetic resins has been used in paints.

The chemical composition and variety of binders have not changed fundamentally with new paint systems or better awareness of health hazards. Binders (in principle oligomers and polymers) of waterborne and UV-curing paints or powder coatings are similar to those of conventional paints, with slight modifications. Water-thinnable resins contain more carboxyl (acid) groups and can be used as stable emulsions when they are neutralized with amines or caustic soda (pH 7–9). Thus, waterborne paints nearly always contain tertiary amines, ammonia or alkali. During drying, the amines evaporate and the hydrophilic binder becomes hydrophobic and resistant. These paints contain only little solvent (up to 10%), often even none. UV-curing paints contain fixed unsaturated groups for polymerization by UV-radiation, as well as monomers and oligomers as thinners (which then polymerize), mostly acrylates, therefore generally not requiring any solvent. The ozone that forms during UV irradiation is removed automatically by the radiation machinery, and bled with the air waste. New developments include less harmful monomers and further technical improvements (Müller & Poth, 2006).

(a) Natural resins and oils

From early times, various natural resins have been used to reinforce linseed oil and other drying oils, since paints based on pigment and oil only yield very soft films. Shellac and insect exudations are natural oleoresins that have been used in paints for centuries (Brock et *al.*, 2000).

Another useful natural resin is rosin (colophony), which is obtained as a residue after distilling pine oleoresin for the production of turpentine. Rosin consists of about 85% rosin acids (abietic acid) and 15% neutral substances, and can be classified into two main types – gum rosin and wood rosin. Rosin has been used in paints (principally alkyd resins) for many years, and is nowadays still used in printing inks. Rosin is often upgraded to yield higher quality resins by chemical reactions, including liming (calcium rosinate), salification, esterification with glycerol, and reactions with trimethylolpropane, phthalic anhydride, maleic anhydride, adipic acid and sebacic acid (Brock *et al.*, 2000).

Vegetable and fish oils have long been used as binders in traditional paints and varnishes. White linseed oil has been the most important oil in standard exterior paints, despite its moderately slow drying rate. It is infrequently used in interior paints because of

yellowing. Other important oils include castor oil, tall oil, soya bean oil, coconut oil, cottonseed oil, tung oil and various fish oils (Brock *et al.*, 2000).

Although raw oils have been useful as paint binders, it is advantageous to use them in conjunction with refined oils and oils treated with heat (heat-bodied oils), which isomerize the raw oil and improve the drying rate of the films. Oleoresinous varnishes are made by cooking oils with natural or synthetic resin, which results in more rapid drying and a harder film (Brock *et al.*, 2000). Today, natural resins are used mainly as raw material to modify synthetic resins, and used in 'bio paints'.

(b) Synthetic resins

A wide variety of synthetic resins has been commercially available since the early 1900s. Those that have been most frequently employed in paints, varnishes and lacquers include cellulosic, phenolic, alkyd, vinyl, acrylic and methacrylic, polyesters and polyurethane resins, chlorinated rubber derivatives, styrene-butadiene, and silicone oils. Mixtures of different synthetic resins provide characteristic properties that cannot be obtained from a single resin. While the amount of resin in paint varies, concentrations of 20–60% are common. The choice of a resin(s) for a particular application depends on factors such as appearance, ease of application, cost, and resistance to mechanical forces, chemicals, heat and wear. Some resins (polyurethanes, epoxys; see IARC, 1999a) are blended with crosslinking agents immediately before use, which results in a hard, serviceable film. Alkyd, acrylic, polyurethane and polyester resins have a broad spectrum of use in paints, including paints for houses, automobiles, furniture and appliances, as well as in the protection of metal surfaces, e.g. in chemical plants and oil refineries (Brock *et al.*, 2000).

(i) *Phenolic resins*

Depending on the type and proportion of components and on the reaction conditions, phenolic resins may be heat-reactive or not. The first product of the reaction is methylol phenol. With an excess of formaldehyde under alkaline conditions, methylol groups react slowly with phenol, are retained in the reaction product (resoles) and can act as reactive sites in varnish preparations or for crosslinking in finished products (Brock *et al.*, 2000).

Heat-sensitive phenolic resins that are insoluble in oil may be dissolved in solvents and used as the sole vehicle for metal coatings, e.g. for wires. Specially formulated water-soluble resoles with free neutralisable carboxyl groups are used in waterborne coatings.

(ii) *Alkyd resins*

The advent of alkyd resins was a major breakthrough in modern paint technology. Alkyds are oil-modified polyester resins produced by the condensation reaction of polyhydric alcohols, polybasic acids and monobasic fatty acids, e.g. linseed or soja fatty acids. The terms 'non-oil' and 'oil-free' alkyd describe polyesters formed by the reaction of polybasic acids with polyhydric alcohols in excess of stoichiometric amounts. These

products are best described as saturated polyesters containing unreacted hydroxyl or carboxyl groups (Bentley & Turner, 1998; Brock *et al.*, 2000).

For example, nitrocellulose lacquers are formulated with alkyd resins, and can have a nitrocellulose content of up to 55%. These lacquers are produced in large quantities. Alkyds modified with short-chain acids, such as those from coconut oil and castor oil, are widely used in high-grade furniture lacquers.

Some water-thinnable alkyd resins that contain sufficient carboxyl (hydrosols) groups or an emulgator (added or incorporated, self-emulsifying) are used for wood protection or to inhibit corrosion (Brock *et al.*, 2000).

Alkyd resins have been used in protective coatings for over 40 years, constituting about 45% of all resins used in organic coatings. Their use in product finishes (machines, equipment, wood and metal) is decreasing because of their slow hardening and low performance compared with modern two-component systems (Stoye & Freitag, 1998).

(iii) *Vinyl resins*

Vinyl polymers and copolymers were among the first synthetic polymers on the market and are widely used in trade paints. Vinyl monomers can polymerize readily by the addition of initiators, such as peroxides and azo compounds, which decompose at reactor temperature to generate free radicals. Polymerization processes involve radical formation, initiation, propagation including chain transfer, and termination (Bentley & Turner, 1998; Brock *et al.*, 2000). The principal vinyl resins of importance in the paint industry are polyvinyl chloride, polyvinyl acetate and polyvinyl butyrate. These are available in a range of different compositions for specific uses, and in grades that can be handled as true solutions in organic solvents, as high-solid dispersions (‘organosols’ or ‘plastisols’), as dry powders or as waterborne latices. Polyvinyl acetate is extensively used in emulsion paints, providing exceptional flexibility, toughness, and water and chemical resistance. Vinyl chloride copolymer coatings are still used in coil coatings, and in industrial and marine coatings (Stoye & Freitag, 1998).

Water emulsions of high molecular-weight polyvinyl acetate are widely used in interior house paints. Copolymers of vinyl acetate with acrylic monomers are also used in exterior emulsion house paints. Latexes of vinyl chloride polymers and copolymers have been commercially important for several years, e.g. as copolymers in exterior house paints, which often include a vinyl chloride–acrylic ester copolymer modified with a specially designed alkyd resin. Polyvinyl acetate and vinyl acetate copolymers are used in latex-based interior and exterior paints. The principal modifying monomers for vinyl acetate include dibutyl maleate and fumarate, butyl-, 2-ethylhexyl- and isodecyl acrylates, and higher vinyl esters. Copolymers of the acrylates and vinyl acetate are commonly called vinyl acrylics and generally contain l5% acrylic monomer by weight.

Polyvinylidene fluoride is a base for organosols for extremely weather-resistant metal coatings, used mainly in coil-coating applications for façades.

(iv) *Acrylic and methacrylic ester resins*

Acrylic resins are divided into four specific types: water-based, solvent-based thermoplastic (lacquer types), solvent-based thermosetting or room temperature-drying, and powder coating resins (Brock *et al.*, 2000).

Acrylic and methacrylic polymers are made from a variety of acrylic and methacrylic monomers (see IARC, 1999a). The major monomers used are the methyl, ethyl, butyl and 2-ethylhexyl esters of acrylic and methacrylic acids, which readily undergo polymerization in the presence of free-radical initiators, such as peroxides, to yield high molecular-weight polymers (Schwartz & Baumstark, 2001). The acetone–cyanohydrin process is the major method for the production of monomeric methacrylate esters.

Several functional groups can be incorporated into acrylic and methacrylic monomers. These are principally amides, carboxyls, hydroxyls and epoxys and are used to confer crosslinking capabilities and thermosetting properties to the resulting polymers. Other monomers, including vinyl acetate (see IARC, 1995), styrene (see IARC, 2002), vinyl toluene (see IARC, 1994), acrylonitrile (see IARC, 1999a) and methylacrylamide are used in conjunction with the acrylic monomers to achieve different properties.

Acrylic and methacrylic polymers are used in the formulation of clear and pigmented lacquers. Dispersions in water and in organic solvents yield latex and organosol coatings, respectively (Schwartz & Baumstark, 2001). In the late 1950s, lacquers of greatly improved durability, based on polymethylmethacrylate or thermosetting acrylic enamels, were adopted by the automobile industry (Fettis, 1995; Goldschmidt & Streitberger, 2002). By the 1960s, the acrylic emulsion polymers had been firmly established in exterior coatings for wood surfaces, a field long dominated by oil paints (Schwartz & Baumstark, 2001). Currently, acrylic resins – solvent-borne or waterborne – are state-of-the-art in the field of top coats for car paints, lacquers and many others high-performance coatings. For best performance, they are used in one-component or two-component products, and cured to improve their functionality. Those containing hydroxyl groups are cured with isocyanates or melamines, those containing carboxyl groups are cured with epoxy-groups, those containing epoxy-groups are cured with (poly)acids or amines, while those containing isocyanate groups are crosslinked with air humidity.

(v) *Epoxy resins*

Epoxy resins were first derived from bisphenol A and epichlorohydrin (see IARC, 1999a), and introduced into the paint industry in the late 1940s. Two major types of epoxy resin exist – glycidyl ether epoxy resins (see IARC, 1989a) and epoxidized olefins, the former being the most common. Epoxy resins based on bisphenol A and epichlorohydrin are the most prominent of the glycidyl ether category. They are produced by a condensation reaction in which bisphenol A and epichlorohydrin are reacted in the presence of alkali. The resultant diglycidyl ether resin has a functionality of two reactive epoxy groups per molecule. Epoxy resins can be polymerized through their reactive epoxy group using acids, amines or polyamides (Brock *et al.*, 2000).

Epoxy resins of a second major type, epoxidized olefins, are based on epoxidation of the carbon-carbon double bond.

To proceed from the relatively low molecular weight of the coating composition, as applied, to the high molecular-weight polymer necessary for optimal film properties, a 'curing' or polymerization must take place. Some of the principal reactions that have been used include chemical crosslinking via the amine–epoxide reaction [anhydride–epoxide reaction], reaction with methylol groups (e.g. between the secondary hydroxyl groups of the higher molecular-weight resins and the methylol groups of phenol–formaldehyde and urea–formaldehyde resins), crosslinking via the isocyanate–hydroxyl reaction and esterification reactions between solid-grade epoxy resins and carboxyl-containing compounds, particularly drying-oil fatty acids (Brock *et al.*, 2000).

Glycidyl ether resins of high molecular weight (number average,[1] about 7000; weight average,[2] about 200 000) are unique among epoxy coatings in that they form coatings by solvent evaporation alone. Because of their toughness, adhesion and corrosion resistance, epoxy resins are used in many applications, including industrial maintenance, automobile primers and coatings for appliances and steel pipes. Epoxys combined with phenolic resins and thermosetting acrylic resins yield high-bake finishes with hardness, flexibility, and resistance to chemicals and solvents (Brock *et al.*, 2000).

(vi) *Polyurethane resins*

Although polyurethanes were synthesized in 1937, the utility of weather-resistant polyurethane coatings became apparent only in the 1960s. Polyurethanes are obtained from the reaction of polyhydric alcohols and (poly- or oligo-)isocyanates. Nonreactive polymers can be prepared by terminating the polymer chains with monofunctional isocyanates or alcohols. Crosslinked polymers are formed from polyfunctional isocyanates or alcohols (Bentley & Turner, 1998; Brock *et al.*, 2000). Isocyanates that have been used include toluene diisocyanate (see IARC, 1999a), isophoronediisocyanate and 1,6-hexamethylene diisocyanate (HDI).

As a result of the wide range of physical properties obtained by varying the formulations of polyurethane coatings, they can be used in industrial and maintenance coatings as well as in coatings for wood, concrete, and flexible structures (Goldschmidt & Streitberger, 2002; Stoye & Freitag, 1998). Polyurethane coatings are being used increasingly for automobiles and aircraft, for wood and plastics, and in architectural coatings. The nomenclature of polyurethanes is sometimes difficult: the term is used for polyurethanes ready to be applied on a substrate as well as for two-pack mixtures of an acrylic resin to be crosslinked with an (oligo)isocyanate. The two-component systems are used as high-performance coatings for maintenance and product finishes.

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[1] Molecular weight value from number of molecules each multiplied by molecular weight and total divided by number of molecules

[2] Molecular weight value from sum of number of grams of materials with a particular molecular weight each multiplied by its molecular weight and total divided by total number of grams

Blocked (capped) isocyanates are used for one-component stoving coatings or coating powders. They are polyisocyanates in which acidic compounds such as phenols, ε-caprolactams, alcohols, malonic esters or secondary amines have been added to the isocyanate group. The blocking agents are separated at a characteristic temperature between 100 and 180°C followed by the rapid start of the curing reaction with a hydroxyl partner.

(vii) *Silicone resins*

Silicones are characterized by a siloxane backbone [-Si-O-Si-O-] with organic groups that determine the properties of the final polymer. The monomeric precursors of silicone polymers are mono-, di- and trisubstituted halosilanes (usually chlorosilanes). Monosubstituted silanols can undergo a condensation reaction to form highly crosslinked polymers, which are mainly used in coatings. The degree of crosslinking and consequent physical properties are controlled by adjusting the ratio between mono- and disubstituted chlorosilanes. Alkyd resins with terminal hydroxyl groups can be reacted with silicones in a condensation reaction to produce hybrid polymers (Heilen, 2005).

Silicone resins are used to waterproof masonry, and are blended with alkyds to formulate industrial maintenance coatings for storage tanks and other metal structure (Heilen, 2005).

Silicone chemistry is an important part of a new class of nano-coatings: the sol-gel chemistry for producing nano-thin layers is mainly based on hydrolysis of alkoxy-substituted silanes, followed by a condensation step at a surface. The result is a very thin layer with good protection properties (Sepeur, 2008).

(viii) *Cellulose derivatives*

Cellulose nitrate, commonly misnamed nitrocellulose, was the first cellulose derivative produced. The development of stable cellulose nitrate with low viscosity resulted in fast-drying lacquer coatings, which were used extensively in automobile and furniture production. In the USA, three types of commercially available cellulose nitrates are distinguished by their nitrogen content and solubility. Each of these types is available in a variety of viscosity grades, which are a measure of the polymer chain length (Stoye & Freitag, 1998).

Cellulose nitrate lacquers have also been formulated to contain resins, plasticizers, solvents and thinners. Plasticizers are usually added at about 10% of the weight of cellulose nitrate. Plasticizers such as triphenyl phosphate, tricresyl phosphate, dibutyl phthalate and butyl tartrate are being used in increasing amounts. The principal solvents used initially with cellulose nitrate include ethyl, butyl and amyl acetates, acetone, ‘diacetone alcohol’, ethanol and mixtures of alcohol with toluene, and of alcohol with esters (Stoye & Freitag, 1998). The main disadvantage of nitro lacquers is their high solvent content.

Another cellulose derivative, ethyl cellulose, is made by treating cellulose from wood pulp or cotton with a solution of sodium hydroxide to obtain primarily what is commonly referred to as ‘alkali’ or ‘soda’ cellulose. Further treatment with ethyl chloride under heat

and pressure yields ethyl cellulose, which can be produced in different viscosities. It is widely used in clear, dyed or pigmented lacquers for flexible substrates.

Cellulose acetate is a linear high-molecular weight polymer obtained by first treating cellulose with a reduced amount of acetic acid to cause a certain amount of swelling, and then reacting it with acetic anhydride in the presence of sulfuric acid. Cellulose acetate lacquers are stable to light and heat and have good resistance to oils, greases and weak acids (Brock *et al.*, 2000).

Methylcellulose, carboxymethyl cellulose and hydroxyethyl cellulose are water-soluble polymers that are used as thickeners in latex-based coatings. Cellulose acetate butyrate is used as a resin modifier in solvent-borne automobile base coats, deposited (underneath a clear coat) based on polymethylmethacrylate or other resins.

1.1.4 *Solvents*

A solvent is a liquid consisting of one or more component(s) that is able to dissolve binder, and is volatile under aplication (Stoye & Freitag, 1998). Solvents are widely used to keep paints in liquid form for easy application. The typical solvent content of paints and coating materials in western Europe is listed in Table 1.2.

Table 1.2. Typical solvent content of paints and coating materials in western Europe, 2006

Coating material		Solvent content in %
Coating powders, silicate paints		0
Emulsion paints for interior use		0–2
Emulsion paints for exterior use, plasters		3–5
Electrodeposition coatings		1–5
Latex coatings (environment-friendly)		5–9
Waterborne coatings (industrial)		3–18
High-solids coatings		20–35
General medium-solids and low-solids paints/coatings		40–50
Dilutions, thinners, cleaning agents	for solvent-borne coatings	100
	for waterborne coatings	0–50

Compiled by the Working Group

Until the late nineteenth century, the solvents used were almost exclusively turpentine and alcohol. Since the early 1900s, the number of solvents has increased considerably to encompass a broad range of petroleum and coal-tar distillates, alcohols, esters, ketones, glycols, synthesized glycol ethers and esters (mainly ethylene), and propylene glycol derivates. A large variety of mixtures of these classes of chemicals is also used. The choice

of solvent depends on properties such as adequate polarity, possibility of hydrogen-bridge linkages, volatility and evaporation, cooling effects while atomization, surface tension, viscosity, flash point and flammability and – more and more importantly – physiological harmlessness. Derivatives of ethyleneglycol monoethylether (ethyl glycol) have been removed from many formulations since the 1980s in western Europe. Since 1990, the use of styrene, the main reactive solvent in putties and paints based on unsaturated polyesters, has been reduced by legislation of the European Community.

Waterborne coatings generally require water-soluble solvents such as glycol ethers (butylglycol), *n*-butanol or sometimes *N*-methyl-pyrrolidone.

1.1.5 *Additives*

Additives are defined as those chemicals that perform a special function or impart a special property to paints or coatings. They are present at low concentrations, generally 0.1–5% wt. Additives include surfactants and dispersing agents, driers, rheological agents, plasticizers, biocides, anti-skinning agents, antifoam agents (defoamers), corrosion inhibitors, light (UV) stabilizers and catalysts (Brock *et al.*, 2000; Stoye & Freitag, 1998).

In the last 5 years, nanoparticle-based additives have appeared on the market (see below under ix). Many additives are adapted to the new paint systems, by modifications of the existing products rather than by the development of new ones.

(a) Surfactants and dispersing additives

Surfactants, which are classified into anionic, cationic, amphoteric or nonionic are used as pigment dispersants in both nonaqueous and aqueous systems. Dispersants employed in nonaqueous systems include lecithin, zinc or calcium naphthenate or octoate, oleates, and oleic acid. Polymeric organic surfactants (polyurethanes, polyamides and others) are also used increasingly because of their better colloidal stabilizing properties. Ionizable dispersants usually used in aqueous systems include polyphosphates, pyrophosphates, salts of arylalkyl-sulfonic acids and salts of polycarboxylic acids, e.g. polyacrylic acid (Oyarzún, 2000; Müller & Poth, 2006).

In addition to pigment dispersion, surfactants are used in paints as emulsifying agents, protective colloids, wetting agents and antifoaming agents.

Surfactants used in waterborne paints include aluminium stearate, cellulose ethers, polydimethyl siloxanes, polyethylene, alkali metal phosphates and sodium dioctyl sulfosuccinate.

A variety of other surface-active agents are added to paints to control flow, levelling, sagging, settling and viscosity, including hydrogenated castor oils, lecithin, metallic soaps (e.g. linoleates, palmitates and stearates), treated montmorillonite clays, peptized oil gels, polyol esters, siloxan-polyester resins, silicas, and soap solutions (Brock *et al.*, 2000; Müller & Poth, 2006).

Defoaming agents must be able to enter the foam lamellae. There, they destabilize the lamella, whereupon the foam collapses. The two main groups of defoaming agents are mineral oils and specially modified siloxanes.

(b) Driers

The driers (siccatives) used in solvent-borne and waterborne paints containing unsaturated polymers are principally metal salts (lead, calcium, cobalt, manganese, zirconium, vanadium, barium, zinc, cerium and lanthanum) of naphthenic acid, tall oil acid, 2-ethylhexanolic acid and neodecanoic acid, generally at concentrations ranging from 0.3 to 0.8% (Brock *et al.*, 2000). Cobalt-based driers are the most commonly used commercially and are active catalysts in both air-drying and heat-cure systems. Other metal driers serve as auxiliary driers and are usually used in combination with cobalt and manganese. Lead (IARC, 2006a) driers were at one time the major auxiliary driers, but legislation limiting the amount of lead that can be used in coatings has practically elimininated its use since 1990–2000. The most suitable replacements for lead are reported to be zirconium, calcium and cobalt-zirconium compounds (Müller & Poth, 2006).

(c) Rheological additives

The rheological properties of a coating material are of prime importance for optimum performance during application ('good flow without dripping'). They also influence its storage life.

Water-soluble hydrophilic colloids include agents such as gum arabic, gum tragacanth, starch, sodium alginate, methyl cellulose, hydroxyethyl cellulose, polyvinyl alcohol, ammonium caseinate, polyurethane derivates, and polyacrylates. Acrylate salts, casein and cellulosics are widely used in acrylic paints, while the major thickeners for styrene–butadiene paints are alkali-soluble proteins (soya bean proteins). Methyl cellulose and hydroxyethyl cellulose are common thickeners for polyvinyl acetate paints (Brock *et al.*, 2000).

Non-cellulosic agents used in waterborne and solvent-borne paints include maleic anhydride copolymers, mineral fillers, such as colloidal attapulgite (see IARC, 1997), and treated magnesium montmorillonite clays, pyrogenic silicic acid (SiO_2), natural products (e.g. alginic acid, casein and soya bean protein), polyacrylamides, polyacrylic acid salts and acid-containing crosslinked acrylic emulsion copolymers. Associative thickeners consist of molecules with hydrophilic and hydrophobic moieties (Brock *et al.*, 2000).

(d) Plasticizers

Following the use of castor oil and glycerine in the late nineteenth century and of triphenyl phosphate after 1912, the use of plasticizers expanded by the mid-1920s with the introduction of di(2-ethylhexyl)phthalate (see IARC, 2000), and dibutylphthalate in the mid-1930s.

Plasticizers are generally added in quantities of up to about 2% wt and include dibutyl-, diethyl-, diethylhexyl- and dioctylphthalates and, to a lesser extent, the low molecular-weight esters of adipic and sebacic acid, tributyl phosphate, and castor oil. Polyester resins, including maleic residues, sulfonamides, triorthocresyl phosphate and chlorinated diphenyls, are used occasionally (Stoye & Freitag, 1998).

(e) Biocides (fungicides, preservatives and 'mildewcides')

Waterborne paints contain organic substances and represent an ideal growth medium for fungi, algae and bacteria. With the reduced content of residual monomers and organic solvents, which often have anti-microbial action, the risk for microbial contamination is increased in new formulations. This is followed by discoloration of the paint, changes in rheological behaviour and pH, coagulation, odour, and gas evolution. The growth of microorganisms in the coating or later in the film can be reduced or even prevented by adding chemical biocides to paint at concentrations below 1% wt (Brock *et al.*, 2000; Schwartz & Baumstark, 2001).

In-can preservatives protect against attack during production, transportation and storage. Commonly used substances are formaldehyde (decreasingly so) and its reaction products with alcohols, amines and amides, as well as *N*,*S*-heterocyclic compounds such as isothiazolinones and chloroacetamide (Brock *et al.*, 2000).

In-film preservation is the protection of the applied film against attack by bacteria, moulds, algae or mosses. Their need depends on the exposition of the applied film to humidity, shadow, heat, etc. Substances that are used currently include several *S*- and *N*-containing compounds, often cyclical compounds such as dithiocarbamates, thiophthalimide derivates, benzimidazole derivates and trialkyl compounds, as well as some ecologically unsafe substances such as organic mercury compounds. This category also compasses *antifouling additives* in marine paints, which are designed to prevent marine growth on ships´ hulls and port installations (Brock *et al.*, 2000).

(f) Antiskinning agents

Antiskinning agents are added to paints to retard the formation of skin on the surface of the liquid coating, in either closed or open tins, without delaying the drying of the product. The principal antiskinning agents are oximes or phenol derivatives. The oxime used most commonly is methyl ethyl ketoxime; smaller quantities of butyraldoxime and cyclohexanone oxime are used. The phenol derivatives used are mainly methoxyphenol, *ortho*-aminophenol, and polyhydroxyphenol. Minor quantities of cresols, guaiacol, hydroquinone (see IARC, 1999a), isobutoxysafrol and lignocol have also been used as antiskinning agents.

(g) Corrosion inhibitors

Corrosion inhibitors can be divided into inorganic pigments and organic inhibitors (Brock *et al.*, 2000).

Red lead and chromate-containing pigments have both a chemical and an electrochemical action. Pigments containing red lead are still used in heavy-duty anti-corrosion systems because they possess excellent protection properties. Some zinc chromates are still essential for the protection of aluminium on aircraft.

Lead and chromate-containing pigments are increasingly being substituted by phosphates (zinc, chromium(III), aluminium, calcium and magnesium phosphates). Zinc dust primers are widely used in the protection of steel structures. The synthetic micaceous iron oxide pigment (haematite, Fe_2O_3) acts through a physical mechanism, mainly by the barrier effect of its crystal lattice structure (platelets).

The most important member of the group of organic inhibitors is the zinc salt of 5-nitrophthalic acid.

(h) Asbestos

In the early twentieth century, asbestos was used as a filler to improve the technical properties of paints, particularly those used in shipyards and those applied to bridges. The paints may have contained up to about 20% asbestos. Usage decreased after about 1950, although specialist textured paints or coatings continued to be widely used in home decoration until the early 1990s. These paints contained approximately 5% chrysotile asbestos (Williams *et al.*, 2007).

(i) Nanoparticles

Nanoparticles [substances of < 100 nm in more than one dimension] are mostly metal oxides such as special transparent titanium dioxide, silver or silver compounds, aluminium oxide, fullerenes, and other organic compounds. The use of particles in the range of 10–100 nm – contained in amounts of 0.5-5% wt – remarkably improves the properties of paint layers in terms of scratch resistance, hardness, gloss, wheather stability and crosslinking/hardening. Interestingly, nanoparticles have been used for a long time: carbon black, silicas and ferrous oxides, which have been used for hundreds of years, can have particle sizes down to about 20–100 nm.

Nanoparticles are present as single particles only at the time of manufacturing. Single particles increase in size by agglomeration and by absorption of polymers and tensides onto their surface (which is important for better stabilization, preservation of the required properties and better flow behaviour of the paint). During drying of the paint, the particles continue to agglomerate and are incorporated irreversibly into the polymer matrix. As a result, painters are not exposed to single nanoparticles as such. In addition, since nanoparticles are made by special manufacturers and sold as slurry (aqueous or solvent-

based), because of the strong potential for agglomeration, workers in the paint manufacture do not come into contact with individual nanoparticles either (Aitken *et al.*, 2006).

(j) Light stabilizers

Platelet-shaped aluminium pigments (with their "mirror effect") have been used for many years in high-weather resistant masonry coatings. Modern light stabilizers for coatings are multifunctional. They can be divided according to their mode of action into UV absorbers and radical captors (Brock *et al.*, 2000).

UV absorbers convert UV radiation into heat. Four classes of substances possess the appropriate absorption coefficient: 2-hydroxybenzophenones, 2-hydroxyphenylbenzitriazoles, oxalanilides, and 2-hydroxyphenyltriazines.

Radical interceptors quench the reactive radicals being formed in upper layers and convert them into stable compounds. This interrupts the radical reaction chain of photochemical degradation of the binder. The most commonly used types are the HALS type products (hindered amine light stabilizer), which are all derived from 2,2,6,6-tetramethyl piperidine.

1.2 Production and use of paint products

1.2.1 *Production*

(a) Production processes

The modern manufacture of paints, which are produced mostly in batches, sometimes also continuously, involves three major steps: (i) mixing and grinding of raw materials; (ii) tinting (shading) and thinning; and (iii) filling operations.

Manufacturers first load an appropriate amount of pigment, resin and various liquid chemicals for homogenizing into a stirrer. The homogenized mixture is then transferred to a roller mill, which is a large rotor-stator steel cylinder. Mills for grinding primers or dark pigments are partly filled with steel balls or ceramic pearls of about 0.1–3 mm in diameter. Mills for grinding light colours usually contain flattened ceramic or zirconium dioxide spheres (pebbles) of about 0.1–2 mm in diameter. Depending on the type of mill used, the grinding process lasts for about 0.5–2 hours or until the pigment has been ground to a sufficiently fine paste. After that stage, the grinding pearls are removed and more resin and solvent are added to the paste, and the process repeated. The paste is then pumped out of the mill through a strainer to a holding tank (Brock *et al.*. 2000; Goldschmidt & Streitberger, 2002).

The 'tinting' step involves comparing samples in the holding tank with colour standards. Small amounts of shading pastes, which are highly concentrated blends of ground pigments, and a vehicle are added as required to match the standard. After the batch has been shaded to specifications, it is thinned to the desired viscosity by the addition of solvent, filtered and poured into containers for shipment (Brock *et al.*, 2000; Goldschmidt & Streitberger, 2002).

The complexity of paint technology is indicated by the numerous types of raw material required. A plant that produces a broad line of trade, maintenance, and industrial paints requires over 1000 different raw materials as well as intermediates including oils, pigments, extenders, resins, solvents, plasticizers, surfactants, metallic driers, and other materials.

The modern manufacture of unpigmented lacquers is generally a cold-cutting or simple mixing operation. For example, cellulose nitrate solutions are made by adding the nitrated cellulose from alcohol-wet cotton to the solvent mixture and agitating for 1–2 hours in a paddle or turbine blade mixer. Alkyd resins, which are supplied in solution, can be added directly to the cotton-based solution. Hard resins may be dissolved separately and added as solutions, or the lumps may be dissolved directly in the cotton-based solution by stirring.

The new paint systems are usually produced in the same sequence and with similar equipment as solvent-borne paints. Coating powders, by contrast, need other machineries, such as the extruders used in the plastics industry.

A general trend in the production is the reduction of exposure of workers to the material. Pigment, fillers and solvents (and solvent-based binder solutions) are increasingly removed by ventilation exhausts or by totally-closed automatized production lines. However, many small manufacturers, especially in low-resource countries, still produce paints with a technology without exhausts.

(b) Production volume

Traditionally, two types of coatings are produced: trade sale paints and industrial product finishes.

Trade sale paints are primarily for exterior and interior coatings for houses and buildings, although sizeable amounts of automobile and machinery refinishes, traffic paints and marine shelf-goods are also dispensed through trade sales outlets.

Industrial product finishes or chemical coatings are produced to user specification and sold to manufacturers for factory applications on such items as automobiles, aircraft, appliances, furniture, plastic parts, and metal containers. They also include the category of industrial maintenance coatings, which are specially formulated and are used to maintain industrial plants and equipment (e.g. as resistance to corrosion).

World production of surface coatings in 2005 by selected countries or regions is given in Table 1.3. In 2005, North America produced 6.3 million tonnes (23.1%), western Europe 6.6 million tonnes (24.1%), and eastern Europe 2.5 million tonnes (9.1%). China produced 3 million tonnes (10.9%), with a strong trend in increasing production.

Table 1.3. World production of surface coatings by selected country or regions in 2005

Region	Production (in thousands of tonnes)	%
USA	5373	19.6
NAFTA	6330	23.1
Western Europe	6600	24.1
Germany	1810	6.6
Eastern Europe	2500	9.1
Russia	750	2.7
Asia	8700	31.7
Japan	1512	5.5
China	3000	10.9
Latin America	1540	5.6
Brasil	674	2.5
Rest	1750	6.4
Total	27430	100.0

NAFTA, North American Free Trade Agreement
From CHEM Research GmbH (2006)

The worldwide production of industrially applied paints grew from 6.3 million tonnes in 1980 to 10.5 million tonnes in 2006. In contrast, for the same period, solvent consumption barely increased from 4.1 to 4.2 million tonnes – a consequence of the increasing use of solvent-reduced paints (Streitberger, 2007). Table 1.4 gives details of the production of paints and coatings in Germany by type of resin.

Table 1.4. Production of paints and coatings

Type of resin	Production (in thousands of tonnes) by type of resin
Solvent-borne	
Alkyd	110.4
Acryl	50.9
Natural oils	6.1
Vinyl, styrene	26.2
Epoxy	68.4
Urethane	68.2
Cellulosic	26.7
Polyester	55.7
Phenolic, melamine, urea	4.2
Bitumen, tar	28.5

Table 1.4 (contd)

Type of resin	Production (in thousands of tonnes) by type of resin
Shellac etc.	5.7
High Solids	32.9
Other resins	42.9
Total	526.9
Powder coatings	73.5
Waterborne	
Dispersions (interior)	639.5
Dispersions (exterior)	174.7
Primers	80.3
Synthetic resin plasters	199.2
Glue paints etc.	22.7
Silicate wall paints	30.4
Silicate plasters	27.1
Dispersion laquers	91.7
Electrodip coatings	36.7
Phenolic, melamine, urea	1.0
Putties	189.4
Silicon resin paints	10.6
Silicon resin plasters	19.3
Other resins, synthetic	121.3
Other resins, natural	2.2
Total	1646.1
Thinners (organic solvents)	231.3

From Verband Der Deutschen Lackindustrie (2007)

1.2.2 *Application methods*

The uses and properties of polymer systems in industrial coatings are described in Table 1.5 and 1.6. The various methods of paint application are presented in Table 1.7.

Most paints are applied by simple methods such as brushing or rolling, yielding high transfer efficiency, and with no spray dust formation. Electrodeposition of paint, introduced during the 1960s, was an important milestone in industrial painting and has proven especially advantageous for painting automobile bodywork and other parts thanks to its superior corrosion resistance. In this technique, the coating is an aqueous dispersion of low solid content. The binder particles carry ionized functional groups which may be positive or negative, thus having either anodic or cathodic deposition.

Table 1.5. Uses of polymer systems in industrial coatings

Polymer systems	Coil	Metal	Appli-ance	Furni-ture	Hard-board	Lumber and plywood	Marine	Main-tenance	Auto-mobile OEM	Auto-mobile refinish	Tins
Natural and modified polymers											
Drying oils				(+)	(+)	+	+	+			(+)
Cellulose esters		+		+		+			+	+	
Cellulose ethers				+						+	
Condensation systems											
Alkyd resins	+	+	+	+	+	+	+	+	(+)	(+)	(+)
Polyesters, high molecular weight	+	+	+		+	+					
Amino resins	+	+	+	+	+	+			+	+	
Phenolic resins	+	+	+				+	+	+		+
Polyamides		+					+	+			+
Polyurethanes		+	+	+	+	+	+	+	+	+	+
Epoxy resins	+	+	+	+	+		+	+	+	+	+
Silicones	+	+	+				+	+		+	+
Vinyl polymers and copolymers based on:											
Butadiene								+			+
Acrylic or methacrylic ester	+	+	+	+	+		+	+	+	+	+
Vinyl acetate				+	+	+	+	+			

Table 1.5 (contd)

Polymer systems	Coil	Metal	Appli-ance	Furni-ture	Hard-board	Lumber and plywood	Marine	Main-tenance	Auto-mobile OEM	Auto-mobile refinish	Tins
Vinyl chloride	+	+	+	+	+	+	+	+	+		+
Vinylidene chloride							+	+			
Styrene		+	+		+			+	+	+	+
Vinyl acetal or butyral	+	+		+				+		+	+
Fluorocarbons	+							+			
Resin combinations											
Acrylic and amino	+	+	+	+	+				+		+
Acrylic and epoxy		+	+						+		+
Acrylic and silicone	+	+						+			
Alkyd and amino	+	+	+	+	+				+	+	+
Alkyd and acrylic		+	+	+				+	+	+	+
Alkyd and epoxy		+	+					+	+		
Alkyd and silicone	+	+	+								
Polyester and epoxy		+	+					+	+		+
Polyester and silicone	+	+			+						

Table 1.5 (contd)

Polymer systems	Coil	Metal	Appli-ance	Furni-ture	Hard-board	Lumber and plywood	Marine	Main-tenance	Auto-mobile OEM	Auto-mobile refinish	Tins
Cellulose ester and urethane				+							
Alkyd, acrylic and amino					+						
Polyester and amino											+
Phenolic and epoxy							+	+			+
Epoxy and amino											+
Phenolic and amino											+
Alkyd and vinyl chloride polymers							+	+			

Updated from IARC (1989a) by Working Group
OEM, original equipment manufacturer

Table 1.6. Properties of paint systems for different uses

System	Use for	Advantages	Limitations	Use trends
(Nitro)cellulosics physical drying	Furniture, small mass articles	Fast drying, scratch resistant, alcohol resistant, thin layers possible	Poor light and solvent stability, poor solids content, high solvent content	Declining
2K-PUR ('DD-paints') and 1K-PUR-heat curing paints	Furniture (kitchen), high performance exterior, e.g. vehicles, ships, metal, aircraft	Mechanically and chemically very stable, elastic	Expensive, time in which the material must be used before hardening in the can	Increasing
Acid-curing enamels, urea–formaldehyde resin +Alkyd resin	Similar to 2K-PUR	Similar to 2K-PUR	Formaldehyde emission	Declining
Oil-based resins (alkyd resins)	Exteriors, wall paints, DIY	Good gloss and surface, resistant against weather and chemicals	Slow hardening, often brittling, sensitive against alkali	Declining
Unsaturated Polyesters (UP-paints)	High performance, glossy surfaces e.g. pianos. Putties	Scratch resistant high gloss, low solvent content, high thickness possible	Not light stable, short processing time (2K), poor storage stability and adhesion	Constant for special uses
Waterborne: Acrylate- and PUR-dispersions	Interior furniture, DIY	Low VOC content, light stable	Slow drying, expensive, strong roughening at wood surfaces	Increasing
UV-curing paints, also: electron beam coating	Furniture, specially in schools, parquet	Extremely fast and resilient curing, very low VOC	UV: limited pigmentability	Increasing
Powder coatings (esp. acryl-, polyester-based)	Metal, appliance, machineries, automotive parts	Solvent-free, fast hardening	Heatability of object (plastics and wood very difficult)	Increasing

Table 1.6 (contd)

System	Use for	Advantages	Limitations	Use trends
Polyester (1K, 2K)	Primers, various interior uses	Cheap, mechanically resistant	Poor weather and chemical stability	Declining
Thermoplastic acrylates	Industrial metal coating, low performance appliances	Weather stability, flexible, chemically stable	Poor hardness, heat-softening, expensive	Declining
Melamin resins (oven-curing with OH-polyester, -acrylate,- alkyd)	Weather-stable top coats: vehicles, machinery, appliances, coil coating	Hardness, resistance, adhesion to substrate	Properties not really at level of 2K-PUR	Declining
Epoxy resins (esp. 2K)	Vehicle primers, corrosion and construction protection, Tank interior	Excellent adhesion (especially on zinc, a difficult substrate), resistance, flexibility	Poor weather stability: yellowing, chalking	Constantly high level
Phenolic resins and similars, different hardeners	Primers, electro insulation, tin interiors	Temperature- and chemical-resistant	Yellowing	Special uses
Polyvinylbutyral	Metal primer, e.g. washprimer, shop primer	Excellent adhesion, corrosion protection, also on aluminium	Not for top coats	Constant
Silicon resins	Construction protection	Temperature and weather resistance	Expensive	Increasing
Chlorine-, fluorine-containing polymers	Corrosion protection, coil coating, dirt repellent top coats	Good adhesion on plastics, temperature- and weather-stable	Halogen content (environment, waste disposal), expensive	Special uses, declining

1K, 1-component material; 2K, 2-components material (also two-pack material); 1K-PUR, 1-component polyurethane; 2K-PUR 2-components polyurethane; DIY, Do-It-Yourself
Compiled by the Working Group

Table 1.7. Application methods

Application	Surface quality	Limitations			Throughput	Solvent emissions	Transfer efficiency
		Dimensions	Geometry	Others			
Brushing	Medium to good	Small areas	-	-	Very low	Low	Very good
Rolling	Good		Accessibility	-	Medium	Low	Very good
Drawing (putty)	-	Small areas	-	-	Low	Low	Very good
Wiping	Poor	Large parts	-		Low	Low	Very good
Conventional dipping	Medium	Limit in object volume	No scooping parts	Edge covering	High	Low	Very good
Coating in barrel	Poor	Small parts	Pourable	-	High	Low	Very good
Centrifuging	Poor	Small parts	Pourable	-	High	Low	Very good
Flooding	Medium	Limit in object volume	No scooping parts	Edge covering	High	Low	Very good
Flow Coating	Medium	Working width	No scooping parts	Edge covering	High	Low	Very good
Curtain coating	Very good	Working width	Nearly flat objects	-	High	Low	Very good
Roller coating/Coil coating	Medium	Working width	Flat surfaces	-	Very high	Low	Very good
Electrodipping	Low	Limit in object volume	No scooping parts	-	High	Low	Very good

Table 1.7 (contd)

Application	Surface quality	Limitations			Throughput	Solvent emissions	Transfer efficiency
		Dimensions	Geometry	Others			
Air – low-pressure atomization	Good	-	-	-	Low	High	Poor
Air – high-pressure atomization	Excellent	-	-	-	Low-to-medium	Very high	Very poor
Air – high-pressure HVLP	Very good	-	-	-	Low	High	Poor
Airless atomization	Medium	-	-	-	High	Medium	Medium
Airmix atomization	Good	-	-	-	Medium	High	Medium
Electrostatically aided air atomization	Very good	-	No Faraday cages	Electricity-conducting substrate	Medium	High	Good
High speed rotation atomization	Very good	-	No Faraday cages	Electricity-conducting substrate	Medium	High	Good
Electric powder coating	Good	-	-	Electricity-conducting substrate	Medium	No	Good
Fluidized bed coating	Poor	-	-	Thick layers	Medium	Low	Very good

HVLP, high-volume low-pressure
Compiled by the Working Group

The anodic type typically uses amino- or alkali-solubilized polycarboxylic resins and the cathodic type, salts of amine-treated resins, such as epoxy resins (Stoye & Freitag, 1998).

For high quality surface requirements ("appearance," gloss, smoothness), paints are often applied by direct contact or by deposition by atomization processes.

Deposition by atomization processes includes conventional spray, hot spray, electrostatic spray, and powder coating (Brock *et al.*, 2000).

Probably the greatest advance during the early 1900s in the field of paint technology was the introduction of the spray gun. Its advent helped the introduction of cellulose nitrate lacquers and their application to automobile assembly line production. Electrostatic spraying was first introduced in the USA in the 1940s, and then later in the United Kingdom.

The solvent-free electrospray powder spray application was introduced in 1965 in the coating industry. In this process, the powder is first fluidized in a closed container by compressed air. The so-formed aerosol is transported by an injector to the spray gun. There, the powder particles are charged electrostatically and sprayed onto the object, which is earthed. The electrostatic charge allows the transport of the particles to the object and their adhesion to it.

Since the early-to-mid 1990s, – initiated mainly by Rule 1151 in southern California – the high-volume low-pressure technique has allowed savings on paint material by reducing spray dust. The modified spray technique, which requires new nozzles and a new spray gun interior, allows a 10–20% reduction in paint consumption. This technique is applied worldwide.

1.3 Formulation and application methods by trade

1.3.1 *Construction painting*

Paints that are used on architectural structures (indoor and outdoor surfaces) are comprised of primers or undercoats and matt, semigloss or gloss-finishing coats. The primers and finishing coats differ primarily in the pigment/vehicle balance and in additive and vehicle types. Primers (usually called 'primers/sealers') are used to seal the variable porosity of the substrate (e.g. wood) and to adhere to the substrate and to subsequent coats of paints.

(a) Exterior house paints

Traditionally, linseed oil and oleoresinous vehicles have accounted for the bulk of architectural (house) paints. Several other oils have been used, but to a much lesser degree and often in conjunction with linseed oil. The most important have been tung oil, perilla oil, soybean oil, fish oils, safflower oil, and dehydrated castor oil. More modern oil-based house paints generally contain a combination of untreated drying oil (unbodied oil) and drying oil treated (polymerized) so that its viscosity is increased (bodied oil). A wide variety of

thinners and solvents were employed in the formulation – white spirits, benzene and solvent naphtha.

Between 1950 and 1960, the first exterior water-based house paints were introduced. Most of these were based on acrylic-type latexes, and the paint had excellent colour retention on exterior exposure. Since that time, water-soluble and emulsified linseed oil house paints have been marketed, which combine the advantage of an oil paint and a water-based paint in one product. Because of the ease of application, cleaning ability with soap and water and good service, latex paints constitute most of the exterior paint market. Among the more common latexes are the acrylics, polyvinylacetate–dibutylmaleate copolymers, ethylene copolymers and acrylate copolymers (Schwartz & Baumstark, 2001).

The pigments used in interior and exterior construction or architectural paints include primarily inorganic and organic pigments that are stable against UV light, water and acid rain.

(b) Interior paints

The principal pigments used for interior white paints are titanium dioxide, zinc oxide and iron oxides as well as various carbonates and siliceous extenders, which are used to control pigment volume and gloss. Since 1927, with the development of alkyd resins, a variety of architectural enamels for interior and exterior use have been based on these resins. The bulk of enamels produced for interior use contains oil treated to increase viscosity (bodied oil), and/or varnish.

Water-based interior paints contain three types of latex polymers: styrene–butadiene types, polyvinyl acetate types, and acrylics. Copolymer blends of styrene and acrylate have also been used, combining the most durable features of each monomer into a single polymer (Schwartz & Baumstark, 2001).

Extender pigments used in latex paints include clays, calcium carbonates, silicates, diatomaceous earths, silicas, barytes, and talcs (IARC, 1997, 1987, 2010a), as well as white and coloured pigments. Surfactants, pigments and other additives are usually incorporated into the formulation along with latex to obtain a stable and satisfactory product. These other additives include thickeners, defoaming agents, freeze–thaw stabilizers, coalescents, and pH adjusters (ammonia amines or potassium hydroxide). The thickeners used most commonly are cellulosics – principally hydroxyethyl cellulose and methyl cellulose – polyacrylates, polyacrylamide, polyvinyl alcohols, and many others. Propylene glycol and monoethers of this glycol and other glycols serve as freeze–thaw stabilizers. Coalescents are additives designed to optimize the coalescence of latex particles and include hexylene glycol, butyl cellosolve, and butyl carbitol. In the last 20 years, the solvent content has decreased from about 3–5% to nearly 0%. As a result, interior paints must be protected against microbial attack (fungi, bacteria) by in-can preservatives such as imidazoline derivatives (Schwartz & Baumstark, 2001).

(c) Masonry paints

Latex-based primers/sealers are state-of-the-art for masonry surfaces. The latex vehicle is generally more resistant to alkali than earlier casein-based paints and permits evaporation of water from masonry surfaces without disruption of the film. Both alkyd and latex vehicles adequately seal porous surfaces (Schwartz & Baumstark, 2001). Oil paints and styrene–butadiene copolymer, polyvinyl acetate emulsion, resin emulsion and chlorinated rubber paints are also used on masonry surfaces.

Concrete floor coatings – and coatings for other cementitious substrates – must possess good water and alkali (saponification) resistance and adhesion over damp surfaces. Concrete is first covered with a solvent primer. A satisfactory floor paint can be formulated using a styrene–butadiene latex fortified with an epoxy ester. An example of a concrete floor enamel formulation is presented in Table 1.8. Acrylic emulsion paints are widely used outdoors on concrete, stucco and cinder block because of their durability, adhesion, and flexibility (Stoye & Freitag, 1998).

Table 1.8. Example of formulation of vinyl acetate-based masonry paint for interior use

Component	Percentage
Water	26.9
Dispersant (polycarbonate, polyacrylate)	0.7
Thickener (polyurethane, cellulose derivates)	0.5
Defoamer (mineral oil)	0.1
Sodium hydroxide (25 %)	0.1
Dipropylene glycol-*n*-butyl ether	0.5
In-can preservative (isothiazolinone)	0.2
Titanium dioxide (rutile)	5.7
Calcite	29.7
Chalk	12.5
Calcium carbonate (precipitated)	8.0
Talc	9.1
Vinyl acetate-ethylene copolymer dispersion, 53 %	6.0
Total	100.0

From Müller & Poth (2006)

(d) Waterproof paints

Waterproof paints are applied on the outside of unpainted concrete, brick, stucco, and so forth and are formulated in a variety of ways to include components such as wax, aluminium stearate, and silicone resins. A significant advance in the manufacture of waterproofing paints in the mid-1950s involved the use of silicone resins. Typically, silicone waterproof paints contain silicone resin and solvent or water, or special silicones, such as sodium methyl siliconate, in aqueous solution (Heilen, 2005).

1.3.2 *Surface coating in the wood industry*

Five properties are considered to be essential in furniture varnish: quick, hard, tough drying (3–4 hour); good sanding and polishing properties; good resistance to water, heat and chemicals; good processing properties; and environment friendliness (e.g. free of formaldehyde, low VOC emissions). Table 1.9 gives an example of a formulation for a parquet lacquer of matt clear varnish.

The types of organic dyes found in wood stains (IARC, 1981) include anthraquinones, acid azo metal complexes, phthalocyanines, triphenylmethane salts, coumarins, perinones, methines, pyrazolones, quinophthalones, various other metal complexes, and several food dyes (Prieto & Kiene, 2007).

Finishing operations for wood include staining, 'wash coating' [the application of a clear thin coat of lacquer before use of a filler], filling (if necessary), sealing, sanding, application of one or two lustre coats, and polishing. Two types of oil or water stains – soluble and suspended pigment type – impart the desired colour to wood. Wood stains are dissolved in a vehicle that enables them to seep into the wood rather than simply stick to its surface as a film. After the staining operation, 'wash coating' stiffens the protruding fine wood fibres, and can be removed by light sanding. In some procedures, a filler is used to fill the depressions before the sealer and finish coats are applied. These finishes are dried by evaporation of solvent or water; finish coats usually contain physically drying dispersions, UV-curing lacquers or two-component polyurethane systems. Formulations of paint used for furniture depend on the end-use. Nursery furniture, for example, requires extremely hard, tough coatings containing non-toxic pigments. A wide variety of coatings has been used on furniture, based on the chemical systems mentioned above.

Current trends are towards solventless UV-curing paints, often as replacement for existing waterborne systems. The main advantages are a higher performance and longer lifetime of the coated parts. The first attempts with powder coatings on fibre plates are under way.

1.3.3 *Painting in the metal industry*

(a) Metal primers, finish coats and corrosion inhibition paints

As iron and steel rust in contact with moisture and oxygen, many products made with these metals are coated with rustproof primers and finishing coats.

Primers are vehicle-rich coatings intended for application as foundation and adhesion-promoting coats. Metal primers are used to form a firm adhesive bond with the surface and also serve as an impermeable barrier between the environment and the metal surface.

Table 1.9. Example of formulation of a parquet lacquer of matt clear varnish in western Europe, 2000

Type of product and ingredients	Parts per weight
Mixture 1	
Solvents	
Propylene glycol-*n*-butyl-ether	40
Propylene glycol	10
Dipropylene glycol monomethyl ether	20
Additives – total	25
Water	30
Butyl glycol	20
Mixture 2	
Acrylic dispersion, 45% wt	400
Polyurethane dispersion, 40% wt	400
Wax dispersion	45
Defoamer, levelling agent	10
Procedure	
Introduce mixture 2 and add mixture 1 while stirring	

From Schwartz & Baumstark (2001)

When active rust prevention is essential, rust-inhibitive pigments that retard oxidation chemically are used.

Zinc chromate (zinc yellow; [a double salt of zinc and potassium and chromic acid]) was introduced in the early 1940s and is still used in some areas, especially for aircraft. Because of restrictions on the use of lead and chromates in the early 1960s, the pigments favoured in the past 20 years in industrial maintenance coatings have been mainly zinc metal, zinc oxide, zinc molybdates and zinc phosphates (Brock *et al.*, 2000; Buxbaum & Pfaff, 2005).

Finishing coats cover the metal primer and seal it. Some metal products are covered by enamels that contain alkyd resins, and dry by oxidation. The most durable coatings available are generally used on machinery and other industrial equipment, and are based on epoxy or polyurethane resins that are cured by chemical reaction. Typical formulations are shown in Table 1.10.

Since the 1980-1990s, an increasing percentage of metal parts used in the industry, household and machinery are coated with coating powders. The use of powders however is limited by the following factors inherent to the system: geometry (not too complex), resistance against oven temperature of 160–220°C, and electrical conductivity. Until the mid-1990s, the technologically very good hardener triglycidyl isocyanurate was used. Because of its teratogenicity, this hardener is no longer used in western and northern Europe, although it is still used in southern Europe, and in many other countries outside Europe. Other aromatic glycidylesters and β-hydroxyalkylamide may be used as substitute (Gillis de Lange, 2004).

Table 1.10. Examples of formulations of metal paints

Type of paint and ingredients	Weight (%)
Iron oxide primer (from 2000)	
Water soluble alkyd resin (75% in butyl glycol)	16.7
Styrene–butadiene copolymer dispersion	25.4
Ammonia (25%)	1.0
n-Butoxypropanol	1.2
Butyl glycol	1.7
Fillers (talc, calcite)	11.5
Zinc phosphate	7.4
Metal complex dryer (catalyst) 10%	0.4
Iron oxide pigment	6.7
Wetting and dispersing agent	3.6
Defoamer	0.3
Water	26.2
White epoxy powder indoor paint (from 2002)	
Epoxy resin (Bisphenol A-based)	55.7
Dicyanamide curing agent	2.8
Calcium carbonate (extender)	1.5
Titanium dioxide (pigment)	24.4
Barium sulfate (filler)	12.7
Acrylic polymer flow additive	2.9
Water-based red epoxy enamel for can coating (from 2000)	
Phenol epoxy resin emulsion (55% solids)	68.2
Butyl glycol	10.0
Hexamethoxy melamine curing agent	2.0
Iron oxide red pigment	9.8
Water	10.0
Polyurethane clear coat, solvent-borne, 2-pack, for metal (from 2000) (similar for wood or plastics)	
Hydroxyl-functional acrylic resin (60% in solvents)	81.0
Cellulose acetobutyrate (20% in butyl acetate)	2.0
Dibutyl tin dilaurate (catalyst) (1% in butyl acetate)	1.0
Hydroxyphenyl benzotriazol (UV absorber)	0.8
N-Alkyl piperidine derivative (radical catcher)	0.6
Silicone oil (1% in xylene)	1.0
Glycol monobutyl ether acetate	4.0
Polyisocyanate (90% in solvents)	32.2
Butyl acetate	18.5
Xylene	8.9
Total (100 of component 1 + 50 of component 2)	150.0

From Müller & Poth (2006)

(b) Marine paints

Paints for surfaces that are continuously immersed in seawater must be formulated with antifouling properties to resist the growth of marine flora and fauna. The accumulation of vegetable and animal vegetation at the hull produces a "biological roughness", which leads to weight gain of the ship and the loss of its hydrodynamic form (Grüner, 2007).

Antifouling coatings based on derivatives of triphenyl or tributyl tin have been introduced since the 1990s. In some coatings, an organotin compound, such as the acetate, chloride, fluoride or oxide, is simply mixed into the formulation. These coatings are known as 'free-association' coatings and are characterized by a high leach rate of organotin when the coating is new which rapidly diminishes, until the concentration of the coating becomes insufficient to prevent fouling. A more useful formulation is obtained when the organotin in 'copolymer' coatings is covalently bound to the resin of the coating and is released when the bond hydrolyses in sea water. Due to the high toxicity of these combinations, the use of organotin compounds is forbidden since 2003. According to the Navy Environmental Protection Committee of the International Maritime Organization (IMO), their presence on ships is illegal since 2008 (IMO, 2008).

More recent strategies have focused on nontoxic alternatives. These include the use of fluoropolyurethane foulant-release coatings. Paints based on "Controlled Depletion Polymer" have a high rosin content (> 50%) and few film formers, so that water-soluble films are formed in which the biocides are soluted. The "Self-Polishing Copolymer" is based on an acrylate resin, which is largely hydrophobic, water swellable. The biocides are bound to the polymer chemically and their activity occurs through hydrolysis (Grüner, 2007).

(c) Automobile coatings

Cellulose nitrate lacquers, introduced in the early 1920s, were followed by the introduction of alkyd enamels to the automobile industry in the early 1930s. These compositions were usually modified with small amounts of amino resins to provide harder, more thoroughly crosslinked films. These were followed by the adoption of thermosetting acrylic enamels in which alkyds were replaced by acrylic copolymers containing hydroxyl groups which could still react with melamine modifiers (Fettis, 1995).

In the late 1950s, lacquers of greatly improved durability and gloss, based on polymethylmethylacrylate or thermosetting acrylic enamels, were adopted by the automobile industry (Fettis, 1995).

Nowadays, many polymers (including maleic resins, amino resins (urea–formaldehyde and melamine–formaldehyde polymers), silicones, epoxides, polyesters and polyurethanes) form the basis of highly diverse coating systems. In addition, nonaqueous dispersion lacquers and acrylic enamels have been developed. Steel used in automobiles is pretreated with a conversion coating (phosphating or bonderizing) to improve corrosion resistance and

adhesion. Today, most cars are galvanized and phosphated (Goldschmidt & Streitberger, 2002).

The earlier solvent-borne primers have been almost completely replaced since 1960 by waterborne electrodeposited primers. The original anodic type has been largely replaced since 1980 by the cathodic type, which is superior in corrosion protection. The binders for cathodic deposition are typically acid salts of amino-treated epoxy. The formulations contain polyepoxides or mostly blocked polyisocyanates which crosslink the coating when it is baked. Prior to application of the top coat, a coat of solvent or waterborne epoxyester primer–surfacer is applied (Fettis, 1995; Goldschmidt & Streitberger, 2002).

Waterborne base coats have been used in Europe since 1980–1990 and are still state-of-the-art today. In other regions, their use is increasing. Very high solid content top coats are being used increasingly; conventional thermosetting acrylic enamels that can be applied in about 60–65% volume solids are now available (Fettis, 1995; Goldschmidt & Streitberger, 2002). Top coats (especially clear coats) have been used in only a few plants since the mid-1990s. Some manufacturers already apply powder clear coats. The trends are towards more waterborne products, more powder and less paint consumption by application of thinner layers as well as by elimination of whole layers (surfacer).

A broad range of inorganic and organic pigments is used in automotive finishes (top coats). These include inorganic types such as titanium, nickel titanium and iron oxides, carbon black, aluminium and other effect pigments (Fettis, 1995). Organic pigments include diarylide yellow, anthrapyrimidine, isoindolinones, quinacridones, thioindigos, perinones (diimides of naphthalene-1,4,5,8-tetracarboxylic acid), perylenes (diimides of perylene-3,4,9,10-tetracarboxylic acid), copper phthalocyanines and anthraquinones, naphthol reds and maroons (monoazo pigments such as the copper precipitation product from the coupling of diazotized 4-nitroanthranilic acid with Naphthanil RC).

Table 1.11 gives a typical formulation of a lacquer for an automobile top coat.

Table 1.11. Formulation of a metallic base coat for automobile paint in western Europe, 2004

Type of paint and ingredients	Weight (%)
Blue metallic lacquer	
Polyacrylate dispersion (24% in water)	48.0
Melamin resin (80% in water)	4.7
Butyl glycol	7.4
Dimethylethanolamine (10% in water)	1.1
Aluminium flakes pigment (65% in aliphatic hydrocarbon)	3.8
Saturated polyester (60% in butyl glycol)	5.0
Water	30.0

From Müller & Poth (2006)

(d) Car repair finishes

Automotive repair finishing coatings, unlike assembly line coatings, are not stoved but instead dried or cured at temperatures below 80°C. They are usually force-dried at 50–60°C. Increasingly, they are coated by portable infrared radiators. Nevertheless, the coating is both visually and technologically comparable with the stoved primary coat, even though the coating systems are completely different, particularly in terms of binders and solvents (Brock *et al.*, 2000; Goldschmidt & Streitberger, 2002).

To meet these requirements, mainly products of the rapid and high peformance two-component polyurethane and two-component epoxy coating chemistry have been used since the 1970s. Alkyd resins, cellulose nitrate combination products and other older systems are also widely used, being tailored to local equipment and to requirements (Brock *et al.*, 2000).

The preparation zone is used for cleaning, degreasing, dust removal, levelling, priming, filling and sanding. The coating/drying station may be combined as one station or separated into two booths (Brock *et al.*, 2000).

Primer, surfacer and clearcoat are usually solvent-based. The base coat is also solvent-based in most countries. Since 2007, only waterborne basecoats are allowed in the European Community (EC).

(e) Coil coatings

One of the growing areas of industrial coating is coil coating. The coil stock consists of enormous rolls of thin-gauge (galvanized) steel or aluminium, which are coated at steel mills, aluminium mills or by specially equipped contractors. The coils are unwound, coated on high-speed roller coaters, heat-cured, sometimes then laminated and rewound. Binder compositions include alkydamino–formaldehyde combinations, vinyl chloride–vinyl acetate copolymers (see IARC, 1987, 1995, 2008) and thermosetting acrylics, often modified with small amounts of epoxy, which produces coatings that are flexible, durable and adhesive. In the coil-coating industry, which still uses solvent-borne materials only, solvent vapours are collected and disposed of by incineration (thermal recycling) (Goldschmidt & Streitberger, 2002).

Powder coating and UV-curing systems are used increasingly. Where this is not possible for technical reasons, waterborne paints are introduced.

1.3.4 *Other painting trades and paint products*

(a) Traffic paints

The major requirements for traffic (road) paints are fast and hard drying, and environmental compatibility. Since the 1990s, many public authorities in Europe demand the use of waterborne materials as much as possible for coating bus fleets, trains, and trams.

The paints generally contain a high pigment volume, fast-drying vehicles, such as resin combinations with low oil content or oil-free synthetic resins, and low-boiling solvents (e.g. petroleum fractions with distillation ranges of 100–150°C) or water.

Conventional alkyd formulations account for many traffic paints still used in numerous countries. However, there has been a significant increase in the use of more durable pavement-marking materials, such as two-component polyester, polyurethane and epoxy systems and one-component hot extruded thermoplastic types.

(b) Fire-retardant paints

Fire-retardant or intumescent paints, when applied to wood or other combustable, as well as to steel and aluminium surfaces, retard the spread of fire by foaming at elevated (but less than charring) temperatures. Several intumescent formulae contain a chemical combination of polyol (e.g. pentaerythritol), a mono- or diammonium phosphate or polyphosphate, aluminium hydroxide (as water degasser), and an amide. Certain pigments such as red phoshorous (glassy polyphosphoric acid protects against oxygen) and borates are also added to enhance the fire-resistant properties of such paints. Other intumescent paint formulae contain polyvinyl acetate and acrylic latexes.

(c) Aerosol colours

A large variety of paints have been packaged in aerosol tins for touching up and painting small areas, graffitis, hobby aircrafts and other such objects. The principal types of paint used are of alkyd composition, are thinned out to a low viscosity (generally with ketones and aromatic hydrocarbons) to allow atomization, and contain a gaseous propellant which is liquid under pressure (propane, butane, isobutane or sometimes dichloromethane, which has replaced dichlorofluoromethane in many countries). Other aerosol paint compositions include acrylic and cellulosic lacquers and epoxyester systems. In early 2000, the first two-component aerosol tins appeared. The two components are brought into contact by crashing a hardener cartridge inside, followed by intensive shaking.

(d) Paint and varnish strippers

Dichloromethane (see IARC, 1999a) was for a long time a widely used and effective paint stripper base. Other chlorinated hydrocarbons that were used with dichloromethane were, in order of decreasing effectiveness, perchloroethylene 1,2-dichloroethane (see IARC, 1999a), propylene dichloride, dichloroethyl ether and *ortho*-dichlorobenzene (see IARC, 1999b). Today, halogenated solvents are avoided in many countries. Other solvents that can soften paint films are, in approximate decreasing order of effectiveness, ketones (e.g. methyl ethyl ketone), dibasic and other esters, aromatic hydrocarbons, alcohols and aliphatic hydrocarbons, often combined with the use of ultrasonic impulses (Brock *et al.*, 2000; Goldschmidt & Streitberger, 2002).

The main inorganic paint strippers are alkalis, principally in the form of a hot solution of sodium hydroxide and, to a lesser degree, potassium hydroxide and lime or soda ash (anhydrous sodium carbonate). Additives such as sequestering agents (e.g. gluconic acid and alkali metal gluconates), surfactants (e.g. sodium resinate, fatty acid soaps, sodium lignin sulfonate, alkylarenesulfonates and petroleum sulfonates), water-soluble activators (e.g. phenolic compounds and their sodium salts – cresol, chlorocresol, sodium pentachlorophenate) and solvents (e.g. monoethers of ethylene glycol and diethylene glycol) are often used to increase the stripping rates of inorganic paint removers. Plants today use hot alkaline tenside solutions when possible. Paint removers that are used on steel, aluminium and other nonferrous alloys often contain corrosion inhibitors such as phosphates (Goldschmidt & Streitberger, 2002).

Molten and fused alkali baths are also employed sometimes to salvage ferrous metal parts with defective finishes. At temperatures of up to 500°C, even heavy films of epoxy and silicone coatings can be removed rapidly.

(e) Substrate preparation by sanding and air blasting

Substrates contaminated with corrosion products, dirt, dust, oil, grease and other contaminants must be sanded or – if possible or necessary – cleaned by air blasting (Goldschmidt & Streitberger, 2002).

Sanding is performed wet or dry, by hand or machines. The resulting dust may contain old paint, rust, zinc salts, and metal dust from the underlayer.

(f) Paints for artists

Art painters use pigments in oil paints, acrylics, watercolour paints, gouache, encaustic, poster paints, casein paints, and tempera. The range of pigments used in art paints is greater than that used in commercial paints. McCann (2008) highlights the following toxic metals in pigments used in art paints: arsenic in emerald green and cobalt violet (cobalt arsenate); antimony in true Naples yellow (lead antimonate); cadmium in various cadmium pigments; chromium in chromium oxide green, zinc yellow, strontium yellow, viridian; lead in flake white, mixed white, true Naples yellow; manganese in manganese blue, manganese violet, burnt umber, raw umber, Mars brown; and mercury in vermillion.

1.4 Exposures in the workplace

1.4.1 *Inhalation exposures*

(a) Introduction

Occupational exposure results predominantly from the inhalation of gases and vapours from solvents and additives, of pigment dust, and of complex inorganic and organic mixtures such as dusts from binders, dried coatings, and mists generated during the spraying of paint. The other major route of occupational exposure is through cutaneous contact with the various paint compounds, many of which can be absorbed through the skin. Ingestion related to personal work habits constitutes another potential route of entry.

Workers in the painting trades may also be exposed to several chemical agents originating from other operations that they or fellow workers are involved in, such as cleaning and preparing – by chemical or mechanical means – the object to be painted. Workers may be exposed to crystalline silica dust produced by other construction trades on a building site.

The main substances to which workers may be exposed are listed in Table 1.1. The main agents for which quantitative occupational inhalation exposure data are available are presented in Tables 1.2–1.6, which cover the major painting trades.

Exposure to solvent mixtures is often described using a summary measure, the cumulative exposure index (CEI), i.e. the sum of ratios of various measured levels to the respective occupational exposure limits. If this index exceeds unity, the combined exposure to different components of a solvent mixture is considered to exceed the recommended exposure limit. The values of the CEI are not always comparable because the exposure limits may vary by country and over time.

In some painting operations, personal protective equipment is worn. However, it is common industrial hygiene practice to determine potential exposure by monitoring the breathing zone outside such protective gear.

(b) Manufacture of paints and related products

The potential for occupational exposure depends largely on the types of products being manufactured, the degree of automation of the manufacturing process, the availability of exposure control measures, and the nature of the specific job held. Various job classification systems have been developed for the paint manufacturing industry. Workers have thus been regrouped according to the basic product manufactured – water-based paints, solvent-based paints, lacquer and vehicle – and their function: pre-batch assembler, mixer, tinter, filler, tank and tub cleaner, reactor operator, varnish cooker, filter press operator (Morgan *et al.*, 1981). Additional functions are raw materials handler, laboratory personnel, and others such

as packagers, maintenance personnel, shippers, and warehouse workers (National Institute for Occupational Safety and Health, 1984).

Exposures, both by inhalation and skin contact, occur specifically in operations that can involve manual handling procedures such as weighing ingredients (pigments, extenders, resins, additives), loading them into mixing equipment, adding solvents to mills, and cleaning equipment (mixers, mills, reactors, kettles, tanks, filters). Additional exposure to solvents occurs in thinning, tinting and shading procedures, filling operations, and filtering of varnishes. The cooking of varnishes may produce emissions of various aldehydes such as acrolein, of phenol, ketones, glycerine and fatty acids as well as dusts or vapours of maleic, phthalic and fumaric anhydrides during the loading of kettles. The production of powder coatings can be associated with significant exposure to dust from resin powders, pigments, curing agents and other additives. In the manufacture of radiation-curable coatings, exposures may occur to monomers such as ethyl acrylate, other acrylates, and photoinitiators. Caustic solutions may be used in the cleaning of dispersion equipment (National Institute for Occupational Safety and Health, 1984). In general, the greatest potential for exposure results from spills and the continuous spattering from machines (Adams, 1983).

(i) *Exposure to solvents* (Table 1.12)

Heavy naphthas, toluene and benzene are reported to have been the most commonly used solvents during the 1930s, presumably with high exposure levels. Substitutes for aromatic hydrocarbons, including turpentine, decaline and tetraline, were used in the following decades. Among the solvents most commonly reported from exposure measurements in the paint industry since the 1980s are toluene, xylene, ethyl acetate, *n*-butylacetate, *n*-butanol and ethylbenzene (Table 1.12).

In the paint-manufacturing industry in Sweden, manual cleaning of equipment was associated with outstandingly high exposures to solvents, including dichloromethane/methylene chloride (Ulfvarson, 1977; Lundberg & Håkansson, 1985). Exposure estimates for solvents (CEI) in the Swedish paint-manufacturing industry showed a decreasing trend from 2 in 1950–69, 1.5 in 1970–74, 0.7 in 1975–79 to 0.3 since 1980 (Lundberg, 1986), due in large part to better control measures and to the increasing production of water-based paints.

In two paint-producing factories in the People's Republic of China, the mean benzene concentrations determined by grab samples were 21.4 and 159.5 mg/m^3 (Yin *et al.*, 1987).

More recent studies from Taiwan (China), China, Poland, Germany, Republic of Korea, and France reported mean or median exposures to the most frequently reported solvents toluene and xylene to be less than 30 ppm and CEI to be less than 0.7 (Table 1.12). However, the wide ranges of exposure levels indicate that workers, at times, are exposed to high a concentration of solvents.

In two German studies of varnish production, the mean concentrations of various glycol ethers reported were in the range of <0.1–7.0 ppm (Angerer *et al.*, 1990; Söhnlein *et al.*, 1993).

Table 1.12. Paint manufacture - concentration of solvents in air

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Ulfvarson (1977) Sweden	Personal sampling, 3–66 min	9 paint factories	Organic solvents		CEI		Most common solvents were xylene, toluene, butanol and esters; local exhaust common, respirators not often used. CEI based on Swedish OEL or ACGIH
		Charging solvents		33	2.0	0.2–16	
		Pigment dispersion		18	1.5	0.2–4.4	
		Tinting, thinning		14	0.9	0.1–2.0	
		Can filling, paints		39	1.3	0.02–6.6	
		Can filling, thinners		14	1.8	0.1–7.4	
		Manual cleaning of equipment		51	5.7	0.5–30	
Haglund *et al*. (1980) Sweden	Breathing zone, 30 min; 17 workers	7 paint factories			8h-TWA median (mg/m^3)		Workers presumed to have the highest exposure were measured (17 out of 47)
			Xylene	16	111	14–6074	
			Toluene	16	11	1–1257	
			Isobutanol	15	5	1–354	
			Ethylacetate	14	20	1–129	
			n-Butylacetate	13	14	7–1676	CEI based on Swedish OEL from 1978
			Ethanol	13	13	5–971	
			n-Butanol	13	7	1–1541	
			Methylacetate	8	12	3–169	
			Dichloromethane	3	719	635–2421	
			White spirits	3	45	5–52	
			Isopropanol	1	129		
			CEI	17	0.5	0.1–40	

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Lundberg & Håkansson (1985) Sweden	Breathing zone, 30 min; 47 workers	7 paint manufacturing industries			8h-TWA median (mg/m^3)		Outstandingly high exposures occurred during manual cleaning of paint mixing equipment (9 workers included)
			Xylene	44	82	1–6070	
			Toluene	43	10	1–1260	
			Isobutanol	36	4	1–1040	
			n-Butanol	35	6	1–1540	
			Ethanol	33	12	1–1090	
			Ethylacetate	32	26	1–767	
			n-Butylacetate	31	9	1–1680	
			White spirits	18	44	5–74	
			Methylacetate	11	13	3–169	
			Dichloromethane	5	719	10–2420	
			Methyl ethyl ketone	5	39	8–124	
			Isopropanol	3	129	6–258	
Angerer *et al*. (1990), Germany	Personal full shift diffusive sampling; 12 workers	Production of varnishes containing glycolethers	2-Butoxyethanol	12	1.1	<0.1–8.1	
			2-Ethoxyethanol	12	2.8	<0.1–7.8	
			2-Ethoxyethyl acetate	12	2.7	<0.1–11.1	
			1-methoxypropanol-2-ol	12	7.0	<0.1–24.1	
			2-methoxypropyl-1-acetate	12	2.8	<0.1–13.8	
			Xylene	12	1.7	0.4–6.7	

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Söhnlein *et al.* (1993) Germany	Personal full shift sampling; 12 workers	Varnish production Day 1	2-Butoxyethanol	12	0.5	<0.1–1.4	
			2-Ethoxyethanol	12	2.9	<0.6–15.2	
			2-Ethoxyethyl acetate	12	0.5	<0.1–3.7	
		Day 2	2-Butoxyethanol	12	0.6	<0.1–1.0	
			2-Ethoxyethanol	12	2.1	<0.1–6.2	
			2-Ethoxyethyl acetate	12	0.1	<0.1–0.4	
Wesołowski & Gromiec (1997) Poland	Personal full shift sampling	5 paint and lacquer production plants, including two modern plants – workers in production, laboratory and transport plants		179 total			40 organic solvents measured; only those with a mean concentration >3 mg/m^3 included here; The two modern plants had lower CEI
			Ethylacetate		7.4 mg/m^3	0–182	
			Toluene		4.7	0–88.2	
			n-Butyl acetate		3.1	0–127	
			2-Methoxypropyl acetate		3.8	0–25.7	
			Ethylbenzene		7.0	0.1–95.1	
			Xylene		21.6	0.4–314.1	
			Trimethylbenzene (all isomers)		5.6	0–88.4	
			C-9 Aromatic HC		11.9	0.2–174	
			White spirit		16.9	0.15–274	
			CEI		0.65	0.1–4.94	

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Tsai *et al.* (1997) Taiwan, China	Passive personal sampling	6 paint factories		245 total	Median		CEI based on ACGIH, 1990. Lower exposure in other departments-not included . Benzene found in 4 samples at <2 ppm
		Mixing	Toluene	29	3.1	0–15.1	
			Xylene		4.3	0–18.6	
			n-Hexane		0	0–6.0	
			Methyl isobutyl ketone		0	0–5.3	
			n-Butyl acetone		1.9	0–15.9	
			CEI		0.11	0–0.45	
		Grinding/thinning	Toluene	18	13.7	0–106.5	
			Xylene		15.9	1.2–108.1	
			n-Hexane		0	0–18.8	
			Methyl isobutyl ketone		0	0–36.6	
			n-Butyl acetone		5.0	0–39.5	
			CEI		0.31	0.02–1.51	
		Tinting	Toluene	25	2.3	0–232.4	
			Xylene		4.6	0–391.6	
			n-Hexane		0	0–62.4	
			Methyl isobutyl ketone		0	0–11.6	
			n-Butyl acetone		1.9	0–18.6	
			CEI		0.11	0.01–7.61	

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Tsai *et al.* (1997) Taiwan, China	Passive personal sampling	Packaging	Toluene	39	11.9	0–57.3	
			Xylene		13.7	1.3–89.4	
			n-Hexane		0	0–19.9	
			Methyl isobutyl ketone		0	0–6	
			n-Butyl acetone		4.4	0–14.6	
			CEI		0.3	0.01–1.21	
Krämer *et al.* (1999) Germany	Ambient air, 8 h	Paint production (13 men)	Xylene	13	29	5–58	
			Ehylbenzene		9	2–17	
			Toluene			<1	
		Paint spraying (10 men)	Xylene	10	8	3–21	
			Ehylbenzene		2	1–6	
			Toluene			<1	
Nassiri & Golbabai (1999) Iran	Personal sampling, samples collected 5 days a week for 8 weeks; 54 workers	1 paint manufacturer		175	Range of means		
		Mixing, grinding, tinting, packaging	Toluene	NR	0.6-11.2		
			Xylenes		2.3-25.1		
					Mean		
		Tank cleaning	Toluene	NR	9.5		
			Xylenes		57.1		
		Control laboratory	Toluene	NR	7.6		
			Xylenes		40.0		

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Truchon *et al.* (1999) Canada	Personal full shift passive dosimeters	2 paint production plants		50	Range of 2 means (TWA)		
			Toluene		12–58	1–157	
			Methyl ethyl ketone		4–18	ND–95	
			Xylene		7–13	ND–45	
			Stoddard solvent		ND–13	ND–39	
			VM&P Naphta		12–39	ND–129	
			Methyl isobutyl ketone		1–2	ND–7	
			n-Butyl acetate		2–7	ND–24	
			Ethyl acetate		ND–2	ND–10	
			Methyl isoamyl ketone		ND–1	ND–3	
			Isopropyl alcohol		ND–3	ND–17	

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Yang *et al.* (2000) Korea	Personal full shift low flow sampling	1 paint manufacturer Paint mixing, synthesis			GM		
			N,N-dimethylformamide	13	1.2	0.1–7.4	
			Toluene		1.2	0.2–15.9	
			Methyl ethyl ketone		0.6	0.1–17.8	
			CEI		0.11	0.01–1.0	
		Packing	*N,N*-dimethylformamide	5	0.4	0.1–2.7	
			Toluene		1.8	0.2–14.5	
			Methyl ethyl ketone		0.4	0.1–6.0	
			CEI		0.06	0.01–0.44	
Delcourt & Sandino (2001) France	Personal sampling, mean duration of 420 min	1 car paint manufacturer – Preparation drum cleaning, grinding and packaging	*n*-Butanol	58	6.1 mg/m^3	1.1–16.6	
			Isobutanol	59	2.3	0.5–9.3	
			Methyl ethyl ketone	59	7.5	1.2–27.9	
			Methyl isobutyl ketone	56	28.1	3.3–115.6	
			Ethyl acetate	59	8.1	0.6–29.1	
			n-Butyl acetate	56	38.3	7.2–160.7	
			Toluene	58	12.3	2.5–33.6	
			Ethylbenzene	57	8.1	0.7–19.9	
			m-Xylene	56	21.3	2.1–54.6	

Table 1.12 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean [a]	Range	
Purvis *et al.* (2001) Kenya	Full shift (8–10 h) over 3 days	3 paint manufacturers		96	Ranges of 3 means		Number of samples from the respective section not reported
		Laboratory	Ethylbenzene		1.5–12.1		
			Styrene		ND–0.04		
			Toluene		1.2–39.3		Workers expected to have the highest exposure cross-section in each section were selected.
			Xylenes		5.9–40.9		
			CEI		0.09–0.57		
		Mixing, tinting, filling, transport of raw materials and resins	Benzene		ND–0.13		
			Ethylbenzene		0.4–31.3		
			Styrene		ND–0.35		
			Toluene		1.2–50.3		CEI based on ACGIH TLVs
			o-Xylene		1.4–107.5		
			CEI		0.06–1.7		

[a] Unless otherwise stated

ACGIH, American Conference of Governmental Industrial Hygienists; CEI, cumulative exposure index; ND, not detected; GM, geometric mean; TLV, threshold limit value; TWA, time-weighted average

In the United Kingdom, a total of 341 toluene measurements in paint manufacturing were available in the National Exposure DataBase, covering the period between 1985 and 2002 (Creely *et al.*, 2006a). The mean airborne concentration of toluene was 77.6 ppm (range <0.01–8698 ppm), and a decline in concentration of 11% per year was observed. Based on industry data ($n = 253$), the decrease in the airborne concentration of toluene in paint manufacturing was –44% per year. [The decline is likely due to increased production of paints with low-solvent contents.] While operations were largely manual before the late 1960s, improvements such as local exhaust ventilation were gradually introduced into factory environments in the mid-1960s.

(ii) *Exposure to dusts* (Table 1.13)

In a Swedish investigation covering ten factories manufacturing paint and industrial coatings, exposure to quartz, asbestos, chromium including Cr(VI), and lead was documented in some air samples during the charging operation in some of the companies (Table 1.13).

(iii) *Other exposures*

Exposure to ammonia was reported while charging it during manufacture of water-based paints in a paint industry in Sweden, at average airborne concentrations of 50–80 ppm (35–56 mg/m^3). The levels of pentachlorophenol and phthalic anhydride were below the national occupational health standards of 0.5 mg/m^3 and 2 ppm (12 mg/m^3), respectively (Ulfvarson, 1977). The concentration of diethylene triamine was below the detection limit (0.01 mg/m^3) in the breathing zone of two workers canning epoxy paint-curing agents in a paint factory in Finland (Bäck & Saarinen, 1986).

In a paint-manufacturing company in the USA, the 8-hour time-weighted average (TWA) airborne concentration of vinyl acetate were in the range of 1.0–8.4 ppm (3.6–30.6 mg/m^3; four samples). Personal and area air samples indicated concentrations of ethyl acrylate ranging from below the limit of detection to 5.8 ppm (23.8 mg/m^3); concentrations of butyl acetate were all below the limit of detection (16 samples), except one sample at 0.9 ppm (4.7 mg/m^3; Belanger & Coye, 1980).

(c) Construction painting and lacquering

Usually in the construction industry, the work of painters involves the use of a limited number of types of coatings – mainly decorative water- or solvent-based paints, and wood lacquers and varnishes. The potential for exposure to a variety of substances (mainly solvents and pigments) is high: painting performed inside buildings, where there is poor ventilation, especially in confined spaces such as small rooms, cupboards or bathrooms, can lead to very high levels of air contaminants; whereas when painting the outside of buildings (façades, windows, roofs), natural ventilation is usually effective at reducing exposures. The painting of new buildings usually involves water-based paints and spraying equipment; however, during renovation or maintenance, solvent-based paints are still widely used, and work is usually performed by hand with a brush or roller.

Table 1.13. Exposure to paint mist, dust, silica and metals in air

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
PRODUCTION							
Ulfvarson (1977) Sweden	Personal sampling during charging operations, 5 min–8h	10 paint factories – Charging operations, tinting, handling of bags, compressing empty bags, floor cleaning and emptying air-cleaner filters	Total dust Quartz (5*) Asbestos (4*) CrO_3 (7*) Pb (7*)	61 5 6 14 7		1.7–70 mg/m^3 0.01–0.9 mg/m^3 0.31–5 fibres/m^3 0.003–1.6 mg/m^3 0.006–4 mg/m^3	* Number of factories
CONSTRUCTION INDUSTRY							
Rosensteel (1974) USA	Breathing zone samples; 5 workers	Bridge girders plant – Spraying lead silico-chromate paint			**mg/m^3**		NIOSH report
			Chromium	5	0.08	0.01–0.25	
			Lead	5	0.02	0.01–0.04	
Landrigan *et al.* (1982) USA	NR	Bridge Scraping lead-based paint and priming it Recoating with lead-based paint	Lead			 24–1017 µg/m^3 6–30 µg/m^3	
Spee & Zwennis (1987) Netherlands	Personal, 90–135 min; 5 workers	Steel bridge coated with lead-based paint – Flame torch cutting	Lead	13	12.2 mg/m^3	2.3–38.1	

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Norbäck *et al.* (1995) Sweden	Personal full-shift sampling for 6 days, 3–5 h painting per day; 12 painters	House painters		12	8h-TWA		
		Roller painting water-based paint inside old and new buildings, removing old wall paper, manual sanding, filling walls and sizing wall paper	Total dust		4.1 mg/m^3	0.04–14.3 mg/m^3	
			Organic dust		1.4	0.1–3.7	
			Calcium		0.3	0.07–0.90	
			Iron		0.02	0.004–0.05	
			Titanium		0.01	<0.001–0.05	
			Zinc		0.02	<0.001–0.08	
			Lead		0.001	<0.001–0.003	
			Cobalt		0.001	<0.001–0.003	
Conroy *et al.* (1996) USA	Personal samples, 8–10hrs	**Steel bridge – Abrasive blasting**			Median		
		During blasting:	Lead				
		Blasters and sweepers		64	366 µg/m^3	12–4401	
		Equipment operators		12	219	14–1400	
		Foremen		17	160	26–3423	
		Moving containment, painting, cleaning, maintenance	Lead				
		Blasters and sweepers		11	130	42–2500	
		Equipment operators		15	440	13–1900	
		Foremen		6	46	12–180	
	Area samples, 8–10 hrs	*Bridge*	Lead	9	10970 µg/m^3	196–29950	
			Chromium	4	23.5	1.26–43.7	
			Cadmium	4	15.7	13.5–18.3	
		Viaduct	Lead	10	3277	533–18200	
			Chromium	5	369	9.41–657	
			Cadmium	3	1.31	1.06–1.60	

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Lipton et *al.* (1996) USA	Personal sampling, 62–327 min; inside respirator-helmet for abrasive blasters	Steel bridge Abrasive blasting with silica sand Traffic control within area Flaggers Hopper loader	Crystalline silica	 7 6 3 9	Median TWA 0.02 mg/m^3 0.08 0.02 0.08	 ND–0.2 0.04–0.53 ND–0.02 0.04–0.35	Silica content in respirable dust: 7.1–37.5%
Lange & Thomulka (2000) USA	Personal breathing zone	Steel construction lead-paint removal with needle gun	Lead	13	TWA 7.5 µg/m^3	1.7–20.9	
Daniels *et al.* (2001) USA	Personal	Wet abrasive blasting of lead-based paint from: Wood - method 1 Wood - method 2 Bricks - method 1 Bricks - method 2	Lead	 3 3 6 6	8h-TWA 70.9 µg/m^3 55.1 68.4 81.5		

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Reames *et al.* (2001) USA	Personal approx. 30 min	Dwellings – Lead-paint removal	Lead		GM		Data from 45 samples of multiple tasks not included
		All tasks		175	4.2 μg/m^3	<0.5–146.0	
		External scraping		64	5.1	0.3–123.0	
		Clean-up		25	2.3	0.3–17.1	
		Internal scraping		19	7.7	0.5–139.0	
		Demolition		15	10.3	2.5–80.2	
		Chemical stripping		14	10.2	3.3–20.9	
		Internal wet sanding		14	1.0	0.5–4.9	
		Component removal		8	2.4	0.5–8.0	
		Internal wet sanding and scraping		7	1.0	0.5–6.8	
		External wet sanding and scraping		5	1.0	0.4–3.6	
		Containment preparation		4	1.3	0.5–4.9	
		Water application		4	3.9	3.0–5.4	
Scholz *et al.* (2002) USA	Personal full-shift sampling	Surface preparation on building with lead paint	Lead	25	TWA 57 μg/m^3	0.8–550 μg/m^3	
	30 min task-specific sampling	Heat gun	Lead	6	2.3 μg/m^3	<1(ND)–5	
		Wet sanding		3	3.3	<1(ND)–7	
		Open flame burning		5	9.8	<1(ND)–20	
		Power sanding with exhaust		7	33	4–60	
		Dry scraping		18	71	≤4–230	
		Dry manual sanding		9	420	29–1200	
		Uncontrolled power sanding		10	580	65–3400	

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Rappaport *et al*. (2003) USA	Personal respirable air samples; 12 workers	7 construction sites – Abrasive blasting	Dust Crystalline silica	14 14	13.5 mg/m^3 1.28	1.2–833 0.26–26.2	
Golla & Heitbrink (2004) USA	Task-based respirable dust, breathing zone outside mask	*Concrete parking house – Wet abrasive blasting* at ground level on platform helper	Crystalline silica	 7 9 8	GM 0.22 mg/m^3 0.13 0.06	 0.12–0.43 0.04–0.41 <0.02–0.12	Silica content in respirable dust: 20%
METAL INDUSTRY							
Vandervort & Cromer (1975) USA	Breathing zone samples, 1–3h	Truck body and refuse handling equipment manufacturing – Spray painting operations	Paint mist Lead Chromium$_{tot}$	7 7 7	24.4 mg/m^3 1374 µg/m^3 194 µg/m^3	4.8–47 20–3000 10–400	NIOSH report
Kominsky *et al.* (1978) USA	Personal, 8–174 min	Manufacturing of aeromechanical systems – Spraying primer with zinc chromate	Chromium (VI)	12	606.7 µg/m^3	13.3–2900 µg/m^3	NIOSH report
Elofsson *et al.* (1980) Sweden		*Car refinishing workshops* Spraying activities Grinding activities	 Paint mist Lead Chromium$_{tot}$ Paint mist Lead Chromium$_{tot}$		 7 mg/m^3 100 µg/m^3 26 µg/m^3 3 mg/m^3 20 µg/m^3 6 µg/m^3		

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
O'Brien & Hurley (1981) USA	Sampling time,				GM	GSD	NIOSH report
	25–41 min	Light aircraft finishing, primer	Paint mist Lead $Chromium_{tot}$	3	23.3 mg/m^3 ND 1600 µg/m^3	1.6	
	27–62 min	Light aircraft finishing, topcoat	Paint mist Lead	6	23.3 mg/m^3 ND	1.7	
	19–35 min	Light aircraft finishing, stripping	Paint mist Lead	6	14.1 mg/m^3	2.0 ND–5000	
	15–45 min	Car refinishing	Paint mist Lead	7	8.7 mg/m^3 52 µg/m^3	1.6 1.5	
	8 h	Car refinishing	Paint mist Lead	7	5.0 mg/m^3 30 µg/m^3		
	15–60 min	Railroad car	Paint mist Lead $Chromium_{tot}$	13	43.3 mg/m^3 211 µg/m^3 220 µg/m^3	1.4 1.7 2.2	
	60 min	Heavy equipment	Paint mist Lead $Chromium_{tot}$	3		2.0–36.5 230–1300 31–230	
	8 h	Metal furniture	Paint mist Lead	6		3.7–27.6 ND–1050	
	8 h	Metal furniture, high solids paints	Paint mist Lead $Chromium_{tot}$	6		0.5–6.2 5–26 5–9	
	8 h	Small appliance parts, powder coating electrostatic spraying	Paint mist	3	1.3	1.1	
	8 h	Appliance finishing	Paint mist Lead	4		21.7–54.5 <6–20	

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Hellquist *et al.* (1983) Sweden		Fireplace manufacturing plant – Spray painters	Total dust Chromium oxide Zinc oxide		1.7 mg/m^3 5–8 µg/m^3 20–30 µg/m^3		
Jayjock & Levin (1984) USA	Personal 55–197 min	Car body repair shop – Sanding and grinding of plastic filler	Total dust Respirable dust	2 2		5–40 mg/m^3 0.3–1.2 mg/m^3	
Zey & Aw (1984) USA	Personal	Bus manufacturing – Employees in and around paint booth	Chromium (VI) Lead	5 8	0.23 mg/m^3 0.78 mg/m^3	0.03–0.45 mg/m^3 ND–2.01 mg/m^3	NIOSH report
Booher (1988) USA	Personal full shift	Ship overhaul facility – Paint removal	Lead		GM		
		Chipping with needle gun		10	2.36 µg/m^3	1.0–4.9	
		Sanding		22	60.6	2.6–1570	
Zedd *et al.* (1993) USA	Personal full shift	Shipboard – Lead-paint removal	Lead		TWA		
		Chipping with needle gun		38	91.6 µg/m^3	<2–785	
		Grinding		37	400.5	<2–2500	
		Chipping/grinding		19	375.2	8.2–1610	
		Supervision		13	493.9	2.1–2300	

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Aizenberg *et al.* (2000) USA	Personal 4–6 h sampling (Button sampler)	4 U.S. Air Force facilities – paint and primer removal from aircraft parts or ground equipment by abrasive blasting			Range of 7 means (TWA)		Range of means for 7 surfaces or tasks. Data read from graph
			Lead	67	0.003–0.13 mg/m^3		
			Chromium (VI)	77	0.003–0.2 mg/m^3		
			Cadmium	67	0.001–0.5 mg/m^3		
Jarrett (2003) USA	Personal samples over 28 days	Shipyard – Paint removal	Lead		Range of means		Range of means per worker
		Abrasive blasting (10 workers)		104	824–3187 µg/m^3	308–6522 µg/m^3	
		Labourers within containment structure (6 workers)		11	1194–3852 µg/m^3	577–3852 µg/m^3	
Sabty-Daily *et al.* (2005) USA	Personal 8h breathing zone	Aerospace facility – Spray painting in booths			Range of means (8h-TWA)		
		Field study 1	$Chromium_{tot}$	18	5.3–256 µg/m^3	1.0–364 µg/m^3	6 means
		Field study 2	$Chromium_{tot}$	12	56–332	22–390	4 means
			Chromium (VI)	12	70–214	19–327	4 means

Table 1.13 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Vitayavirasuk *et al.* (2005) Thailand	Personal sampling – full-shift 8 hrs respirable dust, 70 workers	Autobody repair workshop– spray painting not in booth					
		Painters wearing respirators	Lead	20	0.97 μg/m^3	0.08–5.75	
			Cadmium	20	0.01	ND–0.02	
			Chromium	20	0.73	0.31–3.07	
		Painters not wearing respirators	Lead	50	0.62	0.05–5.60	
			Cadmium	50	0.30	ND–5.74	
			Chromium	50	0.64	0.25–2.55	
Blade *et al.* (2007) USA	Personal full shift	Painting and coating facility using chromate-containing paint	Chromium (VI)		GM		
		Spraying, sanding and cleanup		5	16 μg/m^3	3.8–55 μg/m^3	
		Spraying and sanding		13	0.23	<0.02–4.3	
		Helper		4	7.9	2.4–22	
		Steel bridge – Abrasive blasting of chromate-containing paint	Chromium (VI)	8	0.43	0.10–1.3	

GM, geometric mean; GSD, geometric standard deviation; ND, not detected; NR, not reported; TWA, time-weighted average

Surfaces to be coated can be made from plaster- or gypsum-based wall-board composite materials, concrete, wood (for windows, doors and flooring), and more rarely, metal. Construction painters may spend a good proportion of their time in preparatory or accessory work. In a Finnish study of construction painters, 40% of the 231 painters estimated that they spent more time on such work than actual painting (Riala *et al.*, 1984). Removing old paint and preparing surfaces in general may involve the use of paint strippers containing solvents such as dichloromethane, of gas-operated blow torch units or hot air guns which may generate organic pyrolysis fumes, metallic fumes, and dusts from pigments. Other accessory tasks may be polishing, sanding or sandblasting operations, which may generate aerosols of old paint, quartz, concrete, plaster, wood, and metal dusts. Acid or alkali washing solutions may be used, as well as steam generators for removing wallpaper, which can release exhaust gases that contain carbon monoxide. Preparing surfaces also involves filling cracks and holes using plaster, cement, sealers, spackling, taping and dry wall materials, putties and wood fillers, which may result in possible additional exposure to inorganic dusts and fibres (including asbestos), and solvents. Further exposure arises from the use of solvents during the cleaning of equipment as well as from personal cleaning (Ringen, 1982; Huré, 1986; Swedish Work Environment Fund, 1987).

(i) *Exposure to solvents* (Table 1.14)

In a Danish investigation in 1974, exposure to benzene (55 ppm) and trichloroethylene (91 ppm) were particularly elevated. Benzene originated from turpentines used for thinning and for cleaning of painting equipment, and for hand washing (Mølhave & Lajer, 1976). Renovation spray painters in Sweden were exposed to very high concentrations of white spirits (1200–1500 ppm) (Bobjer & Knave, 1977). In a study in Finland involving mainly maintenance construction workers, the overall average airborne concentration of solvents expressed as solvent naphtha exposure, was 132 ppm (77 samples). The solvent naphta contained 17% aromatic hydrocarbons (Riala *et al.*, 1984).

A total of 45 maintenance painters in the Netherlands who worked on 12 different projects were exposed to an 8-hour TWA airborne concentration of combined solvents of 101 mg/m^3 (geometric mean). Benzene was detected at two of the sites at low concentrations (up to 0.2 mg/m^3). C_2- and C_3-substituted benzenes and C_8-C_{11} alkanes were found at most sites, originating mainly from the use of white spirits.

Workers using chlororubber paint in a pumping station were exposed to carbon tetrachloride at concentrations in the range of 10–17 mg/m^3 (Scheffers *et al.*, 1985).

During the application of water-based paints, ethylene glycol butyl ether (2–60 mg/m^3) was measured in concentrations of up to 40% of the Danish occupational exposure limit (Hansen *et al.*, 1987). Swedish housepainters renovating old buildings and painting new buildings by application of water-based paint were exposed to low concentrations of VOCs, formaldehyde and ammonia during indoor work (Norbäck *et al.*, 1995). In the Netherlands, outdoor house painting behind screening also resulted in low exposure to VOCs (Spee *et al.*, 2005).

Table 1.14. Construction industry - concentration of solvents, formaldehyde and ammonia in air

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Mølhave & Lajer (1976) Denmark, 1974	Personal, 1 h	Indoor painting				Max. value	In total, 13 solvents investigated
			Benzene	41	55	289	
			Trichloroethylene	33	91	390	
			Toluene	43	23	91	
			Xylene	31	5	68	
			1,2,4-trimethylbenzene	32	15.8	177	
			CEI	44		<1 (7 samples)–34.6	
Riala *et al.* (1984) Finland	Personal, 15 min–3 h	Indoor painting in houses	Solvent naphtha	77	132		16 maintenance and 2 new sites. Alkyd and urethane painting, and varnishing
		Without ventilation:					
		- Roller and brush painting		43	194		
		- Spray painting		3	235		
		With ventilation:					
		- Roller and brush painting		26	38		
		- Spray painting		5	39		

Table 1.14 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Hansen *et al.* (1987) Denmark	Personal, 20 min	15 workplaces – Application of water-based paint	Butyl acrylate			0–2 mg/m^3	
			Diethylene glycol butyl ether			4–5	
			Diethylene glycol methyl ether			8–32	
			Dipropylene glycol methyl ether			30–40	
			Ethylene glycol butyl ether			2–60	
			Ethylene glycol phenyl ether			0–0.7	
			Propylene glycol			2–70	
			2,2,4-Trimethylpentane-1,3-diol monoisobutyrate			0.5–12	
			Triethylamine			4–6	
			White spirits			40–75	
			Formaldehyde			0–0.4	

Table 1.14 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Norbäck *et al.* (1995) Sweden	Personal full shift sampling, except for formaldehyde and ammonia. Measurements done in two time periods (phase I and II)	House painters – Roller painting with water-based paint, removing old wall paper, manual sanding, filling walls and sizing wall paper; 3–5 h painting per day			2 means	Max. value	Means of phase I and phase II are given
			Toluene	8; 20	109–216 µg/m^3	2120 (µg/m^3)	
			Xylene		107–132	620	
			Ethylbenzene		49–56	170	
			n-Nonane		74–200	2240	
			n-Decane		29–80	4670	
			n-Undecane		29–202	2030	
			Limonene		44–237	2770	
			n-Butanol		103–302	2500	
			Isobutanol		380–750	6570	
			Propylene glycol	20	2630	12700	
			Diethyleneglycol monoethyl ether		820	8060	
			Formaldehyde (8 h)	12	0.05	<0.03–0.10	
			Formaldehyde (peak)	5	0.08	<0.03–0.14	
			Ammonia (8 h)	12	0.9	<0.4–3.9	
			Ammonia (peak)	17	6.2	<1–25	

Table 1.14 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
Burstyn & Kromhout (2002) Netherlands	Personal, 176 min (full-shift)	House painting, mainly rolling and paintbrush					Data from 5 studies in 1980–1998, which include 105 workers. Solvent-based and water-based include 29 and 6 samples, respectively, from shipyards
		Water-based paint (acrylate)	Toluene	49	0.61 mg/m^3	0.004–9.4 mg/m^3	
			Xylenes	48	1.15	0.01–13.1	
			Ethylbenzene	48	0.23	0.002–1.7	
			n-Hexane	48	0.04	0.007–0.3	
			n-Decane	48	1.75	0.01–23.5	
		Solvent-based paint (alkyd, synthetic, turpentine, chloro-rubber)	Toluene	147	1.93	0.004–43.0	
			Xylenes	108	15.26	0.085–233.5	
			Ethylbenzene	108	4.95	0.023–86.0	
			n-Hexane	72	0.20	0.007–10.9	
			n-Decane	94	13.90	0.006–210.0	
Spee *et al.* (2005) Netherlands	Personal	Outdoor painting behind screen			GM		CEI based on MAC in The Netherlands
			VOCs	5	11.7 mg/m^3	3.4–22.9	
		6 painters from 3 sites (4–8 h)	CEI	5		0.01–0.05	
		33 painters from 10 sites (225–520 min)	VOCs	33		31 samples <1	
			CEI	33		<0.05–0.11	31 samples <0.05

CEI, cumulative exposure index; GM, geometric mean; VOC, volatile organic compound

Based on 304 measurements of solvent exposure from 137 house and shipyard painters in the Netherlands between 1980 and 1999, Burstyn & Kromhout (2002) reported a decreasing trend for solvent exposure. Toluene was selected as a marker for solvent exposure. A 12% annual decrease in toluene exposure concentration during application of solvent-based paint was observed. Use of solvent-based paint, painting in small rooms and spray-painting (versus manual painting) was associated with increased exposures. The reduction in exposure over time was comparable to that observed by others in a wide variety of industrial processes (Creely *et al.*, 2006a, 2007).

(ii) *Exposure to metals, dust and silica (*Table 1.13*)*

Substantial exposure to airborne lead was reported for workers in the USA involved in scraping old lead-based paint from the metallic structure of a bridge and priming it (24–1017 μg/m^3) (Landrigan *et al.*, 1982). In this situation, workers wore a respirator. In the Netherlands, workers involved in flame-torch cutting of a bridge steel structure coated with lead-based paints were shown to be exposed to very high concentrations of airborne lead (2.3–38.1 mg/m^3) (Spee & Zwennis, 1987).

During abrasive blasting of a steel bridge in the USA, lead concentrations of personal samples collected inside the air helmet (but outside the half-mask respirators) ranged from 12 to 4401 μg/m^3. A total of 85% of the 125 personal air samples exceeded the 50 μg/m^3 level allowed by OSHA. High lead exposure was also measured during painting, cleaning and setting up or moving the containment structure (range 12–2500 μg/m^3) (Conroy *et al.*, 1996).

When performing lead paint abatement on steel structure surfaces inside a building by needle gun methodology, personal full-shift airborne lead concentrations were in the range of 1.7–20.9 μg/m^3 (Lange & Thomulka, 2000). Personal exposure to lead during wet abrasive blasting of lead-based paint from wood and brick exterior house surfaces (range of mean exposure, 55.1–81.5 μg/m^3) exceeded the Permissible Exposure Limit (PEL) of OSHA (50 μg/m^3) (Daniels *et al.*, 2001). In a residential lead hazard reduction project in the USA, lead concentrations were in the range of <1.0–146.0 μg/m^3 (Reames *et al.*, 2001). The highest exposure occurred during external or internal paint scraping, demolition, and chemical stripping. In another study of surface preparation of buildings in the USA, the airborne lead concentrations measured from full-shift personal samples were in the range of 0.8–550 μg/m^3. Six of the samples were above the PEL of OSHA; all of these involved dry manual sanding and uncontrolled power sanding (Scholz *et al.*, 2002).

Swedish housepainters renovating old buildings and painting new buildings were exposed to relatively high dust levels, sometimes exceeding the Swedish PEL (10 mg/m^3). The highest exposure to dust was recorded during 2 days when manual sanding was taking place (Norbäck *et al.*, 1995).

Crystalline silica concentrations inside the respirator worn in the helmet were reported in the range from below the detection limit to 0.2 mg/m^3 (median, 0.02 mg/m^3) during abrasive blasting of a steel bridge in the USA (Lipton *et al.*, 1996). Painters had high exposure to respirable crystalline silica ($n = 14$, range 0.26–26.2 mg/m^3) during abrasive

blasting at seven construction sites in the USA from 1992 to 2000 (Rappaport *et al.*, 2003). Task-based exposure to crystalline silica was lower during wet abrasive blasting of the exterior walls of a parking garage (range <0.02–0.43 mg/m^3) (Golla & Heitbrink, 2004).

(d) Painting, varnishing and lacquering in the wood industry (Table 1.15)

Application of clear varnish or lacquer finishes on furniture represents the main use of coatings in the wood industry. Paints, varnishes and lacquers are also used in the production of various wooden raw materials (e.g. composite wood boards) and miscellaneous wooden articles (e.g. toys, tableware). Until the mid-1950s, cellulose ester-type lacquers were almost the only ones used in the furniture industry; however, amino-resin-based, polyurethane, and polyester coatings later constituted the main coatings in the industry (Swedish Work Environment Fund, 1987).

Workers are exposed mainly through the inhalation of solvents either from paint mist or from vapours generated by spraying operations, from vapours evolved from finished products or from auxiliary work such as mixing the coatings, cleaning the equipment or applying other products such as wood fillers and sealants. The exposure is influenced by the method of applying coatings; the most common are spraying, usually at low pressure, curtain and roller coating, and dipping. Low molecular-weight resin constituents such as formaldehyde and isocyanates may be released during the application or curing of coatings. Another possible exposure agent is wood dust from the general factory environment, and from preparatory work (sanding).

In an Italian art furniture factory, the average 4-hour airborne toluene concentration to which 20 workers employed in painting and hand-finishing were exposed was 27–182 mg/m^3(Apostoli *et al.*, 1982).

In a wood furniture company in the USA, overall, low air concentrations (0.05–0.24 mg/m^3) of paint mist and organic solvents were reported (O'Brien & Hurley, 1981). The mean short-term exposure to formaldehyde in furniture and plywood factories in Finland, Sweden and Denmark from the period 1975 to 1993 was in the range of 0.20–1.2 ppm (Table 1.15). Exposure to solvents in these studies was relatively low. Priha *et al.*, (1986) reported a decreasing time trend for exposure to formaldehyde between the years 1975 to 1984. A more recent Norwegian study covering 27 woodworking and furniture factories reported the geometric mean airborne formaldehyde concentration to be 0.15 ppm, with about 10% of the samples exceeding the Norwegian Occupational Exposure Limit (OEL) of 0.5 ppm (Thorud *et al.*, 2005). The CEI for solvents in this study was low.

In two studies of parquet lacquerers in Finland, the exposure to glycol ethers measured when primer and final lacquering were spread by steel comb and smooth comb was well below the OEL values (Laitinen & Pulkkinen, 2005; Laitinen *et al.*, 2006).

Table 1.15. Wood industry - concentration of solvents and formaldehyde in air

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					Mean	Range	
O'Brien & Hurley (1981) USA	27 workers	Furniture company – Spray painting and finish wiping		27			
		Acrylic base coat	CEI			0.05–0.11	
		Oil-based glaze	CEI			0.06–0.10	
		Cellulose nitrate lacquer	CEI			0.08–0.24	
		All tasks	Paint mist (8h-TWA)		0.1–2.5 mg/m^3		
Apostoli *et al.* (1982) Italy	20 workers Personal 4h sampling	Art furniture factory – Painting and hand-finishing	Toluene			27–182 mg/m^3	Acetone, isobutanol, ethanol, ethyl acetate were also found
Kauppinen (1986) Finland	Personal sampling for solvents; area sampling for formaldehyde	Plywood industry – Coating				ppm (mg/m^3)	
		Polyurethane paint 1975–1984	Methyl isobutyl ketone	12		2–28 (8.2–115)	
			Butylacetate	12		8–50 (38–238)	
			Xylene	12		10–25 (43–108)	
			Cyclohexane	12		1–28 (3.4–95)	
		Alkyd paint 1975–1984	Toluene	8		2–3 (7.5–11.3)	
			Xylene	8		7–12 (30.4–52)	
			Isobutanol	8		7–11 (21–33)	
			Trimethylbenzene	8		1–9 (5–44)	
		Coating	Formaldehyde				
		1965–74		7	1.0	0.5–1.8	
		1975–84		28	0.26	<0.01–0.6	

Table 1.15 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
Priha *et al.* (1986) Finland 1975–84	Sampling during active painting. Personal for solvents (0.5–1.5 h); personal and area for formaldehyde (15–30min)	50 furniture factories					
		Spray painting	Formaldehyde	60	0.97	0.2–4.0	Decreasing time trend for formaldehyde, not for solvents
		Spray painting assistance		10	1.02	0.2–1.6	
		Operation of curtain painting		18	1.11	0.2–6.1	
		Feeding of painting machine		14	1.11	0.3–2.7	
		Receiving painted pieces		34	1.48	0.1–4.2	
		Receiving painted pieces after drying oven		14	0.94	0.2–5.4	
		Overall tasks	Xylene	394	19		Only those solvents present in >50% of samples given
			Butanol	394	17		
			Ethanol	394	32		
			Toluene	394	17		
			Butylacetate	394	11		

Table 1.15 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
Alexandersson & Hedenstierna (1988) Sweden	Breathing zone, 15 min; 38 workers	Furniture factory – Acid-hardening varnishes and paint	Formaldehyde				Short-term samples basis for calculation of 8h-TWA
			(8h-TWA)	38	0.4 mg/m^3	0.12–1.3	
			(15 min)	38	0.7	0.14–2.6	
			Xylene		18		
			Ethanol		17		
			Toluene		15		
			Isobutanol		10		
			All solvents (8h-TWA)	38	0.15	0.02–0.52	
Vinzents & Laursen (1993) Denmark	Personal sampling; formaldehyde, 15 min; solvents, 2h	Furniture factories – Painting			GM	GSD	CEI based on Danish OEL
			Formaldehyde (28 factories)	43	0.20 mg/m^3	2.25	
			CEI for organic solvents	55	8h-TWA		
					0.21	2.57	
Laitinen & Pulkkinen (2005) Finland	22 workers	Parquet lacquer spread with steel comb and smooth comb			8h-TWA	SD	8h-TWA based on personal task samples
			DEGME	3	0.23	0.07	
			DEGEE	16	0.08	0.07	
			DEGBE	16	0.05	0.03	

Table 1.15 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
Thorud *et al.* (2005) Norway	86 workers Personal parallel samples Sampling time, 141 min (range 21–291 min); 2–3 consecutive samples per worker per shift; sampling during 3 years	27 woodworking and furniture factories – Surface coating with acid-curing lacquers and paint: manual and automatic spray painting, curtain painting, dip painting, manual painting (roller, brush etc.), grinding, mounting			GM		
			Formaldehyde	557	0.15	0.01–1.48	
			n-Butyl acetate	550	2.09	0.02–155	
			Ethanol	521	6.73	0.06–397	
			Ethyl acetate	500	0.86	0.02–65.2	
			1-Butanol	496	0.81	0.02–32.6	
			2-Methyl-1-propanol	327	0.39	0.02–13.0	
			Aliphatics C4-C8	313	0.54	0.02–33.7	
			m & *p*-Xylene	288	0.19	<0.01–3.73	
			1-Methoxy-2-propylacetate	284	0.35	0.01–11.6	
			o-Xylene	269	0.06	<0.01–1.12	
			1-Methoxy-2-propanol	241	0.99	0.01–19.7	
			2-Propanol	228	1.45	0.03–37.7	
			Toluene	216	0.29	0.02–72.7	
			Ethylbenzene	185	0.06	<0.01–1.98	
			Aliphatics C9-C13	124	0.32	0.02–6.17	
			Ethyl 3-ethoxypropionate	45	0.55	0.09–2.52	
			1-Propanol	33	0.53	0.10–1.82	
			2-Butanone	22	0.48	0.12–2.83	
			4-Methyl-2-pentanone	20	0.44	0.07–8.40	
			Acetone	19	0.36	0.04–1.70	
			Styrene	9	0.10	0.01–1.47	
			CEI	557	0.13	<0.01–5.08	

Table 1.15 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm		Comments
					8h-TWA	SD	
Laitinen *et al.* (2006) Finland	22 workers, 30–242 min	Parquet lacquer spread with steel comb and smooth comb	PGME	15	1.9	1.3	8h-TWA based on personal task samples
			PGBE	11	1.0	1.4	
			DPGME	11	0.2	0.3	

DEGME: 2-(2-methoxyethoxy)ethanol
DEGEE: 2-(2-ethoxyethoxy)ethanol
DEGBE: 2-(2-butoxyethoxy)ethanol
PGME: 1-methoxy-2-propanol
PGBE: 1-butoxy-2-propanol
DPGME: 1-(2-methoxy-1-methylethoxy)-2-propanol
CEI, cumulative exposure index; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation

(e) Painting in the metal industry

Protection from corrosion is the primary purpose of painting metal. Mild steel is thus almost always subjected to the application of a primer coat containing corrosion inhibitors such as iron and lead oxides or of zinc powder, further covered with a decorative paint. Aluminium may be covered with a zinc chromate primer before a decorative coat is applied.

During the preparation of metal parts, painters may be exposed to cleaning and degreasing agents, such as solvents, alkalis and acids, and to abrasive dusts, such as crystalline silica generated during blast cleaning. Depending on the industry, metal painters may be exposed to a variety of dusts, solvents, fumes and gases resulting from operations such as mixing paints, maintaining equipment, applying fillers, sealers or putty, or background metal welding or assembling operations. Many coatings used in the metal industry are solvent-based, and spray painting is the main method of application, leading to potential exposures to paint mist and solvents. Two-component paints, such as those based on epoxy and polyurethane resins, play a major role, implying potential exposure to reactive substances such as isocyanates and epoxides. Air-drying or baking after application results in the release of solvents and, possibly, thermal degradation products of resins (Peterson, 1984).

(i) *Exposure to organic solvents* (Table 1.16)

Aircraft industry: Exposure of spray painters to solvents was measured in several industries in the USA, including aircraft finishing. Three studies on spray painting of aircraft up to 1977 reported exposure to relatively high concentrations of organic solvents such as toluene, methyl ethyl ketone and ethylacetate (Table 1.16). In another study, overall exposure levels were found to be low, except in railroad car painting. Analyses of bulk air samples indicated no detectable benzene (O'Brien & Hurley, 1981). Exposure concentrations to organic solvents were, however, still relatively high during spray painting of aircraft in France in 1994, with a mean CEI of 3.4–4.9 (Vincent *et al.*, 1994). The exposure concentration of ethylene glycol monoethyl ether acetate largely exceeded the French VME (permissible exposure level) of 5 ppm (27 mg/m^3). In a recent study from Taiwan, China, xylene and toluene concentrations and personal exposure to these during spray painting of primer and surface paint were low. Benzene was detected in all series of spraying samples (range of six means, 0.14–0.94 ppm) (Uang *et al.*, 2006).

Employees in the USA working in and around jet aircraft during the paint stripping process were exposed to dichloromethane ranging from 38 to 2820 mg/m^3 (Okawa & Keith, 1977). In a French study (Vincent *et al.*, 1994), very high levels of methylene chloride (mean 783.4 mg/m^3) was also measured during paint stripping of an aircraft. Personal respiratory protection was not used during the stripping process. During paint stripping of aircraft in Taiwan, China (Uang *et al.*, 2006), the range of mean airborne methylene chloride concentrations in different areas was 20.4–42.0 ppm. Exposure was highest during the first 4 hours of stripping.

Table 1.16. Metal industry - concentration of solvents, isocyanates and other agents in air

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
SOLVENTS - Aircraft							
Greenburg *et al.* (1942) USA	106 painters	Large airplane factory	Toluene (8h-TWA)			ppm (mg/m^3) 100–1100 (377–4147)	
Hervin & Thoburn (1975) USA	Personal samples Short-term sampling (10–50 min)	Large aircrafts – Spray painting of intermediate and final coat	Toluene	12	583 mg/m^3	140–1230	NIOSH report
			Methyl ethyl ketone	12	1436	240–3250	
			Ethyl acetate	12	1231	160–3520	
			Naphtha	12	44	20–120	
			Butyl acetate	12	64	20–150	
			Xylene	12	318	60–1330	
			Cellosolve acetate	12	4843	670–25170	
			Dichloromethane	12	654	ND–2840	
	Long-term sampling (1–3h)	Spray painting of intermediate and final coat	Ethyl acetate	10	264	10–1100	
			Methyl ethyl ketone	10	197	20–440	
			Toluene	10	162	30–450	
			Butyl acetate	10	11	ND–50	
			Naphta	10	10	ND–160	
			Xylene	10	69	10–270	
			Cellosolve acetate	10	640	70–2490	
			Dichloromethane	10	100	ND–760	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Okawa & Keith (1977) USA	Breathing zone	Aircraft maintenance facility			mg/m^3		NIOSH report
		Paint stripping					CEI based on short time samples, not recalculated into TWA
		Wide body aircraft (56–126 min)	Dichloromethane	23	393	79–950	
		Narrow body aircraft (16–33min)	Dichloromethane	20	795	38–2820	
		Prime coat application (19–38 min sampling)	Toluene	13	112	51–179	
			Methyl ethyl ketone		39	8–77	
			Butylacetate		72	29–130	
			n-Butanol		25	9–47	
			Isopropanol		51	ND–132	
			Cyclohexanone		10	ND–23	
			CEI		0.74	0.28–1.35	
		Top coat application with white enamel (25–37 min sampling)	Ethyl acetate	11	333	ND–857	All the highest values were from the same sample
			Methyl ethyl ketone		69	ND–219	
			Methyl isobutyl ketone		44	ND–117	
			Butyl acetate		80	ND–210	
			Xylene		21	ND–49	
			Cellosolve acetate		18	ND–46	
			CEI		0.76	ND–1.76	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
O'Brien & Hurley (1981) USA	Personal Sampling time, 25–41 min	Light aircraft finishing, primer	2-Butanone	3	GM 42 mg/m^3	GSD 2.1	CEI based on OSHA permissible exposure levels
			Toluene		60	1.2	
			Ethanol		26	1.6	
			Isopropanol		19	1.6	
			CEI		0.9	1.5	
	Sampling time, 27–62 min	Light aircraft finishing, topcoat	Ethylacetate	7	77	1.3	
			Ethoxyethylacetate		44	1.4	
			Aliphatic hydrocarbons		34	1.2	
			CEI		0.15	1.3	
	Sampling time, 19–35 min	Light aircraft finishing, stripping	Ethylacetate	6	52	2.5	
			Ethoxyethylacetate		30	2.7	
			Aliphatic hydrocarbons		73	1.5	
			CEI		0.13	2.5	
	Sampling time, 15–60 min	Railroad car	Toluene	14	188	1.5	
			Xylene		14	2.6	
			Other aromatic compounds		217	1.4	
			Aliphatic hydrocarbons		840	1.4	
			CEI		1.3	1.4	
	Sampling time, 60 min	Heavy equipment	Refined solvents	12		21–96 (range)	
			Other solvents		<5		
			CEI			0.01–0.05	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
O'Brien & Hurley (1981) USA	Sampling time, 8h	Metal furniture, solvent and water-based paints	Toluene	5		12–61	
			Xylene			7–48	
			n-Butyl acetate			22–109	
			Diisobutyl ketone			<1–23	
			2-Ethoxyethyl acetate			1–14	
			Aliphatic hydrocarbons			33–180	
			CEI			0.10–0.46	
	Sampling time, 8h	Metal furniture, high-solids paints	Xylene	6		6–55	
			Aromatic distillates			5–60	
			Other solvents			<10	
			CEI			0.07–0.31	
	Sampling time, 8h	Appliance painting	Toluene	4		88–204	
			Xylene			112–225	
			CEI			0.38–0.79	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Vincent *et al.* (1994) France	13 painters	Aeronautical industry			mg/m^3		No personal respiratory protection during stripping
	Personal sampling, 120–330 min	Paint stripping (2 days): application, scraping and brushing, washing	Methylene chloride	38	783.4	299–1888	
			Phenol (area sampling)	9	5.7	3.4–9.5	
					Range of 3 means		
	Personal sampling, 95–250 min	Painting (3 days): Surface cleaning, mixing paint, spray painting, cleaning equipment	Methyl ethyl ketone	23	14.7–33.3	<0.3–79.5	
			Ethyl acetate		64.4–123.2	29.1–187.2	
			n-Butyl alcohol		<0.3–45.9	<0.3–68.7	
			Methyl isobutyl ketone		<0.4–37.7	<0.4–52.5	
			Toluene		94.5–199.8	57.0–259.1	
			n-Butyl acetate		16.1–122.5	11.8–162.7	
			Ethylbenzene		15.2–66.5	7.8–89.6	
			Xylenes		30.9–122.2	14.3–167.0	
			EGEEA		63.2–110.2	29.2–150.1	
			CEI		3.39–4.90	1.49–6.75	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Uang *et al.* (2006) Taiwan, China	Personal samples, 2h	Aircraft maintenance – Paint stripping	Methylene chloride			SD	
		Ground		11	42.0	31.9	
		Platform, right wing		9	23.4	12.8	
		Platform, left wing		13	20.4	11.4	
		Platform, nose		8	21.6	14.9	
					Range of 3 means	Range	
	Area sampling, 4h	Paint stripping	Phenol	17	0.83–1.21	0.23–3.81	
					Range of 6 means		
	Personal samples, 1–2h	Spray painting	Methyl isobutyl ketone	39	0.9–3.7		
			n-Butyl acetate	39	1.3–4.6		
			Butanone	39	ND–1.8		
			Xylene	39	0.5–7.3		
			Acetone	39	0.2–18.9		
			Isobutyl ketone	39	0.1–14.3		
			Toluene	39	3.1–10.7		
			Benzene	39	0.1–0.9		
			Cyclohexanone	39	0.1–3.3		
			Ethyl acetate	39	ND–2.5		
			Styrene	39	ND–2.0		

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Shipyard							
Mikulski *et al.* (1972)	Area samples; at least 6	Shipyard – Painting in small spaces and in			Range of 4 means	ppm	
Poland	samples at 1-h intervals during 1 shift	large holds with chlorinated rubber and epoxy	Benzene	6	ND–9	ND–11	
			Toluene	6	7–53	7–88	
			Xylene	6	59–398	23–538	
Cherry *et al.* (1985)	8 painters studied over 2	Dockyard – Painting with:	Main solvent:		TWA		
UK 1980	days	- White interior (4 painters)	White spirits	NR	577.4 mg/m^3		
		- Paint stripper (1 painter)	Dichloromethane	NR	214.7		
		- Chlorinated rubber (3 painters)	White spirits	NR	124.6		
Sparer *et al.* (1988)	Personal sampling over	Shipyard – Brush painting (n=76), spray			ppm (mg/m^3)	ppm (mg/m^3)	
USA	3 days; 36 workers	painting (n=8) and not painting (n=6)	2-Ethoxyethanol	90	2.6 (9.9)	0–21.5 (0–80.5)	
			2-Methoxyethanol	81	0.8 (2.6)	0–5.6 (0–17.7)	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Kim *et al.* (1999) Korea	Personal sampling > 6 hours excluding breaks	Shipyard			GM		
		Mainly spray painting in closed spaces/tanks (high exposure group)	Toluene	18	12.0	ND–154.6	
			Xylene	18	28.2	1.1–249.8	
			Methyl isobutyl ketone	18	4.6	0.03–159.2	
			EGEEA	18	3.0	ND–18.3	
		Spraying and brush painting, wiping, preparation work (low exposure group)	Toluene	12	0.7	0.05–8.6	
			Xylene	12	8.5	1.2–74.0	
			Methyl isobutyl ketone	12	1.4	ND–6.9	
			EGEEA	12	1.8	ND–8.1	
Chang *et al.* (2007) Taiwan, China	Personal dosimeter ≥ 6 hours for 3 days; 15 workers	Shipyard – Spray painting			8h-TWA	SE	
		Outside mask	Ethylbenzene	40	59.2	10.4	CEI >1 for 27.5% of the samples
			Xylene	40	29.4	4.7	
		Inside half mask	Ethylbenzene	33	2.6	0.49	
			Xylene	33	1.2	0.22	
Links *et al.* (2007) Netherlands	Personal	3–7 boatyards – Antifouling paint					
		Rolling	Dichlofluanid	15	0.01 mg/m^3	0.004–0.03	
		Spraying	Copper	12	3.0	0.3–9.0	
		Paint filling	Copper	10	1.0	0.1–2.5	
		Sand blasting	Copper	12	0.8	0.04–1.9	
		Grit filling	Copper	3	1.4	0.10–3.9	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Cars							
Husman (1980) Finland	Personal, 1 h; 40 workers	6 garages – Car painting		54	ppm (mg/m^3)	Maximum ppm (mg/m^3)	
			Toluene		30.6 (115)	249 (940)	
			Xylene		5.8 (25)	36 (156)	
			Butylacetate		6.8 (32)	128 (608)	
			White spirits		4.9	150	
			Methyl isobutyl ketone		1.7 (7)	39 (160)	
			Isopropanol		2.9 (7)	85 (209)	
			Ethyl acetate		2.6 (9)	14 (50)	
			Acetone		3.1 (7)	25 (60)	
			Ethanol		2.9 (6)	27 (51)	
Elofsson *et al.* (1980) Sweden	80 workers	Car refinishing workshops – Spray painting	Toluene	106	39 mg/m^3		
			Xylene		14		
			Ethyl acetate		11		
			CEI		0.3		
O'Brien & Hurley (1981) USA	Personal, 15–45 min	Car refinishing			GM	GSD	CEI based on OSHA PELs
			Toluene	7	39 mg/m^3	1.6	
			Xylene	7	10	1.0	
			Petroleum distillates	7	NR	21–63 (range)	
			Other solvents	7	<10		
			CEI	7	0.09	1.5	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Takeuchi *et al.* (1982) Japan	Personal ; 13 workers	Car repair painting	8h-TWA		ppm (mg/m^3)	SD ppm (mg/m^3)	
			Toluene		19 (72)	13 (49)	
			Xylene		8 (35)	8 (35)	
			Ethyl acetate		6 (22)	4 (14)	
			Isobutanol		5 (15)	5 (15)	
			CEI		0.38	0.25	
Jayjock & Levin (1984) USA	Personal, short-term exposures	1 small car body repair shop					Levels dependent on fans off/on and winter/summer (open doors) CEI based on STEL
		Lacquer spray painting	Toluene	5	249.4	30–590	
			Xylene	5	7.2	ND–12	
			Benzene	5	0.6	ND–1.1	
			CEI	5	1.9	0.2–4.7	
		Enamel containing 4–9% aliphatic polyisocyanates	Toluene	13		ND–86	
			Xylene	13		15–230	
			Benzene	13		ND–11	
			CEI	13		0.1–3.3	
de Medinilla & Espigares (1988) Spain	Personal, 30 min	11 car repair shops – Painting in booth equipped with local extraction fans	Toluene	11		2.7–467.0 mg/m^3	CEI based on TLV list of ACGIH (1984–85)
			Xylenes	11		1.0–297.2	
			Ethylbenzene	11		0.5–125.0	
			Trimethylbenzene	11		ND–34.1	
			n-Butylacetate	11		ND–180.0	
			n-Hexane	11		ND–15.8	
			Benzene	11		ND–6.0	
			Dichloromethane	11		ND–26.2	
			CEI (STEL)	11		0.06–10.68	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Winder & Turner (1992) Australia	Personal, 4–7h; 64 workers	46 car painting shops – Spray painting of acrylic and polyurethane paint, duration 10min–4h	Toluene	66*	43.5 mg/m^3	ND–323 mg/m^3	*Number of positive samples out of 70 samples
			Xylenes	42*	8.7	ND–26	
			Trimethylbenzene	22*	4.1	ND–15	
			Methyl ethyl ketone	20*	12.2	ND–30	
			C5–C7 aliphatics	16*	32.2	ND–71	Means based on samples above detection limit
			Acetone	10*	34.1	ND–77	
			Butanols	9*	4.4	ND–12	
			2-Butoxyetanol	8*	2.0	ND–3	CEI based on composite exposure standard
			High-boiling point hydrocarbons	8*	19.5	ND–85	
			Butylacetate	7*	11.7	ND–23	
			n-Hexane	6*	3.8	ND–10	
			Methyl isobutyl ketone	4*	6.8	ND–13	
			Ethanol	4*	88.3	ND–217	
			Benzene	3*	1.0	ND–1	
			Ethyl acetate	1*	17.0		
			CEI		0.19	0.01–0.99	
Moen & Hollund (2000) Norway	Personal sampling inside mask when in use, 15–282 min; 28 workers	6 car repair shops – Paint mixing and spraying		30		Range of 6 means	
			Toluene		2.6	0.2–11.1	
			Xylene		3.8	0.2–0.8	
			Ethylbenzene		0.1	0.1–0.3	
			Isopropanol		1.7	ND–4.0	
			Acetone		0.9	ND–1.6	
			Butylacetate		0.6	0.3–1.0	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Bråtveit *et al.* (2004) Norway	Personal full shift sampling outside mask, over 3 days, for 5–9 h	8 car repair shops – Sanding, cleaning surfaces, masking, paint mixing and spraying, cleaning of equipment Solvent-based paint (6 shops, 17 painters)		51	GM	Range of 6 means	
			Toluene		0.80	0.02–9.17	CEI based on Norwegian limit values
			Xylene		0.34	0.09–1.8	
			Ethylbenzene		0.07	ND–0.36	
			Trimethylbenzene		0.06	ND–0.30	
			Isopropanol		0.29	ND–6.41	
			Acetone		0,09	ND–12.1	
			Butylacetate		0.58	0.13–2.78	
			2-Propylacetate		0.02	ND–0.68	
			CEI		0.15	0.01–1.60	
		Water-based paint (4 shops, 10 painters)		28		Range of 4 means	
			Toluene		0.08	0.03–0.20	
			Xylene		0.25	0.06–0.42	
			Ethylbenzene		0.05	0.02–0.07	
			Trimethylbenzene		0.05	0.02–0.09	
			Isopropanol		0.01	ND–0.04	
			Acetone		0,01	ND–0.07	
			Butylacetate		0.23	0.11–0.37	
			2-Propylacetate		0.02	ND–0.34	
			CEI		0.05	0.01–0.22	
Vitali *et al.* (2006) Italy	personal dosimeters, 236–323 min; 8 painters;	8 small car repair shops – varnishing (preparation, spraying, tool cleaning, etc.)	Toluene	8	17.8 mg/m^3	1.9–93.8 mg/m^3	Masks were not used
			Xylene	8	20.1	1.2–75.0	
			Ethylbenzene	8	7.2	0.4–23.8	
			Butylacetate	8	19.5	<0.1–100.2	
			Benzene	8	9.8	0.4–53.1	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Other industries							
Chrostek (1980), USA	Breathing zone; 3 workers	Paint stripping from wood and metal	Dichloromethane (TWA)	7	NR	633–1017 mg/m^3	
Hellquist *et al.* (1983) Sweden		Fireplace production – Spray painters	Toluene Isobutyl acetate			3–18 mg/m^3 2–44	
ISOCYANATES – Aircraft & Cars							
Okawa & Keith (1977) USA	Breathing zone; 17–77 min	Airline maintenance – Spraying of enamel top coat	HDI	15	1.1 mg/m^3	<0.04–3.20 mg/m^3	
O'Brien & Hurley (1981) USA	Breathing zone; 5–13min	Car repainting shop – Spraying	HDI	3		<130 µg/m^3	
	Breathing zone; 7–21min	Light aircraft finishing	HDI	8		<70 (7 samples) – 250 (1 sample)	
Rosenberg & Tuomi (1984) Finland	Personal, 5–10 min samples	4 car paint shops – Spray painting with HDI-based polyurethane paint	TWA HDI HDI-biuret oligomer	 10 10	 49 µg/m^3 1440	SD 22 1130	
Alexandersson *et al.* (1987) Sweden	43 workers	Car repair shops (8h-TWA)	HDI HDI-biuret oligomer		1.0 µg/m^3 115	 10–385 µg/m^3	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Pisaniello & Muriale (1989) Australia	Task-based breathing zone samples, 18 min on average	14 car body repair shops – Spray painting			GM		
		Primer undercoat (in open workshop)	NCO	NR	29 µg/m^3	7–180	
		Topcoat (in booth)					
		solid colours	NCO	NR	202	8–3500	
		clearcoat	NCO	NR	70	9–550	
Carlton & England (2000) USA	Task-based breathing zone samples, generally less than 25 min.	4 Aircraft bases – Spray painting with polyurethane enamel in booths or painting inserts	HDI				
			Task	57	15.5 µg/m^3	3.05–53.1	
			8-hr TWA	57	0.67	0.31–3.51	
			HDI Oligomer				
			Task	53	0.33 mg/m^3	<0.01–3.36	
			8-hr TWA	53	0.01	<0.01–0.17	
Sparer *et al.* (2004) USA	Task-based personal sampling	Auto body shop – Spray painting (% NCO in hardener)			Median	25–75th percentile	
		Primer (8%)	NCO	31	66.5 µg/m^3	16.9–165	
		Sealer (11%)	NCO	29	134	48.4–296	
		Clear (10%)	NCO	93	358	157–855	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Woskie *et al.* (2004) USA	Task-based sampling (1–493 min) for 2 days; personal samples unless specified	33 auto body shops –			Median	Range or maximum	* % of samples >LOD Total NCO: total NCO based on HDI monomer, HDI polyisocyanate (biuret and isocyanurate) and isophorone diisocyanate [IPDI] polyisocyanate
		Spraying inside and outside booth	HDI (90%)*	166	1.69 µg/m^3	ND –56.16	
			Total NCO	166	205.53	5519	
		Bystander to spraying (area and personal samples)	HDI (54%)*	37	0.03	ND–1.17	
			Total NCO	37	0.93	108.7	
		Background (area samples)	HDI (40%)*	107	0.01	ND–0.24	
			Total NCO	107	0.05	12.6	
		Mixing and cleaning equipment	HDI (38%)*	45	0.04	ND–2.38	
			Total NCO	45	0.17	118.3	
		Sanding or compounding coated surfaces	HDI (28%)*	25	0.05	ND–0.71	
			Total NCO	25	0.27	36.1	
Boutin *et al.* (2006) Canada	Breathing zone, 15 min	Car body shops – Paint removal by thermal degradation					
		Cutting	Total NCO	10		1.07–9.80 µg/m^3	
		Grinding		10		0.63–3.62	
		Sanding		NR		ND–1.29	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Pronk *et al.* (2006a) Netherlands	Mainly personal task-based samples, 1–113 min, 1–2 days per company; 109 workers	24 autobody repair workshops		475 total	Median NCO**		*Number of samples >LOD
			HDI factor	256*	8.55 μg/m^3	0.002–1124 μg/m^3	**Median and range for samples >LOD
			TDI factor	111*	0.07	0.001–5.38	
			MDI factor	12*	0.10	0.02–0.54	
			Thermal degradation products	103*	0.12	0.001–4.64	
			Monomers	217*	0.42	0.002–15.5	
			Oligomers	217*	27.92	0.02–1122	
			Total	293*	5.13	0.01–1124	
		5 industrial painting companies – spray painters		36			
			HDI factor	35	6.67	0.01–2643	
			TDI factor	11	0.02	0.004–0.65	
			MDI factor	0	-	-	
			Thermal degradation products	17	0.17	0.01–3.95	
			Monomers	34	0.11	0.01–28.8	
			Oligomers	29	14.21	0.12–2614	
			Total	35	6.68	0.01–2643	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Pronk *et al.* (2006b)	Personal task-based samples,	6 car body repair shops		95	Median NCO**		* % of the samples >LOD
Netherlands	1–40 min	Mixing polyurethane	HDI (20%*)	15	1.0 µg/m^3	0.2–2.7 µg/m^3	**Median and range for
		lacquer	Oligomers (27%)	15	1.4	0.3–33.1	samples >LOD
		Spraying	HDI (65%)	31	2.1	0.2–6.5	
			Oligomers (87%)	31	116.3	2.5–728.4	Oligomers; uretidine,
		Spray gun cleaning	HDI (0%)	19	-	-	isocyanurate, biuret,
			Oligomers (32%)	19	11.1	1.6–45.3	diisocyanurate,
		Welding	HDI (33%)	3	0.04		unknown oligomer of
			Oligomers (33%)	3	0.1		HDI
	Personal task-based samples, 4–41 min	5 industrial painting companies for ships and harbour equipment					
		Spraying polyurethane	HDI (100%)	10	3.7	0.03–28.8	
		lacquer	Oligomers (100%)	10	199.6	6.4–2613.8	
		Rolling/brushing	HDI (100%)	11	0.02	0.01–0.1	
			Oligomers (46%)	11	0.7	0.1–5.3	
		Mixing	HDI (67%)	3	0.5	0.01–1.0	
			Oligomers (67%)	3	10.8	1.6–20.0	
		Assisting spray painter	HDI (100%)	3	0.3	0.09–4.4	
			Oligomers (100%)	3	14.2	6.3–347.7	
OTHER AGENTS							
Larson (1978)	Full-shift	8 plants.	Coal-tar pitch volatiles			Max.	
USA	samples	Pipeline coating with coal-tar enamel (heat)	Benzo[*a*]pyrene (respirable fraction)		133 µg/m^3	24 mg/m^3	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Chrostek & Levine (1981) USA	Personal breathing zone, 3–8 h	Steel structure finishing – spray painting with epoxy paint or oil-based paint	Epichlorohydrin Bisphenol A glycidyl ethers	13 9	64.9 mg/m^3 9.8 µg/m^3	2.4–138.9 mg/m^3 <0.6–28.6 µg/m^3	NIOSH report
Bäck & Saarinen (1986) Finland	Breathing zone ; 1 worker	Spray painting of paper machine and pulp tanks	Diethylene triamine (component of curing agent)	3		0.02–0.07 mg/m^3	
Herrick *et al*. (1988) United Kingdom		Painting of tank and ceiling using epoxy coating	Epoxide functional groups		2.7–12 µEq/ m^3		
Allmaras (2003) USA	Personal samples, 57 min	Powder paint coating Spraying paint line-facility 1	1,3,5-Triglycidyl isocyanurate	3	0.092 mg/m^3	0.041–0.16 mg/m^3	
		Spraying paint line-facility 2		1	31 mg/m^3 TWA		
Lee *et al.* (2003) Korea	Breathing zone sampling, 6h for 3 days; 25 workers	Shipyard – spraying coal-tar paint	Total PAHs	25	4.82 µg/m^3	0.08–22.49	

Table 1.16 (contd)

Reference Country, year of study	Sampling type and duration; No. of workers	Site/job/task	Agent	No. of samples	Air levels in ppm [a]		Comments
					Mean	Range	
Blomqvist *et al.* (2005) Sweden	Personal + area samples, 5–7h	2 powder paint shops Shop 1 personal samples area samples Shop 2 inside booth outside booth	Trimellitic anhydride	 5 5 1 NR	 NR NR 0.2 mg/m^3 -	 0.006–0.18 mg/m^3 0.015–1.04 mg/m^3 - <0.001–0.003	No trimellitic anhydride detected inside breathing protection device

[a] unless otherwise stated;

CEI, cumulative exposure index; EGEEA, ethylene glycol monoethyl ether acetate; GM, geometric mean; GSD, geometric standard deviation; HDI, 1,6-hexamethylene diisocyanate; MDI, methylene diphenyl diisocyanate; NCO, isocyanates; ND, not detected; NR, not reported; SD, standard deviation; SE, standard error; TDI, toluene diisocyanate.

Shipyards: In Poland, shipyard painters working in small spaces of superstructures and in large holds were exposed to levels of benzene ranging from undetectable to 11 ppm [35 mg/m^3]. Concentrations of toluene and xylene were 7–88 ppm and 23–538 ppm, respectively (Mikulski *et al.*, 1972).

United Kingdom shipyard painters working in ships' accommodation and bilges were exposed to various mean concentrations of organic solvents, depending on their job: 125 mg/m^3 for three painters using a chlorinated rubber paint with white spirits as solvent, 215 mg/m^3 for a worker using paint stripper with dichloromethane as the main solvent, and 577 mg/m^3 for four men using white interior paint with white spirits as the main solvent (Cherry *et al.*, 1985).

In the Republic of Korea, nine of the 18 shipyard painters who were spray painting in closed spaces/tanks were exposed to concentrations of ethylene glycol monoethyl ether acetate that exceeded the threshold limit value (TLV) of the American Conference of Industrial Hygienists (ACGIH) of 5 ppm. Solvents such as toluene and xylene were found at relatively low concentrations (Kim *et al.*, 1999). During spray painting inside the block units of assembled ships in Taiwan, China, 11 of 40 samples had a CEI exceeding 1, based on the TLV-ACGIH (Chang *et al.*, 2007).

Car refinishing: A large study of car refinishing workshops in Sweden was carried out and results showed that toluene and xylene were present at mean concentrations of 39 and 14 mg/m^3, respectively. A reconstitution of working conditions in 1955 indicated that exposure levels to solvents at that time were higher than those in 1975, which were considered to be representative of the 1960s and 1970s. In particular, when benzene was used as a solvent in 1975–77, the CEI reached 0.8 (Elofsson *et al.*, 1980).

In Finland (Husman, 1980) and Japan (Takeuchi *et al.*, 1982), personal exposure measurement of solvents were reported with a highest mean concentration for toluene (30.6 ppm [115 mg/m^3] for 1-hour samples and 19 ppm [72 mg/m^3] for full-shift TWA samples).

Personal samples were taken during short-term spray painting operations in a small autobody repair workshop in the USA (Jayjock & Levin, 1984). In winter, when the spraybooth fan was turned off to conserve heat, maximal concentrations of toluene of 590 ppm were recorded during lacquer spray painting, and of 230 ppm xylene, and 11 ppm benzene during enamel spray painting.

In a study in 11 car paint workshops in Spain, toluene (2.7–467.0 mg/m^3), xylene and ethylbenzene were found in all air samples; benzene was detected in three workshops at 0.6, 1.7, and 6.0 mg/m^3 (de Medinilla & Espigares, 1988). In 46 autobody repair workshops in Australia (Winder & Turner, 1992), toluene was detected in nearly all samples (n = 70), and average concentrations across the workshops ranged up to 323 mg/m^3 (mean 43.5 mg/m^3). Benzene was detected in three workplaces at an exposure level of 1 mg/m^3 in each case.

Exposure to solvents was generally low in two Norwegian studies of spray painters using water-based or solvent-based paint systems in car-repair shops. All shops had spraying booths with downdraft ventilation and enclosed mixing room with air supply and exhaust hoods (Moen & Hollund, 2000; Bråtveit *et al.*, 2004). In Italy, personal exposure of

car painters was measured in eight workshops with ventilated spray booths but not any general mechanical ventilation. The individual levels of toluene, *n*-butylacetate, xylene, and ethylbenzene were low, except for two workshops where concentrations ranging up to 100.2 mg/m^3 were measured. Benzene was detected in all workshops. In two workshops, benzene concentrations were considerably higher (18.8 and 53.1 mg/m^3) than in the others. Exposure to benzene concentrations was mainly due to fuel vapour and to gasoline used for degreasing and dilution of paints (Vitali *et al.*, 2006).

Other industries: In a plant in the USA where paint was stripped from wood and metal, average breathing-zone TWA concentrations of dichloromethane were in the range of 633–1017 mg/m^3 (Chrostek, 1980).

In another plant in the USA where truck bodies and refuse-handling equipment were manufactured, breathing-zone concentrations of xylene during spray painting operations were in the range of 5–140 ppm (22–608 mg/m^3) (Vandervort & Cromer, 1975). Exposure to low solvent concentrations was observed for spray painters in a plant manufacturing fireplaces in Sweden (Hellquist *et al.*, 1983).

In a study in China, the range of mean benzene concentrations determined by grab samples at 18 unspecified paint workplaces was reported as 15–1105 mg/m^3 (Yin *et al.*, 1987).

(ii) *Exposure to isocyanates* (Table 1.16)

Use of polyurethane-type paints can result in exposure to diisocyanate monomers and their oligomers. Concentrations of HDI during the spray application of an enamel top coat at a US airline maintenance facility had a mean of 1.1 mg/m^3 (Okawa & Keith, 1977). Exposure concentrations of HDI during polyurethane enamel spray painting of aircrafts or aircraft components at Air Force bases were low (8h-TWA; 0.67 μg/m^3) compared to the TLV-ACGIH of 34 μg/m^3 (Carlton & England, 2000).

In a US car repainting shop, short-term breathing zone samples taken during spray painting operations were measured for HDI with reported concentrations of <130 μg/m^3. Similar measurements taken during various aircraft finishing operations reported HDI concentrations below 70 μg/m^3, except for one operation with a level of 250 μg/m^3 (O'Brien & Hurley, 1981). In Finland, average HDI and HDI-biuret oligomer concentrations in short-term personal samples during spray painting of cars were 49 μg/m^3 and 1440 μg/m^3, respectively. All spraying chambers were fitted with exhaust ventilation systems (Rosenberg & Tuomi, 1984). In Sweden, 43 car repair painters were exposed to average concentrations of 115 μg/m^3 HDI-biuret oligomer and 1.0 μg/m^3 HDI (Alexandersson *et al.*, 1987).

Spray painting of topcoat (solid colours) resulted in the highest short-term exposure concentrations (mean, 202 μg/m^3 isocyanate (NCO)) compared to spraying of undercoat and clearcoat in a survey of 45 crash repair workshops in Australia (Pisaniello & Muriale, 1989). Sparer *et al.* (2004) characterized isocyanate exposure in the autobody industry as a part of the epidemiological study SPRAY. Personal samples were measured and contained median concentrations of 66.5 μg/m^3 NCO for primer, and 358.5 μg/m^3 NCO for clearcoat.

As part of the same study, Woskie *et al.* (2004) reported an exposure concentration of 206 μg/m^3 NCO for spray operations. In the Netherlands, task-based assessment of isocyanate exposure was carried out as part of an epidemiological study among autobody repair shop workers and industrial spray painters (Pronk *et al.*, 2006a,b). Oligomers of HDI dominated over the monomer during all tasks in both industries. In both branches, exposure was highest during those tasks where paint was aerolised, i.e. when spraying cars (median concentration of HDI oligomers, 116.3 μg/m^3), and ships and harbour equipment (199.6 μg/m^3) (Pronk *et al.*, 2006a).

Airborne isocyanates generated during thermal degradation of car paint in body repair shops were determined in France (Boutin *et al.*, 2006). They found that the concentration of NCO in the breathing zone was in the range of 1.07–9.80 μg/m^3 during cutting, 0.63–3.62 μg/m^3 during grinding, and 0–1.29 μg/m^3 during sanding of painted surfaces.

(iii) *Exposure to paint mists, dusts and specific metals* (Table 1.13)

In a larger study of car refinishing workshops in Sweden, average concentrations of 7 mg/m^3 paint mist, 100 μg/m^3 lead, and 26 μg/m^3 chromium were measured during spraying activities. The conditions were thought to be representative of those in the 1960s and 1970s. Simulation of work conditions in 1955 led to measurements of low concentrations of lead during the use of all colours except for red, when the Swedish exposure limit was exceeded 70-fold (Elofsson *et al.*, 1980).

Substantial but short-term lead exposure was encountered in situations where lead-based pigments were used, such as in painting transportation and heavy equipment (O'Brien & Hurley, 1981). Elevated but brief exposures to chromium were noted during the spraying of aircraft with primer (O'Brien & Hurley, 1981). At a plant in the USA where truck bodies and refuse handling equipment were made, breathing zone concentrations during various spray painting operations were 20–3000 μg/m^3 lead, and 10–400 μg/m^3 chromium (Vandervort & Cromer, 1975). A manufacturer of aero-mechanical systems in the USA reported workers a mean exposure concentration to hexavalent chromium of 606.7 μg/m^3 when spraying aircraft wheels with zinc chromate primer (Kominsky *et al.*, 1978).

Breathing-zone samples were taken during short-term spray painting operations in a small autobody repair workshop in the USA. Only one of eight samples, corresponding to exposure to a red paint formula, contained significant levels of chromium (490 μg/m^3), and lead (210 μg/m^3) (Jayjock & Levin, 1984). At a plant in the USA where buses were manufactured, employees working in and around the paint booth were exposed to hexavalent chromium at mean concentrations of 0.23 mg/m^3 and to lead at mean concentrations of 0.78 mg/m^3 (Zey & Aw, 1984). In a Finnish registry of occupational exposure measurements, average exposure concentration of painters to hexavalent chromium and nickel were reported as 180 μg/m^3 and 100 μg/m^3, respectively (Kiilunen, 1994).

In a recent study of spray painters in automobile body repair shops lacking isolated spraying rooms in Thailand, low full-shift exposure concentrations of lead (0.05–

5.8 μg/m^3), cadmium (nd–5.7 μg/m^3) and chromium (0.25–3.1 μg/m^3) were reported (Vitayavirasuk *et al.*, 2005).

At a coating and painting facility that used products containing hexavalent chromium (1–30% chromates) in the USA, full-shift exposure concentrations of painters and helpers during spray painting and removal of chromate-containing paint were in the range of 2.4 to 55 μg/m^3 (Blade *et al.*, 2007). Spray painting with chromate-containing paint in booths at an aerospace facility in the USA was measured for personal 8h-TWA exposure to hexavalent chromium and was reported in the range of 19–327 μg/m^3 (Sabty-Daily *et al.*, 2005).

The mass median aerodynamic diameters of paint overspray aerosols during spraying of high-solid paint in a down-draft spraying booth ranged from 2.9 to 9.7 μm (D'Arcy & Chan, 1990); that of total chromium particles in the paint aerosol during spraying chromate-containing paint at an aerospace facility was 7.5 μm (Sabty-Daily *et al.*, 2005).

During removal of lead-containing paint at a shipyard in the USA, geometric mean personal exposure to lead was 60.6 μg/m^3 during sanding, and 2.36 μg/m^3 during chipping (Booher, 1988). High airborne mean-TWA lead concentrations were found when lead paint was removed aboard a ship in the USA: during chipping with needle gun, 91.6 μg/m^3, during grinding, 400.5 μg/m^3, and during chipping and/or grinding, 375.2 μg/m^3 (Zedd *et al.*, 1993). During maintenance of a large hammerhead crane on a shipyard in the USA, company data indicated that paint removal by abrasive blasting was associated with high lead exposure for blasters (range 309 to 6522 μg/m^3) and for labourers (578–3852 μg/m^3) within the containment structure (Jarrett, 2003). Personal 8h-TWA exposure to cadmium, lead and hexavalent chromium were up to 250, 6 and 5 times higher than the PELs, respectively, when paint and primer were removed by abrasive blasting from aircraft parts and ground equipment at four US air force facilities (Aizenberg *et al.*, 2000).

(iv) *Other exposures*

Epoxide levels of 2–12 μEq/m^3 epoxide functional group were recorded during the painting of a tank with coal-tar epoxy coatings, and the painting of a metal ceiling using an epoxy architectural coating (Herrick *et al.*, 1988). In a company in the USA where steel products were blasted with steel shot or sand and spray-painted with two-component epoxy paints or oil-based paints, epichlorohydrin and bisphenol A glycidyl ethers were detected in the workers' breathing zone (Chrostek & Levine, 1981).

Diethylene triamine, which is a component of curing agents of epoxy paints, was measured in three samples collected from the breathing zone of a painter during spray painting of paper machine cylinders and pulp tanks at concentrations in the range of 0.02–0.07 mg/m^3 (Bäck & Saarinen, 1986).

In plants where coal-tar enamel protective coating was applied to pipelines with heat, the workers were exposed to high concentrations of coal-tar pitch volatiles (see IARC, 1985) of up to 24 mg/m^3 of benzene-soluble matter (full-shift samples). The overall respirable concentration of benzo[*a*]pyrene in the plants averaged 133 μg/m^3 (Larson, 1978). In a shipyard in the Republic of Korea, painters using coal-tar paints were exposed to concentrations of total polycyclic aromatic hydrocarbons (PAHs) in the range of 0.08–22.49

µg/m^3 (mean, 4.82 µg/m^3) (Lee *et al.*, 2003). The composition of the total PAHs was 64.1% naphthalene, 11.3% acenaphthene, 6.2% fluorene, 3.9% anthracene, 3.3% pyrene, 2.9% benzo[*a*]anthracene, 2.8% fluoranthene, 2.0% acenaphthylene, 0.7% chrysene, and <0.1% benzo[*a*]pyrene.

During powder paint coating operations in the USA, the occupational exposure to 1,3,5-triglycidyl isocyanurate was high (31 mg/m^3) in one of the facilities visited by OSHA (Allmaras, 2003). In Sweden, two of five personal samples exceeded the Swedish limit value for trimellitic anhydride of 0.04 mg/m^3 during powder coating (Blomqvist *et al.*, 2005).

In an asbestos job exposure matrix, painters (classified as bystanders) were assigned a relative exposure intensity of 3 on a 1–4 scale, where 4 was highest (Rice & Heineman, 2003).

1.4.2 *Dermal exposures*

(a) Introduction

Schneider *et al.* (1999) have provided a generalized conceptual model of dermal exposure processes. They argue that the amount of any hazardous substance in the contamination layer on the surface of the skin is linked to transfer from the air, from contact with surfaces, and from direct transfer from the source. In addition, the air and surface compartments in their model are linked so that contamination on surfaces is in part caused by deposition from the air and vice versa. Clothing may play an important part in protecting the skin from exposure, particularly in the case of solids and non-volatile liquids, and this is incorporated into the model as twin compartments, i.e. inside and outside clothing layers. It is conventional to describe exposure measured on the outside of clothing or protective gloves as "potential" exposure, and measurements made directly on skin as "actual" exposure.

Once the hazardous substance deposits in the skin contamination layer, there are three possible outcomes:

- It may evaporate and be removed from contact with the skin before it passes through the stratum corneum;
- It may be retained in the stratum corneum or skin contamination layer, and be removed at some later time by washing or because of skin cells sloughing off; or
- It may diffuse through the stratum corneum and be available for systemic uptake.

Only in the latter situation is there any contribution to risk of disease, although most exposure measurement methods include at least some contribution from material that will not be taken up through the stratum corneum.

(b) Measurement of exposure

Unlike inhalation exposure assessments, the methods available for measuring dermal exposures are not standardized, and it is therefore more difficult to compare studies that have used different approaches. The available methods include:

• *Interception methods*, where the sampling medium comprises a cotton pad (for solids and non-volatile liquids) or an activated-charcoal-based pad (for volatile liquids);

• *Removal techniques*, where the contaminant is removed from the subjects' skin by wiping, washing or skin stripping;

• *Direct techniques*, where some property of the contaminant, such as its ability to fluoresce under ultraviolet light, is used to determine exposure.

These methods do not have the same sampling efficiencies, but more importantly they do not measure the same aspect of exposure. For example, an interception method using a cotton pad for metal exposure in a painting task will obtain a measure of the total flux of metal-containing particles onto the skin over the duration that the sampler is worn. However, using a removal method such as swabbing the skin with a moist wipe will determine the mass of metal retained on the skin at the time the measurement was made. Both approaches provide measures that may be linked with the mass of metal taken up through the skin, but the numeric value of exposure, in mg or mg per unit area of skin, may be very different. For painting activities, many studies have used interception methods to assess dermal exposure.

The available literature on dermal exposure has been reviewed to assess the magnitude of dermal exposure in terms of total paint formulation or some constituent part of the paint, and whether dermal exposure is associated with inhalation exposure.

(c) Magnitude of exposure

Brouwer *et al.* (2000) measured dermal exposure during airless spray painting of a 36 m^3 container. They used a fluorescent tracer added to the paint to assess the mass of paint deposited onto the skin of the subject and the coverall worn. On average, 72% of the contaminant mass landed on the legs, 13% on the torso, and 13% on the hands and arms. Hughson & Aitken (2004) demonstrated that dermal exposure of spray painters was greatest on the hands and that other body parts were only sporadically affected, while Links *et al.* (2007) corroborated this finding with results for highest exposure for the hands, followed by the front torso, and the lower arms.

Dermal exposure during painting of wood preserve and antifouling paints was described by Garrod *et al.* (2000). They found whole body median potential exposure rates of 5.06 mg/min for brushing wood preserve and 16.4 mg/min for antifouling agents (assuming a body area of 1.8 m^2, the corresponding values are 0.28 and 0.91 μg/cm^2/min).

Liu *et al.* (2000, 2007) made qualitative assessments of isocyanate contamination on the skin of workers and environmental work surfaces in three autobody workshops. Work surfaces such as painters' work benches, spray equipment and work tools were contaminated with isocyanates. Painters frequently contacted contaminated surfaces with

their hands, often without wearing gloves. Moderate-to-heavy contamination of some skin surfaces was found for painters from two of the three autobody workshops. The use of latex gloves did not protect the painters from dermal exposure.

In a study of potential dermal exposure of vehicle spray painters using an interception method, Delgado *et al.* (2004) found that, during filling of the spray gun, exposure occurred mainly on the hands and ranged from 0.68 to 590 μg paint/cm^2/min with a geometric mean of 24 μg paint/cm^2/min, based on the amount of aluminium measured and the concentration of aluminium in the paint. During spraying, the geometric mean exposure rate was 0.9 μg paint/cm^2/min (range 0.2 to 4.4) for the body and 2.7 (range 0.40 to 13) μg paint/cm^2/min for the hands. While cleaning the spray gun, the hands were again the principal area exposed, with exposure of 17 (range 0.44 to 213) μg paint/cm^2/min. These figures represent the cumulative amount of paint on the skin or clothing over the duration of spraying.

Data from spray painters and their assistants in a naval dockyard applying antifouling paint to the outside of a ship showed the geometric mean dermal exposure rate for the hands during spray painting was 46 μg/cm^2/min, with the corresponding value for the rest of the body of 2.9 μg/cm^2/min (Hughson & Aitken, 2004). The geometric mean for mixing the relatively large quantities of paint used in this workplace (up to about 200 L in two hours) were 520 μg/cm^2/min for the hands and 5.5 μg/cm^2/min for the rest of the body. These data were obtained as potential exposure using an interception method similar to that used by Delgado *et al.* (2004).

Dermal exposure during the filling, loading and brushing of paint products containing 2-(2-butoxyethoxy)ethanol was obtained using cotton interception samplers (Gijsbers *et al.*, 2004). The geometric mean exposure rate for the hands during filling was 11.5 μg/cm^2/min, and whole body exposure during filling was 0.016 μg/cm^2/min. The corresponding exposure rate for hands during brush application was much lower at 1.7 μg/cm^2/min.

Roff *et al.* (2004) studied the exposure of painters using dry powder spray paints containing triglycidyl isocyanurate or other compounds. Workers wore Tyvek suits and some also wore cotton sampling gloves. The samples were then analysed using a portable X-ray fluorescence spectrometer. The geometric mean potential exposure rate was 0.7 μg/cm^2/min for the body, and 16 μg/cm^2/min for the hands (the Pearson correlation coefficient between hands and body was 0.67).

Fent *et al.* (2006) used a tape-stripping method to measure dermal exposure to HDI among autobody shop workers. Samples were collected at the end of a painting task. The workers wore a respirator but no protective gloves or protective clothing. The measured geometric mean concentrations were 5.1, 6.6 and 3.4 pmol/cm^2 HDI for the arms, hands and forehead, respectively.

Flynn *et al.* (2006) presented a simple theoretical model to predict the deposition of paint droplets on the skin and some further measurements of isocyanate skin levels using the tape-stripping method of Fent *et al.* (2006). The model provided a reasonable prediction of exposure for the circumstances for which data were available, although it tended to underestimate exposure at higher levels. The main determinant of dermal exposure in this

model was the air concentration in the vicinity of the painter. The HDI exposure concentration on the hands or forearms of a spray painter ranged from 7.5 to 31.8 pmol/cm^2.

An interception sampling approach to measuring dermal exposure to isocyanates was used by Pronk *et al.* (2006b) for workers in car body shops and industrial painting companies. The samples were collected on nitrile rubber gloves; at the end of the sampling period the gloves were submerged into di-*n*-butylamine in toluene. Analysis for HDI and its oligomers was performed by liquid chromatography-tandem mass spectrometry (LC-MS/MS). For the car body shop workers, between 39% and 47% of the samples had detectable levels of HDI; NCO levels ranged from 0.3 to 20 μg on both hands (equivalent to 0.36 to 24 ng NCO/cm^2, assuming the area of the gloves was 840 cm^2). Exposure of the industrial painters was much lower, with one out of 27 samples having detectable levels of HDI. Exposure to HDI oligomers were higher, with 32–53% of samples from the car body shop workers and about 90% of samples from the industrial painters having detectable levels. The highest geometric mean exposures to oligomers in the car workshop were for mixing (geometric mean, 207 μg NCO on hands or 246 nm NCO/cm^2), then spraying (133 μg NCO or 158 ng NCO/cm^2), and cleaning (34 μg NCO or 40 ng NCO/cm^2). Corresponding data for the industrial painters were: 63 μg NCO for mixing (75 ng NCO/cm^2), 44 μg NCO spraying (52 ng NCO/cm^2) and 16 μg NCO rolling/brushing (19 ng NCO/cm^2). The authors noted that inhalation exposure was strongly associated with tasks during which aerosolization occurred and dermal exposure occurred during tasks that involved direct handling of paint.

Links *et al.* (2007) also presented data from the spraying of antifouling paint using an interception method based on the use of Tyvek suits, cotton gloves, socks, underclothing and outer protective gloves as sampling media. They showed that the geometric mean potential exposure rate was 1075 mg/hour (equivalent to about 1 μg/cm^2/min, assuming that the total body surface area was 1.8 m^2). Corresponding values for mixing of paint and application of paint by roller were slightly higher (equivalent to 3.5 and 2.4 μg/cm^2/min, respectively). The main potential dermal exposure was to the hands (52% for rolling and 78% for spraying). The actual exposures were much lower than the potential exposures, demonstrating the protective effect of a simple Tyvek suit and protective gloves; actual exposure of the hands was 0.42% of the potential exposure for spraying, and 0.01% for rolling and mixing.

Exposure to solvents from painting is difficult to measure because they evaporate rapidly from the sampling medium. Chang *et al.* (2007) measured dermal exposure using an interception sampler with two layers of charcoal cloth fixed to an impervious backing that was attached to the skin of dockyard spray painters. The authors measured exposure to ethyl benzene and xylene for workers inside and outside "spraying blocks" over 2-hour periods. The average whole body exposure was equivalent to 282 and 153 μg/cm^2/min for ethyl benzene and xylene inside blocks, respectively, and 49 and 30 μg/cm^2/min, respectively, outside blocks.

As Cherrie (2008) pointed out, any solvent from paint droplets that land on the skin is likely to evaporate before it is taken up through the skin, with only a small proportion

diffusing through the stratum corneum and being available for systemic distribution. However, solvent in droplets that landed on the charcoal pads used by Chang *et al.* (2007) would have been almost completely adsorbed onto the sampler. This results in an overestimation of actual dermal exposure, which is a reported limitation of this dermal sampling methodology. Based on the data by Chang *et al.* (2007), there would have been about 0.3 kg whole body dermal exposure to xylene, and a similar mass of ethyl benzene.

Some researchers have developed models to estimate dermal exposure (Brouwer *et al.*, 2001a; Semple *et al.*, 2001). The former study presented a model for deposition of paint aerosol that provided a reasonably good rank correlation with measured exposure, although it tended to overpredict the actual level of exposure. The latter study extended the model to calculate the flux of solvent through the stratum corneum and thus the total dermal uptake, and provided a demonstration of the modelling approach for spray painters using a xylene-based paint. The painter was assumed to have been wearing a cotton overall with his sleeves rolled up to the elbows, no gloves or respiratory protective equipment, leaving his forearms, hands, head and face uncovered. The average airborne xylene concentration was assumed to be 100 ppm (441 mg/m^3), and the task to continue for 10 minute. In this example, approximately 12% of the xylene burden was estimated to be received dermally. In a range of work scenarios investigated with this model, the highest dermal contribution to total exposure (58%) occurred in a simulation where the painter wore respiratory protective equipment.

This methodology was applied in an epidemiological study of dockyard painters to estimate both inhalation and dermal exposure to a range of solvents (Semple *et al.*, 2000; Dick *et al.*, 2002). Dermal exposure generally contributed a small fraction of total solvent exposure, with about 75% of subjects having less than 10% of their solvent exposure from skin exposure, and about 95% having less than 20% of their exposure by the dermal route (Semple, 2002).

(d) Comparison of inhalation and dermal exposures

As detailed above, there are good theoretical reasons for believing that inhalation and dermal exposures are correlated. For spray painting the volume of paint sprayed is likely to be the main determinant of the air concentration and the amount of paint aerosol depositing on the worker's skin or clothing (Semple *et al.*, 2001). Similar considerations would apply to brush or roller application although it would be expected that the association between inhalation and dermal exposure would be less strong because the process of aerosolization is less consistent. In all cases, direct contact with paint applied to surfaces or with the paint source will tend to reduce the association between inhalation and dermal exposure.

The relationship between inhalation and potential dermal exposure was investigated by Links *et al.* (2007) during application and removal of antifouling paint. They found that the correlation between dermal exposure and inhalation exposure was relatively high for spraying (Pearson correlation coefficient, 0.46 to 0.80 depending on the body part).

However, it was poorer for roller application of paint (–0.03 to 0.60), and paint filling (–0.13 to 0.77).

Pronk *et al.* (2006b) found that in autobody repair workshops there was an association between airborne concentration and dermal exposure. However, most of the workers wore respiratory protection when spraying and about 50% when mixing so that their actual inhalation uptake would have been much lower than that measured.

In the study mentioned above, Chang *et al.* (2007) also undertook biological monitoring of methyl hippuric acid and mandelic acid in urine. The average increase of methyl hippuric acid over a work shift was 61.4 mg/g creatinine. Jacobson & McLean (2003) calculated that this level of methyl hippuric acid increase would be consistent with airborne exposure to about 4 ppm xylene, which is similar to the levels Chang *et al.* (2007) measured inside the respirators worn by the painters (i.e. average 1.2 ppm). These data suggest that the urinary metabolites may result from exposure by inhalation and that the dermal exposure contributed the equivalent of 2–3 ppm of inhaled vapour for xylene and a similar level for ethyl benzene.

Chang *et al.* (2007) also found a strong correlation between ambient air concentration and dermal exposure to xylene, which is indicative that the dermal samplers were strongly influenced by the air concentrations of the solvents or paint aerosol.

1.5 Biomarkers of exposure

Biological monitoring provides an insight into the exposure received by workers from all routes, including inhalation and skin contact. However, to obtain an insight into the relative contributions from these routes of exposure, it is necessary to have some data on inhalation exposure levels and dermal exposure levels. Biological monitoring can also provide information about the effectiveness of personal protective equipment. Biomonitoring studies generally use one or two analytes to act as markers of exposure to the complex mixture of substances that make up the paint.

1.5.1 *Benzene, toluene and xylene*

In Poland, phenol and hippuric acids were measured in 51 urine samples from shipyard painters working in small spaces within the ship superstructure and in large holds. The average values of phenol in urine were 12.4–66.4 mg/L compared to 7.9 mg/L on average for a control group. Urinary phenol was attributed to benzene: the benzene concentration in air ranged from undetectable to 11 ppm (35 mg/m^3). The average concentrations of hippuric acids in urine (sum of hippuric and methyl hippuric acids) were in the range of 1812–5500 mg/L compared to 790 mg/L in a control group. Concentrations of toluene and xylene in air were 7 to 88 ppm (26–332 mg/m^3) and 23–538 ppm (100–2335 mg/m^3), respectively (Mikulski *et al.*, 1972). Elevated values of hippuric acid (up to 6700 mg/L) and methyl hippuric acid (up to 7100 mg/L) were also measured in the urine of shipyard workers in Japan (Ogata *et al.*, 1971).

Several biomonitoring studies among painters have focused on exposure to toluene. Apostoli *et al.* (1982) measured the exposure of 20 workers employed in painting and hand-finishing in an art furniture factory. Inhalation exposure concentrations of toluene were in the range of 10–200 mg/m^3. Alveolar toluene concentrations were significantly correlated with environmental toluene concentrations (r = 0.62). Duydu *et al.* (1999) studied furniture workers involved with painting. They measured urinary hippuric acid and compared the data with inhalation exposure levels. The 8h-TWA air toluene concentration in the two painting areas were 44 and 66 ppm, and the corresponding urinary hippuric acid concentrations were 0.79 and 1.1 g/g creatinine.

Katsuyama *et al.* (1998) studied the exposure of shipyard painters to toluene and xylene while working in very confined spaces. Air concentrations were high in six of the 14 workplaces where monitoring was undertaken, i.e. the exposure to the total mixture of solvents in air exceeded the combined occupational exposure limit. Urinary excretion of hippuric acid and methyl hippuric acid in the highly exposed painters varied at the end of the shift from 0.07 to 0.92 (geometric mean, 0.22) g/g creatinine and from 0.02 to 0.42 (geometric mean, 0.11) g/g creatinine, respectively. Based on the study by Loizou *et al.* (1999), exposure to 50 ppm xylene would be expected to result in the excretion of about 1.25 g/g creatinine of methyl hippuric acid at the end of the exposure period. Concentrations of toluene and xylene in the end-of-exhale air varied from <0.1 to 5.0 ppm and <0.1 to 10.6 ppm, respectively. The biological monitoring data were lower than that expected from inhaling the high concentrations prevalent in these workplaces, which was because the workers wore either a chemical cartridge respirator or a "body-mounted gas mask" (breathing apparatus).

Krämer *et al.* (1999) measured exposure levels to inhaled xylene plus concentrations of blood xylene and urinary methyl hippuric acid in a group of paint manufacturers and a group of paint sprayers. Average xylene air concentrations for sprayers were 8 ppm (3 to 21 ppm) and the corresponding average concentrations of xylenes in blood were 130 μg/L (49 to 308 μg/L). They also excreted on average 485 mg/L (range 65–1633 mg/L) methyl hippuric acid in their urine.

1.5.2 *Isocyanates*

Several researchers have used biological monitoring to evaluate exposure to isocyanates from spray painting. Williams *et al.* (1999) developed a method for measuring HDI in the urine of exposed workers, based on an analysis of hexamethylene diamine by gas chromatography-mass spectrometry (GC-MS). They measured exposure in 22 workers associated with paint spraying in automobile repair: 11 sprayers who wore respiratory protection, three bystanders and eight unexposed people. Hexamethylene diamine was detected in four sprayers and one bystander. No hexamethylene diamine was detected in the urine of the unexposed subjects. The detectable levels were in the range of 1 to 12 μmol/mol creatinine.

Pronk *et al.* (2006b) also analysed urinary hexamethylene diamine levels in autobody workshop workers and industrial painters. A total of 36% of the autobody workshop workers and 10% of the industrial painters had detectable levels of hexamethylene diamine in their urine. Positive samples were found in all groups of workers present in the autobody workshops, including welders, bystanders and office workers. Workers spraying paint wore respiratory protection but less consistently wore gloves (40% in autobody repair shops and 75% in industrial painting companies). For the autobody workshop workers, wearing gloves significantly decreased the odds ratio for having a urine sample positive for hexamethylene diamine (OR, 0.22; 95% CI: 0.09–0.57).

Creely *et al.* (2006b) measured inhalation exposure and all urinary isocyanate metabolites (methylenedianiline; 2,4-toluene diamine; 2,6-toluene diamine; 1,6-hexamethylene diamine; and isophorone diamine) in a wide range of work situations, including spray painting and roller application of paints. Overall, the geometric mean total isocyanate metabolite level for the data set was 0.29 mmol/mol creatinine (range 0.05–12.64 mmol/mol creatinine). Hexamethylene diamine was the most commonly detected metabolite in the urine samples. The geometric mean total isocyanate metabolite level for roller painting was 0.39 mmol/mol creatinine, and for spray painting, 0.29 mmol/mol creatinine. Inhalation exposure concentrations were low (geometric mean of 1 μg/m^3 for both painting operations), and the spray painting workers wore respiratory protection and gloves. The authors suggested that dermal exposure, and possibly ingestion, were important contributors to total exposure.

1.5.3 *Other solvents*

Kawai *et al.* (2003) investigated unmetabolized methyl isobutyl ketone and methyl ethyl ketone in the urine of workers in a furniture factory where spray painting and gluing were performed. The correlation between inhalation exposure concentration and the concentration of the corresponding solvent in the end-of-shift urine sample was significant both for methyl isobutyl ketone and for methyl ethyl ketone ($r = 0.98$ and 0.79, respectively). The authors calculated that approximately 0.12% of methyl isobutyl ketone inhaled would be excreted into the urine, and approximately 0.19% of the inhaled methyl ethyl ketone.

Exposure to ethylene glycol monoethyl ether acetate was assessed in two groups of shipyard painters: a "low" exposure group mostly involved with brush painting and other duties ($n = 27$), and a "high" exposure group involved with spraying or assisting with the spraying ($n = 30$), along with an unexposed control group ($n = 41$) (Kim *et al.*, 1999). Workers in the high-exposure group wore half-mask respirators while the other workers only occasionally wore respiratory protection. Urinary ethoxyacetic acid and methyl hippuric acid was measured for all subjects. The mean and range of inhalation ethylene glycol monoethyl ether acetate exposure concentrations were 3.03 ppm (not detectable to 18 ppm) and 1.76 ppm (not detectable to 8.1 ppm) for the high and low groups, respectively. The geometric mean concentrations of methyl hippuric acid in the three

exposure groups were 0.08, 0.03, and 0.01 g/g creatinine; the corresponding values for ethoxyacetic acid were 9.2, 0.6, and 0.1 mg/g creatinine. The authors noted that the levels of ethoxyacetic acid that they had measured were lower than in another study of shipyard painters, which they suggested may be due to the wearing of respiratory protection and percutaneous absorption.

Laitinen & Pulkkinen (2005) measured the inhalation exposure to 2-(2-alkoxy)ethoxy ethanols and urinary 2-(2-alkoxyethoxy)acetic acids in a group of floor lacquerers ($n = 22$). The 8-hour average inhalation exposures of floor lacquerers to 2-(2-methoxyethoxy)ethanol, 2-(2-ethoxyethoxy)ethanol and 2-(2-butoxyethoxy)ethanol were on average 0.23 ppm, 0.08 ppm, and 0.05 ppm, respectively. The excretion levels of the corresponding metabolites 2-(2-methoxyethoxy)acetic acid, 2-(2-ethoxyethoxy)acetic acid and 2-(2-butoxyethoxy)acetic acid were on average 4.9 mmol/mol creatinine, 9.3 mmol/mol creatinine, and 9.2 mmol/mol creatinine, respectively. A linear relationship was found between the urinary 2-(2-alkoxyethoxy)acetic acid concentrations and the inhalation exposure to 2-(2-alkoxyethoxy)ethanol.

1.5.4 *Polycyclic aromatic hydrocarbons*

Paints containing coal tar are used in shipyards, for example in the Republic of Korea, and they account for 13% of all shipyard paints used. Lee *et al.* (2003) used urinary 1-hydroxypyrene glucuronide as a marker of exposure to polycyclic aromatic hydrocarbons (PAHs) in three groups: 111 painters using coal-tar paints, 70 painters using general paints, and 27 on-site controls who used no paint. Average urinary 1-hydroxypyrene glucuronide levels for the group exposed to coal-tar paints was 2.24 μmol/mol creatinine, for general painters 1.38 μmol/mol creatinine, and for the controls 0.62 μmol/mol creatinine. The elevated 1-hydroxypyrene glucuronide in general painters was attributed to bystander exposure from working alongside coal-tar painters and from low levels of PAHs in general paints.

1.5.5 *Metals*

Higher blood lead levels have been measured in painters involved in paint removal using sand blasting or other mechanical means (Jarrett, 2003). Blood lead levels in 21 workers in two autobody workshops were in the range of 2–38 μg/dL (Enander *et al.*, 2004). The highest levels were found in workers who were involved in sanding painted surfaces and who ate, drank or smoked cigarettes in areas contaminated with lead dust.

Saito *et al.* (2006) reported results of blood lead monitoring carried out between 1990 and 2000 from more than 7500 workers in 259 lead-handling facilities in Japan. The mean concentration for 82 people painting or baking was 5.4 μg/dL (range 1.4–21.1 μg/dL), which was one of the lowest for the groups of workers studied.

Kiilunen (1994) reported the results from a large database of urinary metal concentrations made by the Finnish Institute of Occupational Health between 1980 and

1989; 9377 urinary chromium and 3172 urinary nickel analyses were made. The mean end-shift urinary chromium level among the 265 painters in the database was 0.04 μmol/L with 95% of the results being less than 0.12 μmol/L. The corresponding values for urinary nickel were 0.3 and 0.61 μmol/L, although in this case there were only 10 workers for whom data were available.

1.6 Personal protective equipment

Wearing of clothing and gloves protects the skin from paint, and the use of respiratory protection may reduce inhalation exposure. Normal work clothing or gloves will substantially reduce contact of the skin with solid components in paints and can reduce contact of liquids with the skin. However, volatile liquids will permeate through some relatively impervious materials such as rubber, and to obtain effective protection, it is important to carefully select the protecting material according to the chemical properties of the paint ingredients.

Respiratory protection is generally not widely used by painters. The main exceptions have been situations where painters have used solvent-based paints in confined spaces, e.g. in some shipyard applications, or where relative hazardous compounds are used in the paint formulation. The appropriate respiratory protection must be carefully selected to ensure that the filter/adsorbent removes all contaminants present in each work situation.

The Assigned Protection Factor for respirators and protective clothing is a measure of the reduction in exposure that might be expected from properly wearing a personal protective device (Brouwer *et al.*, 2001b). For example, a device with an Assigned Protection Factor of 4 would reduce exposure by 4 times, e.g. to 25% of what it otherwise might have been. For respiratory protection, the authorities in the United Kingdom recommend Assigned Protection Factors from 4 to 40 for different designs of respiratory protection, with the lower factors for half-mask respirators, and the higher values for power-assisted full-face devices. Other authorities recommend higher protection factors based on the results from laboratory tests. Studies of the effectiveness of personal protective equipment in real work situations have shown that protection is lower than achieved under laboratory conditions. This is explained by the workers either not wearing the equipment sufficiently carefully or for the whole period of exposure. Similarly, biological monitoring studies that have assessed the potential reduction in exposure from wearing respirators or protective gloves have shown that, in general, the protection factors are lower than expected. This may in part be due to exposure by skin contact or because the workers do not wear the respirators for all tasks.

1.6.1 *Respiratory protection*

Liu *et al.* (2006) investigated 36 autobody repair workshops to assess the quality of their respiratory protection, and to investigate the protection factors for the respirators in use. Only about a third of workshops had a written respiratory protection programme. For

22 painters, air samples were obtained from inside and outside air-purifying half-facepiece respirators with organic vapour cartridges and paint prefilters to assess the Workplace Protection Factor during spray-painting and priming activities. The samples were analysed for isocyanate concentration as NCO. The geometric mean Workplace Protection Factor of total NCO was 319 (geometric standard deviation (GSD), 4) and the 5th percentile was 54. The Workplace Protection Factor was positively correlated with the duration of painting task.

Bolsover *et al.* (2006) assessed the Workplace Protection Factor for air-fed visors, which are commonly used for protection against exposure to airborne isocyanates during paint spraying. They did not consistently measure any contamination inside the mask, but the external contaminant concentrations were generally quite low, making an accurate determination of the protection difficult. The median Workplace Protection Factor was between about 100 and 200 depending on the assumption of detection limit for the measurement method.

Vitayavirasuk *et al.* (2005) measured inhalation exposures and biological monitoring of lead, cadmium and chromium levels in automobile spray painters. The workers were divided into two groups, those who wore an aerosol-removing respirator while spraying and those who did not (Table 1.13). On-site observations revealed that improper use of the respirator, lack of an isolated spraying room, and poor personal hygiene habits, i.e. resulting in inadvertent ingestion exposure, resulted in the respirators being ineffective.

Vincent *et al.* (1994) measured the exposure of painters to ethylene glycol mono ethyl ether acetate during the painting of an aircraft. The workers wore gloves, boots and an apron, and a charcoal-based filtering respirator while spraying. The inhalation exposure to ethylene glycol monoethyl ether acetate was measured along with an assessment of internal exposure to ethylene glycol monoethyl ether acetate by measuring its urinary metabolite, ethoxy acetic acid. Ethylene glycol monoethyl ether acetate concentrations were in the range of 29–150 mg/m^3. The average urinary ethoxy acetic acid concentrations were 108 mg/g creatinine in pre-shift and 139 mg/g creatinine in post-shift samples. Despite the workers wearing respiratory protective equipment during paint spraying, the ethoxy acetic acid urinary concentrations were high and the authors suggested that dermal uptake was the main route of exposure for ethylene glycol monoethyl ether acetate.

1.6.2 *Gloves and clothing*

Some measure of the protection afforded by gloves that is often used is the "breakthrough time," i.e. the time from initial use until the contaminant is detected inside the glove. For example, Liu *et al.* (2007) demonstrated that latex gloves worn while using polyurethane paints in autobody workshops were ineffective at preventing dermal exposure to isocyanates, although a nylon coverall was. Pronk *et al.* (2006b) showed that by selecting the appropriate type of gloves, the chance of spray painters having a positive urinary sample for isocyanate was substantially reduced.

Chang *et al.* (2004) defined a Protective Effectiveness Index (PEI) as a measure of the protection afforded by gloves. The authors used the urinary and plasma metabolite levels from workers who wore gloves (cotton and butyl rubber) compared with the levels from those who did not to assess the protective effectiveness in workers exposed to 2-methoxyethanol. Cherrie (2004) calculated that the protection factor for these butyl rubber gloves would be about 4 (PEI of 74%); for the cotton gloves, 1.1 (PEI of 11%) for "special" workers who had high 2-methoxyethanol exposure, and 0.85 (PEI of –17%) for "regular" workers. The protection factor for butyl rubber gloves appeared to be particularly low in comparison with what might have been expected, suggesting that other factors were reducing the effectiveness of these gloves. Zellers *et al.* (1992) found that this type of glove from the same manufacturer provided up to 4 hours' protection against 2-methoxyethanol without any breakthrough.

For most volatile agents, uptake through the skin from the vapour phase is negligible. However, Shih *et al.* (2000) investigated uptake of 2-methoxyethanol from vapour. Volunteers were exposed to 300 ppm or 25 ppm 2-methoxyethanol. Uptakes during a 4-hour period were 65 mg and 7 mg, respectively, with corresponding uptake rates of 13.2 μg/cm^2/hr and 1.36 μg/cm^2/hr. The authors concluded that vapour absorption through skin is a significant contributor to overall glycol ether exposure, which is substantiated by other studies (WHO, 2006).

1.7 Regulations

Regulations concerning the work environment for the painters, which include the national OELs for specific agents in paint, are not covered in this monograph. These limits usually take into account not only health issues, but also economic concerns, and technological feasibility to control exposure.

Product regulations deal with restrictions on hazardous materials. In 1998, The Federal Environmental Protection Agency (EPA) in the USA developed final rules for national VOC emission standards for architectural coatings and for automobile refinish coatings (EPA, 1998a,b). These rules set limits to the VOC content of 61 architectural and seven automobile-coating categories. The regulations do not apply to coatings supplied in nonrefillable aerosol containers. Further, the regulations do not apply to architectural paints sold in containers less than 1 litre, or to automobile topcoats or their components. In southern California, an analogous regulation set more stringent limits to the VOC content of architectural coatings than that of the Federal standards (Rule 1113 on architectural and maintenance coatings).

Legislation that limits the VOC content of decorative paint or restrict the use of high-VOC paints exist in Denmark, Sweden, and the Netherlands (European Community, 2000). In the Netherlands, a legal ban on high-VOC paint for interior use by professional painters came into force in 2000. The maximum VOC content for interior paint is 60 g/L for wall paints, and 100 g/L for other paints (European Community, 2000).

In April 2004, the European Union published the Directive 2004/42/CE of the European Parliament and of the Council on the limitation of the emissions of VOCs due to

the use of organic solvents in certain paints and varnishes and vehicle refinishing products (European Union, 2004). These were to come in over two phases commencing January 2007 and January 2010. Maximum VOC content limit values are set for 12 subcategories of both water-based and solvent-based paints and varnishes. They are coatings applied to buildings, their trim and fittings, and associated structures for decorative, functional and protective purpose. Maximum VOC content limit values for vehicle-refinishing products are set for five subcategories of products used for the coating of road vehicles carried out as part of vehicle repair, conservation or decoration outside of manufacturing installations. VOC means any organic compound having an initial boiling point below or equal to 250°C measured at a standard pressure of 101,3 kPA.

The EC Regulation No 1907/2006 (Annex XVII) (European Union, 2006) relates to restrictions on the marketing and use of certain dangerous substances and preparations. Several of the agents listed are of relevance for paint products:

• Benzene shall not be used in concentrations equal to, or greater than, 0.1% by mass in substances or preparations placed on the market.

• Lead carbons and lead sulfates shall not be used as substances and constituents of preparations intended for use as paints, except for the restoration and maintenance of works of art and historic buildings.

• Mercury and arsenic compounds shall not be used as substances and constituents of preparations intended for use to prevent the fouling by microorganisms, plants or animals of the hull of boats, equipment used for fish farming and on any totally or partly submerged appliances or equipment.

• Organostannic compounds shall not be placed on the market for use as substances and constituents of preparations when acting as biocides in free association paint or to prevent the fouling by microorganisms, plants or animals.

• Cadmium shall not be used to give colour to paint. In any case, the cadmium content may not exceed 0.01% by mass. However, if the paint has a high zinc content its residual concentration of cadmium shall be as low as possible and at all events not exceed 0.1% by mass.

• Metallic coating; deposit or coating of metallic cadmium on a metallic surface are prohibited in some specific sectors such as equipment and machinery for food production and agriculture.

• Substances which appear in Annex I to Directive 67/548/EEC classified as carcinogen, mutagen or toxic to reproduction in categories 1 or 2 shall not be used in substances and preparations placed on the market for sale to the general public in individual concentration equal to or greater than specified in Council Directives. The provision does not apply to artists' paint covered by Council Directive 1999/45/EC.

The US Consumer Product Safety Commission has declared that paint and similar surface-coating materials for consumer use that contain lead or lead compounds and in which the lead content is in excess of 0.06 percent of the weight of the total nonvolatile content of the paint or the weight of the dried paint film are banned hazardous products (16 CFR Part 1303). In addition to those products which are sold directly to consumers, the ban

applies to products which are used or enjoyed by consumers after sale, such as paints used in residences, schools, hospitals, parks, playgrounds, and public buildings or other areas where consumers will have direct access to the painted surface. Paints and coatings for motor vehicles are not covered by the ban. Artists' paints are also exempt from the regulation (US CPSC, 2001).

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2. Studies of Cancer in Humans

2.1 Cohort, record linkage and proportionate mortality studies

2.1.1 *Background*

In 1989, the International Agency for Research on Cancer (IARC) classified painting as an occupation as *carcinogenic to humans* (Group 1) (IARC, 1989, Volume 47). At the time, the epidemiological evidence for the evaluation was primarily based on a total of eight studies (five record linkage and three cohort studies), listed in Table 23 of that volume. The primary findings in these data were relatively consistent excesses for all cancers (standardized mortality ratio [SMR] 1.21, 9100 cases), and for cancer of the lung (SMR 1.41, 468 cases). The lung cancer excess was noted to be above what could reasonably be expected to be due to confounding by smoking. Other findings which drew comment in Volume 47 were excesses for cancers of the oesophagus, stomach, and bladder, although these excesses were smaller than for cancer of the lung and were less consistent across studies. It was noted that results from a few studies showed excesses of leukaemia, and cancers of the buccal cavity, and of the larynx.

Cohort studies generally represent a stronger study design than record linkage studies. In the latter, the exposure is often taken from census employment data, is typically less accurate than the employment records upon which cohort studies are usually based, and does not usually take into account duration of employment. However, in the case of the cohort and record linkage studies listed in Table 23 by IARC in 1989, findings from both types of studies were reasonably consistent.

2.1.2 *Cohort studies since IARC Monograph Volume 47* (Table 2.1)

Yin *et al.* (1987) studied workers who were employed at least 6 months within different factories in the People's Republic of China. They compared 13 604 benzene-exposed painters to 28 257 production workers without occupational benzene exposure with a similar sex and age distribution. Mortality follow-up occurred from 1972–1981, and the authors presented the leukaemia mortality rates separately for painters (15.9/100 000 person–years) and the comparison cohort (2.01/100 000 person–years). [The painters, not including paint-production workers, had a mortality rate ratio of [7.9] (14 leukaemia deaths) compared to workers in other production jobs without benzene exposure (four leukaemia deaths). This high rate ratio is presumably due to the selection of these painters for specifically benzene exposure.] No other cancer outcomes were presented.

Hrubec *et al.* (1995) followed a cohort assembled from a roster of approximately 300 000 caucasian, male WWI and WWII veterans for mortality from 1954–1980. These men served in the US Armed Forces at some time during 1917–1940, and held active

government life insurance policies. Personal data on usual occupation and smoking habits were obtained by mailed questionnaire in the 1950s. SMRs were calculated using Poisson regression, using all other occupations as the reference. After adjustment for smoking, age and calendar time, 1178 construction and maintenance painters had an SMR for all cancers of 1.0 (90% CI: 0.84–1.11, based on 140 cancer deaths). Cancer mortality was not remarkable for most anatomical sites. For anatomical sites with more than five deaths, the SMRs were 0.8 (90% CI: 0.42–1.61; six deaths) for cancer of the stomach, 1.0 (90% CI: 0.69–1.51; 18 deaths) for cancer of the colon, 1.6 (90% CI: 0.89–2.86; eight deaths) for cancer of the rectum, 1.1 (90% CI: 0.84–1.47; 36 deaths) for cancer of the respiratory system, 0.5 (90% CI: 0.27–0.78; ten deaths) for cancer of the prostate, 0.9 (90% CI: 0.48–1.67; seven deaths) for lymphoma, and 1.2 (90% CI: 0.69–2.10; nine deaths) for leukaemia. A smaller number of non-construction painters ($n = 140$) provided little extra information on cancer mortality owing to the small numbers involved.

Alexander *et al.* (1996) conducted a cohort study of 2429 chromate-exposed workers in the aerospace industry, of whom 62% had ever worked as a painter. A total of 15 cases of lung cancer were observed among the entire cohort, which was less than expected based on incidence data (SIR, 0.8; 95% CI: 0.4–1.3). No exposure–response trends with hexavalent chromium was seen, although the number of cases of lung cancer were too small to draw any meaningful conclusions. There was an inverse trend of lung cancer with duration of employment for painters, although sanders and polishers (exposed to dusts rather than mists) had a somewhat positive trend with duration. None of these results were statistically significant.

van Loon *et al.* (1997) conducted a population-based cohort study in the Netherlands that prospectively followed 58 279 men, aged 55–69 years, for cancer incidence from 1986–1990. Rate ratios were estimated by a case–cohort analysis (524 cases, 1630 non-cases in the subcohort). Self-reported lifetime job history, reviewed by experts on a case by case basis, was used to create a job exposure matrix (JEM) for exposure to paint dust (none, low, high). Positive non-significant increases in lung cancer were found for the 'low' exposed group (RR, 2.29; 95% CI: 0.61–8.63) and the 'high' exposed group (RR, 2.48; 95% CI: 0.88–6.97) compared to the unexposed group, after adjustment for age, smoking, diet, and other occupational exposures; although the test for trend was significant ($P < 0.01$). [This study was limited owing to the small sample size (14 'high' and '4' low exposed lung cancer deaths) and the use of a JEM to assign exposure level based on self-reported employment information.]

Boice *et al.* (1999) conducted a retrospective cohort study among 77 965 aircraft industry employees in California (1216 painters), employed for at least one year on or after 1960, with registry-linked mortality follow-up through 1996. There was little detail available on the type of painting done, except that the paints contained chromates. There were 101 cancer deaths among painters (all cancer SMR, 0.87; 95% CI: 0.71–1.06). The SMR for cancer of the lung was 1.11 (95% CI: 0.80–1.51; 41 deaths).

Table 2.1. Cohort, linkage and proportionate mortality studies of painters published since Monograph Volume 47, 1989

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Yin *et al.* (1987) China	13 604 benzene-exposed workers in China employed in factories ≥ 0.5 yrs during 1972-81; leukaemia mortality follow-up 1972-81; controls were 28 257 workers not occupationally exposed to benzene	Information on occupational history, history of benzene poisoning, working conditions and workplace atmospheric benzene concentrations were collected from factory records.	Leukaemia			Mortality rate ratio = 7.9	None; controls had similar age and sex distributions	Compared to benzene-unexposed workers
				Painters (not including paint producers)	14	Mortality rate: 15.9/100 000 person-years		
				Benzene-unexposed workers	4	Mortality rate: 2.01/100 000 person-years		
Hrubec *et al.* (1995) USA 1954–80	1178 painters were followed during 1954–80 within a cohort assembled from a roster of approximately 300 000 white male WWI veterans who served in the US Armed Forces some time during 1917–40 and who held active government life insurance policies	Mailed questionnaire that inquired about tobacco use, usual industry of employment and occupation, coded using 1950 Census Occupation and Industry codes				**SMR (90% CI)**	Smoking, age, calendar time	Usual occupation was recorded
			Respiratory system	Construction and maintenance painters	36	1.1 (0.84–1.47)		
			Stomach		6	0.8 (0.42–1.61)		
			Colon		18	1.0 (0.69–1.51)		
			Rectum		8	1.6 (0.89–2.86)		
			Prostate		10	0.5 (0.27–0.78)		
			Lymphoma		7	0.9 (0.48–1.67)		
			Leukaemia		9	1.2 (0.69–2.10)		

Table 2.1 (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Alexander *et al.* (1996) Seattle, WA, USA 1974–94	2429 chromate exposed workers employed ≥6 months in the aerospace industry during 1974–94 were assembled from company work-history records; 62% had ever worked as a painter; incidence follow-up 1974–94 with linkage to the SEER registry; median 42 yrs of age	Exposure to chromium [VI] was estimated from industrial hygiene measurements and work-history records; cumulative exposure to chromium [VI] = years in each job x TWA for each exposure category	Lung			**SIR (95% CI)**	Standardized by age, race, gender and calendar time using the Puget Sound population during 1974–94 as reference	No information on smoking; no trend with cumulative exposure to chromium (VI) but slightly positive trend with duration of employment as a sander/polisher; small numbers preclude conclusions
				Entire cohort	15	0.8 (0.4–1.3)		
				Years worked as a painter				
				0	9	1.1 (0.5–2.0)		
				<5	3	0.8 (0.2–2.4)		
				≥5	3	0.4 (0.1–1.2)		
van Loon *et al.* (1997) the Netherlands 1986–90 Europe	58 729 men, aged 55–69 yrs, enrolled from the general Dutch population and followed for lung cancer incidence from 1986–90 by linkage to national and regional registries	Paint exposure was obtained from job history as part of a self-administered questionnaire and case by case expert assessment	Lung	Low exposure to paint dust	4	2.29 (0.61–8.63)	Age, other occupational exposures, smoking habits and dietary intake of vitamin C, beta-carotene and retinol	No paint exposure was the reference; cumulative probability of exposure = probability x duration of exposure
				High exposure to paint dust	14	2.48 (0.88–6.97)		
				P value for trend		<0.01		

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Boice *et al*. (1999) Lockheed Martin Plant Burbank, Los Angeles county, California, USA 1960–96	1216 painters (1139 men, 77 women) employed ≥1yr in the aircraft industry, followed-up retrospectively for mortality	Detailed job history was obtained from work-history records		Painter		**SMR (95% CI)**	Age, sex, race, calendar year	Other cancer causes non-informative due to small numbers of deaths; painting not described in detail except that paints contained chromates
			Lung		41	1.11 (0.80–1.51)		
			Oesophagus		21	0.61 (0.07–2.20)		
			Liver		1	0.36 (0.01–2.03)		
			Non-Hodgkin lymphoma		3	0.72 (0.15–2.12)		
			Multiple myeloma		4	1.70 (0.46–4.35)		
			Leukaemia		3	0.74 (0.15–2.16)		
Steenland & Palu (1999) California, Missouri, New York, Texas, USA 1975–94	42 170 painters and 14 316 non-painters with ≥1 yr union membership were identified from union records and followed from 1975–94 by linkage to national and local registers; Restricted to white men (98% of the cohort).	Job titles were inferred from union membership records which identified the specialty affiliation and trade of the local union for all members		Painter		**SMR (95% CI)**	Restricted to caucasian men (98% of the cohort). Stratification by age and calendar time	No information on trade of individual members; SMRs compared painters to the general US population; SRRs compared painters to non-painters
			All cancers		4674	1.12 (1.09–1.15)		
			Lung		1746	1.23 (1.17–1.29)		
			Bladder		166	1.23 (1.05–1.43)		
			Stomach		197	1.39 (1.20–1.59)		
			Liver		119	1.25 (1.03–1.50)		
			Pharynx		49	1.15 (0.85–1.52)		
			Oesophagus		110	1.12 (0.92–1.35)		
			Larynx		48	0.97 (0.71–1.29)		
			Non-Hodgkin lymphoma		137	1.06 (0.89–1.25)		
			Hodgkin disease		16	1.30 (0.74–2.11)		
			Multiple myeloma		64	0.97 (0.75–1.24)		
			Leukaemia		138	0.92 (0.78–1.11)		

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Zeegers *et al*. (2001) Netherlands 1986–92	58 729 men, aged 55–69 yrs, were enrolled from the general Dutch population and followed for bladder cancer incidence from 1986–92 by linkage to national and regional registries	Paint exposure was obtained from job history as part of a self-administered questionnaire and case by case expert assessment	Bladder	No paint exposure Low Medium High	483 8 20 19	1.00 (reference) 0.75 (0.33–1.72) 1.78 (0.94–3.37) 1.31 (0.72–2.40)	Age, other occupational exposures, and cigarette smoking amount and duration	Same Dutch cohort as that described in van Loon *et al*. (1997)
Zeegers *et al.* (2004) Netherlands 1986–92	58 729 men, aged 55–69 yrs, were enrolled from the general Dutch population and followed for bladder cancer incidence from 1986–92 by linkage to national and regional registries	Paint exposure data obtained from job history as part of a self-administered questionnaire, and job titles were coded using the Dutch Occupation Classification system	Prostate	Ever painter Painter as one's usual occupation	12 7	1.10 (0.39–3.08) 1.28 (0.31–5.30)	Age, diet, cigarette and alcohol use, family history of prostate cancer, education and physical activity	Same Dutch cohort as that described in van Loon *et al.* (1997)
Linkage studies								
Malker *et al.* (1987) Sweden 1961–79	1960 Swedish census linked to the Swedish Cancer Registy to follow-up for bladder cancer incidence from 1961–79	Occupations and industries obtained from the 1960 census and coded using ILO standards.	Bladder	Painter as one's specific occupation Artistic painter	186 42	**SIR (*P*-value)** 1.0 (not given) 1.7 ($P<0.01$)	Age, sex, region	No adjustment for smoking. The census code not given for 'artistic painters' and thus may correspond to the Swedish 'pictorial artists' studied in Brown *et al.* (2002)

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Carstensen *et al.* (1988) Sweden 1961–79 Scandinavia	1 622 547 Swedish men in the 1960 national census, aged 30–64 years and gainfully employed, were linked to the Swedish Cancer Registry and followed for cancer incidence from 1961–79	Occupations and industries were obtained from the 1960 census and coded using ILO standards. Smoking data were obtained from a large survey among an age-stratified random sample of the Swedish population in 1963	Lung			**SIR (95% CI)**	Indirect smoking adjustment. SIRs were standardized using the age and residential distribution in the total population	It is likely that paperhangers work in the same job environment as painters or may also paint, and it is reasonable to consider this category as a whole as 'painters'. This study population overlaps with that of Malker *et al.* (1987)
				Painters and paperhangers	425	1.01 (0.88–1.16)		
Lynge & Thygesen (1988) Denmark	Persons aged 20–64 years in the 1970 Danish census linked to the national cancer registry and followed for cancer incidence through 1980	Data on industry and occupation captured in the 1970 census. Industry coded using ISIC codes and occupation coded using a special Danish code.	Pharynx	All painters (n = 19163)	10	2.27 (1.09-4.18)	RRs (SIRs) were age-standardized according to the age distribution of the subcohort	
				Skilled workers, painter in paint workshop (n = 9703)	6	3.30 (1.21-7.18)		
				Self-employed, painter in paint workshop (n = 5150)	3	1.73 (0.34-5.07)		
				Skilled workers, painter in metal industry (n = 2564)	1	1.95 (0.05-10.92)		
				Skilled workers, painter/other industries (n = 1746)	0	NG		

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Gubéran *et al.* (1989) Switzerland 1971–84	1916 male painters from the 1970 Geneva census were linked to the Geneva Cancer Registry and followed for cancer incidence during 1971–84	Occupational classifications were obtained from the 1970 census				**SIR (90% CI)**	Standardized by sex-, age- and matrimonial status-specific incidence rates of the Geneva population	Regarding non-cancer outcomes, painters showed a significant excess mortality from alcoholism (SMR, 6.25; 90%CI: 2.46–13.14; 5 deaths) and a borderline significant excess mortality from cirrhosis (SMR, 1.59; 90%CI: 0.96–2.49; 14 deaths), suggesting excess alcohol consumption among painters
			All cancers	Painters	159	1.20 (1.05–1.37)		
			Lung		40	1.47 (1.11–1.91)		
			Bladder		13	1.71 (1.01–2.72)		
			Buccal cavity, pharynx (ICD-8, 140-149)		13	1.49 (0.88–2.38)		
			Oesophagus (ICD-8, 150)		2	0.67 (0.12–2.10)		
			Liver		5	1.39 (0.55–2.92)		
			Gallbladder		3	3.75 (1.02–9.69)		
			Larynx (ICD-8, 161)		5	1.14 (0.45–2.39)		
			Testis		5	3.13 (1.23–6.57)		
			Non-Hodgkin lymphoma (ICD-8, 200, 202)		2	0.80 (0.14–2.52)		
			Leukaemia (ICD-8, 204-207)		1	0.43 (0.02–2.06)		
Carstensen *et al.* (1990) Sweden 1961–79	2.1 million men and 820 000 women aged 20–69 years and gainfully employed obtained from the 1960 Swedish population census and linked to the Swedish Cancer Registry to follow for cancer incidence from 1961–79	Occupations and industries obtained from the 1960 census and coded using ISIC and ILO standards	Thyroid			**SIR (*P*-value)**	Indirect standardization by year of birth, year of follow-up, region of residence	The whole population used as the reference. Nearly the same design as used in Carstensen *et al.* (1988) but did not adjust for smoking. This study population overlaps with that of Malker *et al.* (1987)
				Male painters (occupation)	11	0.67 (NG)		
				Male painters (construction industry)	5	0.36 (P<0.05)		

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Dolin & Cook-Mozaffari (1992) England and Wales 1965–80	Male British painters, aged 25–64, who died from bladder cancer during 1965–80	Information on occupation and industry of usual employment was extracted from death certificates and coded according to British standards	Bladder			**SMR (95% CI)**	Indirect standardization by age and urbanization	Degree of urbanization used as a proxy for smoking data that were unavailable
				All painters	65	1.27 (0.99–1.61)		
				Coach painter	5	7.03 (2.28–16.38)		
				Painter, decorator	57	1.20 (0.93–1.56)		
				Spray painter	3	0.92 (0.19–2.70)		
Firth *et al.* (1993) New Zealand	Male cancer deaths during 1973–86 obtained from the New Zealand Cancer Registry and linked to census data from 1976, 1981, and 1986	Occupation obtained from census data and coded using the New Zealand Standard Classification of Occupations	Multiple myeloma	Painter	NG	**SMR (95%CI)** 3.52 (1.40–7.29)	Standardized by age and social class	Only select findings reported
Skov *et al.* (1993) Denmark 1970–80, Finland 1971–80, Norway 1961–84, Sweden 1961–79 Scandinavia	87 004 economically active, male painters and lacquerers included in the national census of 4 Scandinavian countries were followed-up for cancer incidence by linking individual records with national cancer registries	Painters were identified by combining census codes for occupation and industry		Painter		**SIR (95%CI)**	Standardized by birth cohort, site and sex	Entire census population used as a reference
			Lung		1043	[1.30][1.22–1.38]		
			Mouth (ICD-7, 143-144)		48	[1.51][1.12–2.01]		
			Pharynx (ICD-7, 145-148)		64	[1.43][1.10–1.83]		
			Oesophagus (ICD-7, 150)		98	[1.29][1.05–1.57]		
			Liver		122	[1.11][0.92–1.32]		
			Larynx (ICD-7, 161)		95	[1.05][0.85–1.28]		
			Bladder		380	[1.05][0.95–1.16]		

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
OPCS (1995) England and Wales	29 689 male painters and decorators, aged 20–74 years, who died during 1979–80 or 1982–90, linked to census denominators	Last full-time occupation obtained from death certificates		Painters and decorators		**PMR (95%CI)**	Age, social class	
			Lung		4110	1.12 (1.09–1.16)		
			Oral cavity		75	1.33 (1.03–1.70)		
			Kidney		130	0.77 (0.64–0.91)		
Andersen *et al.* (1999) Denmark 1971–87, Finland 1971–90, Norway 1971–91, Sweden 1971–89 Scandinavia	65 868 male and 2121 female painters and wallpaper hangers, aged 25–64 years at 1970 censuses, were followed-up for cancer incidence during 1987–91 by linkage to national cancer registries	Occupation was obtained from census data and coded according to national adaptations of the Nordic Occupational Classification or according to a special Danish nomenclature		Male painters and wall paper hangers		**SIR (95%CI)**	Standardization by age, gender and time period	National populations as the reference. The Swedish component partly overlaps Brown *et al.* (2002) who also included painters from the 1960 Swedish census. Also overlaps the 4-country study by Skov *et al.* (1993), who reported on fewer cancer sites with shorter follow-up
			All cancers		7070	1.06 (1.03–1.08)		
			Lung		1450	1.22 (1.16–1.28)		
			Pleura		47	1.70 (1.25–2.26)		
			Bladder		566	1.10 (1.01–1.20)		
			Mouth (ICD-7, 143-144)		48	1.21 (0.89–1.60)		
			Pharynx (ICD-7, 145-148)		72	1.31 (1.02–1.64)		
			Oesophagus (ICD-7, 150)		95	1.11 (0.90–1.36)		
			Larynx (ICD-7, 161)		116	1.03 (0.86–1.24)		
			Rectum (ICD-7, 154)		406	1.14 (1.04–1.26)		
			Hodgkin disease (ICD-7, 201)		48	1.04 (0.76–1.37)		
			Non-Hodgkin lymphoma (ICD-7, 200,202)		184	0.97 (0.84–1.12)		
			Multiple myeloma (ICD-7, 203)		103	0.98 (0.81–1.19)		
			Acute leukaemia (ICD-7, 204.3)		67	0.98 (0.76–1.24)		
			Other leukaemia (ICD-7,204.0-2,4)		108	0.96 (0.79–1.16)		

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Andersen *et al.* (1999) (contd)			Lung Bladder Tongue Uterine cervix	Female painters and wallpaper hangers	13 5 3 15	1.55 (0.83–2.65) 1.46 (0.47–3.41) 6.53 (1.35–19.08) 2.01 (1.13–3.32)		
Aronson *et al.* (1999) Canada	242 196 women and 457 224 men employed during 1965–71 and who completed employment surveys linked to the Canadian mortality database for follow-up during 1965–91	Occupation (≥1 year) obtained from employment surveys and coded using standardized Canadian codes	Brain	Male painters, except construction and maintenance	6	**SMR (95%CI)** 3.79 (1.70–8.48)	Age, calendar period; stratification by gender and white- or blue-collar jobs	
Brown *et al.* (2002) Sweden 1971–89 Scandinavia	People in the painting trades or painting industry (42 433 male painters and 6662 male and 2136 female pictorial artists) obtained from 1960 and 1970 Swedish census data were linked to the Cancer Environment Register to follow-up for cancer incidence from 1971–89	Job title and industry were obtained from census data and coded using Swedish occupational codes.	Lung Bladder Pleura Oral cavity Oesophagus Stomach Rectum Liver Extra hepatic bile ducts Larynx Non-Hodgkin lymphoma Hodgkin disease Multiple myeloma Leukaemia	Male painters (classified either in 1960 or 1970)	548 344 19 122 63 276 267 36 22 62 123 25 71 115	**SIR (95%CI)** 1.2 (1.1–1.3) 1.1 (1.0–1.2) 1.6 (0.9–2.4) 1.0 (0.8–1.1) 1.1 (0.9–1.4) 1.0 (0.9–1.1) 1.2 (1.0–1.3) 0.8 (0.6–1.1) 1.5 (1.0–2.3) 1.2 (0.9–1.6) 1.0 (0.8–1.2) 1.0 (0.6–1.4) 1.0 (0.8–1.3) 0.9 (0.8–1.1)	Standardized by gender, age and calendar year	Bladder cancer risk was significantly increased by about the same magnitude in male and female artists, although this association was not significant in women. Female artists were at increased risk of cancer of the uterus. Lung cancer risk was not increased among artists

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Proportionate mortality studies								
Miller *et al.* (1986) USA United States of America	630 caucasian male painters were identified from a registry of death certificates of 1757 artists deceased during 1940–69	Artists identified from obituaries	Bladder Leukaemia	Painters	14 10	**PCMR (95%CI)** 3.5 (2.1–5.7) 3.1 (1.8–5.6)	Race, sex, age, calendar time	Total number of cancer deaths for all sites combined was used as the comparison group. The PMR for lung cancer was not significantly elevated
OPCS (1995), no. 10 England, 1981–87	Men, aged 20–74 years, England 1981–87	Occupation recorded at the time of cancer registration/death	Lung, bronchus, trachea (ICD9 162)	Painters & decorators Other spray painters	1664 213	**PRR (95% CI)** 1.08 (1.03–1.14) 1.11 [0.97–1.27]	Age, social class, region of registration	
OPCS (1995), no. 10 England & Wales 1979–80, 1982–90	29 689 male painters and decorators, aged 20–74 years, who died during 1979–80 or 1982–90, linked to census denominators	Last full-time occupation was obtained from death certificates	Lung, bronchus, trachea (ICD9 162)	Other spray painters Painters & decorators Coach painters	557 4110 69	**PMR (95% CI)** 1.26 (1.16–1.37) 1.12 (1.09–1.16) 0.87 [0.68–1.10]	Age, social class	Data for 1981 were omitted because of questionable quality

Table 2.1. (contd)

Reference, location, time period	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	RR (95% CI)	Adjustment for potential confounders	Comments
Peto *et al.* (1995) England, Wales, Scotland 1979–80, 1982–90	British painters, aged 16–74 years, who died during 1979–80 and 1982–90 were obtained from a UK register	Last full-time occupation obtained from death certificates	Mesothelioma	Male painters and decorators	100	**PMR (*P*-value)** 1.31 ($P<0.05$)	Age, calendar year	This study partially overlaps with the Registrar General's report (1996)
Terstegge *et al.* (1995) Netherlands 1980–92	9812 Dutch male painters identified from a registry and deceased during 1980–92	Painters obtained from a registry with which nearly all commercial painters are affiliated	All cancers Lung Bladder Non-Hodgkin lymphoma	Commercial painters	3266 1480 132 65	**PMR (95%CI)** 1.07 (1.03–1.11) 1.20 (1.14–1.26) 1.19 (1.00–1.41) 1.28 (0.99–1.64)	Age, time period	Total Dutch male population during 1980–1992 used as a comparison
Wang *et al.* (1999) North Carolina, USA	All male construction workers who lived and died in North Carolina during 1988–94	Usual occupation obtained from coded death certificates	Lung Pharynx	Painters, wallpaper hangers, plasterers	NG NG	**PMR** 1.18 1.78	Gender and race	No confidence intervals or number of deaths provided

CI, confidence interval; ILO, International Labor Office and the United Nations Statistical Office; ISIC, International Standard Industrial Classification; NG, not given; PCMR, proportionate cancer mortality ratio; RR, rate ratio or relative risk; SIR, standardized incidence ratio; SMR, standardized mortality ratio; TWA, time-weighted average

Other cancer categories had very few deaths and provided little information. More detail can be found in Table 2.1.

Steenland & Palu (1999) updated a previous large cohort study of US painters by Matanoski *et al.* (1986): 42 170 painters and 14 316 non-painters were assembled from union records and followed for mortality through local and national registries from 1975–1994. The update added 15 years of follow-up during which time the number of deaths increased from 5313 to 23 458. When painters were compared to the general US population, the updated data showed significant but modest excesses for all cancers (SMR, 1.12; 95% CI: 1.09–1.15; 4674 deaths), cancers of the lung (SMR, 1.23; 95% CI: 1.17–1.29; 1746 deaths), of the bladder (SMR, 1.23; 95% CI: 1.05–1.43; 166 deaths), of the stomach (SMR, 1.39; 95% CI: 1.20–1.59; 197 deaths), and of the liver (SMR, 1.25; 95% CI: 1.03–1.50; 119 deaths). In an additional analysis comparing painters and non-painters directly at other anatomical sites, the standardized rate ratios (SRRs) were 1.23 (95% CI: 1.11–1.35) for cancer of the lung, 1.77 (95% CI: 1.13–2.77) for cancer of the bladder, 0.92 (95% CI: 0.68–1.25) for cancer of the stomach, and 1.36 (95% CI: 0.87–2.11) for cancer of the liver. Further analyses restricted to painters with at least 20 years of membership in the union, showed reductions in the SRRs for cancers of the bladder, stomach, and liver while the SRR for cancer of the lung increased slightly (to 1.32). Both painters and non-painters showed significant excesses of cirrhosis compared to the US population (SMRs, 1.21; 95% CI: 1.07–1.35, and 1.26; 95% CI: 1.03–1.51, respectively), suggesting an excess of alcohol consumption compared to the US population; nonetheless, as noted above, the excess of liver cancer persisted in a direct comparison of painters to non-painters.

The data were also adjusted indirectly for smoking using detailed information on smoking in the general population from two large US surveys (see Axelson & Steenland (1988) for the description of methods). The authors found that confounding by smoking when comparing painters to the US population would have resulted in a rate ratio of 1.14 for lung cancer and 1.05 for bladder cancer, compared to the observed SMRs of 1.23 and 1.23, respectively. While this suggested that confounding by smoking may have accounted for some of the lung cancer excess, the case for an occupational etiology was strengthened by the finding of an SRR of 1.23 (95% CI: 1.11–1.35) through a direct comparison painters to non-painters in the same union as both these groups were expected to have similar smoking habits.

The same Dutch cohort described by van Loon *et al.* (1997) was studied for incident cancers of the bladder (532 cases, 1630 subcohort members) and of the prostate (830 cases, 1525 subcohort members), using the same case–cohort design (Zeegers *et al.,* 2001, 2004). Using a case by case expert assessment, and adjustment for age, other occupational exposures as well as the amount and duration of cigarettes consumed, a positive trend for exposure to paint components was observed, with incident rate ratios of 1.00, 0.75 (95% CI: 0.33–1.72), 1.78 (95% CI: 0.94–3.37), and 1.31 (95% CI: 0.72–2.40) for increasing levels of estimated exposure (none, low, medium and high, respectively; *P*-value for trend, 0.09), based on 483, 8, 20, and 19 bladder cancer cases, respectively (Zeegers *et al.*, 2001). For the 765 prostate cancer cases that reported occupational history, job titles were coded using the

Dutch Occupational Classification system. Incident rate ratios were presented for ever being a painter (RR, 1.10; 95% CI: 0.39–3.08; 12 cases), and for being a painter as one's usual occupation (RR, 1.28; 95% CI: 0.31–5.30; seven cases), after adjustment for age, diet, cigarette and alcohol use, family history of prostate cancer, education and physical activity (Zeegers *et al.*, 2004).

2.1.3 *Record Linkage studies since IARC volume 47* (Table 2.1)

Malker *et al.* (1987) conducted a record linkage study of bladder cancer in Sweden, linking the 1960 census with the Swedish National Cancer Registry to follow up for cancer incidence from 1961–1979. Age- and sex-specific bladder cancer incidence rates for painters were compared to the general Swedish population cancer incidence rates. They found no excess of bladder cancer in painters (SIR, 1.00; 186 cases; adjusted for age and region), but an elevated risk in artistic painters (SIR, 1.70; $P < 0.01$; 42 cases). [The census code corresponding to 'artistic painters' is not given and thus it is not clear if this corresponds to Swedish 'pictorial artists' (census code 081) as in the study by Brown *et al.* (2002). The results were not adjusted for smoking.]

The Swedish Cancer-Environment Registry was used to evaluate occupational risks of renal cancer (McLaughlin *et al.*, 1987). This is a record linkage study involving the Swedish Cancer Registry with employment data from the national census. For this study employment data came from the 1960 census and cancers were diagnosed between 1960 and 1979. Among Swedish men there were 7405 cases of renal cell cancer and 821 renal pelvis cancer. Standardized incidence ratios (SIR) were calculated based on national cancer incidence rates. The SIR from painting and paperhanging, adjusted for age and geographic region, was 0.94 for renal cell cancer, and 0.69 for renal pelvis cancer.

Carstensen *et al.* (1988) conducted a record linkage study in Sweden focusing on male lung cancer. Census records from 1960 were linked to the Swedish Cancer registry to follow-up for cancer incidence from 1961–1979. SIRs were standardized using the age and residential distribution in the Swedish general population as the comparison group. Indirect adjustment for smoking was done using a 1963 large survey of smoking habits in Sweden. Painters and paperhangers as a combined group had a smoking-adjusted SIR for lung cancer of 1.01 (95% CI: 0.88–1.16; 425 exposed cases). [It is likely that paperhangers work in the same job environment as painters or may also paint, and it is reasonable to consider this category as a whole as "painters."]

Lynge & Thygesen (1988) studied painters, obtained from the 1970 Danish census, who were linked to the national cancer registry to follow-up for cancer incidence through 1980, and compared them to the economically active Danish population. Only selective findings were reported. Painters had a relative risk of 3.30 (95% CI: 1.21–7.18; six exposed cases) for incident cancer of the pharynx.

Gubéran *et al.* (1989) studied 1916 painters in the 1970 Geneva census who were linked to the Geneva Cancer Registry and followed for cancer incidence during 1971–1984. Regional incidence rates, standardized by age, sex, and marital status were used as a comparison. Painters had significant excess incident cancers for all anatomical sites (SIR,

1.20; 90% CI: 1.05–1.37, 159 cases), lung (SIR, 1.47; 90%CI: 1.11–1.91, 40 cases), urinary bladder (SIR, 1.71; 90%CI: 1.01–2.72, 13 cases), gall bladder (SIR, 3.75; 90%CI: 1.02–9.69; three cases), and testis (SIR, 3.13; 90%CI: 1.23–6.57, five cases). More detail can be found in Table 2.1. Regarding non-cancer outcomes, painters showed a significant excess mortality from alcoholism (SMR, 6.25; 90%CI, 2.46–13.14; five deaths) and a borderline significant excess mortality from cirrhosis (SMR, 1.59; 90%CI: 0.96–2.49; 14 deaths), suggesting excess alcohol consumption among painters.

Malker *et al.* (1990) provided some evidence of an increase in mesothelioma incidence among Swedish painters followed from 1961–1979, although largely without quantified data. [A more detailed article on the same subject by Malker *et al.* (1985), cited in Monograph 47, predates Malker *et al.* (1990).]

Carstensen *et al.* (1990) obtained information on occupation and industry on gainfully employed individuals (2.1 million men and 820 000 women aged 20–69 years) from the 1960 Swedish population census, and linked them to the Swedish Cancer Registry to follow-up for thyroid cancer incidence from 1961–1979. [They used nearly the same design as in Carstensen *et al.* (1988).] Painters had a reduced risk of cancer of the thyroid (SIR, 0.67; 11 cases).

Dolin & Cook-Mozaffari (1992) linked 2457 death certificates for English and Welsh men age 25–64 who died of bladder cancer from 1965–1980. They determined that painters had an SMR of 1.27 (95% CI: 0.99–1.61, 65 deaths).

Firth *et al.* (1993) used death certificates in New Zealand from 1973–1986, for men aged 15–64 years, considering all different types of cancer and occupations. Denominator data came from the 1976, 1981 and 1986 censuses. Only selective positive findings were reported, including an SMR of 3.52 (95% CI: 1.40–7.29) for multiple myeloma among painters.

Skov *et al.* (1993) studied cancer incidence among painters for selected sites in four Scandavian countries by linking census data (1960 for Norway and Sweden, 1970 for Finland and Denmark) for those who were economically active (generally under age 70) to cancer incidence registries for follow-up extending to 1984 and 1979 in Norway and Sweden respectively, and to 1980 in Finland and Denmark. The study included 87 004 painters and lacquerers, grouped together. The SIRs were significantly elevated for cancers of the lung [SIR, 1.30, 95% CI: 1.22–1.38, 1043 cases], oral cavity [SIR, 1.51; 95% CI: 1.12–2.01, 48 cases], pharynx [SIR, 1.43, 95% CI: 1.10–1.83, 64 cases], and oesophagus [SIR, 1.29, 95% CI: 1.05–1.57, 98 cases]. SIRs were not significantly elevated for cancers of the liver, larynx, and bladder with SIRs of [1.11; 95% CI: 0.92–1.32], [1.05, 95% CI: 0.85–1.28], and [1.05, 95% CI: 0.95–1.16] respectively, based on 122, 95, and 380 cases, respectively.

The Registrar General in England and Wales (OPCS, 1995) considered 29 689 male painters and decorators, aged 20–74 years, who died during 1979–80 and 1982–1990. They published selective findings which were statistically significant at the 0.05 level. PMRs were calculated for cancers of the lung, oral cavity, and kidney and were reported as 1.12

(1.09–1.16), 1.27 (1.00–1.59), and 0.77 (0.64–0.91) respectively, based on 4110, 75, and 130 deaths, respectively.

Andersen *et al.* (1999) linked people aged 25–64 years from the 1970 census in four Scandinavian countries to cancer incidence registries in those countries through approximately 1990 (range 1987–1991). This study included 65 868 male painters and 2121 female painters. Data for all cancer sites were reported. For males, the SIR for all cancer was 1.06 (95% CI: 1.03–1.08; 7070 cases), and significant elevations were found for cancers of the lung (SIR, 1.22; 95% CI: 1.16–1.28; 1450 cases), pleura (SIR, 1.70; 95% CI: 1.25–2.26; 47 cases; [presumably mesothelioma]), bladder (SIR, 1.10; 95% CI: 1.01–1.20; 566 cases), pharynx (SIR, 1.31; 95% CI: 1.02–1.64; 72 cases), and rectum (SIR, 1.14; 95% CI: 1.04–1.26; 406 cases). More detail can be found in Table 2.1. Subsequent work with the Norwegian component of this study by Haldorsen *et al.* (2004) showed that indirect adjustment for smoking increased the lung cancer SIR from 1.38 to 1.52 (95% CI: 1.3–1.7, 260 cases). The Swedish component of this study partly overlaps with Brown *et al.* (2002) who also included painters from the 1960 Swedish census. It also overlaps the four country study by Skov *et al.* (1993), who reported on fewer cancer sites with shorter follow-up, and also overlaps Scandanavian record linkage studies by Malker *et al.* (1987), Carstensen *et al.* (1988, 1990), and Lynge & Thygesen (1988).

Aronson *et al.* (1999) conducted a record linkage study of 457 224 Canadian men and 242 196 Canadian women employed during 1965–1971, with follow-up for mortality from 1965–1991. Only selected positive findings were reported. A significant excess of brain cancer (SMR, 3.79; 95% CI: 1.70–8.48) was observed for male painters, based on only six deaths.

Brown *et al.* (2002) linked Swedish census data from 1960 and 1970 (for those employmed as a painter) to cancer incidence and mortality data from 1971–1989. This study focused specifically on male painters, male paint-manufacturing workers, as well as male and female pictorial artists (see section below for results). There were 42 433 male painters in the study, and although significant excesses for cancers of the lung and bladder were observed, these were very modest (lung SIR, 1.2; 95% CI: 1.1–1.3, 548 cases; bladder SIR, 1.1; 95% CI: 1.0–1.2, 344 cases). The SIR for mesothelioma was 1.6 (95% CI: 0.9–2.4, 19 cases). Incident cancer of the extrahepatic bile ducts was also increased (SIR, 1.5; 95% CI: 1.0–2.3, 22 cases), but liver cancer itself was not (SIR, 0.8; 95% CI: 0.6–1.1; 36 cases). More detail can be found in Table 2.1. The authors also studied 6662 male pictorial artists and found significantly elevated cancer incidence was found for cancers of the oral cavity (SIR, 1.5; 95% CI: 1.0–2.1, 29 cases), and of the bladder (SIR, 1.5; 95% CI: 1.2–1.9, 71 cases). Non-significant elevations were found for the incidence of cancers of the oesophagus (SIR, 1.4; 95% CI: 0.7–2.4, 11 cases), and of the liver and biliary tract (SIR, 1.4; 95% CI: 0.8–2.2, 18 cases). The incidence of lung cancer was not elevated (SIR, 1.0; 95% CI: 0.80–1.3, 69 cases). Among 2136 female pictorial artists there was a significant excess incidence of cancer of the uterus (SIR, 1.6; 95% CI: 1.10–2.3, 31 cases). [The Working Group noted that the percentage of pictorial artists who were painters was not known, although presumably a significant proportion were likely to also be painters.]

2.1.4 *Proportionate mortality studies since IARC Monograph volume 47* (Table 2.1)

Miller *et al.* (1986), in the United States, conducted a proportionate mortality study of deaths among 1746 caucasian pictorial artists who died during 1940–1969. Proportionate cancer mortality ratios (PCMR) were significantly elevated for bladder cancer (PCMR, 2.6; 95% CI: 1.5–4.4, 14 deaths), and leukaemia (PCMR 2.3; 95% CI: 1.2–4.5, ten deaths). Terstegge *et al.* (1995) conducted a proportionate mortality study of Dutch painters among whom 9812 deaths were observed during 1980–1992. These authors found significant excesses of mortality from cancer of the lung (PMR, 1.20; 95% CI: 1.14–1.26, 1480 deaths), and all cancers (PMR, 1.07; 95% CI: 1.03–1.11, 3266 deaths). Mortality from bladder cancer was borderline significant (PMR, 1.19; 95% CI: 1.00–1.41, 132 deaths) as was mortality from non-Hodgkin lymphoma (PMR, 1.28; 95% CI: 0.99–1.64, 65 deaths). Results for most sites were provided but were generally unremarkable.

Peto *et al.* (1995) studied mesothelioma mortality among men aged 16–74 in England, Scotland and Wales during the years 1979–1980 and 1982–1990. The PMR for mesothelioma in painters was reported as 1.31 ($P < 0.05$, 100 deaths).

Wang *et al.* (1999) studied American construction workers, which included a group of painters, paperhangers, plasterers, and supervisors, who died during 1988–1994. [As noted previously with regard to Carstensen *et al.* (1988), this grouping may be relevant for paint exposures as these workers are all likely to work together and to be exposed to paint fumes.] Significantly excess mortality was seen for cancers of the of the lung (PMR, 1.18), and of the pharynx (PMR, 1.78) with significantly decreased mortality seen for cancers of the kidney, brain, colon, and leukaemia. No confidence intervals or number of cause-specific deaths were given. [This was a proportionate mortality study and the elevation of some cancer PMRs may have been artificial and due to the observed low heart disease among healthy workers in this occupation (PMR, 0.87). No correction was made via use of PCMRs.]

2.1.5 *Study of paint-manufacturing workers since 1989*

Paint-manufacturing workers have different exposures than painters, and were judged separately by IARC in 1989. IARC concluded in 1989 that occupation as a paint-manufacturing worker is *not classifiable as to its carcinogenicity to humans* (Group 3).

Lundberg & Milatou-Smith (1998) studied cancer incidence among 411 workers in paint manufacturing that had been exposed to organic solvents for at least 5 years during 1955–1975. This was an update of an earlier study that included follow-up from 1961–1992. A total of 83 incident cancers were observed, versus 80 expected (SIR, 1.0; 95% CI: 0.8–1.3). There were no notable cancer excesses with the exception of a borderline increased risk for multiple myeloma (SIR, 3.2; 95% CI: 0.9–8.3), and cancer of the prostate (SIR, 1.5; 95% CI: 1.0–2.2).

Brown *et al.* (2002) studied 5741 male paint- and lacquer-manufacturing workers in a record linkage study in Sweden (see description above), and found significant elevations of

incident cancers of the lung (SIR, 1.5; 95% CI: 1.2–1.9, 87 cases), of the small intestine (SIR, 2.6; 95% CI: 1.0–5.4, seven cases), of the colon (SIR, 1.3; 95% CI: 1.0–1.7, 52 cases), of the pancreas (SIR, 1.7; 95% CI: 1.1–2.4, 30 cases), and non-lymphocytic leukaemia (SIR, 2.1; 95% CI: 1.1–3.6, 13 cases). [The relevance of these findings for paint-manufacturing workers specifically is difficult to judge as they are combined with lacquer-manufacturing workers, who may have had different exposures].

2.2 Case–control studies

2.2.1 *Cancer of the lung* (Table 2.2)

In 1989 (Monograph 47), nine case–control studies of lung cancer and two multisite case–control studies, which included lung cancer, were evaluated. These studies are summarized in Table 24 of Monograph 47 (IARC, 1989).

(a) Europe

Jahn *et al.* (1999) carried out a pooled analysis of the two case–control studies on lung cancer conducted in Germany: the Bremen Institute for Prevention Research and Social Medicine (BIPS) study in the Bremen and Frankfurt/Main areas, during 1988–1993, and the GSF-National Research Center for Environment and Health (GSF) study in Nordrhein-Westfalen, Rheinland-Pfalz and Bayern, Saarland, Thuringen, and Sachsen, during 1990–1996. The results from the BIPS study had been reported earlier by Jöckel *et al.* (1992, 1998) for both sexes combined. The Jahn *et al.* (1999) analysis was restricted to women, and included 686 cases aged 75 or less at diagnosis, of German nationality, residing in the study regions. All cases were confirmed by histology or cytology. Population controls, 712 individuals, were randomly selected from population registries or by random digit dialling, and were individually (BIPS study) or frequency- (GSF study) matched to cases by age, and region. A standardized questionnaire, with full occupational history and supplementary job-specific modules, was administered during face-to-face interviews. The response rate was 73% among cases, and 45% in controls. An odds ratio (OR) of 3.00 (95% CI: 0.73–12.33) was found after adjustment for smoking and asbestos exposure (age and region of residence were strata-defining variables in the conditional logistic regression models) for the occupation of 'ever' painter. [A major strength of this study was exposure definitions, based on complete and accurate occupational histories, and expert-based quantitative exposure assessment for a series of carcinogens. However, the low response rate among controls might have led to selection bias].

Brüske-Hohlfeld *et al.* (2000) also carried out a pooled analysis of the two case-control studies described above (the BIPS and GSF studies). The results from the BIPS study had been reported earlier by Jöckel *et al.* (1992, 1998) for both sexes combined. This analysis was restricted to men, and included 3498 cases aged 76 or less at diagnosis who lived in Germany for at least 25 years and resided in the study regions. All cases were confirmed by histology or cytology. Population controls, 3541 individuals, were randomly selected from population registries or by random digit dialling, and were individually (BIPS study) or

frequency- (GSF study) matched to cases by age and region. A standardized questionnaire, with full occupational history and supplementary job-specific modules, was administered during face-to-face interviews. The response rate was 77% among cases, 41% in controls. An OR of 1.42 (95% CI: 1.05–1.92) was found after adjustment for smoking and asbestos exposure (age class and region of residence were strata-defining variables in the conditional logistic regression modelling) for the occupation of "ever painter/lacquerer." [A major strength of this study was the exposure definition, based on complete and accurate occupational histories, aiming to expert-based quantitative exposure assessment to a series of carcinogens. However, the low response rate among controls might have led to selection bias].

Pohlabeln *et al.* (2000) conducted a case–control study among non-smokers in 12 European study centres in Germany, Italy, Portugal, Sweden, United Kingdom, France and Spain to evaluate the role of occupational risk factors among non-smokers. Non-smoking cases and controls were defined as subjects who smoked fewer than 400 cigarettes during their lifetime. Lifetime occupational histories in face-to-face interviews were obtained from 650 non-smoking cases (509 females, 141 males) and 1542 non-smoking controls (1011 females, 141 males). Community-based controls were selected in six centres, hospital-based controls in five centres, and both community and hospital-based controls in one centre. Hospital controls were selected from diseases not related to tobacco smoking. Painting was among the three occupations where an excess risk was identified in males (OR, 1.84; 95% CI: 0.59–5.74; based on six cases). Numbers of females involved were too small to produce reliable estimates of effect. [This is the only case–control study of non-smokers, sufficiently large to study occupational exposures.]

Bouchardy *et al.* (2002) identified 58 134 incident cancer cases in men from five cantonal Swiss Cancer Registries (Basel, Geneva, St Gall, Vaud, and Zurich), 1980–9193. The overall proportion with histological or cytological confirmation of diagnosis was 95.1%. The study was restricted to cases aged 25 years or more at registration (and less than 65 year in St Gall and Vaud). The longest, current or most recent occupation at registration was recorded (the main or most accurately specified occupation was used in the Zurich Registry). Subjects with unknown occupation were not reported separately. The association between different cancer sites and work in a pre-defined set of industries and occupation was studied by estimating ORs adjusted for age, registry, civil status, period of diagnosis, nationality, urban/rural residence, and socioeconomic status. For each neoplasm, registrants for the other cancer sites were used as reference. Overall, 9106 lung cancer cases were registered, 273 of those were plasterers and painters in the construction industry. A total of 49 028 non-lung cancer cases were registered, 867 of whom were painters. The OR for cancer of the lung among painters was 1.1 (95% CI: 1.0–1.3), adjusted for all variables. The OR when adjusted for all variables except socioeconomic status was 1.4 (95% CI: 1.2–1.6). [ORs could not be adjusted for smoking.]

Richiardi *et al.* (2004) carried out a population-based case-control study in two industrialized areas of Northern Italy (city of Turin and Eastern Veneto) in 1990–1992, including 1132 lung cancer cases and 1553 controls less than 75 years of age. Histologically

or cytologically confirmed cases were identified through weekly monitoring of all hospitals in the study areas. Population controls were frequency-matched with cases by sex, study area and 5-year age groups. Response proportions for Turin and Eastern Veneto were, respectively, 86% and 72% among cases, and, respectively, 85% and 74% among controls. A face-to-face interview was used to collect information on each subject's occupation lasting >6 months, record the job title and industry and the time period of employment. Occupational histories were coded according to international classifications and evaluated for employment in occupations known (list A) or suspected (list B) to determine any exposure to lung carcinogens. This was done using a previously suggested translation of lists A and B into combinations of codes for job titles and industries (Ahrens & Merletti, 1998). Analyses on specific list A occupations, including painters, was limited to men (956 cases and 1253 controls). Compared to men who were never employed in occupations in lists A or B, painters had an OR for cancer of the lung of 2.0 (95% CI: 1.4–3.3) after adjusting for matching variables, smoking and number of job periods, and of 1.7 (95% CI: 1.1–3.0) if additionally adjusting for educational level.

Baccarelli *et al.* (2005) conducted a study in the Leningrad province (the Russian Federation), during 1993–1998 on lung cancer cases diagnosed at autopsy: 540 cases (474 men, 66 women) diagnosed at postmortem examination at the St Petersburg central pathology laboratory, serving 88 state hospitals in the study area, were included along with 582 (453 men, 129 women) individuals with diagnoses of non-cancer, non-tobacco related conditions, frequency-matched by sex, age, area, year of death. Postmortem examinations were conducted in about 95% of decedents in the state hospitals involved. Full occupational records were retrieved for all cases and all controls. Information on smoking was abstracted from medical records at local health centres; however the proportion of success for data abstraction and data quality are not stated. An OR of 0.6 (95% CI: 0.3–1.4) was found for occupation as 'ever painter', 0.5 (95% CI: 0.2–1.5) for < 10 years of employment as a painter, and 0.8 (95% CI: 0.2–3.0) for ≥ 10 years of employment as a painter, adjusted for age, sex, and smoking.

Zeka *et al.* (2006) conducted a multicentre case–control study of lung cancer in several European countries between 1998–2002. A total of 223 'never' smoking cases (48 men, 175 women) and 1039 non-smoking controls (534 men, 505 women) were included in the analysis. In-person interviews were conducted to obtain lifetime occupational histories for jobs held ≥1 year. Occupation as a painter was associated with a non-significant increased risk of lung cancer among women (OR, 1.8; 95% CI: 0.53–6.0, based on six cases and six controls), adjusted for age and study centre.

Table 2.2. Case-control studies of lung cancer among persons with occupation as a painter

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Europe *Studies since Vol. 47*								
Jahn *et al.* (1999); Brüske-Hohlfeld *et al.* (2000) BIPS study in Bremen area and Frankfurt/Main area (Germany) 1988–93 GSF study in Nordrhein-Westfalen, Rheinland-Pfalz and Bayern, Saarland, Thuringen, and Sachsen (Germany) 1990–96	686 women, ≤75 yrs of age at diagnosis, of German nationality 3498 men, ≤76 yrs of age at diagnosis, living in Germany for at least 25 years, resident in the study region 100% confirmed by histology or cytology. Response rate 63% BIPS, 77% GSF [73% overall]	712 female and 3541 male population controls randomly selected from population registries or by random-digit dialling, individually (BIPS study) or frequency (GSF study) matched to cases by sex, age, and region. Response rate 60% BIPS, 41% GSF [45% overall]	Standardized questionnaire with full occupational history and supplementary job-specific modules, administered during a face to face interview; jobs coded according to the classification of the German Statistical Office (Statistiches Bundesamt)	Ever painters (women) Ever painters/ lacquerers (men) Ever painters/ lacquerers (men and women)	13 147 [160]	3.0 (0.73–12.33) 1.42 (1.05–1.92) [1.47 (1.09–1.97)]*	Smoking, asbestos, education, age, region of residence	Low response rate among controls with potential for selection bias; frequency matched cases and controls of the GSF-study were post-hoc stratified according to the matching variables age, region; *fixed effects model used to calculate a weighted average; these studies have substantial overlap with Kreuzer *et al.* (2001) that presented results for painters in lifetime non-smoking men [2.31 (0.57–9.47)] and women (OR=1.2), respectively. BIPS study overlaps with Jöckel *et al.* (1998)

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Pohlabeln *et al.* (2000) 12 centres in Germany, Italy, Portugal, Sweden, UK, France and Spain 1988–94	650 non-smoking cases (509 women, 141 men)	1542 non-smoking controls (1011 females, 531 males); community based controls in 6 centres, hospital controls (diseases not related to tobacco smoking) in 5 centres and both community and hospital-based controls in 1 centre	In-person interview for lifetime occupational history, coded using ISCO and ISIC classification; non-smokers = subjects who smoked <400 cigarettes during their lifetime	Ever painters (men)	6	1.84 (0.59–5.74)	Age, centre	This is the only case-control study of non-smokers sufficiently large to study occupational exposures. Controlling for other confounders (occasional smoking, residence in urban/rural area, dietary habits, ETS) did not change the estimate. There is a small overlap with Jahn *et al.* (1999), Brüske-Hohlfeld *et al.* (2000), Richiardi *et al.* (2004)

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Bouchardy *et al.* (2002) Cantons of Basel, Geneva, St Gall, Vaud and Zurich, Switzerland 1980–93	9106 men from cantonal Cancer Registries, aged 25 or more (and 65 or less in St Gall and Vaud)	49 028 male non-lung cancer registrants from the same registries and period	Longest, current or most recent occupation as recorded at the time of registration (main or best specified occupation in Zurich Registry), coded using the ASCR Classification of Occupations	Plasterers and painters (in the construction industry)	273	1.1 (1.0–1.3)	Age, registry, civil status, period of diagnosis, nationality, urban/rural residence, socio-economic status, histological confirmation, information from death certificate only (cases)	OR adjusted for all variables except socioeconomic status was 1.4 (95% CI 1.2–1.6). Adjusting for SES may over-adjust for occupational risk factors but serve as a surrogate for smoking. Overall 95.1% microscopic confirmation for all sites
Richiardi *et al.* (2004) Turin and Eastern Veneto, Italy 1990–92	956 men from active search in all hospitals of the study areas; aged less than 75; response rate: 86% in Turin, 72% in Eastern Veneto; all cases histologically or cytologically confirmed	1253 male population-based controls, matched by study area, 5-year age groups; response rate: 85% in Turin, 74% in Eastern Veneto	Lifetime occupational history obtained from interviewer-administered questionnaire, coded using ISCO and ISIC codes	*Ever painters* Small cell carcinoma Construction painters Painters, n.e.c.	62 4 42 20	1.7 (1.1–2.8) 5.2 (1.2–23) 1.7 (1.0–3.0) 1.7 (0.8–3.7)	Age, study area, smoking (never, ex-, active smokers), number of job periods, education	OR adjusted for all variables but education 2.0 (1.4–3.3)

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Baccarelli *et al.* (2005) Leningrad province (Russia) 1993–98	540 (474 men, 66 women) autopsy cases from the St Petersburg central pathology laboratory, serving 88 state hospitals in the study area. Occupational records retrieved for all cases	582 (453 men, 129 women) individuals with autopsy-based diagnoses of non-cancer and non-tobacco related conditions, frequency matched by sex, age, area, year of death (20 painters). Occupational records retrieved for all controls	Lifetime occupational histories were obtained from personal records ("Green Book"), coded based on ISCO and ISIC classification	Ever painters *<10 years* *≥10 years*	10 6 4	0.6 (0.3–1.4) 0.5 (0.2–1.5) 0.8 (0.2–3.0)	Age, sex, smoking	Post-mortem examinations were conducted in about 95% of decedents. Information on smoking was abstracted from medical records at local health centres, but neither the proportion of success nor the quality of data assessed were stated. Occupational histories from the "Green Books" are reported to be complete

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Zeka *et al.* (2006) Czech Republic, Hungary, Poland, Romania, Russia, Slovakia, UK 1998–2002	223 never smoking cases (48 men, 175 women) diagnosed at participating centers; 20–74 years; lived in the study area for ≥1 year; 100% confirmed by histology or cytology; 86% participation rate	1039 non-smoking controls (534 men, 505 women); selected from patients that did not have malignant neoplasms, respiratory diseases, or other smoking related disorders or selected from healthy individuals in the general population (Warsaw, Liverpool only); 85% participation rate	In-person interview to obtain lifetime occupational histories for jobs held ≥1 year; jobs coded by ISCO or NACE	*Painters* Men Women	6 0 6	[1.81 (0.72–4.59)] NG 1.8 (0.53–6.0)	None None Sex, age, study centre	Never smokers = smoked <100 cigarettes in lifetime; painters were classified as working in construction, automotive industry and other users

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Studies in Vol. 47								
Coggon *et al.* (1986) Cleveland, Humberside, Cheshire counties, UK 1975–80	738 male bronchial cancer cases, aged 18–54 yrs, identified from hospital and cancer registry records	1221 other cancers	Occupation from mailed questionnaire	Painters and decorators	20	1.3 [0.62–2.72]	Age, smoking, residence, respondent	52.1% overall response rate; the variance was doubled to approximate an adjusted 95%CI. The unadjusted 95%CI was 0.78–2.18. *Included in the analysis restricted to case-control studies but excluded from the combined meta-analysis because of possible overlap with OPCS (1986)*

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Kjuus *et al*. (1986) Norway 1979–83 Scandinavia	176 male incident lung cancer cases (ICD 162-163), <80 years; 99% response rate	176 age-matched hospital controls excluding those with physical or mental handicaps, poor general health, or diagnosed with chronic obstructive lung disease; 99% response rate	Interview and worksite records for longest job held; coded using Nordic Classification of Occupations; Exposed if worked ≥3 years	Painting, paper-hanging (occupation)	5	1.7 (0.4–7.3)	Age, smoking	
				Paints, glues, lacquer (exposure)	17	1.2 (0.6–2.6)		

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Ronco *et al.* (1988) Italy 1976–80	126 men who died from lung cancer; 77% participation rate	Random sample of 384 men who died from causes other than from smoking-related or chronic lung diseases; matched by year of death and age (± 10 yrs); 78% participation rate	Lifetime occupational history from interview with next of kin; coded using ILO classification	Painter	5	1.33 (0.43–4.11)	Age, year of death, smoking, other employment in suspect high-risk occupations	

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
North America *Studies since Vol. 47*								
Vineis *et al.* (1988) Analysis of 5 case-control studies in Louisiana, Florida, Pennsylvania, Virginia and New Jersey, USA, 1970s and 1980s	2973 men from cancer registries, co-operating hospitals or death certificates, resident in selected areas of the states; response rate range: 70%–93%.	3210 men from hospital records, decedents, death certificate, licensed drivers, matched by characteristics varying from study to study, with age always included; response rate range: 63%–89%	Life-time occupational history obtained during interviews with subjects or next of kin, coded using SIC and 1970 Census Classification	Painters	201	1.1 (0.9–1.4)	Age, birth cohort, smoking	Unexposed group: selected occupations and industries without a well-established or suspected carcinogenic exposure; studies analyzed: Correa *et al.* (1984), Blot *et al.* (1980, 1982, 1983), Schoenberg *et al.* (1987)

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Zahm *et al.* (1989) Missouri, USA 1980–85	4431 white male cases with histological type and grade recorded at Missouri Cancer Registry, residing in Missouri	11 326 white male non-lung cancer registrants from the same Registry and period, excluding cancers of lip, oral cavity, esophagus, lung, bladder, ill-defined or unknown sites	Occupation at the time of diagnosis abstracted from medical records, coded using US Bureau of Census classification	*Painters, paper hangers, plasterers* <60 yrs of age	37 NG	2.0 (1.2–3.3) 3.2 (1.1–10.0)	Age, smoking	

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Burns & Swanson (1991) Detroit metropolitan area, USA Recruitment period not specified, probably 1984–87, as in Swanson *et al.*, (1993)	5935 (3918 males, 2017 females; 77% white, 23% black) from Occupational Cancer Incidence Surveillance System/Metro-politan Detroit Cancer Surveillance System, aged 40–84 years; response rates: 94% for cases and 95% for controls	3956 (1981 males, 1975 females) with colon and rectum cancer, registry-based	Life-time occupational history obtained during telephone interviews to the subjects or to their surrogates, coded using US Bureau of Census classification	Painters (usual occupation, grouped)	97	1.96 (1.23–3.13)	Age at diagnosis, race, smoking, gender	Interviews to surrogates: 53.7% for cases, 27.5 % for controls.
				Painting & spray painting machine operators (male, usual occupation, detailed occupational code)	37	4.5 (1.7–11.8)	Age at diagnosis, race, smoking	Unexposed group: selected occupations and industries with little or no exposure to carcinogens. Proportion of histologic confirmation not given; 93.4% overall response rate

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Swanson *et al.* (1993) Detroit metropolitan area, USA 1984–87	3792 males (2866 white, 926 black) from Occupational Cancer Incidence Surveillance System/Metropolitan Detroit Cancer Surveillance System (participant in SEER), aged 40–84 years; 100% histologically confirmed	1966 males (1596 white, 370 black) with colon and rectal cancer, registry-based; 100% histologically confirmed	Life-time occupational and smoking history obtained during telephone interviews with subjects or their surrogates. Jobs coded using US Bureau of Census classification	**Painting machine operators** *White males* Employment (years) 0 1–9 10–19 20+ *Black males* Employment (years) 0 1–9 10–19 20+ *p* for trend *Black and White* <10 yrs ≥10 yrs <20 yrs ≥20 yrs	 88 23 6 17 12 17 7 10 40 40 53 27	 1.0 1.1 (0.5–2.4) 0.6 (0.2–2.2) 3.9 (1.2–13.0) 1.0 1.5 (0.4–5.6) 9.9 (0.9–109.2) 8.7 (0.9–89.3) ≤0.05 [1.19 (0.61–2.34)]* [2.23 (1.05–4.73)]* [1.15 (0.65–2.04)]* [4.62 (1.61–13.31)]*	Age at diagnosis, pack-years of cigarette smoking	Interviews with surrogates: 56.1% for cases, 29.5 % for controls; unexposed group: selected occupations and industries with little or no exposure to carcinogens. >90% overall response rate; *this paper does not represent an independent set of cases and controls, but is a re-analysis of a sub-group reported in the study of Burns & Swanson (1991). Therefore it was omitted from the overall meta-analysis but kept for the analysis by duration.* **Calculated using a fixed effects model*

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Morabia *et al.* (1992) Detroit, Chicago, Philadelphia, Pittsburgh, New York, Long Island, San Francisco, Birmingham, USA 1980–89 American Health Foundation study	1793 male cases from 24 hospitals; 100% confirmed by histology; response rate not given. Number of cases that were painters not given	3228 controls not hospitalized for lung cancer but including tobacco related conditions; matched by age, race, hospital, smoking history, admission date; response rate not given	Standardized questionnaire, administered during a face to face interview. Only "usual" occupation recorded, plus exposure circumstances to up to 2 agents out of a list of 44 (study period 1980–4), or up to 6 agents (study period 1985–9); Jobs coded using US Bureau of Census classification	Painters	[13]	0.8 [0.32–2.03]	Age, geographic area, race, smoking, study period	The variance was doubled to approximate an adjusted 95%CI. The unadjusted 95%CI was 0.41–1.54

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Muscat *et al.* (1998) New York City, Long Island, Philadelphia, Washington D.C., Detroit, and Chicago, USA 1978–96	365 black men and 185 black women with histologically confirmed lung carcinomas recruited from teaching hospitals	251 male and 135 female black patients admitted to teaching hospitals for conditions unrelated to tobacco use, matched by race, gender, 5 years age groups, month of diagnosis	Interviewer-administered questionnaire. Only "usual" occupation and whether the job entailed regular exposure to an occupational exposure (for a minimum of 8 hours a week) was obtained from interviews with subjects or their next of kin or death certificates	*Ever painters* Men Men (no overlap) Women	[24] 30 [19] 5	[1.32 (1.30–1.35)]* 0.7 (0.3–1.1) [0.68 (0.29–1.59)] 1.8 (0.3–12.3)	Age, education, smoking	Response rate: over 90 % overall (no specific rate by gender or case-control status given); the study partially overlaps with Morabia *et al.* (1992) and thus some estimations were used to eliminate the overlap in men and the estimated variance was doubled to approximate an adjusted CI; *fixed effects model used to calculate a weighted average
Finkelstein *et al.* (1995) Hamilton and Sault Ste-Marie, Ontario, Canada 1979–88	967 men who died of lung cancer, aged 45–75 yrs, residing in the study areas	2821 men who died of any cause other than lung cancer, matched by age, year of death, and city of residence	Occupation (job and industry) as reported on the death certificate	Painters & plasterers	16	1.25 (0.63–2.36)	Age, year of death, city of residence	No information was available on smoking

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Studies in Vol. 47								
Wynder & Graham (1951) St. Louis, MO, USA NG	Subset of 200 cases from a Hospital Chest Service from a total of 709 US male cases of confirmed cases with epidermoid, undifferentiated or unclassified lung cancer	200 controls with a chest disease other than lung cancer from the Hospital Chest Service	Lifetime occupational history from interview	Painter ≥5 years within the last 40 years	11	[5.76 (1.41–23.44)]	None	The chest diseases were not specified. Only 2 painters were nonsmokers (smoked <1 cigarette/day for >20 years). Cases and controls were of similar age and economic status
Breslow *et al*. (1954) California, USA 1949–52	518 patients with histologically confirmed lung cancer from 11 hospitals	518 hospital controls matched by hospital, age, sex, race; excluded admission of lung cancer or a chest disease	Interview	Construction and maintenance painters for ≥5years	22	[1.87 (0.93–3.77)]	Hospital, age, sex, race	The gender distribution is not presented
				Painters, except construction and maintenance for ≥5 years	3	[0.50 (0.14–1.82)]		

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Viadana *et al.* (1976); Decouflé *et al.* (1977); Houten *et al.* (1977) Buffalo, NY, USA 1956–65 United States of America	Lung cancer cases (ICD7 162, 163) from 11591 white male cancer cases at a treatment center, age ≥14 years	Non-cancer admissions from the same cancer treatment center	Lifetime occupation recorded during interview before diagnosis, coded using the Standard Industrial Classification Manual	**Painter**				Unexposed = clerical occupations
				Ever	42	1.71 [1.08–2.77]	Age smoking, age	
				Ever (smoking adj)	42	1.90 [1.32–2.48]		
				<60 yrs old	21	2.12 [1.08–4.18]	Age	
				≥60 yrs old	21	1.42 [0.74–2.73]		
				Worked ≥5 yrs	29	1.31 [0.73–2.26]		
				<60 yrs old	14	1.76 [0.75–4.16]		
				≥60 yrs old	15	1.03 [0.49–2.18]		
Williams *et al.* (1977) Atlanta, Birmingham, Colorado, Dallas-Ft.Worth, Detroit, Minneapolis-St.Paul, Pittsburgh, San Franciso-Oakland, USA 1969–1971 Third National Cancer Survey	432 lung cancer cases that reported an occupation, 95% histologically confirmed	2173 patients with cancers other than lung, larynx, oral cavity, esophagus, bladder that reported an occupation	Main lifetime employment from survey questionnaire, coded using the 1970 census classification	Painting (men)	12	4.21 [1.40–12.65] (p <0.01)	Age, race, education, education, tobacco, alcohol, geographic location	Painting included construction workers, paper-hangers, and pattern & model makers; The CI was estimated by doubling the variance

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Milne *et al*. (1983) Alameda County, CA, USA 1958–62	925 lung cancer deaths (747 men, 178 women)	4880 deaths from other cancers (except pancreas, bladder, nasal, kidney, haema-topoietic) that are not known to be strongly associated with occupational risk factors (reported as the "reduced control group")	Occupation from death certificates, coded using the Bureau of Census Industrial and Occupational Classification System	Painter (men)	24	1.80 [1.09–2.98]	Age	The gender distribution was not presented for the "reduced control group", used to reduce potential exposure bias; the CI was estimated by applying the ratio of reduced/ total controls to the observed cell counts reported for the total control group
Lerchen *et al*. (1987) New Mexico, USA 1980–82	771 cases (333 men, 173 women) identified from a SEER tumor registry; Hispanic whites and whites ages 25–84 years; 89% response rate	771 controls (499 men, 272 women) from randomly selected phone numbers and Medicare rosters; frequency matched by sex, ethnicity, 10-year age category; 83% response rate	Interview for lifetime occupational history; jobs coded using the SIC or SOC	Ever construction painters (males)	9	2.7 (0.8–8.9)	Age, ethnicity, smoking	Exposed = ever employed at least 1 year in an industry/occupation

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Siemiatycki *et al.* (1987) Montreal, Canada, 1979–85	857 male cases (159 oat-cell, 359 squamous-cell, 162 adeno-carcinoma, 177 other types)	Other cancers	Interview to obtain lifetime occupational history; painters coded using Canadian occupation classification	*Mineral spirit exposure*		**OR (90% CI)**	Age, socio-economic status, ethnicity, cigarette smoking, blue/white collar	Of those exposed to mineral spirits, 21% were in construction trades (mostly painters) *Excluded from meta-analysis because risk associated with occupation as a painter is not presented*
				Oat-cell	36	1.1 (0.8–1.4)		
				Squamous cell	92	1.2 (1.0–1.5)		
				Long duration, high exposure	44	1.7 (1.2–2.3)		
				Adenocarcinoma	37	1.0 (0.7–1.3)		
				Other types	32	0.8 (0.6–1.1)		
				Construction workers (mainly painters)	NG	1.4 (NG)		
Siemiatycki (1991) Montreal, Canada, 1979–85	857 incident male cases; aged 35–70 yrs; histologically confirmed; 79% response rate	533 population controls, 1360 cancer controls; 72% response rate	Interview to obtain lifetime occupational history; painters coded using Canadian occupation classification	*Construction painter*			Age, family income, ethnicity, respondent type, cigarette & alcohol index	The ORs were higher and the 90% CIs were narrower when restricted to lung squamous cell cancers
				Any exposure	26	1.4 [0.77–2.17] (90% CI, 0.8–2.3)		
						OR (90% CI)		
				Substantial exposure	14	1.7 (0.8–3.4)		

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
South America								
De Stefani *et al.* (1996) Montevideo, Uruguay, 1993–94	270 male patients from five major hospitals in Montevideo, aged 30–75 years	383 male hospital-based controls: other cancer sites except oral cavity, pharynx, oesophagus, stomach, larynx and bladder	Interviewer-administered questionnaire with life-time occupational history	**Ever painters** *Employment (years)* 1–20 21+ Squamous cell Small cell Adenocarcinoma	18 12 4 2	1.2 (0.6–2.4) 0.9 (0.2–3.0) 1.4 (0.6–3.1) 1.5 (0.6–3.4) 2.8 (0.8–9.9) 0.5 (0.1–2.5)	Age, residence, education, tobacco smoking (pack-years), alcohol consumption	Descriptive characteristics and separate response rates for cases and controls were not given; overall response rate for all cancer sites 97.4%
Wünsch-Filho *et al.* (1998) Sao Paulo, Brazil 1990–91	398 cases (307 men, 91 women) from 14 hospitals, living in the metropolitan area of Sao Paulo; 100% confirmed by histology or cytology	860 controls (546 men, 314 women) hospitalized for non-tobacco related conditions, matched by age, sex, hospital	Standardized questionnaire with full occupational history, administered during a face to face interview	**Ever painters (men)** *Employed* ≥10 years ≥10 years and latency ≥40 years	128 82 70	0.77 (0.56–1.08) 1.29 (0.79–2.11) 1.28 (0.77–2.15)	Age, sex, hospital, smoking, cancer in family, migration history, socio-economic status	

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Pezzotto & Poletto (1999) Rosario City, Argentina 1992–98	367 male newly diagnosed primary lung cancer patients from three medical institutions of Rosario City; mean age 60.3 ± 9.5; 100% histologically confirmed	586 hospital based males controls admitted for a non-smoking related disease at the same hospitals for traumatic conditions, urological diseases, acute surgical conditions, and other illnesses, matched by age (± 3 years); mean age 60.1 ± 10.2 yrs	Standardized questionnaire with lifetime occupational history for each job held >1 year	*House painters* Squamous cell Adenocarcinoma	4 2 1	2.4 (0.4–19.4) 3.3 (0.4–52.9) 1.3 (0.1–30.7)	Age, smoking habit, lifelong cigarette consumption	Unexposed group: never employed in occupations involving exposure to agents classified in group 1, 2A or 2B of the IARC Monographs. Individuals who had more than two jobs were excluded from the study

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Matos *et al.* (2000) Buenos Aires, Argentina 1994–96	200 male cases from four hospitals in Buenos Aires, residing in the town or province of Buenos Aires; 94.5% confirmed by histology or cytology; response rate 93%	397 male controls hospitalized for non-tobacco related conditions, residing in the town or province of Buenos Aires, matched by hospital and age; response rate 99%	Face to face interview using standardized questionnaire for full occupational history, coded using ISCO/ISIC; Further details requested for occupations held >1 year	*Ever painters* General Blowtorch	16 8	1.2 (0.5–2.4) 1.4 (0.5–4.4)	Age, hospital, smoking (pack-years), other occupations with significant ORs (p <0.05)	
De Stefani *et al.* (2005) Montevideo, Uruguay, 1994–2000	338 male patients from four major hospitals in Montevideo, aged 30–89 years; response rate 96.8% (338 subjects); 100% histologically confirmed; restricted to lung adeno-carcinomas	1014 males hospitalized for conditions not related to tobacco smoking, matched by age, residence and urban/rural status; response rate 95.7%	Interviewer-administered questionnaire with life-time occupational history	**Ever painter** *Employment (years)* 1–20 21+ p for trend	26	1.8 (1.0–3.1) 9.6 (2.6–36.0) 1.2 (0.6–2.2) 0.07	Age, residence, urban/rural status, education, smoking status and years since quitting and age at start, number of cigarettes per day	Hospital controls: 20.3% eye disorders, 18.3% fractures, 17.9% abdominal hernias, 11.0% injuries, 7.9% acute appendicitis, 7.2% diseases of the skin, 5.8% varicose veins, 3.9% hydatid cyst, 2.9% blood disorders, 2.6% urinary stones and 2.2% osteoarticular disorders

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Other Regions								
Bethwaite *et al.* (1990) New Zealand 1980–84	4224 male cases had known occupation among 5031 cases identified from the New Zealand Cancer Registry, aged 20 or more at registration; % microscopic confirmation not given	15 680 male non-lung cancer registrants with known occupation, [out of 19 731 identified] from the same Registry and period, aged 20 or more at registration; % microscopic confirmation not given	Current/ most recent occupation as recorded at the time of registration and smoking history obtained through telephone interview, coded using NZSCO	Painter decorators, steel and other construction painters, car painters, spray painters, signwriters, other unclassified painters	88	1.12 (0.93–1.52)	Age	

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Notani *et al.* (1993) Bombay, India 1986–90	246 male patients from Tata Memorial Hospital in Bombay; age not given; 98% histologically confirmed	212 male hospital-based controls diagnosed with cancers of the mouth (n = 160) and oro- or hypo-pharynx (n = 27), and non-cancerous oral disease (n = 25), frequency matched by age and community; age not given	Interviewer-administered questionnaire with life-time occupational history	Ever painters	6	1.62 (0.4–7.0)	Age, community, smoking (two groups)	Descriptive characteristics and response rate for cases and controls not given. Further analysis for painters using a "not-exposed" group of watchmen, policemen, semi-skilled/unskilled workers, office workers, teachers, salesmen, small business employees resulted in an OR of 1.84 (95% CI, 0.4–8.5)

Table 2.2 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Studies in Vol. 47								
Levin *et al.* (1988) China 1984–85	733 incident male cases, aged 35–64, identified through the Shanghai Cancer Registry	760 age-matched population controls	Lifetime occupational history from interview, classified according to the Chinese population census	**Ever painter** *Duration (yrs)*	15	1.4 (0.5–3.5)	Age, smoking	* The variance was doubled to approximate an adjusted 95%CI. #calculated using a fixed effects model
				0	718	1.0 (ref)		
				<10	7	1.9 [0.36–16.60]*		
				10–19	2	2.8 [0.07–62.47]*		
				20–29	5	2.2 [0.26–26.67]*		
				≥30	1	0.3 [0.01–5.81]*		
				>10	8	[1.34 (0.26–6.92)]#		
				<20	9	[2.35(0.44–12.47)]#		
				>20	6	[1.18 (0.18–7.64)]#		

ETS, environmental tobacco smoke; NG, not given; OR, odds ratio; CI, confidence interval; ASCR, Association of Swiss Cancer Registries; SIC, Standard Industrial Classification; SOC, Standard Occupational Classification; ISCO, International Standard Classification of Occupations; ISIC, International Standard Industrial Classification; NZSCO, New Zealand Standard Classification of Occupations; NACE, Nomenclature Générale des Activités Économiques dans les Communautés Européennes

(b) North America

Vineis *et al.* (1988) analysed data from five case–control studies of lung cancer conducted during 1970–1980 in the States of Louisiana, Florida, Pennsylvania, Virginia, and New Jersey, USA (Blot *et al.*, 1980, 1982 and 1983; Correa *et al.*, 1984, Schoenberg *et al.*, 1987). Subjects with a diagnosis of lung cancer resident in selected geographic areas of the respective states were identified from existing cancer registries, from cooperating hospitals or from death certificates. Information was collected by interview, with the enrolled subject or with the next-of-kin, for each job held for 6 months or more. Unexposed subjects were those with an occupation/industry without a well established or suspected carcinogenic exposure (Simonato & Saracci, 1983). Overall, 2973 male cases (201 painters) and 3210 controls (193 painters) were included in the analysis. For painters, the OR for cancer of the lung adjusted by age, birth cohort, and usual cigarette use was 1.1 (95% CI: 0.9–1.4). [The results of the studies included in the analysis had been previously published without focusing on painters only, and therefore were not evaluated in Monograph 47.]

From the Missouri Cancer Registry, 1980–1985, Zahm *et al.* (1989) identified 4431 caucasian male cases with lung cancer (histological type and grade recorded), residing in Missouri. Controls were 11326 caucasian male non-lung-cancer registrants from the same registry and period, excluding cancers of lip, oral cavity, oesophagus, lung, bladder, ill-defined or unknown sites. Occupation at the time of diagnosis was abstracted from the registry records. There were 37 painters, wallpaper hangers, and plasterers among cases, and 39 among controls. Painters, wallpaper hangers, and plasterers had an age- and smoking-adjusted OR of 2.0 (95% CI: 1.2–3.3). Restricting the analysis to cases aged <60 years, an OR of 3.2 (95% CI: 1.1–10.0) was found. [Absence of life-long occupational history may have led to non-differential misclassification of exposure.]

Among residents of the Detroit metropolitan area, Burns & Swanson (1991) examined incident cancer cases selected through the Metropolitan Detroit Cancer Surveillance System (MDCSS), a population-based cancer reporting system in the context of the Occupational Cancer Incidence Surveillance System (OCISS) study. The study enrolled 5935 (3918 males, 2017 females) lung cancer cases and 3956 (1981 males, 1975 females) colorectal cancer cases as control group, all aged 40–84 years, over a non-specified period. Subjects or their surrogates were interviewed by telephone (response rates of 94% for cases, and 95% for controls), and complete lifetime occupational and smoking histories were obtained. Usual occupation was defined by summing up the total number of months a person was employed in a specific occupation over their entire work history, and then selecting the occupation for which the person had accumulated the largest number of months of exposure. Occupations and industries categorized as 'unexposed' were those considered to have the least potential for exposure to carcinogenic agents. For the occupational group of painters (97 cases, 35 controls), the OR was 1.96 (95% CI: 1.23–3.13) after adjusting for age at diagnosis, race, smoking, and gender. When detailed occupation codes (specific occupation) were analysed among males, the elevated risk among painters was found to be concentrated among painting machine operators working in an industrial setting (OR, 4.50; 95% CI: 1.71–11.82; adjusted for age at diagnosis, race, and smoking; based on 37 cases),

rather than among house painters (the cancer sites included in the OCISS study are: salivary glands, oesophagus, stomach, colon, rectum, liver, lung and bronchus, pleura [mesothelioma], urinary bladder, melanoma of the skin, and eye).

Again in the context of the OCISS study, Swanson *et al.* (1993) studied possible differences by race in the relationship between length of employment in specific occupations and the risk of lung cancer. The study included 3792 males (2866 caucasian, 926 black) aged 40–84 years, with incident lung cancer cases from the MDCSS in the period 1984–1987; 1966 males (1596 caucasian, 370 black) with cancers of the colon and of the rectum constituted the referent group. Exposure was collected and coded as per the study of Burns & Swanson (1991). The ORs and corresponding 95% CIs (adjusted for age at diagnosis and pack–years of cigarette smoking) according to number of years employed in the specific occupation of 'painting machine operators' among caucasian males were as follows: 1–9 years, 1.1 (0.5–2.4); 10–19 years, 0.6 (0.2–2.2); ≥ 20 years, 3.9 (1.2–13.0), with a non-significant trend. The same figures among black men were: 1–9 years, 1.5 (0.4–5.6); 10–19 years, 9.9 (0.9–109.2); ≥ 20 years, 8.7 (0.9–89.3), with a significant trend. [Although not clearly stated in the published reports, this paper does not represent an independent set of cases and controls, but is a re-analysis of a subgroup reported in the study of Burns & Swanson (1991).]

Morabia *et al.* (1992) conducted the American Health Foundation study in the US (Detroit, Chicago, Philadelphia, Pittsburgh, New York, Long Island, San Francisco, Birmingham, and Atlanta), during 1980–1989: 1793 male cases from 24 hospitals diagnosed with lung cancer (all confirmed by histology) were included, with 3228 controls hospitalized for diagnoses other than lung cancer but including tobacco-related conditions, matched by age, race, hospital, smoking history, and admission date. A standardized questionnaire was administered during face-to-face interviews. Only the 'usual' occupation was recorded, along with exposure to up to two agents out of a list of 44 (during the study period 1980–1984), or up to six agents (during the study period 1985–1989). The response rate was not reported. An OR of 0.8 was found for occupation as 'ever painter', adjusted for age, geographic area, race, smoking, and study period. Neither the number of cases that ever worked as a painter nor the confidence interval were given, but a 0.33 power to detect an OR of 1.5 was reported. [Full occupational histories were not collected, as only the 'usual' occupation was recorded, so random misclassification of exposure is likely.]

Muscat *et al.* (1998) reported results during 1978–1996 of an on-going hospital-based case–control study in teaching hospitals in New York City, Long Island, Philadelphia, Washington DC, Detroit, and Chicago. The analysis included black subjects only and was "similar to an analysis of occupational factors and lung cancer risk previously performed for white subjects" (Morabia *et al.*, 1992). The case series were 365 black men and 185 black women with histologically confirmed lung carcinomas. Controls were 251 male and 135 female black patients admitted to teaching hospitals for conditions unrelated to tobacco use, matched by race, gender, 5-years age groups, and month of diagnosis. Over 90% of eligible participants who were approached were interviewed by interviewer-administered questionnaire (no specific rates for gender or case–control status were given). Subjects were

asked to provide their usual adult occupation and whether the job entailed regular exposure to an occupational agent (a minimum of 8 hours a week). A list of over 40 occupational exposures was provided. Compared to men who were 'never' painters, the OR for male painters for cancer of the lung was 0.7 (95% CI: 0.3–1.1; based on 30 cases after adjusting for age, education, and pack–years of smoking). Females painters compared to female 'never' painters had an OR of 1.8 (95% CI: 0.3–12.3, based on five cases and one control after adjusting for age, education, and pack–years of smoking). [It was not possible to assess the overlap between Morabia *et al.* (1992) and Muscat *et al.* (1998).]

In two Ontario (Canada) cities, Hamilton and Sault Ste-Marie, Finkelstein (1995) identified 967 men aged 45–75, residing in the study areas, who died from lung cancer during 1979–1988. Decedents ($n = 2821$) of any cause other than lung cancer, matched on age, year of death, and city of residence, were used as reference. The analysis was based on occupation (job and industry) as reported on the death certificate. Painters and plasterers had an OR of 1.25 (95% CI: 0.63–2.36; based on 16 cases, after adjustment for age, year of death, and city of residence). [No information was available on smoking.]

(c) South America

De Stefani *et al.* (1996) conducted a study of 270 male incident lung cancer cases, aged 30–75 years, admitted to five major hospitals in Montevideo, Uruguay, during 1993–1994, as part of a multisite case-referent study. Controls ($n = 383$) were patients with cancer diagnoses other than the lung, oral cavity, pharynx, oesophagus, stomach, larynx, and bladder. Occupational histories and tobacco smoking were collected through face-to-face interviews. The subjects employed in each occupation for at least one year were compared with subjects never employed in the corresponding occupations. The OR for painters (job title) was 1.2 (95% CI: 0.6–2.4; 18 cases), adjusted for age, residence, education, tobacco smoking (pack–years), and alcohol consumption. The adjusted ORs (95% CI) according to length of exposure were: 1–20 years, 0.9 (0.2–3.0); ≥ 21 years, 1.4 (0.6–3.1). The adjusted ORs (95% CI) of lung cancer stratified by cell type were as follows: squamous cell, 1.5 (0.6–3.4); small cell, 2.8 (0.8–9.9); and adenocarcinoma, 0.5 (0.1–2.5).

In the same area of Uruguay, De Stefani *et al.* (2005) examined occupations associated with adenocarcinoma of the lung. During 1994–2000, 349 histologically verified adenocarcinomas of the lung occurring in male patients admitted to four major hospitals in Montevideo, Uruguay, were identified, and 338 were included in the study (response rate 96.8%, 26 painters). During the same period and in the same hospitals, 1060 men were hospitalized for conditions not related to tobacco smoking, and 1014 of them constituted the control series (response rate 95.7%, 38 painters). Controls were frequency-matched on age, residence, and urban/rural status. Complete occupational and tobacco smoking histories were obtained through face-to-face interviews. 'Ever' versus 'never' having worked as a painter was associated with an OR of 1.8 (95% CI: 1.0–3.1), adjusted for age, residence, urban/rural status, education, smoking status, number of cigarettes per day, years since quitting, and age at start of smoking. The adjusted ORs (95% CI) according to length of exposure were: 1–20 years, 9.6 (2.6–36.0), ≥ 21 years, 1.2 (0.6–2.2), P for trend = 0.07.

Wünsch Filho *et al.* (1998) conducted a hospital-based case–control study in Sao Paulo, Brazil, during 1990–1991: 398 cases (307 men, 91 women) living in the metropolitan area of Sao Paulo and diagnosed with lung cancer (all confirmed by histology or cytology) in 14 hospitals were included, as well as 860 controls (546 men, 314 women) hospitalized for non-tobacco-related conditions, matched by age, sex, and hospital. A standardized questionnaire, with full occupational histories, was administered through face-to-face interviews. Response rates were not given. Among men, 'ever' painters with duration ≥ 10 years and latency ≥ 40 years had an OR of 1.28 (95% CI: 0.77–2.15), after adjustement for age, smoking, cancer in family, migration history, and socioeconomic status.

Pezzotto & Poletto (1999) identified 367 newly diagnosed primary lung cancer male patients from three medical institutions of Rosario City, Argentina, admitted during the period 1992–1998. A total of 586 age-matched controls were selected from patients admitted to the same hospitals as cases for a non-smoking-related disease. Lifetime occupational history was collected through standardized questionnaires, and subjects never employed in occupations involving exposure to agents listed in the IARC Monographs in groups 1, 2A or 2B were considered as the reference group. The OR for house painters for cancer of the lung was 2.4 (95% CI: 0.4–19.4; four cases, five controls) after adjusting for age, smoking habit, and lifelong cigarette consumption. An analysis stratified by cell type was also performed (see Table 2.2).

Matos *et al.* (2000) conducted a hospital-based case–control study in Buenos Aires, Argentina during 1994–1996. A total 216 men residing in the town or province of Buenos Aires diagnosed with lung cancer (94.5% confirmed by histology or cytology) were identified in four hospitals, along with 402 controls hospitalised for non-tobacco related conditions, matched by hospital and age. A standardized questionnaire, with full occupational history, was administered through face-to-face interviews, with a response rate of 93% among cases, and 99% among controls resulting in the inclusion of 200 cases and 397 controls. ORs, adjusted for age, hospital, smoking (pack–years), and other occupations with significantly increased ORs, were 1.2 (95% CI: 0.5–2.4; based on 16 cases) for 'ever' painters (general), and 1.4 (95% CI: 0.5–4.4; based on eight cases) for painters who used a blowtorch. Only occupations lasting at least 1 year were considered for the analysis.

(d) Other regions

Bethwaite *et al.* (1990) identified 24 762 incident cancer cases in men from the New Zealand Cancer Registry, 1980–1984. The proportion with histological or cytological confirmation of diagnosis was not stated. The study was restricted to cases aged 20 years or more at registration, and for 19 904 of their total,the current or most recent occupation at registration was recorded. The association between different cancer sites and work as a painter was studied by conducting a series of case–control studies. For each neoplasm, registrants for the other cancer sites were used as reference. Overall, 5031 lung cancer cases were registered, 4224 (84%) with known occupation – 88 of those were painters. Corresponding figures among controls were: 19 731 registered, 15 680 with known

occupation, of which 265 painters. An age-adjusted OR of 1.12 (95% CI: 0.93–1.52) was calculated by the Mantel-Haenszel method. [ORs could not be adjusted for smoking. Absence of life-long occupational history may have led to non-differential misclassification of exposure. The Working Group noted that an excess risk was found for cancers of the kidney, of the bladder, and for multiple myeloma. For multiple myeloma, the risk was higher for car, spray, and signwriter painters (OR: 2.81; 95% CI: 0.73–10.7) than for construction and general painters (OR,1.80; 95% CI: 0.89–3.64).]

Notani *et al.* (1993) identified 246 male lung cancer cases resident in the State of Maharashtra who were admitted to the Tata Memorial Hospital of Bombay, India, and interviewed during 1986–1990. A total of 212 controls were selected from male patients admitted to the same hospital for other cancers (mouth, pharynx, $n = 187$) or non-cancerous oral disease ($n = 25$). The case and control groups had similar age distributions. Occupational history and tobacco use were obtained by interviews conducted in the hospital. The OR for 'ever' painters compared to 'never' painters, adjusted for age and smoking was 1.62 (95% CI: 0.4–7.0; based on six cases). The risk was also not significantly increased when using a reference category of 'unexposed' subjects who had exclusively worked in occupations with little possibility of exposure to any occupational carcinogen (OR, 1.84; 95% CI: 0.4–8.5). [The Working Group noted that the study could be limited by the lack of statistical power, as cited by the authors. The study examined also the association between occupations and 153 cases of bladder cancer.]

2.2.2 *Mesothelioma*

There were two case–control studies on mesothelioma that showed an increased risk (OR, 4.5; 95% CI: 1.0–23.7; 6 exposed cases; Teschke *et al.*, 1997a) and (OR, 2.6; 95% CI: 1.3–5.3; 31 exposed cases; Pan *et al.*, 2005) for persons ever employed as painters.

2.2.3 *Bladder cancer* (Table 2.3)

(a) Europe

González *et al.* (1989) conducted a multicentre case–control study of bladder cancer in four regions of Spain. The study included 497 cases (438 males and 59 females), 583 hospital controls and 530 population-based controls. Employment as a painter was only associated with a slightly increased risk of bladder cancer among males (OR, 1.16; 95% CI: 0.7–2.0; 17 cases).

Table 2.3. Case-control studies of lower urinary tract cancer among persons exposed in painting

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Europe *Studies since Vol.47*								
González *et al*. (1989) Barcelona, Madrid, Cadiz, Guipuzcoa and Vizcaya, Spain 1985–86	497 (438 men, 59 women) from 12 hospitals; below age of 79 years; response rate 71.9%; 100% histologically confirmed	583 hospital-based controls from the same hospitals, 530 population-based controls selected from census or municipal registers; matched by age and sex; response rate 70.5% for hospital controls and 65.7% for population controls	Interviewer-administered standardized questionnaire. All interviews were conducted at the subjects' home and occupational history included any job lasting more than six months	Male Painters	17	1.16 (0.7–2.0)	Exposure to other high risk occupations and cigarette smoking (included in the model in three categories: smokers, ex-smokers and never-smokers)	The hospital controls were selected from hospital patients. Patients with the following diagnoses were excluded from the control selection: chronic respiratory diseases, coronary heart disease, infections of the urinary tract, haematuria and cancer of the respiratory tract. *Excluded from the meta-analysis because of inclusion in Kogevinas et al. (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
La Vecchia *et al.* (1990) Milan, Italy 1985–88	263 (219 men, 44 women) from major teaching and general hospitals; below the age of 75 years; response rate greater than 97%; 100% histologically confirmed	287 (210 men, 77 women) hospital-based controls from the same hospitals; response rate greater than 97%; controls were admitted for acute, non-neoplastic or urinary tract diseases	Interviewer-administered standardized questionnaire to collect information on age at starting and stopping work in 19 industries or occupations, on subjects' role in the industry in terms of direct involvement in production aspects, and on exposure to 14 selected occupational agents or groups of agents	Painting (including spraying) *Dyes/paint exposure* ≤10 years >10 years *p* for trend	NG	1.8 [0.72–4.48] 1.6 [0.70–3.65] 4.8 [1.37–16.78] 0.04	Age, sex, smoking	

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Myslak *et al.* (1991) Dortmund, Germany 1984–87	403 men from three major hospitals; 82% response rate; 100% histologically confirmed	426 hospital-based controls with benign prostate diseases from the same hospitals; 84% response rate	Mailed standardized questionnaire was used to collect information on occupational history and smoking habits	Painters	21	2.8 (1.21–6.28)	None	While smoking information was collected, there was no indication that the study controlled for any confounding effect from smoking. *Excluded from meta-analysis because of overlap with Golka (1999)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Kunze *et al.* (1992) Southern Lower Saxony, Germany 1977–85	675 (531 men, 144 women) cases admitted to hospitals for lower urinary tract cancers; 100% histologically confirmed	675 controls admitted to the same hospitals as cases for non-neoplastic diseases of the urinary tract; matched by age (± 5 years) and sex at a 1:1 ratio	Interviewer-administered standardized questionnaire to collect occupational exposure information. Participants were asked to give a chronologic account of all jobs held at least 6 months and the duration of the employment. Length of employment in a certain occupation was computed from all jobs included in that occupation category	Painters *Dyestuffs and paints* Duration (years) 1–9 10–19 20+ *p* for trend *Lacquer and paint* *Spray paints* Ever Duration (years) 1–9 10–19 20–29 30+ *p* for trend	15 6 4 24 78 52 13 8 14 17	1.3 (0.6–2.7) 1.2 (NG) 1.0 (NG) 2.5 (p <0.05) 0.03 1.5 (1.1–2.2) 2.9 (1.7–4.9) 4.7 (NG) 8.4 (NG) 2.0 (NG) 2.4 (NG) 0.004	Smoking status, lifetime cigarette consumption	63.7% male controls had hyperplasia of the prostate, 72.9% female controls had infection of the lower urinary tract. Cases were diagnosed with benign or malignant epithelial tumors of the urinary bladder, ureters, renal pelvis and urethra. *Excluded from the meta-analysis because included in Kogevinas et al. (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Cordier *et al.* (1993) Paris, Strasbourg, Clermont-Ferrand, Lille, France 1984–87	765 (658 men, 107 women) from seven hospitals, aged under 80 years; 100% histologically confirmed	765 hospital-based controls (no respiratory disease or symptoms suggestive of bladder cancer); matched at a 1:1 ratio by sex, age, ethnic origin and place of residence	Interviewer-administered standardized questionnaire to collect lifelong occupational history for each paid or unpaid job held for at least 6 months	Male painters Male spray painters	19 8	0.97 (0.50–1.88) 6.41 (0.79–51.9)	Hospital, place of residence, and smoking status	*Excluded from the meta-analysis because of inclusion in Kogevinas (2003)*
Barbone *et al.* (1994) Northeast Italy 1986–90	273 (236 men, 37 women) from clinic centres; 97.5% histologically confirmed	573 (390 men, 183 women) hospital-based controls from the same clinic centers.	Interviewer-administered structured questionnaire to collect usual occupation and employment in any of 18 industries and 13 occupational agents	Painting (Males)	6	3.1 (0.7–13)	Age, cigarette smoking, coffee consumption, and area of residence	Controls were patients without bladder cancer, but admitted for trauma, non-traumatic musculoskeletal conditions, acute surgical conditions, eye diseases, and other conditions such as diseases of ears, nose, throat or mouth

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Hours *et al.* (1994) Lyon, France 1984–87	116 cases (97 male, 19 female)	232 hospital-based controls matched by gender, hospital, age, nationality	Job history from in-person interview	Painting (regular leisure-time activity)	12	1.56 (0.56–4.58)	Gender, hospital, age, nationality	*Excluded from the meta-analysis because of inclusion in Kogevinas et al., (2003)*
Porru *et al.* (1996) Brescia, Italy 1992–93	355 (275 men, 80 women) from the General Hospital of Brescia; men aged 24–84 years, women aged 26–87 years; response rate 98.6%; 100% histologically confirmed	579 (397 men, 182 women) hospital-based controls, selected from three hospitals; men aged 19–89 years, women aged 21–86 years; males matched by age; response rate 99.1%	Interviewer-administered structured questionnaire to collect information on lifetime occupation history for each job lasting for at least six months	Male Painters	12	1.4 (0.6–3.5)	Age, residence, education, smoking, and coffee and alcohol consumption	Controls were patients with urological non-neoplastic diseases. If these diseases are also associated with paint exposure, use of the patients with these diseases may cause an underestimation of the association of interest. *Excluded from the meta-analysis because of inclusion in Kogevinas (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Golka *et al.* (1999) Dortmund, Germany 1984–88	412 male cases from urology departments of 3 hospitals in Dortmund, Germany, 1984–88. Response rate 82%	414 male controls with benign prostatic hyperplasia, Response rate 84%	Complete occupational history for jobs held >1 year and at least 10 years before interview	Painters & lacquerers	21	2.24 (1.07–5.13)	Smoking	
Pohlabeln *et al.* (1999) Hessen, West Germany 1989–1992	300 cases (239 male, 61 female) of histologically confirmed cancer of the lower urinary tract (LUT); malignant tumours of the urinary bladder (89.6% ICD9: 188), ureter (1.0%), renal pelvis (3.7%), urethra (1.7%), multiple localizations (4.0%); 92.6% participation rate	300 controls with non-neoplastic diseases of the lower urinary tract individually matched to cases from the same hospitals with respect to sex, age & area of residence; 98% participation rate	Job history from in-person interview			No specific info on painters other than 3-fold increased risk	Age, sex, area of residence	Ex-smokers = stopped smoking ≥1 year before the interview. *Excluded from the meta-analysis because of inclusion in Kogevinas et al., (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Pesch *et al.* (2000a, b) West Berlin, Bremen, Leverkusen, Halle and Jena, Germany 1991–95	1035 cases (704 men, 331 women) of cancers of the urinary bladder, ureter, renal pelvis from hospitals; response rate 84%; 100% histologically confirmed	4298 population-based controls (2650 men, 1648 women) selected from local residency registries, matched by region, age and sex; response rate 71%	Interviewer-administered structured questionnaire to collect information on lifetime occupational history. Two job–exposure matrices and one job task–exposure matrix were used to assess exposure to occupational agents	**Male Painters** *Duration* Medium Long Very long **Paints and Pigments** *Male* Medium High Substantial *Female* Medium High Substantial **Paints** *Male* Medium High Substantial *Female* Medium High Substantial **Use or production of paints** *Male* Medium High Substantial	 12 6 5 97 75 35 9 5 1 57 181 67 25 31 9 29 60 24	No summary OR 1.3 (0.6–2.6) 0.7 (0.3–1.6) 1.6 (0.5–4.7) 1.0 (0.8–1.3) 1.0 (0.8–1.3) 1.3 (0.9–2.0) 1.7 (0.7–3.8) 0.6 (0.2–1.8) 0.3 (0.03–2.5) 1.0 (0.8–1.3) 1.2 (1.0–1.5) 1.2 (0.9–1.7) 0.8 (0.5–1.3) 0.9 (0.6–1.4) 0.9 (0.4–1.9) 0.6 (0.4–0.9) 1.0 (0.7–1.3) 1.4 (0.8–2.3)	Age, study centre, smoking	90.2% of the male cases and 84.3% of the female cases had urinary bladder cancer Categories for exposure duration (short, medium, long and very long) and level of exposure to paints and pigments (low, medium, high and substantial) were defined based on the 30^{th}, 60^{th}, 90^{th} percentile in exposed controls. *Excluded from the meta-analysis because of inclusion in Kogevinas et al. (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Pesch *et al*. (2000a, b) (contd)				*Female*				
				Medium	5	1.0 (0.4–2.8)		
				High	51	1.3 (0.9–1/8)		
				Substantial	22	1.3 (0.8–2.3)		
Bouchardy *et al*. (2002) Cantons of Basel, Geneva, St Gall, Vaud and Zurich, Switzerland 1980–93	3014 male cases from cantonal Cancer Registries, aged 25 or more (and 65 or less in St Gall and Vaud)	55 120 male non-bladder cancer registrants from the same registries and period	Longest, current or most recent occupation as recorded at the time of registration (main or best specified occupation in Zurich Registry), coded using the ASCR Classification of Occupations	Plasterers and painters (in the construction industry)	73	1.1 (0.8–1.4)	Age, registry, civil status, period of diagnosis, nationality, urban/rural residence, SES, histological confirmation, information from death certificate only (cases)	Adjusting for SES may over-adjust for occupational risk factors but serve as a surrogate for smoking. Overall 95.1% histologic confirmation for all sites

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Pelucchi *et al.* (2002) Milan area and Pordenone, Italy 1985–92	110 women from major teaching and general hospitals; aged 30–79 years; response rate greater than 97%; 100% histologically confirmed	298 hospital-based controls from the same hospitals, aged 26–79; response rate greater than 97%	Interviewer-administered standardized questionnaire to collect information on occupation history and selected occupational exposures as well as other potential confounders	Dyestuff and painting industry	3	1.4 (0.3–6.8)	Age, study centre, education, BMI, cigarette smoking, coffee and alcohol consumption	Controls were patients diagnosed with acute, non-neoplastic, non-urinary or genital tract diseases. The study reported dyestuff and painting industry as one exposed group, and dyes have also been linked to bladder cancer

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Kogevinas *et al.* (2003) Germany, France, Italy, Spain, Greece, Denmark 1976–1996 Pooled analysis of 11 case-control studies	3346 male cases aged 30–79 yrs	6840 male hospital-based and population-based controls aged 30–79 yrs; individually or frequency matched on age & geographic area	Lifetime occupational history (for jobs held ≥6 months) or longest job held; coded using ISCO 1968 and ISIC rev2 codes	*Painters* *Automobile painters* Employed ≥25 yrs	116 19 NG	1.17 (0.91–1.50) 1.95 (1.01–3.75) 2.1 (0.6–7.1)	Age, smoking, study centre	Data were pooled from Claude *et al.* (1998), Pohlabeln *et al.* (1999), Pesch *et al.* (2000), Cordier *et al.* (1993), Hours *et al.* (1994), Vineis & Magnani (1985), Porru *et al.* (1996), González *et al.* (1989), Serra *et al.* (2000), Rebelakos *et al.* (1985), Jensen *et al.* (1987); unexposed group excludes subjects who worked in high-risk occupations; 93% cases & 78% controls had ever smoked

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Reulen *et al.* (2007) Limburg, Belgium 2003–05	202 cases (174 men, 28 women), ages 40–96, diagnosed with histologically confirmed transitional cell carcinoma of the bladder; 9% participation rate	390 controls (231 men, 159 women); selected from the general population of the province of Limburg by simple random sampling; >50 years old, Caucasian, with no previous diagnosis of bladder cancer; 26% participation rate	lifetime occupational history (jobs held ≥6 months) from in-person interview coded using ISCO codes	Painters & varnishers	10	2.2 (0.7–7.2)	Sex, age, years of cigarette smoking, number of cigarettes smoked per day, current smoking status, education	

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Golka *et al.* (2008) North Rhine-Westphalia, Germany 1992–95	156 male bladder cancer cases; 63% response rate	336 male controls diagnosed with prostate cancer; 72% response rate	Occupational history (for jobs held ≥6 mo) from mailed questionnaire; coded using a German classification scheme (Statistisches Bundesamt, 1992)	Painter/varnisher	7	1.98 (0.64–6.11)	Age, smoking	The variable smoking pertains to the smoking status 10 yr ago; hence individuals who had quit smoking for more than 10 yr before first diagnosis were included in the nonsmoking group. Proportion of never smokers: 13% for bladder cancer, 26% for prostate cancer

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Studies in Vol. 47								
Vineis & Magnani (1985) Italy 1978–83	512 men	Hospital; other urological and surgical	Interview	Painter in building industry Car painter ≥5 years Carpentry painter Spray painter in different industries	12 7 1 2	1.0 (0.40–2.2) 2.0 (0.60–7.0) 0.6 (0.04–8.4) 1.2 (0.20–5.8)	Age, smoking	*Excluded from the meta-analysis because of inclusion in Kogevinas et al. (2003)*
Jensen *et al*. (1987) Denmark 1979–81	371	Population	Interview	Different painting industries Painter 10 years	13	2.5 (1.1–5.7) 1.4 (1.0–1.9)	Age, sex, smoking	*Excluded from the meta-analysis because of inclusion in Kogevinas et al. (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Schifflers *et al*. (1987) Belgium 1984–85	74	Population	Interview	Painter in high-risk occupation	NG	NG	NG	[A group of 16 jobs, including painting, were defined as hazardous and associated with a high risk for bladder cancer, but exposure to painting as a specific job did not show a significant excess]. No increased risk reported
Claude *et al*. (1988) Germany NG	531 men	Hospital urological and homes for elderly	Interview	Ever painter Lacquer and paint Spray paints	15 78 52	1.3 (0.59–2.7) 1.5 (1.1–2.2) 2.9 (1.7–4.9)		Trend, $p = 0.04$ for exposure to spray paints. *Excluded from the meta-analysis because of inclusion in Kogevinas et al. (2003)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Morrison *et al*. (1985) USA, UK, Japan, 1976–78	UK, 399	Population	Interview	Paint and paint manufacture	23	0.7 [0.42–1.18]	Age, smoking	
Coggon *et al*. (1986) Cleveland, Humberside, Cheshire counties, UK 1975–80	179 male cases of cancer and the bladder and renal pelvis, aged 18–54 yrs, identified from hospital and cancer registry records	1221 other cancers	Occupation from mailed questionnaire	Painters and decorators	10	0.7 [0.27–1.81]	Age, smoking, residence, respondent	52.1% overall response rate; the variance was doubled to approximate an adjusted 95%CI. The unadjusted 95%CI was 0.78–2.18. *Possible overlap with OPCS (1986)*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
North America								
Studies since Vol. 47								
Miller *et al.* (1986) USA 1977–78	2331 white cases; aged 21–84 years; 100% histologically confirmed	4525 white population-based controls; matched by age and sex	Interviewer-administered standardized questionnaire. A list of materials the subjects reported using in each job held for ≥6 months was evaluated to determine exposure to paint	Painter (Artistic) *Duration (years)* <10 years 10+ years *p* for trend	15 4 11	2.5 (1.1–5.7) 1.7 (NG) 3.0 (NG) 0.01	Smoking	Subjects were considered to be exposed if they were ever employed as an artist and had worked with paint. *Excluded from meta-analysis because artistic painters could have different exposures than other occupationally exposed painters*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Silverman *et al.* (1989a) New Jersey, Connecticut, Iowa, New Mexico and Utah, plus Atlanta, Detroit, New Orleans, San Francisco, and Seattle, USA 1977–78	2100 white men from registry; aged 21–84 years; response rate 75%; 100% histologically confirmed	3874 white male population-based controls, selected by random digit dialing for those 21–64 years, stratified sampling from the Health Care Financing Administration's lists for those aged 65–84 years; matched by age and geographic area; response rate 84% for aged 21–64 years, and 83% for aged 65–84 years	Interviewer-administered standardized questionnaire to collect detailed information on every job a subject had held for at least 6 months since the age of 12 years	Construction and maintenance painter	76	1.5 (1.1–2.2)	Age, smoking	Workers within each industry were grouped by occupational code, and occupational codes were grouped by potential for similar exposure. The study transformed 417 census codes into 163 occupational categories that were meaningful for analysis. *The variance was doubled to approximate and adjusted confidence interval; **calculated using a fixed effects model
				Manufactured articles painter	25	1.3 (0.8–2.3)		
				Sign painter	NG	1.1 (0.3–3.7)		
				Artistic painter	13	1.8 (0.8–4.3)		
				All painters	116	1.5 (1.2–2.0)		
				Duration (years)				
				<5	50	1.7 [0.97–2.90]*		
				5–9	14	0.9 [0.38–2.34]*		
				10–24	26	1.6 [0.82–3.74]*		
				25+	22	1.9 [0.75–4.09]*		
				p for trend		0.001		
				<10 yrs	64	[1.44 (0.90–2.29)]**		
				≥10 yrs	48	[1.73 (0.98–3.04)]**		

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Silverman *et al.* (1989a) (contd)				*Duration (years) by initial year of employment as a painter*				
				<1930				
				<5	10	1.2 (NG)		
				5–9	5	1.3 (NG)		
				10+	18	3.0 (NG)		
				1930–1939				
				<5	8	1.5 (NG)		
				5–9	2	0.4 (NG)		
				10+	9	1.5 (NG)		
				≥1940				
				<5	32	2.0 (NG)		
				5–9	7	1.0 (NG)		
				10+	21	1.4 (NG)		

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Silverman *et al.* (1989b) New Jersey, Connecticut, Iowa, New Mexico, and Utah, plus Atlanta, Detroit, New Orleans, San Francisco, and Seattle,USA, 1977–78	126 non-white men from Cancer Registry; aged 21–84 years; response rate 75%; 100% histologically confirmed	383 population-based controls, selected by random digit dialling for those 21–64 years, stratified sampling from the Health Care Financing Administration's lists for those aged 65–84 years; matched by age and geographic area; response rate 84% for aged 21–64 years, and 83% for aged 65–84 years	Interviewer-administered standardized questionnaire	All Painters Painter, construction and maintenance	5 4	1.2 (0.4–3.7) 1.4 (0.4–5.4)	All ORs were adjusted for smoking	Non-white men, 70% cases and 75% controls were black
Silverman *et al.* (1989a,b) See above	See above	See above	See above	All painters (white & non-white)	121	[1.48 (1.16–1.90)]*	See above	*calculated using a fixed effects model

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Burns & Swanson (1991) Michigan, USA, Time period not stated Recruitment period not specified, probably 1984–87, as in Swanson *et al.*, (1993)	2160 (1571 men, 589 women) from the Metropolitan Detroit Cancer Surveillance System; aged 40–84; response rate 94%; 100% histologically confirmed	3979 (1997 men, 1982 women) with cancer of the colon or rectum from the Metropolitan Detroit Cancer Surveillance System; response rate 95%	Life-time occupational history obtained during telephone interviews to the subjects or to their surrogates, coded using US Bureau of Census classification.	Painters	30	1.1 (0.7–1.9)	Cigarette smoking, race, gender, and age at diagnosis	It is unclear about the validity of occupational data from telephone-based surrogate interviews

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Zheng *et al.* (2002) Iowa, USA, 1986–89	1452 (1135 men, 317 women) from the State Health Registry; aged 40–85; response rate 85%; 100% histologically confirmed	2434 (1601 men, 833 women) population-based controls randomly selected from computerized state driver's license records for aged under 65; aged 65 years and older were selected from US Health Care Financing Administration listings; matched by gender and age; response rate 82% for aged under 65 and 80% for aged 65 and older	A standardized questionnaire was mailed to all participants to inquire about history of each job held for 5 years or longer since the age of 16; a telephone interview was done with those who did not complete the mailed questionnaire.	**Male painters (construction and maintenance)** *All* Duration (years) <10 ≥10 **Male painting and paper-hanging** *All* Duration (years) ≥10	 11 5 6 9 6	 2.7 (1.0–7.7) not possible 1.4 (0.4–4.7) 2.9 (0.9–9.1) 1.9 (0.5–6.5)	Age, lifetime pack-years of cigarette smoking, and first-degree relative with bladder cancer	For each job recorded, detailed information was collected on job title, industry, the year the job began and ended, activities associated with the job; 5 cases and 0 controls male construction & maintenance painters exposed <10 years

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Colt *et al.* (2004) New Hampshire, USA 1994–98	424 (331 men, 93 women) from the New Hampshire State Cancer Registry; aged 25–74; participation rate 74.3%; 100% histologically confirmed	645 (407 men, 238 women) population-based controls selected by using population lists from the New Hampshire Department of Transportation for less than 65 years of age, and from the Centres for Medicare and Medicaid Services of New Hampshire for those age 65 years and more; matched by age and gender; participation rate 67.2%	Subjects completed a mailed questionnaire describing detailed lifetime occupational history and responses were reviewed by interviewers during an in-person interview	Male painters Male painters, construction and maintenance	12 7	[0.98(0.45–2.13)] [0.78(0.30–2.03)]	Smoking, age	The risk for painters was listed in a table for jobs with odds ratios less than 1.3. No confidence interval or *p* value was provided. Questionnaire included information on job title and place of work for each job held

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Siemiatycki (1991) Montreal, Canada, 1979–85	484 incident male cases; aged 35–70 yrs; histologically confirmed	533 population controls, 1879 cancer controls	Interview to obtain lifetime occupational history; painters coded using Canadian occupation classification			**OR (90% CI)**	Age, family income, ethnicity, respondent type, cigarette & alcohol index	*Excluded from the meta-analysis and replaced by Ramanakumar et al. (2008) analysis*
				Construction painter				
				Any exposure	13	1.3 (0.8–2.4)		
				Substantial exposure	8	1.7 (0.8–3.4)		
				Other painter				
				Any exposure	9	1.1 (0.6–2.1)		
				Substantial exposure	4	0.8 (0.3–2.2)		

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Siemiatycki *et al.* (1994) Montreal, Canada 1979–86	484 male cases from all large hospitals in the Montreal area; aged 35–70 years; response rate 84%; 100% histologically confirmed	533 population-based controls selected from electoral lists and by random digit dialing; response rate 72%; 1879 cancer controls (except lung or kidney cancer) from the same hospitals; response rate 84%	Interviewer-administered semi-structured questionnaire to collect detailed lifetime job history. Experts translated each job into a list of potential exposures by means of a checklist that included 294 substances	**Construction painters** *Duration (years)* <10 ≥10 **Other painters** *Duration (years)* <10 ≥10	 5 8 5 4	 1.2(0.4–3.2) 1.5(0.7–3.4) 1.1(0.4–3.0) 0.9(0.3–2.7)	Age, ethnicity, socio-economic status, smoking, coffee consumption, and the status (self/proxy) of the respondents	The results presented in the paper were based on pooled controls (cancer and population controls). There was rather little difference between results based on cancer controls and those based on population controls when analyses were carried out separately with cancer controls, population controls, or the pooled controls. *Used only for the duration-response analysis*

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Ramanakumar *et al.* (2008) Montreal, Canada 1979–1986	478 male bladder cancer cases from 18 hospitals in Montreal; aged 35–70 years; 100% histologically confirmed; 82% response rate.	1066 pooled age-matched controls (533 population controls from electoral lists and by random-digit-dialing, 533 controls from other cancers); response rate 72% and 84%	Detailed job history (including specific tasks and protective devices) obtained from in-person interviews and reviewed by a team of chemists and industrial hygienists who translated each job into a list of potential exposures by means of a checklist that included 294 substances	**Ever worked as a painter** *Substantial exposure* Any paint product Metal coatings Wood varnishes, stains Wood and gypsum paints	17 37 13 18 25	1.0 (0.3–2.7) 1.3 (0.7–2.2) 1.7 (0.7–4.4) 1.7 (0.9–3.6) 1.0 (0.5–2.0)	Age, ethnicity, years of school attendance, median family income, the status (self/proxy) of the respondents, smoking and occupational exposure to asbestos, silica, cadmium compounds	No other cancer sites showed any evidence of an association with type of paint or stain. Overlaps with Parent *et al.* (2000); this study population is the same as that of Siemiatycki *et al.* (1994) and therefore used for the overall analysis

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Teschke *et al.* (1997a) British Columbia, Canada 1990–91	105 (88 men, 17 women) from British Columbia Cancer Registry; aged 19–75 years; response rate 88.2%; 100% histologically confirmed	159 (112 men, 47 women) population-based controls selected from provincial voters list, frequency matched to the age and sex distribution of cases of all three types of cancers included in this study (bladder cancer, cancers of the nasal cavity and sinuses); response rate 80.3%	Subjects were interviewed either in person or by telephone using a standardized questionnaire to collect information on occupational history	Ever employed as a painter Employed as a painter with most recent 20 years removed	4 2	2.8 (0.4–21.3) 2.0 (0.1–33.0)	Cigarette smoking, sex, age	Latency analyses were conducted for all occupational groups with the most recent 20 years of employment removed

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Gaertner *et al.* (2004) Newfound-land, Prince Edward Island, Nova Scotia, Manitoba, Alberta, Saskatchewan, and British Columbia, Canada, 1994–97	887 (535 men, 352 women) from 7 Canadian provincial cancer registries; aged 20–74 years; response rate 58% for males, 61% for females, respectively; 100% histologically confirmed	2847 population-based controls matched by age and sex; selected by random digit dialling for controls in Newfoundland and Alberta; others randomly sampled from the provincial health insurance plan database; response rate 59% for males, 65% for females	Information on occupational history was collected through mailed questionnaire	Male painters Female painters	12 3	0.74 (0.36–1.53) 1.08 (0.27–4.37)	Province, age, race, smoking, ex-smoking, and consumption of fruit, fried food, coffee and employment in other suspect occupations	Two to five months after diagnosis, questionnaires were mailed to participants to obtain information on occupational history, smoking and other exposure information. Up to 12 occupations per person were recorded by the type of industry, service, company name, main job duties and job title

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Band *et al.* (2005) British Columbia, Canada, 1983–90	1125 males from the British Columbia Cancer Registry; aged 20 years or older; response rate 64.7%; 100% histologically confirmed	8492 males from the British Columbia Cancer Registry; aged 20 years or older; matched by exact age and year of diagnosis; response rate 60.1%	Self-administered questionnaire (or completed by a proxy respondent) to collect detailed lifetime occupational history	Painters/Paper-hangers related *Ever* *Usual*	 22 10	 1.53 [0.95–2.47] 1.4 [0.71–2.76]	Tobacco smoking (age started smoking, average number of cigarettes, pipe or cigars smoked per day, total years smoked), alcohol drinking, marital status, education, respondent type (self or proxy)	Registry based, used patients with other cancers as controls excluding lung cancer and cancers of unknown primary site
Studies in Vol. 47								
Wynder *et al.* (1963) USA, 1957–61	300	Hospital, without smoking-related disease	Interview	Ever painter	18	[2.2] [1.0–4.5]	None	

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Cole *et al*. (1972) USA, 1967–68	461	General population	Interview	Painter (men)	28	1.2 (0.71–1.9)	Age, smoking	
Decouflé *et al*. (1977); Houten *et al*. (1977) Buffalo, NY, USA 1956–65	Bladder cancer cases (ICD7 181) from 11591 white male cancer cases at a treatment center, age ≥14 years	Non-cancer admissions from the same cancer treatment center	Lifetime occupation recorded during interview before diagnosis, coded using the Standard Industrial Classification Manual	*Painter* Ever <60 yrs old ≥60 yrs old Ever (smoking adj) Worked ≥5 yrs <60 yrs old ≥60 yrs old	 16 3 13 12 1 11	 1.62 [0.92–3.38] 1.68 [0.46–6.29] 1.61 [0.75–3.48] 1.72 (p >0.05) 1.51 [0.78–3.69] 1.04 [0.15–7.76] 1.59 [0.67–3.79]	 Age Smoking, age age	Unexposed = clerical occupations

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Williams *et al*. (1977) Atlanta, Birmingham, Colorado, Dallas-Ft.Worth, Detroit, Minneapolis-St.Paul, Pittsburgh, San Franciso-Oakland, USA 1969–71 Third National Cancer Survey	169 bladder cancer cases that reported an occupation, 95% histologically confirmed	2173 patients with cancers other than lung, larynx, oral cavity, esophagus, bladder that reported an occupation	Main lifetime employment from survey questionnaire, coded using the 1970 census classification	Painting (men)	1	0.42 [0.02–7.14]	Age, race, education, education, tobacco, alcohol, geographic location	Painting included construction workers, paper-hangers, and pattern & model makers; the CI was estimated by doubling the variance
Silverman *et al*. (1983) USA, 1977–78	303 men	Population	Interview	Ever painter Car painter	15 3	1.0 (0.5–2.2) 0.5 (0.1–2.1)	None	
Schoenberg *et al*. (1984) USA, 1978–79	658 men	Population	Interview	Ever painter Paint exposure	34 111	1.4 (0.85–2.3) 1.6 (1.2–2.1)	Age, smoking, other employment	

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Morrison *et al*. (1985) USA, UK, Japan 1976–78	USA, 430	Population	Interview	Paint and paint manufacture	35	1.5 [0.84–2.69]	Age, smoking	
Howe *et al*. (1980) Canada, 1974–76	480 men	Neighbourhood	Interview	Commercial painting Ever spray painting	≥24 ≥16	1.0 (0.6–2.3) 1.8 (0.7–46)	None	After correction for exposure to other suspect 'high-risk' industry, RR for spray painter, 1.0
Siemiatycki *et al*. (1987) Canada, 1979–85	486	Other cancers	Interview	Listed as white spirits, but in exposed group construction is 21% of total, mostly painters	91	1.0 (90% CI, 0.8–1.2)	Age, socioeconomic status, ethnicity, cigarette smoking, blue/white collar work	*Excluded from meta-analysis because the exposure was not specific to painters*
Risch *et al*. (1988) Canada, 1979–82	781	Population	Interview; exposed to paints in full-time job at least 6 months, 8–28 years before diagnosis	*Commercial painting* Men Women *Spray painting* Men Women	 204 14 49 67	 1.1 (0.77–1.6) 3.9 (0.9–26.7) 0.90 (0.39–2.1) 0.91 (0.48–1.7)	Smoking	

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Other Regions								
Studies since Vol. 47								
Bethwaite *et al*. (1990) New Zealand, 1980–84	912 male bladder cancer cases (ICD9 188) had known occupation among 1259 cases identified from New Zealand Cancer Registry; aged 20 or older ; % histologic confirmation not given	18 992 males with cancers other than bladder cancer from New Zealand Cancer Registry; with known occupation, [out of 23 503 identified] from the same Registry and period, aged 20 or more at registration; % histologic confirmation not given	Data were collected through cancer registration, death certification and incidental necropsy findings	**Painters** **Ever** *Age (years)* 20–59 ≥60	 24 9 15	 1.52 (1.00–2.31) 2.3 (1.2–4.5) 1.3 (0.8–2.2)	Age	Potential selection bias for using other cancers to form the control group. Information on exposure was largely based on cancer registration

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Dryson *et al*. (2008) New Zealand, 2003–2004	213 incident cases of bladder cancer (165 men, 48 women); age 25–70 years; notified to the New Zealand Cancer Registry; ~64% participation rate	471 population controls (221 men, 250 women) randomly selected from the 2003 New Zealand Electoral Roll; frequency matched by age according to the 1999 age distribution of cancer registrations for NHL, bladder cancer & leukemia; ~48% participation rate	Full occupational history from in-person interview	**Painters & paperhangers**	11	1.42 (0.56–3.60)	Gender, age group, smoking status, Maori ethnicity, occupational status	Numbers were too small (less than 10 cases 1 controls) for spray painters; *information on duration obtained by contacting authors; **calculated using a fixed effects model
				Men	10	1.28 (0.50–3.30)		
				Women	1	NG		
				Duration (yrs)*				
				0	205	1.0 (ref)		
				1–2	1	0.22 (0.02–2.35)		
				2–10	4	2.20 (0.37–13.08)		
				>10	3	0.98 (0.23–4.24)		
				<10	5	[0.96 (0.23–4.01)]**		
				Painter, decorator and/or paperhanger	7	1.35 (0.42–4.39)		
				Men	7	1.41 (0.44–4.56)		
				Painting and decorating services industry	7	1.13 (0.39–3.29)		
				Men	6	1.11 (0.34–3.56)		
				Women	1	1.38 (0.10–19.76)		

Table 2.3 (contd)

Reference, Location, Time period	Characteristics of cases	Characteristics of controls	Exposure Assessment	Exposure	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Studies in Vol. 47								
Morrison *et al*. (1985) USA, UK, Japan, 1976–78	Japan, 226	Population	Interview	Paint and paint manufacture	5	0.7 [0.25–1.97]	Age, smoking	
Iscovich *et al*. (1987) Argentina, 1983–85	117	Neighbourhood and hospital	Interview	Ever painter	3	0.55 [0.12–2.5]	Age, tobacco smoke	Adjusted for age and tobacco smoke, pooling the two control groups

OR, odds ratio; CI, confidence interval; ASCR, Association of Swiss Cancer Registries; SIC, Standard Industrial Classification; ISCO, International Standard Classification of Occupations; ISIC, International Standard Industrial Classification; NG, not given

La Vecchia *et al.* (1990) conducted a hospital-based case–control study of bladder cancer in the greater Milan area, Italy. The study included 263 cases and 287 controls. While patients diagnosed with acute, non-neoplastic or urinary tract diseases were used as controls, a relative risk of 1.8 (90% CI: 0.8–3.7) was observed for those who worked in the painting (including spraying) industry. Those who had been occupationally exposed to dyes/paints for more than 10 years had an almost 5-fold increased risk of bladder cancer (RR, 4.8; 90% CI: 1.7–13.9), and this risk increased significantly with increasing duration of exposure to dyes/paints (P for trend = 0.04).

Myslak *et al.* (1991) conducted a hospital-based case–control study in the East Ruhr area, a major industrial area of Germany. The cases included in the study were 403 male bladder cancer patients, and the controls were 426 patients diagnosed with benign prostate disease from the same hospital. The study authors reported an increased RR of bladder cancer of 2.76 (95% CI: 1.21–6.28; 21 cases) for painters. [It should be noted, however, that, while smoking information was collected in this study, there was no indication that the study actually controlled for potential confounding effect from smoking.]

In Volume 47 (IARC, 1989), Claude *et al.* (1986, 1988) reported results from a hospital-based case–control study for cancer of the lower urinary tract in northern Germany. Their results showed a significantly increased risk of lower urinary tract cancers associated with exposure to lacquer, paint, and spray paints. With additional cases and controls, Kunze *et al.* (1992) reported an OR of 2.9 (95% CI: 1.7–4.9; adjusted for tobacco consumption) for having ever been exposed to spray paints. The risk of bladder cancer increased significantly with increasing duration of exposure to spray paints in this study (P for trend = 0.004).

Cordier *et al.* (1993) conducted a hospital-based case–control study in five regions of France. This study involved 765 cases (658 men and 107 women), and the same number of controls. Controls were patients admitted to the same hospital as the cases for causes other than cancer, respiratory disease or symptoms suggestive of bladder cancer. Controls were matched 1:1 to cases by sex, age, ethnic origin, and place of residence. This study did not find any association between employment as a painter and a risk of bladder cancer (RR, 0.97; 95% CI: 0.50–1.88; 19 cases). An OR of 6.41 (95% CI: 0.79–51.85), however, was observed for spray painters, based on eight cases and one control.

Barbone *et al.* (1994) conducted a hospital-based case–control study of bladder cancer in northeastern Italy. The study included 273 bladder cancer cases and 573 controls. Controls were patients without bladder cancer, but admitted for trauma, non-traumatic musculoskeletal conditions, acute surgical conditions, eye diseases, and other conditions such as diseases of the ears, nose, throat or mouth. Cases and controls were interviewed at hospitals. A non-significantly increased risk of bladder cancer was found for men employed in the painting industry (RR, 3.1; 95% CI: 0.7–13; six cases) after controlling for major potential confounders, including cigarette smoking.

Hours *et al.* (1994) conducted a case–control study of bladder cancer in Lyon, France between 1984–1987 involving 116 cases (97 male, 19 female) and 232 hospital-based controls matched by gender, hospital, age, nationality. Job history was obtained from in-person interviews. Painting (regular leisure-time activity) was associated with a non-

significantly increased risk of bladder cancer (OR, 1.56; 95% CI: 0.56–4.58; 12 exposed cases) after adjusting for the matching variables.

Porru *et al.* (1996) conducted another hospital-based case–control study in northern Italy. A total of 355 (275 men, 80 women; aged 24–87) bladder cancer cases from the General Hospital of Brescia were included in the study. Controls were patients with urological non-neoplastic diseases. A non-significantly increased risk of bladder cancer was observed for male painters (RR, 1.4; 95% CI: 0.6–3.5; 12 cases), after adjusting for smoking and other major confounders. [Use of patients with urological non-neoplastic diseases as controls may pose an issue for interpreting the results because if there is indeed an association between paint exposure and risk of urological non-neoplastic diseases, use of these patients as controls would cause an underestimation of the association between painting and bladder cancer risk in this study.]

Golka *et al.* (1999) conducted a case–control study of bladder cancer involving 412 male cases from urology departments of 3 hospitals in Dortmund, Germany, and 414 male controls with benign prostatic hyperplasia. Complete occupational history were obtained for jobs held >1 year and at least 10 years before the interview. The smoking-adjusted OR for painters & lacquerers for cancer fo the bladder was 2.24 (95% CI, 1.07–5.13; 21 exposed cases).

Pohlabeln *et al.* (1999) performed a case–control study involving 300 cases (239 male, 61 female) of histologically confirmed cancer of the lower urinary tract (including malignant tumours of the urinary bladder [89.6%, ICD9: 188], ureter [1.0%], renal pelvis [3.7%], urethra [1.7%], multiple localizations [4.0%]), and 300 controls with non-neoplastic diseases of the lower urinary tract individually matched to cases from the same hospitals with respect to sex, age & area of residence. Job history was obtained from in-person interviews. The authors did not provide an OR for cancer of the lower urinary tract but reported a 3-fold increased risk after adjusting for age, sex and area of residence.

Pesch *et al.* (2000a) conducted a multicentre population-based case–control study of urothelial cancers in Germany. Among the 1035 incident urothelial cancer cases (704 men, 331 women), 90.2% of the male patients and 84.3% of the female patients were diagnosed with cancer of the urinary bladder. Job–exposure matrices and a job-task–exposure matrix were used to assess the relationship between exposure to occupational agents and risk of urothelial cancers. An OR of 1.6 (95% CI: 0.5–4.7; five cases) was reported for males who had a very long period of employment as a painter. A borderline significantly increased risk of urothelial cancers was also observed for males who reported to have had high (OR, 1.2; 95% CI: 1.0–1.5; 181 cases) or substantial (OR, 1.2; 95% CI: 0.9–1.7; 67 cases) occupational exposure to paints. [The study, however, did not give a clear definition for exposure duration (medium, long, and very long) and intensity of exposure to paints and pigments (medium, high, and substantial).]

Bouchardy *et al.* (2002) conducted a case–control study based on a cancer registry in Switzerland. The cases in the study were patients diagnosed with cancer of the urinary bladder, and the controls, patients with all other types of cancer. No association was observed between male plasterers and painters and the risk of cancer of the urinary bladder

(RR, 1.1; 95% CI: 0.8–1.4; 73 exposed cases), after adjusting for age, registry, civil status, period of diagnosis, nationality, urban/rural residence, socioeconomic status histological confirmation, and information from death certificate only (cases). [Use of patients with all other types of cancer as controls in this study could complicate the interpretation of the observed association since some of the cancer types may well be linked to exposure to paints, and use of patients with all other types of cancer as controls would cause an underestimation of the association between painting and bladder cancer risk.]

Pelucchi *et al.* (2002) conducted a hospital-based case–control study in Italy that involved 110 histologically confirmed female bladder cancer patients, and 298 sex-matched controls. The controls were patients admitted for acute, non-neoplastic, non-urinary or genital tract diseases. The study found that women who had ever worked in the dyestuff and painting industry had a non-significantly increased risk of bladder cancer (OR, 1.44; 95% CI: 0.30–6.84; three cases). [It is difficult to interpret the study result since the study treated the dyestuff and painting industry as one exposed group, and dyes have also been linked to bladder cancer.]

Kogevinas *et al.* (2003) performed an analysis of pooled data from 11 case–control studies of bladder cancer that were conducted in six European countries during 1976–1996. A total of 3346 male incident bladder cancer cases and 6840 controls, aged 30–79 years, were included in the pooled analyses which adjusted for age, smoking, and study centre. The results showed that men who had ever worked in the manufacture of paints, varnishes and lacquers had nearly three times the risk of bladder cancer (OR, 2.94; 95% CI: 1.48–5.84; 22 cases) compared to those who were not exposed. Painters had an approximately 20% increased risk of bladder cancer compared to non-painters, although this was not statistically significant (OR, 1.2; 95% CI: 0.91–1.50; 116 cases).

Reulen *et al.* (2007) enrolled 202 bladder cancer cases (174 men, 28 women) and 390 controls (231 men, 159 women) selected from the general population of the province of Limburg, Belgium by simple random sampling. Lifetime occupational history for jobs held >6 months was obtained from in-person interviews. Painters and varnishers showed an increased risk of bladder cancer (OR, 2.2; 95% CI: 0.7–7.2; based on ten cases) after adjusting for sex, age, years of cigarette smoking, number of cigarettes smoked per day, current smoking status, and education.

(b) North America

Miller *et al.* (1986) conducted a case–control study to examine the association between employment as an artistic painter and the risk of bladder cancer in the United States. The analysis was restricted to caucasian artists because of the small number of non-caucasian artists. For the case–control study involving 2331 bladder cancer cases and 4525 population-based controls, artistic painters had a significantly increased risk of cancer of the bladder (OR, 2.5, 95% CI: 1.1–5.7; 15 cases), and this increased with prolonged duration of employment as a painter (P for trend = 0.01).

The US National Bladder Cancer Study by Silverman *et al.* (1989a) included 2100 caucasian male bladder cancer cases, and 3874 population-based controls recruited in

ten areas of the United States. Among caucasian men, a 50% increased risk of cancer of the bladder was observed in painters (OR: 1.5; 95% CI: 1.2–2.0; 116 cases). For caucasian painters who had started working before 1930, a significant trend in risk with increasing duration of employment as a painter was apparent with a relative risk of 3.0 was observed for those employed 10 or more years as a painter. With 126 non-caucasian cases and 383 non-caucasian controls, Silverman *et al.* (1989b), however, did not find a significantly increased risk of bladder cancer among painters (RR, 1.2; 95% CI: 0.4–3.7; five cases).

Burns & Swanson (1991) conducted a case–control study in Michigan, the United States, based on the Occupational Cancer Incidence Surveillance Study (OCISS). The OCISS is a population-based study of occupational risk factors for cancers diagnosed among residents of the metropolitan Detroit area. Cases were 2160 patients diagnosed with bladder, and controls 3979 patients diagnosed with cancers of the colon or rectum from the OCISS study. Lifetime occupational history was collected through telephone interviews of the subjects or their surrogates (spouse or first-degree relative of the subject). The study did not find any association between work as a painter and risk of bladder cancer (RR, 1.1; 95% CI: 0.7–1.9; adjusted for cigarette smoking, race, gender, and age at diagnosis; 30 cases). [The Working Group noted that controls in this study were patients diagnosed with cancers of the colon or rectum. While the authors pointed out that persons diagnosed with cancers of the colon or rectum constitute the most appropriate comparison group within OCISS because their cigarette smoking patterns were similar to those of the general population, it is unclear whether these patients also represent the population which produced the cases with regards to the exposure itself (paint exposure). Also, no information was given about the quality and the comparability of lifetime occupational history collected through telephone interviews with the subjects themselves or their surrogates.]

Zheng *et al.* (2002) conducted a population-based case–control study in Iowa, USA. The study included 1452 incident bladder cancer cases (1135 men, 317 women) and 2434 population-based controls (1601 men, 833 women). The study used mailed questionnaires to collect detailed information on occupational history for each job held for 5 years or longer since the age of 16: detailed information was collected on job title, industry, the year the job began and ended, and activities associated with the job. Telephone interviews were conducted with a small number of subjects who did not complete the mailed questionnaires. The study reported a borderline significantly increased risk of bladder cancer among male construction and maintenance painters (OR, 2.7; 95% CI: 1.0–7.7; 11 cases). Men who worked in the painting and wallpaper-hanging industry had a nearly 3-fold increased risk of bladder cancer (OR, 2.9; 95% CI: 0.9–9.1; nine cases).

Colt *et al.* (2004) conducted a population-based case–control study of bladder cancer in New Hampshire, USA. The study included 424 cases and 645 controls. To collect information on occupational exposures, the study mailed a work history calendar to the participants two weeks before the interview date, and the participants were asked to complete information on job title and place of work for each job held. The study interviewers reviewed the responses on the day of the interview for completeness. Information on exposure to other risk factors was collected through in-person interviews.

The study did not find an association between employment as a painter and risk of bladder cancer for men (OR < 1.3, adjusted for age and smoking; 12 cases). There were no women employed as painters in this study. [The risk for painters was listed in a table for jobs with odds ratios less than 1.3. No confidence interval or *P* value was provided.]

Siemiatycki *et al.* (1994) conducted a population-based case–control study in Montreal, Canada during 1979–1986. The study involved 484 bladder cancer cases, 1879 cancer controls, and 533 population-based controls. The job histories of these subjects were evaluated by a team of chemists/hygienists for evidence of exposure to a list of 294 workplace chemicals. A non-significant increased risk was observed for those who had worked as construction painters for 10 or more years (RR, 1.5; 95% CI: 0.7–3.4). No increased risk of bladder cancer was observed for other painters either as a group or stratified by duration of working as a painter.

Ramanakumar *et al.* (2008) reanalysed the data from the population-based case–control study in Montreal by Siemiatycki *et al.* (1994). Risks were estimated for exposure to each of the paint-related agents (metal coatings, wood varnishes and stains, and wood and gypsum paints) and development of bladder cancer, adjusting for several potential confounders, including smoking. While 'ever' work as a painter was not associated with bladder cancer risk in this study (OR, 1.0; 95% CI: 0.3–2.7; 17 cases), a non-significantly increased risk was reported for subjects who had had substantial exposure to metal coatings (OR, 1.7; 95% CI: 0.7–4.4; 13 cases), and for wood varnishes and stains (OR, 1.7; 95% CI: 0.9–3.6; 18 cases).

Teschke *et al.* (1997a) conducted a case–control study in British Columbia, Canada, to study the relationship between occupational exposures and risk of nasal and bladder cancers. The study included 105 cases (88 men and 17 women) and 139 population-based controls (112 men, 27 women) selected from provincial voting lists. Subjects were interviewed either in person or by telephone using a standardized questionnaire to collect information on occupational history and other potential risk factors for these cancers. A non-significantly increased risk of bladder cancer was observed for those who had ever worked as painters (OR, 2.8; 95% CI: 0.4–21.3; four cases). Removal of the most recent 20 years of employment from the analyses made the results even less stable (OR, 2.0; 95% CI: 0.1–33.0; two cases).

A population-based case–control study was conducted in seven Canadian provinces (Gaertner *et al.*, 2004). The study included 887 incident, histologically confirmed bladder cancer cases, and 2847 controls. Approximately 2–5 months after diagnosis, questionnaires were mailed to participants to obtain information on occupational history, smoking and other exposure information. Up to 12 occupations per person were recorded by type of industry, service, company name, main job duties, and job title. Employment as a painter was not found to be associated with an increased risk of bladder cancer among males (OR, 0.74; 95% CI: 0.36–1.53; 12 cases) or females (OR, 1.08; 95% CI: 0.27–4.37; three cases), after adjusting for province, age, race, smoking, ex-smoking, employment in other suspect occupations, and consumption of fruit, fried food and coffee.

Band *et al.* (2005) conducted a case-control study based on the British Columbia Cancer Registry to assess the association between lifetime occupational histories and risk of bladder cancer. The cases in this study were 1125 male incident bladder cancer cases reported to the registry during 1983–1990. Controls were 8492 male incident cancer patients diagnosed with all other types of cancer (excluding lung, and of unknown primary site) reported to the registry during the same time period. A self-administered questionnaire was mailed to male cancer patients to collect lifetime occupational history, including job descriptions, job and industry titles, duration and period of work, etc. A significantly increased risk of bladder cancer was observed for those who had ever worked as painters/wallpaper hangers (OR, 1.53; 95% CI: 1.02–2.28; 22 cases). [Caution must be exercised in interpreting the results because patients with other types of cancer were used as controls (excluding lung cancer and cancers of unknown primary site). If some of the cancer sites were associated with paint exposure, inclusion of these cancer sites in the control group would cause an underestimation of the association of interest. Also, the questionnaires were completed by either the subject himself or by a proxy respondent for information on lifetime occupational history.]

(c) Other Regions

Bethwaite *et al.* (1990) conducted a case–control study based on a cancer registry in New Zealand to investigate the association between employment as a painter and risk of various cancers. A total of 912 male bladder cancer cases who reported an occupation were included in this study as well as 18 992 male control patients of all other types of cancer. Painters were found to be associated with an increased of bladder cancer (OR, 1.52; 95% CI: 1.00–2.31; 24 cases), especially those painters aged 20–59 years (OR, 2.27; 95% CI: 1.15–4.48; nine cases). The risk was not significantly increased for those aged 60 and over (OR, 1.27; 95% CI: 0.75–2.15; 15 cases).

2.2.4 *Lymphatic and haematopoietic cancer*

The Working Group for Volume 47 evaluated five case–control studies of leukaemia among persons exposed to paint and its manufacture.(two with significant excesses). Two small studies on Hodgkin disease and three studies on multiple myeloma also showed excesses (IARC, 1989).

A summary of studies of painters and paint exposures and lymphatic and haematopoietic cancer is presented in Table 2.4.

(a) Europe

Lindquist *et al.* (1987) conducted a study of 125 acute leukaemia cases (76 men and 49 women aged 16–84, diagnosed between 1980–1983), and 125 age- and sex-matched population controls in Sweden. Participants were interviewed in person to obtain information on a variety of factors including detailed lifetime occupational history.

Table 2.4 Case–control studies of lymphohaematopoietic cancer among painters

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Europe							
Lindquist *et al*. (1987) Sweden 1980–83	125 cases (76 men, 49 women), aged 15 to 84 years, from 5 Swedish hospitals that captured most leukemia cases 125 controls, obtained from the population register of the taxation authorities, matched 1:1 by sex and age (± 4 years)	Acute leukaemia	Painters	13	13 (2.0–554)	NG	Lifetime work history from in-person interview; 42% of cases and 48% controls were smokers
Persson *et al*. (1989) Orebro, Sweden 1964–86	54 HD cases (35 men and 19 women) and 106 NHL cases (66 men and 40 women), aged 20 to 79 years. 275 population controls (157 men and 118 women), aged 20 to 77 years	HD NHL	Painters	2 3	Could not be calculated Could not be calculated	Not applicable	Selected occupational exposures, including painting, obtained through a mailed questionnaire. Odds ratios could not be calculated because there were no exposed controls

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
LaVecchia *et al.* (1989) Milan, Italy 1983–1988	69 incident cases of HD (44 men, 25 women), 153 NHL (93 men, 60 women), 110 MM (56 men, 54 women), aged 15 to 74 years. 396 hospital-based controls (269 males, 127 women) admitted for acute conditions to the same hospital network as cases, aged 15 to 74 years.	HD NHL MM	Painting (including spray)	3 6 5	Not presented for painters but there was no significant association with painting for any site	Age, sex, smoking and area of residence	Information on 16 occupations and 13 agents, including painting, obtained by a trained interviewer
Heineman *et al.* (1992) Denmark 1970–1984	835 male cases identified from the Danish Cancer Registry who were ≥18 years at diagnosis 2979 male population controls identified from the Danish Central Population Registry; matched on year of birth; not previously diagnosed with a malignancy	MM	Painter	11	1.0 (0.5–2.1)	Age	Employment history from pension files

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Persson *et al*. (1993) Linkoping, Sweden 1975–84	124 male cases (31 HD; 93 NHL), ≥20 years old, born in Sweden and residing in the hospital catchment area at time of diagnosis, were obtained from the Regional Cancer Registry. 204 male controls randomly drawn from population registers and residing in the same area as cases	HD NHL	Painters	2 NG	**OR (90% CI)** 2.3 (0.4–11) NG	Age, other exposures with a crude OR ≥2.0 or significantly <1	Occupational exposures from a mailed questionnaire
Persson & Fredrikson (1999) Sweden Orebro, 1964–86 Linkoping, 1975–84	199 male cases, ≥20 years old, born in Sweden and residing in the hospital catchment area at time of diagnosis, were obtained from the Regional Cancer Registry. 479 male population controls randomly drawn from population registers and residing in the same area as cases.	NHL	Painters	5	2.5 (0.5–9.6)	Age, other exposures with a crude OR ≥2.0 or significantly <1	Pooled data from two Persson studies (1989 & 1993)

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Mele *et al*. (1994) Rome, Bologna, Pavia, Italy 1986–90	619 cases (252 AML, 100 ALL, 111 RAEB, 156 CML). 1161 controls with nonneoplastic disorders were obtained from the same hematology departments as cases, ≥15 yrs old	AML ALL RAEB CML	Male painter	10 26 9 19	3.2 (0.5–20.8) 4.7 (0.6–34.2) 5.4 (0.5–61) 7.6 (1.5–39.8)	Age, education, residence, other listed occupations	Occupational exposures obtained from in-person interview
Nordström *et al*. (1997) Sweden 1987–92	111 male cases obtained from the Swedish Cancer Registry 400 male controls obtained from the National Population Registry; matched by age and county	HCL	Painter (building)	6	5.7 (1.6–20.8)	Age	Lifetime job history for jobs held 1 year or more obtained through a mailed questionnaire

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Clavel *et al*. (1998) France 1980–90	226 living male cases obtained from 18 French hospitals. 465 male controls selected from the admission lists of inpatients for the same 10 year period as for cases; matched by residential area, date of birth and hospital admission	HCL	Painters Spray painters Artists & designers	6 5 1	1.0 (0.3–3.0) 2.0 (0.5–8.0) 1.3 (0.1–16.7)	Smoking, farming	Lifetime work history through self-administered questionnaires
Costantini *et al*. (2001) 12 areas in Italy 1991–93	1520 male cases (811 NHL+CLL, 383 leukaemia, 193 HD, 133 myeloma) aged 20-74 years, enrolled through periodic surveys of hospitals or the Varese Cancer Registry Age and sex stratified random sample of 918 controls from the general population of the study area	NHL+CLL Leukaemia	Painters	20 10	1.2 (0.6–2.4) 1.7 (0.8–3.8)	Age	Lifetime work history and occupational exposures from in-person interview

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Dryver *et al*. (2004) South Sweden 1990–98	859 cases identified from the South Swedish Tumor Registry; ≥18 years of age 1310 controls identified using Swedish unique personal identification numbers; matched by sex, age and parish	NHL	Painting	46	1.77 (1.13–2.76)	NG	Mailed questionnaire with list of jobs querried including painters and the FINJEM exposure matrix
North America							
Scherr *et al*. (1992) Boston, USA 1980–82	303 cases (152 males, 151 females), median age 65 years. 303 controls identified from a population register; matched on sex, age, town and precinct of residence	NHL	Painter, plasterer, housepainter	3	6.0 (0.9–38)	NG	Occupations held included most recent, 15 years ago, major, second major, and those linked to an exposure list obtained from in-person interviews or mailed questionnaires

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Blair *et al*. (1993) Iowa/Minnesota, USA 1980–83	622 white male cases obtained from state registries. 1245 white male population controls without a hematopoietic or lymphatic malignancy were obtained through random digit dialing (<65 years), Medicare files (≥65 years) or state vital records (for those matched to deceased cases); frequency matched by state, age, year of death (for deceased cases).	NHL	Painting/paper-hanging Painting/plastering/cementing *<10 years* *≥10 years*	16 NG NG	1.9 (0.9–3.8) 0.6 (0.1–2.0) 2.7 (1.1–6.6)	Age, state, smoking, family history of lympho-proliferative malignancies, agricultural pesticide exposure, hairy dye use, direct or proxy respondent	Detailed work history for all jobs held ≥ 1 year since the age of 18
Demers *et al*. (1993) Utah, Washington state, Atlanta, Detroit, USA 1977–81	692 cases identified from SEER registries, <80 years of age. 1683 population controls, aged 40–79 years, identified through random digit dialing and door-to-door sampling	MM	Painters *All respondents* *Self-responders* *With solvent exposure* *<10 years* *≥10 years*	 31 22 14 15 16	 2.1 (1.2–3.6) 2.5 (1.3–4.7) 3.1(1.5–7.5) 1.4 (0.6–2.8) 4.1 (1.8–10.4)	Sex, race, age, study area	Lifetime work history from in-person interview

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Blair *et al*. (2001) Iowa and Minnesota, USA 1980–83	513 white male leukemia cases, ≥30 years old, identified from the Iowa Cancer Registry and Minnesota hospital surveillance network 1087 population controls identified from RDD (<65 years), Medicare Lists (≥65 years), death certificates; frequency matched by 5-year age group, vital status and state of residence	AML CML ALL CLL Myelodyplasia Leukaemia	Painting, plastering, waterproofing, and related occupations ≥10 years employment	4 0 2 7 1	1.9 (0.6–5.9) NG 8.4 (1.4–51.3) 1.3 (0.5–3.2) 1.1 (0.1–8.9) 1.7 (0.7–4.2)	Age, state of residence, proxy interview, post-secondary education, with a lymphatic or hematopoietic tumour	Occupational history for all jobs held 1 year or more and JEM obtained during in-person interview
Kato *et al*. (2005) Upstate New York, USA 1995–98	376 female cases, aged 20–79, were identified from the New York Cancer Registry 463 female, age-matched, population-based controls were obtained through New York State DMV records (<65 years) or Medicare files (≥65 years)	NHL	Paint/varnish exposure	23	0.79 (0.40–1.58)	Age, year of interview, pesticide exposure, use of pain-relieving drugs, use of antibiotics, family history of hematologic cancer, college education, surrogate status, BMI	Paint exposure obtained through telephone interview

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Colt *et al*. (2007) USA (4 SEER areas) 1998–2000	551 cases, aged 20–74 years, identified from the SEER registry. 462 population controls, aged 20-74 years, identified using RDD (<65 years) or Medicare files (≥65 years); frequency matched on age, sex, race, study centre.	NHL	Hobby painting *Ever* *Lifetime hours* 0.5–104 105–520 521–1800 ≥1801	 144 43 39 23 32	 0.9 (0.6–1.2) 1.0 (0.6–1.6) 1.0 (0.6–1.8) 0.6 (0.3–1.1) 0.9 (0.5–1.6)	Age, race, education, sex, SEER study area	Hobby painting/-silkscreening/artwork exposure was obtained during in-person interviews
Ramanakumar *et al*. (2008) Montreal, Canada 1979–86	215 male cases, aged 35–70 years, from all large hospitals in the Montreal area. 1066 pooled controls (533 population controls and 533 other cancer controls) selected from electoral lists, RDD or from the same hospitals as cases	NHL	Ever worked as a painter *Substantial exposure* Any paint product Metal coatings Wood varnishes, stains Wood and gypsum paints	3 16 3 4 11	0.9 (0.2–4.1) 1.2 (0.6–2.6) 2.2 (0.6–8.1) 0.3 (0.1–2.3) 1.0 (0.4–2.6)	Age, ethnicity, years of school attendance, median family income, the status (self/-proxy) of the respondents, smoking and occupational exposure to asbestos, silica, cadmium compounds	Paint exposure from lifetime job history and an extensive checklist of potential exposures during an in-person interview

Table 2.4 (contd)

Reference, location, time period	Characteristics of cases and controls	Organ site	Exposure categories	No. of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Other Regions							
Bethwaite *et al*. (1990) New Zealand 1980–84	Male cases of 23 different cancers (535 NHL, 170 HD, 295 MM, 534 leukaemia), aged 20 years or older, were obtained from New Zealand Cancer Registry. 18 992 males with other cancers were obtained from the New Zealand Cancer Registry.	NHL HD MM Leukaemia MM	Ever painters *Age (years)* 20–59 ≥60	9 1 10 5 5 5	0.97 (0.50–1.90) 0.38 (0.06–2.54) 1.95 (1.05–3.65) 0.54 (0.23–1.30) 4.23 (1.80–9.91) 1.27 (0.52–3.10)	Age	Occupational data were collected through the cancer registry and death certificates
Adegoke *et al*. (2003) Shanghai, China 1987–89	486 cases (81 ALL, 21 CLL, 236 AML, 79 CML) selected from the Shanghai cancer registry; aged ≥15 years. 502 randomly selected general population controls listed in the resident registry, matched by age and sex.	Leukaemia ALL AML CML	Paint exposure *Men* *Women* *<15 years* *≥15 years* *≥15 years* *≥15 years* *≥15 years*	 32 25 30 27 6 10 7	 0.9 (0.5–1.5) 1.7 (0.9–3.4) 0.8 (0.5–1.3) 2.3 (1.2–4.7) 3.4 (1.2–9.5) 1.8 (0.7–4.2) 3.7 (1.4–9.9)	Age, gender, income	Lifetime history for jobs held 3 years or more

ALL, acute lymphocytic leukaemia; AML, acute myeloid leukaemia; BMI, body mass index; CLL, chronic lymphocytic leukaemia; CML, chronic myeloid leukaemia; DMV, Department of Motor Vehicles; HCL, Hairy-cell leukaemia; HD, Hodgkin disease; JEM, job-exposure matrix; NG, not given; NHL, non-Hodgkin lymphoma; MM, multiple myeloma; RAEB, refractory anaemia with excess blasts; RDD, random-digit dialling

The OR for employment as a painter was 13 (95% CI: 2.0–554; 13 cases and one control). Tobacco use was not associated with leukaemia.

Persson *et al.* (1989) assembled cases of lymphoma (Hodgkin disease and non-Hodgkin lymphoma) from the Orebro Medical Centre Hospital in Sweden during 1964–1986 for a study of occupational exposures. There were 54 Hodgkin disease cases (35 men and 19 women), and 106 non-Hodgkin lymphoma cases (66 men and 40 women), aged 20–79. A total of 275 controls (157 men and 118 women) who had originally been drawn from population registries for previous studies were included. A mailed questionnaire was used to gather information on chemical exposures on the job, and during leisure time. Two Hodgkin disease cases and two non-Hodgkin lymphoma cases reported jobs as painters, while no controls were painters.

La Vecchia *et al.* (1989) evaluated occupational exposure and risk of lymphoid neoplasms in a case–control study in Milan, Italy. Study subjects, aged 15–74 years, were assembled from hospitals in the area during 1983–1988. Results reported were 69 cases of Hodgkin disease (44 men and 25 women), 153 cases of non-Hodgkin lymphoma (93 men and 60 women), and 110 cases of multiple myelomas (56 men and 54 women). A total of 396 controls (269 men and 127 women) diagnosed with acute conditions were selected from hospitals providing cases. Trained interviewers obtained information on 16 occupations, 13 occupational exposures, and other potential risk factors. ORs were adjusted for age, sex, area of residence and smoking. Although ORs were not presented, the authors reported no significant association with painting.

Heineman *et al.* (1992) used the Danish Cancer Registry and the Danish Central Population Registry to evaluate occupational exposures and risk of multiple myeloma among men. A total of 1098 cases (diagnosed during 1970–1984) and 4169 age-matched population controls with occupational information were included in the analysis. Only the most recent occupation was available from recent pension records. Industries where the men were employed were available from 1964 to diagnosis. Possible exposures based on occupation and industry were assessed by Danish industrial hygienists. ORs were calculated adjusted for age. The OR for men employed in the paint industry was 2.3 (95% CI: 0.4–11.1; three cases), while occupational painters had an OR of 1.0 (95% CI: 0.5–2.1; 11 cases). Exposure to paints and lacquers classed as 'possible' had an OR of 1.0 (95% CI: 0.8–1.4; 69 cases), and exposure classed as 'probable' had an OR of 0.8 (95% CI: 0.6–1.2; 39 cases).

Cases diagnosed during 1975–1984 from the University Hospital in Linköping, Sweden were assembled for a case–control study of occupational exposures and malignant lymphoma among men (Persson *et al.*, 1993). A total of 31 cases of Hodgkin disease, 93 cases of non-Hodgkin lymphoma, and 204 controls were available for study. Controls were population-based and had been selected for other studies. A mailed questionnaire was used to gather information on occupational exposures, leisure time exposures, and other factors. The OR for Hodgkin disease among painters was 2.3 (90% CI: 0.4–11; two cases).

Persson & Fredrikson (1999) pooled data from two case–controls studies to evaluate the role of occupational exposures in the development of non-Hodgkin lymphoma. The data

came from Swedish studies located in Orebro (Persson *et al.*, 1989), and Linköping (Persson *et al.*, 1993). Described previously, both were population-based studies that used mailed questionnaires to gather information on occupational exposures. The OR for non-Hodgkin lymphoma among painters was 2.5 (95% CI: 0.5–9.6).

Mele *et al.* (1994) conducted a large case–control study (619 cases and 1161 controls) in Italy to study leukaemia, and refractory anaemia with excess blasts. Cases were identified in Rome, Bologna, and Pavia during 1986–1990. Controls with non-neoplastic disorders were obtained from the same haematology departments as cases. Cases and controls were interviewed while in the hospital. ORs were adjusted for age, sex, education, residence outside the study town, and occupations other than painters. Among male painters, the ORs were 3.2 (95% CI: 0.5–20.8; ten cases) for acute myeloid leukaemia, 4.7 (95% CI: 0.6–34.2; 26 cases) for acute lymphocytic leukaemia, 7.6 (95% CI: 1.5–39.8; 19 cases) for chronic myeloid leukaemia, and 5.4 (95% CI: 0.5–61.0; nine cases) for refractory anaemia with excess blasts.

Nordström *et al.* (1997) conducted a case–control study of hairy cell leukaemia in Sweden that included 111 male cases, identified from the Swedish Cancer Registry during 1987–1992, and 400 male controls, drawn from the National Population Registry and matched to cases on age and county. Information, including a complete working history, was obtained by mailed questionnaire. Occupations with more than ten cases and controls combined were analysed, controlling for age. Construction painters had an OR of 5.7 (95% CI: 1.6–20.8; six cases).

Hairy cell leukaemia and occupational exposures was studied among men in a case–control study in France (Clavel *et al.*, 1998). Cases ($n = 226$) diagnosed during 1980–1990 were identified in 18 hospitals around the country. Controls ($n = 425$) were selected from patients from the same hospitals and matched to cases on residence, date of birth, and hospital admission. Mailed self-administered questionnaires were used to gather information on a variety of factors including lifetime occupation. A telephone interview was conducted with subjects who were suspected to have had occupational solvent exposure. Matched analyses were performed and ORs were adjusted for smoking and farming. Painters had no excess of hairy cell leukaemia (OR, 1.0; 95% CI: 0.3–3.0; six cases).

Costantini *et al.* (2001) conducted a case–control study to evaluate occupational risk factors in relation to haematolymphopoietic cancers in Italy. A total of 2737 cases (811 non-Hodgkin lymphoma/chronic lymphocytic leukaemia, 383 leukaemia, 193 Hodgkin disease, and 133 myelomas) among men aged 20–74 years were identified from 12 areas in Italy during 1991–1993. Controls were a random sample of the population matched to the cases by age, sex, and study area. In-person interviews were conducted to gather information on many potential risk factors including a detailed occupational history. Age-adjusted ORs were presented separately for men and women. ORs among male painters were 1.2 (95% CI: 0.6–2.4; 20 cases) for non-Hodgkin lymphoma/chronic lymphocytic leukaemia, and 1.7 (95% CI: 0.8–3.8; 10 cases) for leukaemia. Results were not presented for Hodgkin disease or multiple myeloma.

Dryver *et al.* (2004) conducted a case–control study of non-Hodgkin lymphoma in southern Sweden. A total of 859 cases were enrolled during 1990–1998, and 1310 controls. Controls were matched to cases by age, gender, and parish and were identified using the unique Swedish personal identification number. Mailed questionnaires were used to gather information on demographics, smoking, education, occupations (up to eight), and occupational exposures. The questionnaire specifically enquired whether individuals had held a set of specific occupations that included occupation as a painter. The OR for occupation as a painter was 1.77 (95% CI: 1.13–2.76; 46 cases).

(b) North America

Scherr *et al.* (1992) conducted a population-based case–control study of occupational exposure in relation to non-Hodgkin lymphoma in the Boston area. A total of 152 men and 151 women were diagnosed with non-Hodgkin lymphoma during 1980–1982 and interviewed at nine participating hospitals. Controls were matched to cases by sex, age, town and precinct of residence. The participation rate was 80% for cases and 72% for controls. Participants provided information on a variety of possible risk factors including job held 15 years prior to interview, major occupation, second most major occupation, and up to two occupations. Analyses done to evaluate potential confounding indicated that no covariates needed to be included in the models. From the subjects, 1% were painters ($n = 3$) resulting in an OR of 6.0 (95% CI: 0.9–38).

Blair *et al.* (1993) conducted a case–control study of non-Hodgkin lymphoma among caucasian men in Iowa and Minnesota. Cases were identified from the Iowa State Health Registry during 1981–1983, and a surveillance network of hospitals in Minnesota during 1980–1982. Of 715 cases identified, 622 (87%) were interviewed. A total of 1245 caucasian male population controls – frequency-matched by state, age and by year of death for deceased cases – were selected from random-digit dialling (< 65 years), Medicare files (≥ 65 years), and death certificates (for those matched to deceased cases). Information on all jobs held for more than one year and other potential risk factors were obtained during an interview with subjects or their next-of-kin. ORs were adjusted for age, state of residence, agricultural use of pesticides, hair-dye use, family history of cancer, smoking, and direct or proxy respondent. The OR for employment in the painting/wallpaper-hanging industry was 1.9 (95% CI: 0.9–3.8; 16 cases). ORs for painting, plastering and cementing by duration were 0.6 (95% CI: 0.1–2.0) for < 10 years, and 2.7 (95% CI: 1.1–6.6) for 10 or more years.

Demers *et al.* (1993) conducted a case–control study of occupational exposures in relation to multiple myeloma (682 cases and 1683 controls) using four cancer registries in the Surveillance, Epidemiology and End Results (SEER) of the National Cancer Institute (NCI) located in Washington state, Utah, Atlanta, and Detroit. Population controls, obtained through door-to-door sampling and random digit dialling, had a similar age and sex distribution as the cases but were otherwise representative of the general population. Lifetime occupational histories were collected during in-person interviews. Analyses were performed separately for self and surrogate respondents, adjusted for age, sex, race, and geographic location. ORs for multiple myeloma were 2.1 (95% CI: 1.2–3.6; 31 cases) for

painters overall, and 2.5 (95% CI: 1.3–4.7; 22 cases) among self-respondents. Risks by duration of employment as a painter were 1.4 (95% CI: 0.6–2.8; 15 cases) for < 10 years, and 4.1 (95% CI: 1.8–10.4; 16 cases) for 10 or more years. Risks were greatest among self-responding painters who reported high exposure to paints or solvents (OR: 3.1; 95% CI: 1.5–7.5; 14 cases).

Blair *et al.* (2001) conducted a population-based case–control study of leukaemia among caucasian men in Iowa and Minnesota. Cases (n = 513) were assembled from the cancer registry in Iowa during 1981–1983, and from a surveillance network of hospitals in Minnesota during 1980–1982. Population controls (n = 1087) were selected by random-digit dialling for those aged under 65 years, Medicare files for those aged 65 years or older, and death certificates. Controls were frequency-matched by age, vital status, and state of residence. Information was obtained (including all jobs held more than one year) by in-person interviews. ORs were adjusted for age, state of residence, proxy interview, education, pesticide use, hair-dye use, smoking, and first degree relative with a cancer. Persons employed for 10 or more years in painting, plastering, waterproofing, and related occupations had an OR of 1.7 (95% CI: 0.7–4.2).

Kato *et al.* (2005) conducted a case–control study of non-Hodgkin lymphoma among women from upstate New York. Cases (n = 376) were identified from the New York State Cancer Registry during 1995–1998. Population-based controls (n = 463) were matched to cases by age and selected from the New York state driver's licence files for women aged under 65 years, and from Medicare files for women 65 years or older. Telephone interviews were conducted to obtain information on a variety of factors including exposure to paints and varnishes. ORs were calculated and adjusted for age, year of interview, pesticide exposure, use of pain-relieving drugs, use of antibiotics, family history of haematological cancer, college education, surrogate status, and body mass index (BMI). The OR for non-Hodgkin lymphoma from exposure to paints/varnishes was 0.79 (95% CI: 0.40–1.58; 23 cases). ORs by number of uses of paints/varnishes/lacquers (compared to no use) were 1.00 (95% CI: 0.60–1.68; 55 cases) for one to eight uses, 0.84 (95% CI: 0.50–1.40; 59 cases) for nine to 20 uses, 1.26 (95% CI: 0.77–2.07; 77 cases) for 21 to 59 uses, and 1.17 (95% CI: 0.70–1.97; 85 cases) for 60 or more uses (P for trend, 0.30).

Colt *et al.* (2007) evaluated the risk of non-hodgkin lymphoma in relation to exposures in hobby activities. Cases (n = 551) were men and women from four SEER areas (Iowa, Los Angeles county, Detroit and Atlanta) diagnosed during 1998–2000. Population-based controls (n = 462) were matched to cases by age, sex, race, and study centre, and selected from Medicare files (≥ 65 years) or from random digit dialling (< 65 years). In-person interviews were held to gather information on several potential risk factors including lifetime participation in hobbies involving painting, silk screening, and artwork. ORs were estimated by logistic or polychotomous regression while adjusting for age at interview, SEER area, sex, race, and education. Potential confounding from other exposures and factors was evaluated, but did not need to be included in the model. ORs for categories of lifetime hours of painting as a hobby compared to non-painters were 1.0 (95% CI: 0.6–1.6; 43 cases) for 0.5–104 hours, 1.0 (95% CI: 0.6–1.8; 39 cases) for 105–520 hours, 0.6 (95%

CI: 0.3–1.1; 23 cases) for 521–1800 hours, and 0.9 (95% CI: 0.5–1.6; 32 cases) for 1801 or more hours.

Ramanakumar *et al.* (2008) evaluated painting-related occupations and the risk of non-Hodgkin lymphoma, along with cancers of the oesophagus, stomach, colon, rectum, prostate, bladder, and kidney, in a re-analysis of Siemiatycki *et al.* (1994) data from a large case–control study from Montreal, Canada. The study included 215 non-Hodgkin lymphoma cases, a pooled control group of 533 population and 533 cancer controls, and a detailed assessment of exposures by a team of chemists and industrial hygienists. ORs were adjusted for age, family history, ethnicity, respondent status, education, and smoking. The OR for non-Hodgkin lymphoma among painters was 0.9 (95% CI: 0.2–4.1; 3 cases). ORs for persons exposed to wood and gypsum paints were 0.9 (95% CI: 0.5–1.7; 27 cases) for any level of exposure, and 1.0 (95% CI: 0.4–2.6; 11 cases) for substantial exposure.

(c) Other Regions

Bethwaite *et al.* (1990) conducted a case-control study based on a cancer registry in New Zealand during 1980–1984 to investigate the association between employment as a painter and risk of various cancers, including haematopoetic cancers. Cases (535 non-Hodgkin leukaemia, 170 Hodgkin disease, 295 multiple myeloma, 534 leukaemia) who reported an occupation were included in this study as well as male control patients of all other types of cancer. Painters were found to be associated with an increased risk of multiple myeloma (OR, 1.95; 95% CI: 1.05–3.65; ten cases), especially those painters aged 20–59 years (OR, 4.23; 95% CI: 1.80–9.91; five cases). The risk was not significantly increased for those aged 60 years and over (OR, 1.27; 95% CI: 0.52–3.10; five cases). For multiple myeloma, the risk was higher for car, spray, and signwriter painters (OR, 2.81; 95% CI: 0.73–10.7) than for construction and general painters (OR, 1.80; 95% CI: 0.89–3.64).

Adegoke *et al.* (2003) evaluated occupational exposures and risk of leukaemia in a case–control study from Shanghai, China. A total of 486 cases identified from the Shanghai Cancer Registry during 1987–1989 were interviewed. Controls ($n = 502$) were randomly selected from the urban Shanghai population and matched to cases on age and sex. In-person interviews were held to gather information on a variety of potential risk factors, including all jobs held for at least three years. Self-reported information was also gathered on a variety of specific exposures, including paints. ORs were adjusted for age, gender, and income. Among those ever exposed to paints, ORs were 1.2 (95% CI: 0.8–1.7; 57 cases) for all leukaemia, 1.1 (95% CI: 0.5–2.4; 10 cases) for acute lymphocytic leukaemia, 0.8 (95% CI: 0.5–1.4; 20 cases) for acute myeloid leukaemia, and 1.7 (95% CI: 0.9–3.2; 13 cases) for chronic myeloid leukaemia. For those exposed for 15 years or greater, ORs were reported as: 2.3 (95% CI: 1.2–4.7; 27 cases) for all leukaemia, 3.4 (95% CI: 1.2–9.5; six cases) for acute lymphocytic leukaemia, 1.8 (95% CI: 0.7–4.2; ten cases) for acute myeloid leukaemia, and 3.7 (95% CI: 1.4–9.9; seven cases) for chronic myeloid leukaemia. Those were larger than ORs reported for those exposed for shorter time periods: 0.8 (95% CI: 0.5–1.3; 30 cases) for all leukaemia, 0.5 (95% CI: 0.2–1.6; four cases) for acute lymphocytic leukaemia, 0.5 (95% CI: 0.2–1.1; ten cases) for acute myeloid leukaemia, and 1.0 (95% CI:

0.4–2.5; six cases) for chronic myeloid leukaemia. ORs for all leukaemia from potential exposure to paints differed between men (OR, 0.9; 95% CI: 0.5–1.5; 32 cases) and women (OR, 1.7; 95% CI: 0.9–3.4; 25 cases).

2.2.5 *Solid tumours*

(a) Multiple cancer sites

Case–control studies of solid tumours among persons potentially exposed to paints are listed in Table 2.5.

Bethwaite *et al.* (1990) conducted a case–control study of multiple cancers using data from the New Zealand Cancer Registry. Age-adjusted ORs were calculated comparing painters with a particular cancer against painters without that cancer (and cancers that could be caused by the same exposures as that particular cancer). Occupational information (current or recent jobs) was obtained from the cancer registry. A total of 23 types of cancer were evaluated including buccal cavity, oesophagus, stomach, colon, rectum, liver, gallbladder, pancreas, larynx, lung, soft tissue sarcoma, malignant melanoma, prostate, testis, bladder, kidney, brain/nervous system, non-Hodgkin lymphoma, Hodgkin disease, leukaemia, and others. There were no significant increases in risk except for bladder cancer, and multiple myeloma.

In case–control study, Bouchardy *et al.* (2002) identified 58134 incident cancer cases in men from five cantonal Swiss Cancer Registries (Basel, Geneva, St Gall, Vaud, and Zurich) during 1980–1993. The overall proportion with histological or cytological confirmation of diagnosis was 95.1%. The study was restricted to cases aged 25 years or more at registration (and less than 65 years in St Gall and Vaud). The longest, current or most recent occupation at registration was recorded (the main or most accurately specified occupation was used in the Zurich Registry). Subjects with unknown occupation were not reported separately. The association between different cancer sites and work in a pre-defined set of industries and occupation was studied by estimating ORs adjusted for age, registry, civil status, period of diagnosis, nationality, urban/rural residence and socioeconomic status. For each neoplasm, registrants for the other cancer sites were used as the reference. The results for all sites with at least five exposed cases (excluding cancers of the lung, bladder and haematopoietic system because they are mentioned below) are reported in Table 2.5. There were no notable increases in risk except for cancers of the renal pelvis (OR, 2.2; 95% CI: 1.1–4.2; 14 cases) and liver (OR, 1.4; 95% CI: 1.0–2.0; 39 cases). [Use of patients with all other types of cancers as controls in this study could complicate the interpretation of the observed association since some of the cancer types may well be linked to exposure to paints, and use of patients with all other types of cancers as controls would cause an underestimation of the association between painting and bladder cancer risk.]

Ramanakumar *et al.* (2008) evaluated painting-related occupations and the risk of several different cancers including cancers of the oesophagus ($n = 97$), stomach ($n = 248$), colon and rectum ($n = 754$), prostate ($n = 438$), bladder ($n = 478$), and kidney ($n = 174$), in a re-analysis of data from a large case–control study from Montreal, Canada [Siemiatycki *et*

al. (1994)]. A pooled control group of 533 population and 533 cancer controls was used along with a detailed assessment of exposures by a team of chemists and industrial hygienists. ORs were adjusted for age, family history, ethnicity, respondent status, education, and smoking. The results for all cancer sites (excluding bladder cancer and non-Hodgkin lymphoma) are reported in Table 2.5. The OR for oesophageal cancer among persons who ever worked as painters was 1.8 (95% CI: 0.3–15.0; four cases). ORs for persons exposed to wood and gypsum paints were 1.7 (95% CI: 0.8–3.6; 18 cases) for any level of exposure, and 0.7 (95% CI: 0.2–2.8; five cases) for substantial exposure. No other cancer sites showed any association with exposures to paint.

(b) Upper respiratory tract

Huebner *et al.* (1992) conducted a population-based case–control study of incident oral and pharyngeal cancer in the USA (Los Angeles, Santa Clara, San Francisco, and Atlanta). Cases ($n = 1114$) were identified from population-based cancer registries during 1984–1985. Population-based controls ($n = 1268$), frequency-matched to cases by sex, race, age, and study area, were selected by random digit dialling (aged 18–64 years), and from medicare files (aged 65–79 years). Interviews were conducted in person or with next-of-kin if necessary, and covered information on tobacco and alcohol use, oral hygiene, medical and dental history, demographic characteristics, and a detailed history of all jobs held 6 months or more since the age of 12 years. Potential confounding was evaluated for several factors but only age, race, smoking, alcohol, and study location were included in the final model. The OR for painters was 1.18 (95% CI: 0.58–2.39; 22 cases) for men and 1.12 (95% CI: 0.37–3.36; seven cases) for women. ORs for cancers by anatomical site among male painters were 0.97 (95% CI: 0.33–2.84; five cases) for tongue, 0.71 (95% CI: 0.22–2.34; five cases) for mouth, and 2.03 (95% CI: 0.87–4.71; 12 cases) for the pharynx.

Maier & Tisch (1997) and Maier *et al.* (1997) conducted a hospital-based case–control study of cancers of the upper aerodigestive tract at the University of Heidelberg in Germany. A total of 369 male cancer patients aged 40–85 years (100 cancers of oral cavity, 105 cancers of the pharynx, and 164 cancers of the larynx) and 1476 non-cancer controls matched by age and residence were recruited between 1988–1991. In questionnaire-based interviews, information on tobacco smoking, alcohol drinking, and occupational exposures was collected. For statistical analyses, exposures to paint, lacquer, and solvents were combined, and exposure was defined as being at least once per week and for a duration of at least 10 years. Using this exposure definition, 4.5%, 5.8%, and 12.6% of the matched control groups were considered exposed. The average exposure duration of cases was between 19.9–21.4 years. The ORs, adjusted for smoking and alcohol drinking, for cancer of the oral cavity was 3.6 (95% CI: 1.4–9.3), and for cancer of the larynx 2.3 (95% CI: 1.1–4.5). [Results were not reported for cancer of the pharynx associated with exposures to paint, lacquer, and solvents were combined, although the authors mentioned that risk was not increased.]

Armstrong *et al.* (2000) evaluated occupational exposures and the risk of nasopharyngeal cancer in the Malaysian Chinese population. Cases ($n = 282$) were

identified between 1990–1992 from four centres in the Selangor and the Federal Territory. Controls were selected from among the general Chinese population in the study area by randomly sampling individual houses. Participants provided information on smoking, diet, education, occupation, and housing type during an in-person interview. The OR for a 10-fold increase in exposure to paints or varnishes was 1.08 (95% CI: 0.91–1.29; 16 cases), adjusted for diet and smoking.

Boffetta *et al.* (2003) evaluated occupational exposures and cancer of the larynx and hypopharynx among men from selected areas in France, Italy, Switzerland, and Spain. Cases ($n = 1010$) were identified from cancer registries between 1980–1983. Population controls ($n = 2176$) were selected from census lists, electoral rolls, or population registries. Information on tobacco, alcohol, other risk factors, and all jobs held for at least one year since 1945 was obtained by in-person interviews. ORs were adjusted for age, study area, tobacco, and alcohol use. Construction painters had an OR of 1.36 (95% CI: 0.67–2.74; 18 cases).

Luce *et al.* (1993) indentified cases of cancers of the nasal cavity and paranasal sinuses ($n = 207$) diagnosed between 1986–1988 from 27 hospitals in France for a study of occupational exposures. A total of 409 controls were selected in two ways and pooled for analysis: one set of controls were patients with cancers other than those of the nasal cavity or sinus ($n = 323$), and the second set were individuals named by the cases ($n = 86$). Controls were matched to cases by age, sex and residence (friend controls only). Subjects were interviewed in person about socio-demographic characteristics, smoking habits, alcohol consumption, and a complete job history. Industrial hygienists assessed potential occupational exposures. ORs for specific histological types of nasal cancer were adjusted for multiple factors where appropriate. ORs for histological types of nasal cancer among men with probable or definite medium-to-high level exposure to paints, lacquers or varnishes were 0.9 (95% CI: 0.3–2.7; four cases) for squamous cell carcinoma, 12.2 (95% CI: 6.9–21.6; 35 cases) for adenocarcinoma, and 3.5 (95% CI: 1.3–9.3; six cases) for others.

Teschke *et al.* (1997a) conducted a population-based case–control study of nasal cancer in British Columbia, Canada. Cases ($n = 48$) were registered at the British Columbia Cancer Agency between 1990–1992. Controls ($n = 159$) were identified from provincial voters' lists and matched to cases by age and sex. Subjects, or next-of-kin if necessary, were interviewed in person or by telephone to obtain information on a variety of factors including occupational, residential, smoking, and medical histories.

Table 2.5 Case–control studies of solid cancers among painters grouped by major organ sites

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Multiple organ sites								
Bethwaite *et al.* (1990) New Zealand 1980–84	4224 male cases with known occupation among 5031 cases identified from the New Zealand Cancer Registry, aged 20 or more at registration; % microscopic confirmation not given All (15 680) male non-lung cancer registrants with known occupation, (out of 19 731 identified) from the same Registry and period, aged 20 or more at registration; % microscopic confirmation not given	Current/most recent occupation as recorded at the time of registration and smoking history obtained through telephone interview	Buccal Cavity (140–149) Oesophagus (150) Stomach Colon Rectum Liver Gallbladder Pancreas Larynx(161) Soft tissue sarcoma Melanoma Prostate Testis Bladder Kidney Brain, nervous system	Painter decorators, steel and other construction painters, car painters, spray painters, signwriters, other unclassified painters	10 5 19 28 25 2 3 6 6 1 14 43 5 24 14 10	0.78 (0.41–1.47) 0.70 (0.29–1.71) 1.04 (0.65–1.67) 0.74 (0.50–1.09) 0.99 (0.66–1.50) 0.61 (0.15–2.41) 1.41 (0.45–4.44) 0.57 (0.26–1.27) 1.06 (0.47–2.41) 0.43 (0.06–2.88) 0.73 (0.43–1.25) 1.02 (0.73–1.41) 0.99 (0.37–2.66) 1.52 (1.00-2.31) 1.45 (0.85–2.50) 1.29 (0.68–2.46)	Age	See Table 2.2 for results on lung cancer. See Table 2.3 for results on bladder cancer

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Bouchardy *et al.* (2002) Five cantons in Switzerland 1980–93	58 134 male incident cases from cantonal Cancer Registries, aged 25 or more (and 65 or less in St Gall and Vaud). Male patients with cancers other than the site studied from the same registries and period served as controls and therefore the number varies	Longest, current or most recent occupation as recorded at the time of registration (main or best specified occupation in Zurich Registry)	Oral cavity/ oropharynx (141, 143–6)	Painters/plasterers	40	1.2 (0.8–1.6)	Age, registry, civil status, period of diagnosis, nationality, urban/rural residence, socio-economic status	The Working Group only presented cancers with at least 5 exposed cases
			Other pharynx (148–9)		14	1.1 (0.6–1.9)		
			Oesophagus		21	0.9 (0.6–1.4)		
			Stomach		61	1.0 (0.7–1.3)		
			Cardia		11	0.7 (0.4–1.4)		
			Small intestine		6	1.0 (0.4–2.3)		
			Colon		75	1.0 (0.8–1.3)		
			Rectum		51	0.9 (0.7–1.2)		
			Liver		39	1.4 (1.0–2.0)		
			Gallbladder/ biliary tract		10	1.3 (0.7–2.4)		
			Pancreas		33	1.2 (0.8–1.7)		
			Larynx		24	1.2 (0.8–1.9)		
			Pleura mesothelioma		8	1.3 (0.6–2.8)		
			Soft tissue		5	0.8 (0.3–1.9)		
			Melanoma of skin		19	0.7 (0.5–1.2)		
			SCC		35	0.7 (0.5–1.0)		
			Basal cel carcinoma		100	1.0 (0.8–1.2)		
			Prostate		186	0.9 (0.7–1.0)		
			Testis		15	0.9 (0.5–1.5)		
			Other male genital		7	1.3 (0.6–2.9)		
			Kidney		26	1.0 (0.6–1.4)		
			Renal pelvis		14	2.2 (1.1–4.2)		
			Brain		21	1.0 (0.7–1.6)		
			Thyroid gland		6	0.8 (0.3–1.8)		

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Ramanakumar *et al.* (2008) Montreal, Canada 1979–86	Male cases from 18 hospitals in Montreal (97 esophagus, 248 stomach, 754 colorectal, 438 prostate, 478 bladder, 174 kidney, 215 NHL); aged 35–70 years; 100% histologically confirmed; 82% response rate. 1066 pooled age-matched controls (533 population controls from electoral lists and by random-digit-dialing, 533 controls from other cancers); response rate 72% and 84%	Detailed job history (including specific tasks and protective devices) obtained from in-person interviews and reviewed by a team of chemists and industrial hygienists who translated each job into a list of potential exposures by means of a checklist that included 294 substances	Stomach Colon and rectum Prostate Kidney Oesophagus Oesophagus	Painter *Wood/gypsum paints* Any level of exposure Substantial exposure *Any paint product* Any level of exposure Substantial exposure	7 19 17 6 4 18 5 21 10	0.8 (0.2–2.8) 1.2 (0.6–2.9) 1.1 (0.3–3.4) 1.0 (0.2–4.3) 1.8 (0.3–15.0) 1.7 (0.8–3.6) 0.7 (0.2–2.8) 1.4 (0.7–2.8) 1.8 (0.8–4.3)	Age, family income, ethnicity, respondent status, years of schooling, smoking	No other cancer sites showed any evidence of an association with type of paint or stain. Overlaps with Parent *et al.* (2000)

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Upper aerodigestive tract								
Huebner *et al.* (1992) USA (Los Angeles, Santa Clara, San Francisco, Oakland, Atlanta, New Jersey) 1984–85	1114 white and black cases (762 men, 352 women) from population-based cancer registries; aged 18–79 years; 100% histologically confirmed; 75% participation rate 1268 population controls (837 men, 431 women) obtained by RDD (aged 18–64 years) and from Medicare files (aged 65–79 years); frequency matched by age, race, sex, study area; 76% participation rate	Detailed occupational history for all jobs held ≥ 6 months since the age of 12 years obtained from in-person interview	Oral cavity, pharynx (141, 143-146, 148, 149)	Paints/varnish use/ manufacturing *Males* *Females* Painter: *Women* *Men* by subsite: *Tongue (141)* *Mouth (143-145)* *Pharynx (146, 148, 149)*	125 13 7 22 5 5 12	 0.99 (0.71–1.38) 0.89 (0.37-2.14) 1.12 (0.37–3.36) 1.18 (0.58–2.39) 0.97 (0.33–2.84) 0.71 (0.22–2.34) 2.03 (0.87–4.71)	Study location, age, race, sex, smoking, alcohol	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Maier & Tisch (1997); Maier *et al.* (1997) Germany 1988–91	369 male cases (100 oral cavity, 105 pharynx, 164 larynx) from the Otorhino-laryngology Department at the University of Heidelberg, Germany 1476 male noncancer hospital controls matched to cases on age and residence	Information on occupational exposures by questionnaire	Oral cavity Larynx	Exposed to paint, lacquer, or solvents ≥ once per week for ≥ 10 years	12 20	3.6 (1.4–9.3) 2.3 (1.1–4.5)	Smoking, alcohol use	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Armstrong *et al.* (2000) Malaysia (Selangor and Federal Territory) 1990–92	282 Chinese cases (195 men, 87 women) from 4 centres with radiotherapy; aged 19–74 years; 100% histologically confirmed SCC; 53% participation rate. 282 randomly selected Chinese population controls; matched by age and sex; 90% overall participation rate	Detailed lifetime occupational history obtained from an in-person interview	Nasopharynx	Tenfold increase in exposure to paints and varnishes	16	1.08 (0.91–1.29)	Smoking and diet	42% prevalent cases and 58% incident cases

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Boffetta *et al.* (2003) France, Italy, Switzerland, Spain 1980–83	1010 male cases from cancer registries; 100% histological confirmed 2176 male population controls from census lists, electoral rolls or population registries; same age distribution as cases	Occupational history for all jobs held one year obtained from in-person interviews	Larynx and hypopharynx (146.4, 146.5, 148, 149.8, 161)	Construction painters	18	1.36 (0.67–2.74)	Age, centre, alcohol, tobacco	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Luce *et al.* (1993) France 1986–88	207 cases; (167 men, 40 women) from 27 French hospitals; 99.5% histologically confirmed; 68.3% participation rate 409 pooled cancer and friend controls (320 men and 89 women); frequency matched by age, sex, residence (friend controls only); participation rates of 95% (cancer controls) and 83.5% (friend controls)	Detailed occupational history and exposures obtained from in-person interview; industrial hygienist exposure assessment	Nasal cavity and paranasal sinuses *SCC* *Adenocarcinoma* *Other*	Paints, lacquers, varnishes (men only) *low* *med/high* *low* *med/high* *low* *med/high*	 8 4 20 35 3 6	 1.0 (0.4–2.3) 0.9 (0.3–2.7) 3.9 (2.7–7.2) 12.2 (6.9–21.6) 1.0 (0.3–3.6) 3.5 (1.3–9.3)	Age	Men only for paint exposure analysis

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Teschke *et al.* (1997a), British Columbia, Canada 1990–92	48 cases (33 men, 15 women) selected from from the British Columbia Cancer Agency, aged 19–75 years; response rate 88.9%; 100% histologically confirmed 159 population-based controls (128 men, 31 women) selected from provincial voter lists, frequency matched to the age and sex distribution of cases; response rate 81.5%	Occupational history obtained by in-person or telephone interview	Nasal cavity and sinuses	Ever painter Employed as a painter with most recent 20 years removed	2 2	2.2 (0.2–17.9) 2.6 (0.2–24.8)	Cigarette smoking, sex, age	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Brown *et al.* (1988) Texas, USA 1975–80	183 white male SCC cases (136 alive, 47 dead) from hospital records and tumor registries; aged 30–79 years; 100% histologically confirmed; participation rates of 69.5% (living cases) and 67.5% (dead) 250 white male population controls (179 alive, 71 dead) from mortality tapes, driver's license records (< 65 years) and Medicare files (≥ 65 years); frequency matched by age, vital status, ethnicity and county of residence; participation rates of 62.8% (dead), 60.9% (< 65 years), 85.7% (≥ 65 years)	Detailed lifetime occupational history for all jobs held 6 months from in-person interview	Larynx (161, 231.0)	Painter Paints	11 32	2.30 (0.84–6.31) 1.79 (1.00–3.22)	Smoking, alcohol	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Wortley *et al.* (1992) Seattle, WA, USA 1983–87	235 cases from the SEER registry; aged 20–74 years; 100% histologically confirmed; 80.8% participation rate 547 population controls RDD; matched by age and sex; 80% participation rate	Detailed lifetime occupational history for jobs held, ≥ 6 months, obtained from in-person interview	Larynx (161.0-161.9)	Painters *10 year lag* Spray paint machine operators Construction painters	14 14 NG NG	2.8 (1.1–6.9) 2.3 (0.9–5.7) 2.4 (0.5–11.2) 1.6 (0.4–6.6)	Alcohol, smoking, age, education	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Gastrointestinal tract								
Parent *et al.* (2000) Montreal, Canada 1979–85	99 male cases who were Montreal residents; aged 35–70; 100% histologically confirmed (63 SCC); 75% response rate. 533 age-matched population controls selected from electoral lists by RDD; 71% response rate	Lifetime work history obtained from in-person interview and exposures were assessed by industrial hygienists	Oesophagus *All subtypes* *SCC*	Other paints/ varnishes *Any exposure* *Non-substantial* *Substantial* *Any exposure* *Non-substantial* *Substantial*	 18 12 6 16 10 6	 1.5 (0.8–2.6) 2.0 (1.0–4.1) 1.0 (0.4–2.4) 2.3 (1.2–4.4) 2.8 (1.2–6.3) 1.8 (0.7–4.7)	Age, birthplace, education, respondent type, smoking, alcohol, β-carotene intake	Overlaps with Ramanakumar *et al.* (2008)
Jedrychowski *et al.* (1990) Poland 1986–90	562 male adenocarcinoma cases; aged < 75 years; 100% histologically confirmed 572 male age-matched non cancer hospital controls	Occupational histories obtained during in-person interviews	Stomach	Painters/tanners	12	4.0 (1.3–12.7) 3.4 (1.1–11.1)	Age, education, residency, occupational status Above factors, diet, vodka drinking	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Cocco *et al.* (1998) 24 States in USA 1984–92	1056 male cases (1023 whites, 33 blacks) from death certificates; aged ≥ 20 years 5280 persons who died from non-malignant disease; matched to cases on geographic region, race, gender, and 5-year age group	Usual occupation and industry from death certificate	Gastric cardia	Painters, construction and maintenance	6	0.6 (0.2–1.4)	Age, marital status, urban versus rural, marital status, socio-economic status	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Ji *et al.* (1999) Shanghai, China 1990–93	446 cases (260 men, 186 women) from the Shanghai Cancer Registry; aged 30–74 years; 100% histologically confirmed; 78.2% response rate 1551 population controls (845 men, 696 women) randomly selected from Shanghai residents; frequency matched by age, gender	Lifetime work history from in-person interview	Pancreas	Glass manufacturer, potter, painter, construction worker *Men* <35 years 35+ years *Women*	 10 7 3 4	: 2.6 (1.1–6.3) 2.5 (0.9–6.8) 3.0 (0.7–13.8) 0.6 (0.2–1.9)	Age, education income, smoking, other occupations	
Alguacil *et al.* (2000) eastern Spain 1992–95	164 cases (96 men, 68 women); 89% participation rate 238 hospital controls (167 men, 71 women); 90% participation rate	Job history and list of 10 activities, other activities performed ≥ 6 years obtained from in-person interview	Pancreas	Male painters, varnishes, related workers *Years worked* < 20 years 20+ years *Exposure window before diagnosis* 5-15 years >15 years	 0 3 2 0	 0.1 (0.0–2.0)[a] 5.3 (0.5–61.2) 1.6 (0.2–14) 0.3 (0.0–7.1)[a]	Age, hospital, smoking, coffee, alcohol, tobacco	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Kaerlev *et al.* (2002) Denmark, Sweden, France, Germany, Italy 1995–97	84 cases (51 men, 33 women); aged 35–69; 85% participation rate 2070 controls (1447 men, 623 women) from population registers; matched by age, sex, residence; 62% participation rate	Detailed history of all jobs held 6 months or more obtained from in-person and/or telephone interview	Small bowel carcoid tumor	Construction painters *No lag* *10 year lag* *25 year lag*	 3 3 3	 3.3 (0.9–12.0) 3.5 (1.0–12.8) 3.6 (1.0–13.1)	Sex, country, birth year	
Reproductive and genitourinary organs								
Habel *et al.* (1995) Washington state, USA 1988–90	537 white female cases from the SEER registry; aged 50–64 years; 100% histologically confirmed; 81.4% participation rate 492 white female population controls selected by RDD; aged 50–64 years; 73% participation rate	Detailed history of the 3 longest jobs held since age 17 obtained from in-person interview	Breast	Painters/sculptors/ printmakers *Any* *5 year duration* *10+ years latency*	 5 3 4	 1.7 (0.4–7.4) 1.0 (0.2–4.9) 1.4 (0.3–6.2)	Age, parity, education, alcohol, BMI	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Shu *et al.* (1989) Shanghai, China 1984–86	229 cases; aged 18–70 years; 94.3% histologically confirmed; 88.8% participation rate	Occupation obtained through in-person interview	Ovary *Epithelial* *Non-epithelial*	Painters, chemical processors and related workers, rubber and plastic products makers, leather workers	 6 4	 2.7 (0.6–13.9) 1.0 (0.2-3.8)	Education, number of livebirths, ovarian cyst, age at menarche	
	229 age-matched population controls		*Epithelial* *Non-epithelial*	Occupational exposure to paint	18 4	2.2 (0.8–5.9) 3.7 (0.4–34.2)		
Brownson *et al.* (1988) Missouri, USA 1984–86	1239 white male cases selected from the Missouri cancer registry.	Usual occupation and industry from registry records	Prostate	Paint/varnish manufacturing	5	5.7 (1.4–24.3)	Age	
	3717 white male cancer controls selected from the Missouri cancer registry							

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Sharpe *et al.* (2001) Montreal, Canada 1979–85	400 male cases; aged 47–70 years; 97% histologically confirmed; 80.6% participation rate 476 male population controls selected from electoral lists or by RDD; aged 45–70 years; matched by age and residence; 64.3% participation rate	Lifetime work history and leisure activities were obtained during in-person interviews to estimate exposures	Prostate	Often painting, stripping or varnishing furniture for leisure Leisure exposure to paints, lacquers, or stains	10 50	2.1 (0.7–6.7); 1.0 (0.6–1.5)	Age, ethnicity, respondent type, family income, BMI, smoking and alcohol use	
Asal *et al.* (1988) Oklahoma, USA 1981–84	315 cases from 29 hospitals in Oklahoma. 313 hospital controls matched to cases on sex, race, age, hospital and date of admission; 336 population controls selected by RDD and matched to cases on sex and age	Longest job held more than one year and industrial exposures obtained during an interview	Renal cell	Painting/paint manufacturing (men only)	22	1.3 (0.7–2.6)	Age	[There was no information on conditions of the hospital controls.]

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Delahunt *et al.* (1995) New Zealand 1978–86	914 cases (710 men, 204 women) from the New Zealand Cancer Registry with an active occupational code; age > 20 years 12 756 male cancer controls with non-urinary tract tumours	Current or most recent occupation at the time of registration	Renal cell	Male painters	NG NG	1.59 (1.00–2.43) 1.79 (1.31–3.44)	Age only Age and smoking	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Pesch *et al.* (2000b) Germany 1991–95	935 cases (570 men, 365 women) from hospitals; 88.5% response rate; 100% histologically confirmed 4,298 population-based controls (2650 men, 1648 women) selected by RDD, matched by region, age and sex; response rate 71%	Lifetime occupational history obtained from in-person interview. Two JEMs and 1 JTEM were used to assess exposure to occupational agents	Renal cell	Painters,tanner,dyers and related occupations *Women* *Men* *Duration* Medium Long Very long	 1 19 12 10 5	 0.6 (0.1–5.2) 1.9 (1.1–3.3) 1.6 (0.8–3.0) 1.4 (0.7–2.8) 2.3 (0.8–6.8)	Age, study centre and smoking	It is not clear if the "painters, dyers" for the duration analyses are the same as the "painters, tanners, dyers, and related occupations" for the ever/never analyses. Also for the duration analysis, the sum of exposed cases for "painters, dyers" is 26, while the number for the ever/never analysis is 19

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Mattioli *et al.* (2002) Bologna and surrounding Province, Italy 1987–94	249 cases from the University Hospital in Bologna; 100% histologically confirmed; 76.9% response rate 238 hospital controls without renal cell carcinoma matched on gender, age, birthplace, district, same cluster of small towns, and in plains or hill; 73.5% response rate	Written questionnaire obtained occupational history; occupational exposures coded by an industrial hygienist	Renal cell	Male painters	5	0.31 (0.06–1.56)	Adjustment factors not clear. Used conditional logistic regression thus matching factors should already be adjusted for	No data for women

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Brüning *et al.* (2003) Germany, 1992–2000	134 cases who had undergone a nephrectomy at a hospital in Arnsberg; no age restriction; 100% histologically confirmed; 82.7% response rate 401 hospital controls selected without dementia or cancer; matched to cases by sex and 5-year age category	In-person interviews obtained every job held at least one year; Specific exposures estimated using a British JEM	Renal cell	Paints and Pigments *Low exposure (below median)* *High exposure (above median)*	 10 9	 2.35 (0.94–5.87) 2.14 (0.86–5.31)	Age, gender, smoking	18 out of 19 substances evaluated resulted in elevated ORs
Brain tumours								
Krishnan *et al.* (2003) USA 1991–94 and 1997–99	879 adult cases from the Northern California Cancer Center SEER registry 864 controls from RDD; matched to cases by age, race, and gender	Lifetime job history for all jobs longer than 3 months (1991-1994) or longer than 1 year (1997-1999) from in-person interview	Brain (Gliomas) Astrocytoma Nonastrocytoma	Painters *Ever* *Longest job* *Men* *Women* Painters	 17 6 4 2 5 1	 1.04 (0.52–2.07) 1.02 (0.33–3.17) 0.78 (0.21–2.93) 2.16 (0.19–24.0) 1.20 (0.36–4.00) 0.59 (0.07–5.14)	Age, ethnicity, gender	Overlaps with study by Corozza *et al.* (2000) (see text)

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Rajaraman *et al.* (2004) Phoenix, Boston, Pittsburgh, USA 1994–98	293 cases (197 meningioma, 96 acoustic neuromas); ≥ 18 years old; > 93% participation rate 799 hospital controls; frequency matched by hospital, sex, race, age, residence; 86% participation rate	Detailed history of all jobs held 6 months or more obtained from in-person interview	Brain (Meningioma)	Painters *Ever worked* *Worked ≥ 5 years*	 2 1	 0.5 (0.1–2.2) 0.9 (0.1–7.2)	Hospital, sex, race, age, residence	No cases of acoustic neuroma had ever worked as a painter
Other sites								
Serraino *et al.* (1992) Northeastern Italy 1985–91	93 cases (53 men, 40 women); aged 16–79 years; 100% histologically confirmed 721 hospital controls (371 men, 350 women); aged 17-79 years	Employment in 17 industries and exposure to 15 occupational agents obtained through interview	Soft-tissue sarcoma	Dyes/paints *≤10 years* *>10 years*	 4 4	 0.9 (0.3–2.9) 0.9 (0.2–2.7)	Age, sex	

Table 2.5 (contd)

Reference, study location and period	Characteristics of cases and controls	Exposure assessment	Organ Site (ICD-9)	Exposure categories	No.of exposed cases	OR (95% CI)	Adjustment for potential confounders	Comments
Fritschi & Siemiatycki (1996) Montreal, Canada 1979–85	103 male cases; aged 35–70 years; 100% confirmed histologically; 83% response rate. 1066 pooled male controls (533 population controls and 533 other cancer controls) selected from electoral lists, RDD or from the same hospitals as cases; 71% response rate	Detailed lifetime job history obtained through in-person interviews. Responses reviewed by chemists and industrial hygienists	Melanoma	Paint and varnish *Insubstantial* *Substantial* *Any*	 14 2 16	 3.0 (1.5–6.0) 0.4 (0.1–1.9) 1.7 (0.9–3.1)	Age, ethnicity, education	
Teschke *et al.* (1997b) British Columbia, Canada 1990–92	51 histologically confirmed cases selected from the British Columbia Cancer Agency; aged ≥ 19 years. 154 age-and sex-matched population controls selected from electoral lists	Occupational history obtained by in-person or telephone interview	Pleural mesothelioma	Painters *Ever employed* *Last 20 years removed*	 6 5	 4.5 (1.0–23.7) 5.4 (0.9–39.3)	Age, sex	

[a] Crude or computed using the Woolf-Haldane correction

Self-reported exposure information associated with these cancers was also.collected. ORs were adjusted for age, sex, and cigarette smoking. Some analyses were sex-specific. The ORs for persons ever employed as a painter was 2.2 (95% CI: 0.2–17.9; two cases), and 2.6 (95% CI: 0.2–24.8; two cases) with most recent 20 years of exposure removed.

Brown *et al.* (1988) conducted a population-based case–control study of cancer of the larynx among caucasian male residents of the Texas Gulf Coast to assess occupational risk factors. A total of 183 laryngeal cancer cases (136 alive, 47 dead) were identified from hospitals in a six-county area of the Gulf Coast between 1975–1980, and the alive cases interviewed. Controls ($n = 250$) from the area were matched to cases by age, vital status, ethnicity and county of residence, and were selected from Texas mortality files, driver's licence records for those under age 65, and Medicare files for those over age 65. Interviews were conducted with subjects, or next-of-kin, to obtain information on alcohol and tobacco use, diet, demographic factors, and lifetime occupational and residential histories. Tobacco and alcohol use was included in all models. Vital status, age, education, county of residence and certain dietary factors were evaluated as potential confounders but were not included in the final models. The adjusted OR for painters for cancer of the larynx was 2.30 (95% CI: 0.84–6.31; 11 cases). Workers with potential exposure to paints had an adjusted OR of 1.79 (95% CI: 1.00–3.22; 32 cases). ORs by years of exposure were 1.7 (95% CI: 0.7–3.8) for < 5 years, 2.3 (95% CI: 0.7–7.4) for 5 to 14 years, and 1.6 (95% CI: 0.5–4.8) for 15 or more years.

Wortley *et al.* (1992) conducted a case–control study of cancer of the larynx in western Washington state, USA. A total of 291 cases were identified between 1983–1987 through the cancer surveillance system of the the Fred Hutchinson Cancer Research Centre in Seattle, WA, of which, 235 were interviewed. Controls ($n = 547$), identified by random-digit dialling, were matched to the age and sex distribution of cases. In-person interviews were held to gather information on a variety of factors, including lifetime occupational histories, and tobacco and alcohol use. ORs for cancer of the larynx were adjusted for age, tobacco, alcohol, and education. ORs for painters and sculptors were 1.0 (95% CI: 0.2–6.3; three cases) for those ever employed as a painter or sculptor, and 1.2 (95% CI: 0.2–7.7; three cases) excluding the most recent 10 years of exposure. ORs for painters were 2.8 (95% CI: 1.1–6.9; 14 cases) for those ever employed as a painter, and 2.3 (95% CI: 0.9–5.7; 14 exposed cases) excluding the most recent 10 years of exposure. Among the painters, the ORs for spray paint machine operators was 2.4 (95% CI: 0.5–11.2), and 1.6 (95% CI: 0.4–6.6) for construction painters. [The definition of 'painters, sculptors' and 'painters' is not clear.] No trend by years of employment or exposure was evident.

(c) Gastrointestinal cancers

In a study to evaluate gastrointestinal cancer among workers exposed to asbestos, Kang *et al.* (1997) also provided PMRs for various occupations, including construction painters. The study included over four million deaths in 28 states in the USA during 1979–1990. The proportion of deaths from gastrointestinal cancer in occupations of specific interest were compared to the proportion in all other occupations, adjusted for age, and stratified by race

and sex. There were 89 deaths from gastrointestinal cancer among construction painters. PMRs among construction painters were 89 (95% CI: 81–124) for gastrointestinal cancer, 132 (95% CI: 75–214) for oesophageal cancer, 113 (95% CI: 67–178) for gastric cancer, and 91 (95% CI: 68–118) for colorectal cancer.

Parent *et al.* (2000) reported on a population-based case–control study of oesophageal cancer among men in Montreal which was part of a study of many cancers in the Montreal area (Siemiatycki, 1991). A total of 99 histologically confirmed cases of oesophageal cancer recorded during 1979–1985 were included. A control group of patients with other cancers ($n = 2299$) and population controls ($n = 533$) selected from electoral lists by random digit dialling were included. A pooled group ($n = 1066$) of 533 population controls and 533 cancer controls were included in the analysis. Information was obtained by questionnaire on a variety of factors including age, birth place, education, tobacco and alcohol use, and a detailed lifetime occupational history. 'Other paints and varnishes' was one of the exposure categories based on evaluation of occupational histories by a team of chemists and industrial hygienists. ORs for any exposure to 'other paints and varnishes' were 1.5 (95% CI: 0.8–2.6; 18 cases) for all histological types, and 2.3 (95% CI: 1.2–4.4; 16 cases) for squamous cell carcinoma. ORs for non-substantial exposure were 2.0 (95% CI: 1.0–4.1; 12 cases) for all histological types, and 2.8 (95% CI: 1.2–6.3; ten cases) for squamous cell carcinoma. ORs for substantial exposure were 1.0 (95% CI: 0.4–2.4; six cases) for all histological types, and 1.8 (95% CI: 0.7–4.7; six cases) for squamous cell carcinoma.

A hospital-based case–control study of stomach cancer drew cases from nine university hospitals in Poland during 1986–1990 (Jedrychowski *et al.*, 1990). A total of 562 adenocarcinoma cases were identified among men. Male controls ($n = 572$) were surgical patients admitted for various conditions, such as accidents or orthopaedic problems. Patients were interviewed in the hospital before surgery to obtain information on demographic characteristics, food preparation, alcohol use, and occupation. ORs were adjusted for age, education, residency, and occupational status. The OR for cancer of the stomach among painters and tanners was 4.0 (95% CI: 1.3–12.7; 12 cases), and 3.43 (95% CI: 1.07–11.08), respectively, when further adjusted for dietary habits, and vodka drinking.

Cocco *et al.* (1998) conducted a case–control study of gastric cardia between 1984–1992 using data from a mortality file from 24 states in the USA. Deaths from gastric cardia cancer ($n = 1056$) were matched to five control subjects ($n = 5280$) who died from non-malignant disease by geographic region, race, gender, and age. Usual occupation and industry were abstracted from death certificates. The OR was calculated by logistic regression, and adjusted for age, marital status, rural versus urban residence, and socioeconomic status (based on occupation). It was reported as 0.6 (95% CI: 0.2–1.4) for caucasian male construction and maintenance painters.

Ji *et al.* (1999) conducted a population-based case–control study of pancreatic cancer in Shanghai between 1990–1993. Cases ($n = 451$) were identified from the Shanghai Cancer Registry. Control ($n = 1541$) were selected from the resident population of Shanghai and matched to the cases by age and gender. Subjects were interviewed in person to obtain information on demographic and residential characteristics, diet, tobacco and alcohol use,

medical and family history, and lifetime occupational history. ORs were calculated and were adjusted for age, education, income, smoking, and other high risk occupations. Other potential confounders were evaluated and found not to affect ORs. ORs for the grouping of glass manufacturer, potter, construction worker, and painter were 2.6 (95% CI: 1.1–6.3; ten cases) among men, and 0.6 (95% CI: 0.2–1.9; four cases) among women. ORs by years of working in this occupational grouping among men were 2.5 (95% CI: 0.9–6.8; seven cases) for employment of < 35 years, and 3.0 (95% CI: 0.7–13.8; three cases) for those employed 35 years or longer, compared to individuals never employed in these jobs.

Alguacil *et al.* (2000) conducted a case–control study of occupation and pancreatic cancer in five hospitals in eastern Spain during 1992–1995. A total of 164 cases, and 238 hospital controls were included. Controls were patients without pancreatic cancer who were initially admitted to the hospital with a suspicion of chronic pancreatitis or pancreatic or biliary cancer. Subjects were interviewed in the hospital to obtain information on occupation and lifestyle. ORs were calculated and were adjusted for age, smoking, coffee consumption, and alcohol use. Among male painters, varnishers, and related workers, compared to no employment in these jobs, the ORs were 0.1 (95% CI: 0.0–2.0; no cases; crude OR computed with the Woolf-Haldane correction) for those employed less than 20 years, 5.3 (95% CI: 0.5–61.2; three cases) for those employed 20 or more years, and 1.6 (95% CI: 0.2–14; two cases) for those exposed 5–15 years before diagnosis.

Kaerlev *et al.* (2002) conducted a population-based case–control study of small intestine carcinoid tumours in Sweden, Denmark, France, Germany, and Italy. A total of 84 cases and 2070 controls, matched to the cases by age, sex, and residence, were selected from population registries and interviewed. Interviewers obtained information on a variety of lifestyle factors and all jobs held for at least 6 months. ORs were calculated and were adjusted for sex, country and year of birth. ORs for construction painters were 3.3 (95% CI: 0.9–12.0; three cases) for no exposure lag, 3.5 (95% CI: 1.0–12.8; three cases) for a 10-year lag, and 3.6 (95% CI: 1.0–13.1; three cases) for a 25-year lag. ORs for specific occupational activities among painters were 5.6 (95% CI: 0.7–43.3; three cases) for sandblasting, 7.6 (95% CI: 0.9–66.3; five cases) for paint stripping with a blowtorch, 2.1 (95% CI: 0.2–26.6; six cases) using a solvent-based paint, 6.0 (95% CI: 0.5–74.7; six cases) using a rust-preventive paint, and 9.1 (95% CI: 0.8–107; six cases) using of a rust-preventive paint containing lead.

(d) Reproductive and genitourinary organs

Habel *et al.* (1995) evaluated occupational risks for breast cancer among caucasian women in a population-based case–control study in Washington state, USA. A total of 537 cases were identified from a cancer registry covering western Washington during 1988–1990. Population controls ($n = 492$) were selected by random digit dialling and matched to cases by age. In-person interviews were held to gather information on a variety of risk factors including a detailed history of the three occupations held for the longest period of time since the age of 17 years. ORs were adjusted for age, parity, BMI, education, and alcohol consumption. The OR for employment as a painter, sculptor or printmaker was 1.7 (95%

CI: 0.4–7.4; five cases). Employment in these occupations by duration of employment were 1.0 (95% CI: 0.2–4.9; three cases) for 5 or more years, and 1.4 (95% CI: 0.3–6.2; four cases) for 10 or more years.

Shu *et al.* (1989) conducted a population-based case–control study of ovarian cancer in Shanghai. Cases ($n = 229$) were identified from the Shanghai Cancer Registry during 1984–1986. Controls were selected from the Shanghai general population and matched to cases by age. Participants were interviewed to obtain information on demographic characteristics, reproductive history, medical history, familial cancer history, personal habits, diet and occupation. ORs were adjusted for education, reproductive history, ovarian cysts, and age at menarche. ORs for occupational exposure to paint was 2.2 (95% CI: 0.8–5.9; 18 cases) for epithelial ovarian cancer, and 3.7 (95% CI: 0.4–34.2; four cases) for non-epithelial ovarian cancer.

Brownson *et al.* (1988) evaluated occupational risks for cancer of the prostate in cases ($n = 1239$) selected from the Missouri Cancer Registry during 1984–1986.. Age-matched controls were selected from other cancer cases ($n = 3717$). Information on smoking and alcohol use as well as occupation (occupation held for the longest period of time) were available from registry files. ORs were calculated using two control groups: all-controls and all-controls except for lung and bladder cancer. The OR among persons employed in the manufacture of paints and varnishes using all-controls was 5.7 (95% CI: 1.4–24.3; five cases). No controls in the second control group were employed in this industry.

Sharpe *et al.* (2001) reported on occupational exposures and prostate cancer in a case–control study among men from Montreal. Cases ($n = 400$) were identified during 1979–1985. Population controls ($n = 476$) were selected from electoral lists or by random-digit dialling. Subjects were interviewed at home or in the hospital. Information on a variety of risk factors and a detailed history on occupations and occupational exposures as well as non-occupational exposures was gathered. Specific occupational exposures were assessed by chemists and industrial hygienists. ORs were adjusted for age, ethnicity, respondent status, income, BMI, and tobacco and alcohol consumption. The OR among individuals reporting painting, stripping or varnishing furniture often during leisure time was 2.1 (95% CI: 0.7–6.7; ten cases). The OR for self-reported exposure to paints, lacquers, or stains was 1.0 (95% CI: 0.6–1.5; 50 cases).

Asal *et al.* (1988) evaluated occupational risk factors renal cell cancer in case–control study (cases, $n = 315$) recorded during 1981–1984 from 29 hospitals in Oklahoma, USA. Hospital ($n = 313$) controls were matched to cases on age, sex, race, hospital and date of admission. Population controls ($n = 336$) selected by random digit dialling were matched to cases by age and sex. Information gathered was analysed to identify occupations held for longet than 1 or more years. The OR for men employed in painting or paint manufacturing was 1.3 (95% CI: 0.7–2.6; 22 cases).

Delahunt *et al.* (1995) conducted a case–control study of occupational risk factors for renal cell carcinoma within the New Zealand Cancer Registry (NZCR) during 1978–1986. The NZCR captures and codes the current and most recent occupation at the time of registration. A total of 914 cases (710 men, 204 women) with an active occupation coded

were identified as well as 12 756 male controls with non-urinary tract tumours. Women were excluded from the analysis due to a low representation of female cases with "at-risk" occupations. Among painters, the OR for renal cell carcinoma was 1.59 (95% CI: 1.00–2.43) when adjusted for age only, and 1.79 (95% CI: 1.31–3.44) when stratified by age and smoking history.

Pesch *et al.* (2000b) conducted a population-based case–control study of renal cell carcinoma in Germany. Cases (570 men and 365 women) were recorded during 1991–1995 from five regions (West Berlin, Bremen, Leverkusen, Halle, and Jena). Population controls (2650 men and 1648 women) were selected from local residency registries and matched to cases by region, age, and sex. Occupational histories covered all occupations held for at least one year. Job exposure matrices (JEMs) developed in Germany and Great Britain were used to assess specific exposures. Conditional logistic regression was used to calculate ORs, adjusting for smoking as a potential confounder. The ORs for painters, tanners, dyers, and related occupations were 1.9 (95% CI: 1.1–3.3; 19 cases) for men, and 0.6 (95% CI: 0.1–5.2; one case) for women. The ORs for male painters and dyers by duration of employment were 1.6 (95% CI: 0.8–3.0; 12 cases) for the 30th percentile, 1.4 (95% CI: 0.7–2.8; ten cases) for the 31st to 60th percentile, and 2.3 (95% CI: 0.8–6.8; five cases) for the 60th percentile or greater. [It is not clear if the "painters/dyers" for the duration analyses were the same as the "painters, tanners, dyers, and related occupations" for the ever/never analyses. Also, in the duration analysis, the sum of exposed cases for "painters/dyers" was 26, while the number for the ever/never analysis was 19.] ORs from the British JEMs on paints were for "paints and pigments" (0.9, 1.1, and 1.6 for medium, high, and substantial exposure among men, and 1.8, 1.1, and not calculable for the same categories among women). The German JEM for paints produced ORs of 1.1, 1.3, and 1.1 for medium, high and substantial exposure to paints among men, and 1.2, 1.2, and 0.6 for the same categories among women.

Mattioli *et al.* (2002) evaluated risk for renal cell cancer in a hospital-based case–control study in northern Italy. A total of 324 cases were identified at the University Hospital of Bologna during 1987–1994. Controls ($n = 324$) were individuals admitted to the hospital for anything other than renal cell cancer and residing in the same geographic area. Controls were matched to cases by age, gender, place of birth, same urban area, same cluster of small towns, and plains or hills. The OR for male painters was 0.31 (95% CI: 0.06–1.56; five cases). ORs were calculated by matched analysis and additionally adjusted for BMI, smoking, alcohol consumption, use of phenacetin and diuretics, meat consumption, coffee consumption, occupation titles and related exposures.

Brüning *et al.* (2003) conducted a case–control study of renal cell carcinoma in Arnsberg and surroundings, Germany. Interviews were completed with 134 cases identified during 1992–2000. Controls ($n = 401$) without dementia and with no diagnosis of cancer were selected from the same hospitals and matched to cases by age and sex. Information was obtained on all occupations held for longer than 1 year. A British JEM was used to classify jobs by exposure. Conditional regression was used to calculate ORs, adjusted for gender, age, and smoking. The OR for individuals potentially exposed to paints/pigments at

low levels was 2.35 (95% CI: 0.94–5.87; ten cases), and 2.14 (95% CI: 0.86–5.31; nine cases) for high levels.

(e) Other solid tumours

Carozza *et al.* (2000) assessed occupational risk factors for gliomas in a population-based case–control study. Histologically confirmed glioma cases ($n = 476$), aged 20 years and older, were identified from the Northern California Cancer SEER registry and interviewed. Controls ($n = 462$) were identified by random digit dialling and frequency-matched to cases by 5-year age groups, gender, and race/ethnicity. Lifetime job histories were obtained through in-person interviews. ORs for those who had ever worked as painters, adjusted for age, gender, years of education and race, were 1.6 (95% CI: 0.5–4.9; ten cases) for all gliomas, and 1.8 (95% CI: 0.5–5.8; eight cases) for astrocytic tumours.

Krishnan *et al.* (2003) updated the study by Carozza *et al.* (2000) to assess occupational risk factors for adult glioma. A total of 879 cases from the Northern California Cancer SEER registry and 864 population controls, matched to cases by age, gender and race, were interviewed. The OR for 'ever' working as a painter was 1.04 (95% CI: 0.52–2.07; 17 cases).

Rajaraman *et al.* (2004) conducted a hospital-based case–control study of brain tumours in Arizona, Massachusetts, and Pennsylvania, USA. Cases (197 meningiomas, and 96 acoustic neuromas) were identified during 1994–1998. Controls ($n = 799$) were admitted to the same hospitals for a variety of non-neoplastic diseases and matched to cases by hospital, sex, race, age, and proximity of their residence to the hospital. In-person interviews were held to gather information on a variety of risk factors including every occupation held for 6 months or more since the age of 16 years. In addition, job-specific questions developed by an industrial hygienist were used to assess the probability, frequency, duration and intensity of specific chemical occupational exposures. ORs were adjusted for hospital, sex, race, age, and proximity of the residence to the hospital. ORs for meningioma were 0.5 (95% CI: 0.1–2.2; two cases) for having 'ever' worked as a painter, and 0.9 (95% CI: 0.1–7.2; one case) for 5 or more years' employment as a painter. No cases of acoustic neuroma had ever been employed as a painter.

Serraino *et al.* (1992) conducted a hospital-based case–control study of soft-tissue sarcoma and occupational exposures. Cases ($n = 93$) were obtained from hospitals in north-eastern Italy. Controls ($n = 721$) were patients admitted to the hospital for a variety of conditions, except cancer and diseases associated with tobacco consumption or diet modification. A questionnaire was designed to gather information on a variety of factors including age at start and stop of employment in 17 industries or occupations, and exposure to 15 occupational agents. ORs were adjusted for age and sex. ORs for exposure to dyes and paints were 0.9 (95% CI: 0.3–2.9; four cases) for a duration of 10 years or less, and 0.9 (95% CI: 0.2–2.7; four cases) for a duration of more than 1 years.

Fritschi & Siemiatycki (1996) evaluated occupational exposures and the risk of melanoma among men in a population-based case–control study in Montreal, Canada. A total of 103 cases, identified during 1979–1985, were interviewed. A pooled group of 1066

controls was used: population controls ($n = 533$) selected from electoral lists and by random digit dialling, and also other cancers patients ($n = 533$). The interviews held gathered information on a variety of risk factors including detailed information on all occupations. A team of chemists and industrial hygienists translated interviews into specific occupational exposures. ORs were adjusted for age, education, and ethnicity. The OR for potential exposure to some paints and varnishes were 1.7 (95% CI: 0.9–3.1; 16 cases) for any exposure, 0.4 (95% CI: 0.1–1.9; two cases) for substantial exposure, and 3.0 (95% CI: 1.5–6.0; 14 cases) for non-substantial exposure.

Teschke *et al.* (1997b) conducted a population-based case–control study of mesothelioma in British Columbia, Canada. This study also included nasal and bladder cancers, which have already been previously discussed (Teschke *et al.*, 1997a). Cases ($n = 51$) were registered at the British Columbia Cancer Agency during 1990–1992. Controls ($n = 154$) were identified from provincial voters' lists and matched to cases by age and sex. Subjects, or next-of-kin if required, were interviewed in person or by telephone to obtain information on a variety of factors including occupational, residential, smoking and medical histories. The OR for persons 'ever' employed as a painter was 4.5 (95% CI: 1.0–23.7; six cases), and 5.4 (95% CI: 0.9–39.3; five cases) with the most recent 20 years of exposure removed.

2.2.6 *Review articles and meta-analyses since 1989*

There have been several review articles on cancer risk associated with occupation as a painter in addition to the individual post-Monograph (IARC, 1989) studies cited above. Lynge *et al.* (1997) presented a brief review of seven painter studies after the 1989 IARC Monograph 47, but their review is primarily oriented toward the effects of solvents in general.

Yamaguchi *et al.* (1991) conducted a meta-analysis to investigate employment as a painter and the risk of bladder cancer. The meta-analysis included 27 case–control studies of occupational exposures and the risk of bladder cancer published during 1972–1989. A summary relative risk was calculated from extracted ORs for each occupation as a geometric mean weighted by the numbers of bladder cancer cases in the case–control studies. Employment as a painter was found to be associated with a 50% increased risk of bladder cancer in this pooled study (RR, 1.48; 95% CI: 1.06–2.08).

In a meta-analysis of occupational cohort studies, Chen & Seaton (1998) found significant excess mortality for cancers of the oesophagus (SMR, 1.70; 95% CI: 1.22–2.37, 35 deaths), stomach (SMR, 1.27; 95% CI: 1.01–1.60, 79 deaths), colon (SMR, 1.18; 95% CI: 1.00–1.38, 152 deaths), rectum (SMR, 1.20; 95% CI: 1.01–1.44, 124 deaths), liver (SMR, 1.76; 95% CI: 1.37–2.26, 63 deaths), with borderline significance for cancers of the lung (SMR, 1.21; 95% CI: 1.12–1.31, 640 deaths), bladder (SMR, 1.26; 95% CI: 0.98–1.62, 63 deaths), larynx (SMR, 1.40; 95% CI: 0.94–2.09, 24 deaths), and leukaemia (SMR, 2.21; 95% CI: 0.95–5.13, 72 deaths). Heterogeneity between studies was significant only for leukaemia ($P < 0.001$).

Bosetti *et al.* (2005) systematically reviewed bladder cancer among painters, looking at post-1989 evidence (after IARC volume 47) through to 2004. They included four cohort studies on the incidence of bladder cancer among painters, and calculated a meta-RR of 1.10 (95% CI: 1.03–1.18; 893 cases). The corresponding meta-RR from four cohort studies on mortality was 1.23 (95% CI: 1.11–1.37; 370 deaths). The meta-RR from 14 case–control studies and a pooled-analysis of another 11 case–control studies was 1.35 (95% CI: 1.19–1.53; 465 exposed cases). Overall, the meta-RR from all epidemiological studies was 1.17 (95% CI: 1.11–1.27).

2.2.7 *Comprehensive meta-analyses of studies on painters and cancers of the lung and of the bladder*

[These meta-analyses were completed by members of the Working Group during the Volume 98 Monograph meeting. After the meeting, they were further developed by the IARC Secretariat and the members of the Working Group, taking into account studies published after the Volume 98 meeting. The methods are summarized below (Guha *et al.*, 2010a, b)]

(a) Selection criteria

All epidemiological studies included in the previous IARC Monographs were considered (IARC, 1989). Reports in any language describing lung or bladder cancer in painters referenced in or published after the previous IARC monograph (IARC monograph volume 47 published in 1989) (IARC, 1989) until October 2007 were searched for in PubMed using the search terms "(paint*[tw] OR varnish*[tw] OR lacquer*[tw]) AND (cancer OR neoplasms[mh]) AND (case-control study[mesh] OR cohort study[mesh] OR meta-analysis[mh] OR review[pt] OR risk factors[mh] OR neoplasms/epidemiology OR neoplasms/etiology OR neoplasms/CI OR occupational diseases/etiology OR occupational diseases/epidemiology OR occupational diseases/CI OR occupational diseases/MO OR occupational exposure/adverse effects OR death certificates[mh] OR epidemiologic methods[mh]) AND bladder AND lung." The search was restricted to studies in humans. Certain studies were excluded from the PubMed search because they were either not an epidemiological study, did not include original data (review articles), did not assess occupation as a painter, overlapped with another population already included in the meta-analysis, or lung or bladder cancers were not the outcomes. The reference lists of pertinent articles were also reviewed to capture relevant publications that may not have been identified with the search criteria.

To be included in this meta-analysis, studies had to report estimates of the relative risk (RR, OR, SIR, SMR) with corresponding 95% confidence intervals (CIs) for 'ever' versus 'never' occupation as a painter or have provided enough information that allowed for their computation. For studies that did not report the 'ever' versus 'never' painter category, the risk estimates and 95% CIs for these categories were estimated (see statistical analysis section). For studies that reported only point estimates without corresponding CIs, *P*-values or standard errors, or did not report the distribution of data to allow for computation of

relative risks and CIs, conservative assumptions were made to estimate relative risks and 95% CIs from the data provided on a study-by-study basis. These conservative assumptions underestimated the relative risk (towards the null) and overestimated the width of the CI (i.e. by doubling the variance to approximate a 95% CI adjusted for multiple factors). Studies were excluded if estimation was impossible. Square brackets indicate the relative risks and 95% CIs calculated by the Working Group (Tables 2.1, 2.2, 2.3, 2.6). For studies with overlapping populations, only the publication with the most complete study population was included.

(b) Data abstraction

All articles were assessed independently by three reviewers who extracted data that included authors, publication date, country of origin, characteristics of the study population including gender and any details on the definition of painters, incidence versus mortality, lung or bladder cancer histology, observed and expected cancer cases (for cohort and proportionate mortality studies), number of exposed cases and controls (for case-control studies), yes/no adjustment for smoking or other occupational carcinogens, relative risks with corresponding 95% confidence intervals and results on exposure-response (Tables 2.1, 2.2, 2.3, 2.6). If adjusted and unadjusted results were reported, the most valid point estimate (i.e. adjusted for smoking and other variables) was abstracted. Any discrepancies in data collection were resolved by two other reviewers.

(c) Summary statistics calculated for inclusion in the meta-analysis

For cohort and record linkage studies, risk estimates (SIR, SMR) were computed by dividing the observed number of cases by the expected number, based on an external reference population. The corresponding 95% CIs were estimated using the PAMCOMP program (Taeger *et al.*, 2000). If only subgroup results (e.g. by gender, race, or duration of exposure) were reported, fixed effects models were used to combine stratum specific data into one summary estimate.

Subgroup analyses were conducted by further restricting to studies with stronger methodologies, such as those studies that adjusted for smoking, other occupational risk factors or population-based case–control studies that adjusted for smoking. Only two of the cohort and record linkage studies provided information on smoking status.

To allow for inclusion in the meta-analysis, 95% CIs were calculated if they were not presented in the original paper. If a 90% CI was presented and if the upper (UL) and lower limit (LL) were proportionally symmetric around the risk ratio (for RR and OR; i.e. if UL/RR = RR/LL), an estimate of the standard error (SE) was calculated by SE = (ln UL – ln LL/3.29), where 3.29 = 2 * 1.645 for 90% CIs. If only a *P*-value for the null hypothesis was presented, then a "test-based" SE was estimated using SE = (ln RR)/Z_p, where Z_p is the value of the standard-normal test statistic corresponding to the *P*-value using a two-tailed test. The UL and LL of the 95% CI were estimated by exp[ln(RR) ± 1.96(SE)], where $Z_p = 1.96$ if $P = 0.05$ using a two-tailed test (Rothman & Greenland, 1998). A 95% CI

corresponding to an unadjusted RR was used in the meta-analysis if a paper did not present enough data to allow for estimation of the adjusted CI.

(d) Statistical analysis

For cohort and record linkage studies, incidence and mortality data were compared. Because cancer incidence data are often more accurate than mortality data, SIRs were used in the combined analyses instead of SMRs whenever both were presented. Assuming that the different effect estimates (e.g. SMR, SIR, RR, OR) represent the relative risk, the data were combined for all of the cohort, record linkage and case–control studies. Separate meta-analyses were also done by study design.

Many of the cohort and record linkage studies used an external reference population to calculate the expected cases. When the external reference rates that are used to calculate the expected cases were usually assumed to be known without error, an estimate of the exposure coefficient in a regression could be obtained by a weighted linear regression of the natural log of the adjusted SMR on exposure (Sutton *et al.*, 2000). The risk estimates from nested case–control studies were included with the analysis of cohort studies because, essentially, this design can represent a more efficient way to analyse cohort studies and does not suffer from the problems associated with control selection in a case–control study. Summary odds ratios (meta-OR) were obtained separately from the meta-analysis of case–control studies. Subgroup analyses were performed stratified by gender, study region, study design, types of adjustment, and by duration of employment.

The I^2 statistic quantified the extent of inconsistency among the studies (Higgins & Thompson, 2002). I2 values of 25–50% indicate moderate inconsistency, while values larger than 50% reflect large inconsistencies among studies. The I2 values were presented instead of the Cochran's Q-statistic because the Q-statistic only informs about the presence or absence of heterogeneity but does not quantify the extent (Huedo-Medina *et al.*, 2006). Both random- and fixed-effect models, with weights equal to the inverse of the variance, were used to calculate a summary risk estimate (DerSimonian & Laird, 1986). Results from random-effect models, which account for heterogeneity among studies, are presented.

Influence analyses were conducted by dropping one study at a time and examining its influence on the summary effect estimates. Forest plots were used to graphically display the data (Lewis & Clarke, 2001). In the forest plot, the risk estimate for each study is represented by a black square that is proportional to the sample size, the horizontal line shows the corresponding 95% CI, a dashed line marks the summary estimate, while the vertical solid line represents the null result. Publication bias was visually assessed using Funnel plots (Deeks *et al.*, 2005). All statistical analyses were performed by using STATA (version 10.0; StataCorp, College Station, TX), employing the "metan" command for the meta-analyses (Bradburn, 2004).

Table 2.6. Proportionate mortality studies of painting and lung cancer, organized by geographical region and publication date.

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
Terstegge *et al* (1995) Netherlands 1980–92	9812 Dutch male painters deceased during 1980–92, identified from a registry	Painters were obtained from a registry with which nearly all commercial painters are affiliated	Lung, trachea, bronchus, pleura, thymus, heart, mediastinum, less defined parts of respiratory tract (ICD 162–165)	Commercial painters	1480	1.20 (1.14–1.26)	Age, time period	Reference = proportion of lung cancers among all deaths within the Dutch male population during 1980–1992
OPCS (1958) England & Wales 1949–53 UK	Registered deaths of men and women aged ≥65 yrs in the broad occupational category of painters and decorators	Occupation at time of death or last occupation from death certificates; Occupations coded according to the Census 1951, Classification of Occupations	Lung, bronchus, trachea, primary cancer (ICD6 162)	Other painters & decorators Men Aerographers, paint sprayers	 461 5	 1.30 [1.18–1.42] 1.67 [0.54–3.90]	Age, sex	Reference = mortality rates of painters taken from the 1951 national census
OPCS (1971) England & Wales 1959–63 UK	Registered deaths of men and women aged 65–74 in England and Wales	Last occupation recorded on the death certificate	Lung, bronchus & trachea (ICD7 162, 163)	Painters & decorators Men (15–64 yrs) Men (65–74 yrs) Single women Aerographers, paint sprayers Men (15–64 yrs)	 728 849 1 98	 1.22 [1.13–1.31] 1.31 [1.22–1.40] 1.81 [0.05–10.08] 1.48 [1.20–1.80]	Age, sex	

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
OPCS (1978), no.1 England & Wales 1970–72 UK	Registered deaths of 277,168 men, aged 15–64	Last occupation recorded on the death certificate, as coded by the *1970 Classification of Occupations*	Lung, bronchus, trachea (ICD8, 162)	Painters & decorators	847	1.25 [1.17–1.34]	Age	Reference = proportions of all deaths in the population of England & Wales during 1970–1972; The occupation unit of 'painters and decorators' was comprised of aerographers, paint sprayers; painters, decorators n.e.c.; coach painters
				Painters, decorators nec	728	1.22 [1.13–1.31]		

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
OPCS (1986), no.6 UK (Scotland, England & Wales) 1979–80, 1982–83 UK	Men aged 20–64 and married women aged 20–59 in Great Britain during 1979–80 and 1982–83	Last full-time occupation recorded on the death certificate	Lung, bronchus, trachea (ICD9,162)	Painters, decorators, French polishers				Female mortality was from England & Wales only
				Men	779	1.21 [1.13– 1.30]		
				Women	128	1.33 [1.11–1.58]		PRR indicates the differences in the proportions of all cancer registrations for a given occupation attributable to particular sites
						PRR (95% CI)		
				Other spray painters, males	34	1.56 [1.08–2.18]		
	Men aged 15–74 in England & Wales in 1981			Painters & decorators nec French polishers	226	1.25 [1.09–1.42]		
	Women aged 15–74 in 1981 or aged 20–74 in England & Wales during 1979–80 and 1982–83			Painting, assembling, & related occupations nec (women)				
				15–74 yrs of age	21	1.79 [1.11–2.74]		
						PCMR (95% CI)		
				20–74 yrs of age	39	1.01 [0.72–1.38]		

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
OPCS (1995), no. 10 Roman & Carpenter (1995) England, 1981–87 UK	Men, aged 20–74 years, England 1981–87	Occupation recorded at the time of cancer registration/death	Lung, bronchus, trachea (ICD9 162)	Painters & decorators Other spray painters	1664 213	**PRR (95% CI)** 1.08 (1.03–1.14) 1.11 [0.97–1.27]	Age, social class, region of registration	
OPCS (1995), no. 10 Winter (1995), Coggon (1995) England & Wales 1979–80, 1982–90 UK	29 689 male painters and decorators, aged 20–74 years, who died during 1979–80 or 1982–90, linked to census denominators	Last full-time occupation was obtained from death certificates	Lung, bronchus, trachea (ICD9 162)	Other spray painters Painters & decorators Coach painters	557 4110 69	**PMR (95% CI)** 1.26 (1.16–1.37) 1.12 (1.09–1.16) 0.87 [0.68–1.10]	Age, social class	Data for 1981 were omitted because of questionable quality

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
Peto *et al* (1995) England, Wales, Scotland 1979–80, 1982–90 UK	British painters, aged 16–74 years, who died during 1979–80 and 1982–90 were obtained from a UK register	Last full-time occupation was obtained from death certificates	Mesothelioma			**PMR (95% CI)**	Age, calendar year	This study partially overlaps with the Registrar General's report (1996); *Mesotheliioma excluded from the meta-analysis*
				Male painters and decorators	100	1.31 [1.07–1.59]		
Enterline & McKiever (1963) USA								Overlaps with Guralnick (1963)

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
Chiazze *et al*. (1980) 1970–76 USA	226 deceased white male spray painters from a cohort of workers in 10 automobile assembly plants Nested case–control study using 263 lung cancer deaths among white males and 1001 controls deceased from circulatory system disease or accidents, matched by age (± 2 years) and plant	Complete work history from plant records	Lung, bronchus, trachea (ICD8, 162)	Spray painter Ever ≥1 year ≥3 years ≥5 years	21 21 16 13 11	**PMR (95% CI)** 1.41 [0.87–2.15] **OR (95% CI)** 1.43 [NG] 1.36 [NG] 1.29 [NG] 1.15 [NG]	Race, sex, age, cause of death	Reference was general population where each plant is located

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
Dalager (1980) 1959–77 USA	202 deaths in white male spray painters among 977 male painters employed ≥3 months and terminated employment at one of 2 large aircraft maintenance plants between 1949–59; followed up for mortality through 1977 (deaths certificates 90% complete)	Occupation	Respiratory organs (ICD7, 160–164)			**PCMR (95% CI)**	Age, time	Primer paints used were primarily chromium base compounds, especially zinc chromate, but epoxy paints were also used; Reference calculated using cancer mortality for US white males. *Calculated using a fixed effects model
				Painters	21	1.84 [0.90–2.23]		
				Years employed				
				<5	9	1.25 [0.57–2.37]		
				5–9	6	1.50 [0.55–3.26]		
				≥10	6	1.88 [0.69–4.08]		
				<10	15	[1.34 (0.77–2.34)]*		

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
Milham (1983) 1950–79 USA	Death records of 429,926 men and 25,066 women in Washington state. Deaths of 5287 painters, 832 paperhangers and decorators (painters), 428 body/fender repairmen and auto painters	Occupation from death certificate	Lung, bronchus, trachea (ICD6-8 162) Bronchus and lung (ICD6-8 162.1, 163)			**PMR (95% CI)**	Age, calendar time	Findings presented for white males (95% of study population). Expected: The age-adjusted number of deaths that would have occurred in a specific occupation and cause-of-death group, if that occupation had the same mortality experience as the entire cohort
				Painters, mainly construction and maintenance	251	1.21 [1.06–1.37]		
				Age 20–64 years	103	1.12 [0.91–1.36]		
				Auto painters & body/fender repairmen	39	1.48 [1.05–2.02]		
				Age 20–64 years	29	1.84 [1.23–2.64]		
				Paperhangers and decorators (painters)	50	1.40 [1.04–1.85]		
				Age 20–64 years	21	1.39 [0.86–2.12]		
Miller *et al.* (1986) USA	630 white male painters were identified from a registry of death certificates of 1757 artists deceased during 1940–69	Artists were identified from obituaries	Lung	Artistic painters	17	**PCMR (95%CI)** 0.8 (0.4–1.7)	Race, sex, age, calendar time	Total number of cancer deaths for all sites combined was used as the comparison group. The PMR for lung cancer was not significantly elevated

Table 2.6 (contd)

Reference, location	Cohort description	Exposure assessment	Organ site (ICD code)	Exposure categories	No. of cases/ deaths	PMR (95% CI)	Adjustment for potential confounders	Comments
Wang *et al.* (1999) North Carolina, USA	All male construction workers who lived and died in North Carolina during 1988–94	Usual occupation was obtained from coded death certificates	Lung	Painters, paperhangers, plasterers	NG	**PMR** 1.18 [1.01–1.35] ($p<0.05$)	Gender and race	No confidence intervals or number of deaths provided.

OPCS, Office of Population Censuses and Surveys; nec, not elsewhere classified; NG, not given; SPIR, standardized proportional incidence ratio; CI, confidence interval; ILO, International Labor Office and the United Nations Statistical Office; ISCO, International Standard Classification of Occupations; ISIC, International Standard Industrial Classification; NG, not given; PCMR, proportionate cancer mortality ratio; RR, rate ratio or relative risk; SIC, Standard Industrial Classification; SIR, standardized incidence ratio; SMR, standardized mortality ratio; SMSA, Standard Metropolitan Statistical Area; TWA, time-weighted average; PRR, proportional registration ratio

2.2.8 *Results of the meta-analysis of lung cancer risk in painters*

The combined analysis of 17 cohort and linkage studies (meta-RR, 1.36; 95% CI: 1.28–1.44; I2 = 74.4%, $P = 0$) and 29 case–control studies (meta-OR: 1.35; 95% CI: 1.22–1.51; I2 = 48.4%, $P = 0.002$) demonstrated a significantly increased risk overall in persons who had ever reported occupation as a painter (meta-RR, 1.34; 95% CI: 1.28–1.41; I2 = 62.2%, $P = 0$) (Fig. 2.1). A total of 13 proportionate mortality studies, although not included in the combined analysis, also demonstrated a significantly increased risk of lung cancer in painters (Table 2.6). An influence analysis showed that dropping individual studies did not significantly alter the results (data not shown).

Stratification by study region showed that risks where highest in Asia (meta-RR, 1.47; 95% CI: 0.66–3.28; I2 = 0%, $P = 0.87$), similar in Europe (meta-RR, 1.37 95% CI: 1.28–1.47; I2 = 69.3%, $P = 0$) and North America (meta-RR, 1.35; 95% CI: 1.26–1.45; I2 = 56.4%, $P = 0.001$), and lower in South America (meta-RR, 1.17; 95% CI: 0.77–1.76; I2 = 48.8%, $P = 0.10$). Stratification by gender showed higher odds ratios in women (meta-RR, 2.05; 95% CI: 1.35–3.10; six studies) (Muscat *et al.*, 1998; Jahn *et al.*, 1999; OPCS, 1958; OPCS, 1971; Zeka *et al.*, 2006; Andersen *et al.*, 1999) than in men (meta-RR, 1.35; 95% CI: 1.27–1.42; 39 studies). Of the few studies that reported results for specific histologies (De Stefani *et al.*, 1996; De Stefani *et al.*, 2005; Pezzotto & Poletto, 1999; Richiardi *et al.*, 2004; Siemiatycki *et al.*, 1987), risks were generally highest among those diagnosed with small cell cancer, though the confidence intervals were wide due to the small number of cases and results for the different histological entities were not reported consistently.

Visual inspection of the funnel plot for 29 independent case–control studies demonstrated some evidence of publication bias: the plot was slightly skewed with a deficit of smaller non-positive studies (represented by large standard errors) (Fig. 2.2). When restricting the analysis to the larger case–control studies that showed both positive and negative results, the meta-OR remained significantly elevated (meta-OR, 1.31; 95% CI: 1.18–1.45; I2 = 51.6%, $P = 0.003$). There was little difference in the results of case–control studies stratified by hospital-based controls (meta-OR, 1.37; 95% CI: 1.09–1.74; I2 = 59.3%, $P = 0.002$) or population-based (meta-OR, 1.34; 95% CI: 1.18–1.51; I2 = 25.9%, $P = 0.16$), though the population-based studies were less heterogeneous.

Restricting to population-based case–control studies that adjusted for smoking demonstrated less heterogeneity between studies and strengthened the results (meta-OR, 1.41; 95% CI: 1.23–1.61; $I^2 = 0\%$, $P = 0.45$). Three cohort studies reported smoking-adjusted results (Dunn & Weir 1965; Hrubec *et al.*, 1995; van Loon *et al.*, 1997) with a meta-RR of 1.16 (95% CI: 0.96–1.40; I2 = 9.3%, $P = 0.33$) which was slightly lower than the meta-RR for cohort studies that did not adjust for smoking (meta-RR, 1.38; 95% CI: 1.30–1.46; I2 = 77.3%, $P = 0$). An analysis restricting to never-smokers (meta-RR, 2.00; 95% CI: 0.80–5.02; I2 = 0%, $P = 0.79$) (Kreuzer *et al.*, 2001; Zeka *et al.*, 2006) and never- and non-smokers (meta-RR, 1.94; 95% CI: 0.95–3.96; I2 = 0%, $P = 0.96$) (Pohlabeln *et al.*, 2000) demonstrated a 2-fold increased risk of lung cancer among painters.

Figure 2.1. Forest plot of studies assessing lung cancer in painters, stratified by study design

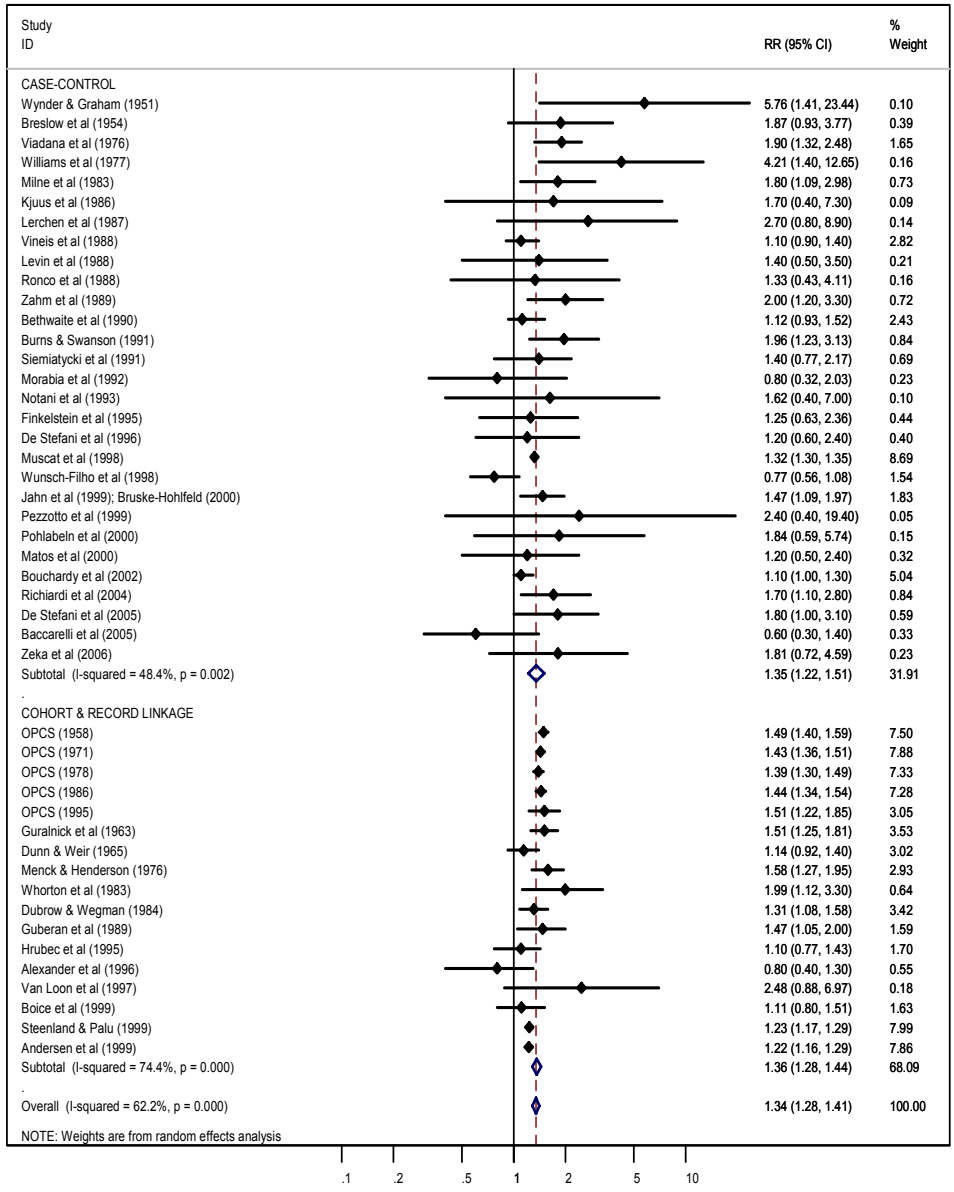
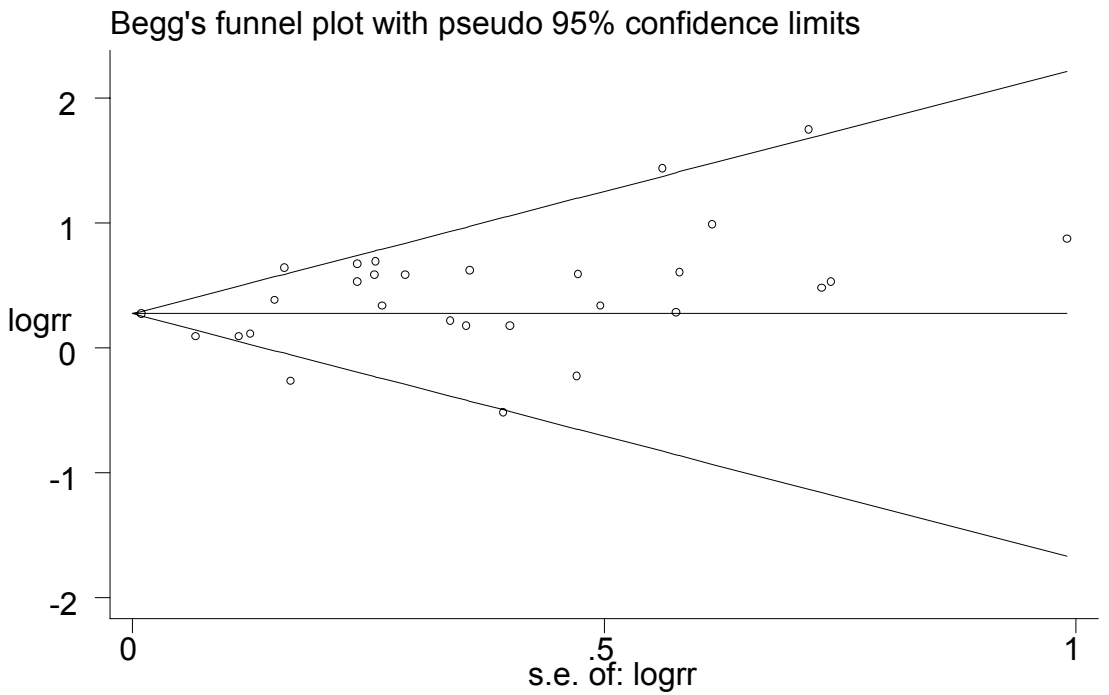


Figure 2.2. Funnel plot to assess publication bias in case-control studies of lung cancer in painters



Regardless of study design, those studies that adjusted for other occupational exposures as well as smoking further strengthened the results (meta-RR, 1.57; 95% CI: 1.21–2.04; I2 = 0%, $P = 0.68$). Analysis by duration of exposure (< 10 years versus ≥ 10 years, < 20 years versus ≥ 20 years) (Baccarelli *et al.*, 2005; Dalager *et al.*, 1980; Levin *et al.*, 1988; Swanson *et al.*, 1993) showed that those exposed ≥ 10 years (meta-RR, 1.75; 95% CI: 1.06–2.89; I2 = 0%, $P = 0.61$) or ≥ 20 years (meta-RR, 2.10; 95% CI: 0.88–5.02; I2 = 16.4%, $P = 0.18$) had a higher risk than those exposed < 10 years (meta-RR, 1.13; 95% CI: 0.73–1.74; I2 = 14.7%, $P = 0.32$) or < 20 years (meta-RR, 1.19; 95% CI: 0.72–1.96; I2 = 0%, $P = 0.67$) (reference category was 0 years exposure), respectively.

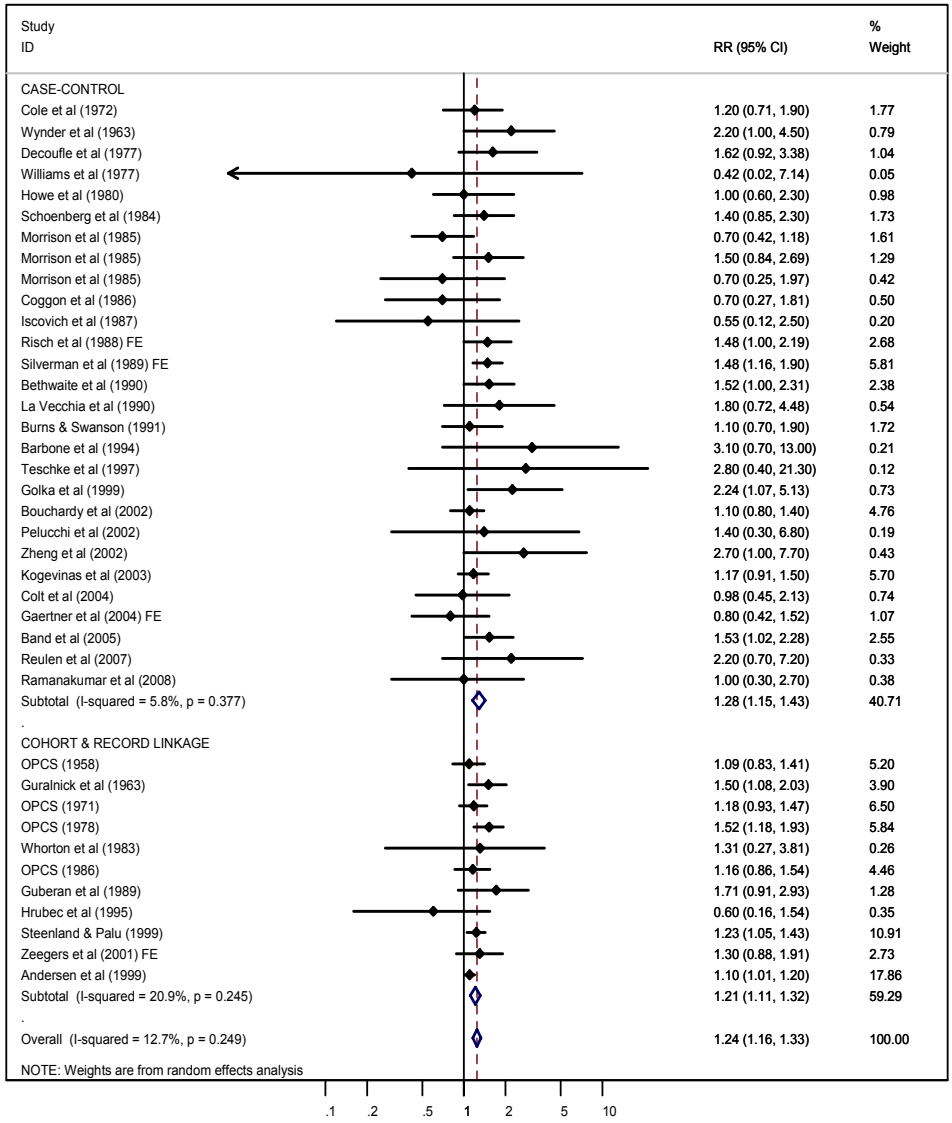
2.2.9 *Results of the meta-analysis of bladder cancer risk in painters*

The combined analysis of 11 cohort and record linkage studies (meta-RR, 1.21; 95% CI: 1.11–1.32; I2 = 20.9%, $P = 0.25$) and 28 case–control studies (meta-OR, 1.28; 95% CI: 1.16–1.43; I2 = 0.8%, $P = 0.38$), demonstrated a significantly increased risk overall in persons who had ever reported occupation as a painter (meta-RR, 1.24; 95% CI: 1.16–1.33; I2 = 12.7%, $P = 0.25$) (Fig. 2.3). An influence analysis showed that dropping individual studies did not significantly alter the results (data not shown).

Risks were higher in female painters (meta-RR, 1.54; 95% CI: 1.03–2.31) (Gaertner *et al.*, 2004; Pelucchi *et al.*, 2002; Risch *et al.*, 1988) than in males (meta-RR, 1.27; 95% CI: 1.18–1.36). It is notable that although there were only three studies among female painters, the meta-RR was statistically significant. Stratification by study region showed that risks were elevated in North America (meta-RR, 1.32; 95% CI: 1.20–1.46; I2 = 0%, $P = 0.73$) and Europe (meta-RR, 1.19; 95% CI: 1.08–1.31; I2 = 24.1%, $P = 0.18$).

Additional analyses were performed to examine the summary risk estimates when restricted to population-based case–control studies or studies with stronger design or analytical methods (adjusting for smoking or other occupational exposures). Restricting to studies that adjusted for smoking (meta-OR, 1.27; 95% CI: 1.13–1.43; $I^2 = 6.3\%$, $P = 0.37$), population-based case–control studies that adjusted for smoking (meta-OR, 1.26; 95% CI: 1.09–1.45; I2 = 16.9%, $P = 0.25$), or studies that adjusted for other occupational exposures as well as smoking (meta-RR, 1.27; 95% CI: 0.99–1.63; I2 = 0.1%, $P = 0.39$) did not significantly change the results from the overall estimate. Only two cohort studies reported smoking-adjusted results (Zeegers *et al.*, 2001; Hrubec *et al.*, 1995) with a meta-RR of 1.07 (95% CI: 0.55–2.07; I2 = 37.6%, $P = 0.21$). One of the two cohort studies was based on only four exposed cases (SMR, 0.60; 95% CI: 0.16–1.54; Hrubec *et al.*, 1995) while a second study was based on 47 exposed cases [RR, 1.30; 95% CI: 0.88–1.91] (Zeegers *et al.*, 2001), with higher risks in the medium- and high-exposure categories. Analysis by duration of exposure (la Vecchia *et al.*, 1990; Silverman *et al.*, 1989a; Zheng *et al.*, 2002; Siemiatycki *et al.*, 1994) showed that those exposed > 10 years (meta-RR, 1.92; 95% CI: 1.21–3.05; I2 = 18.3%, $P = 0.30$) had a higher risk than those exposed < 10 years (meta-RR, 1.45; 95% CI: 1.01–2.08; I2 = 0%, $P = 0.91$) (reference category was 0 years exposure).

Figure 2.3. Forest plot of studies assessing bladder cancer in painters, stratified by study design



There appeared to be no evidence of publication bias overall or among the case–control studies, as assessed by visual inspection of the funnel plot (Fig. 2.4). The meta-OR was higher in the seven studies using hospital-based controls (meta-OR, 1.54; 95% CI: 1.15–2.07; I2 = 0%, $P = 0.62$) than in the 21 studies using population-based controls (meta-OR, 1.25; 95% CI: 1.11–1.41; I2 = 11.6%, $P = 0.31$), though the hospital-based studies were less heterogeneous.

2.3 Childhood cancer (Table 2.7)

Studies providing information on childhood cancer and parental occupation as painters or paints are listed in Table 2.7.

Reviews by Savitz & Chen (1990), Colt & Blair (1998), and McBride (1998) of childhood cancer and parental occupation and environmental exposures provide excellent overviews of the literature. They note that occupations with potential exposure to paints have been associated with increased risk for leukaemia, lymphoma, cancer of the nervous system, hepatoblastoma, and rhabdomyosarcoma.

2.3.1 *Chilhood leukaemia*

The Children's Cancer Study Group (CCSG), a cooperative of clinical trials involving approximately 100 members in the USA and Canada, conducted a case–control study of parental occupational exposure and the risk of acute non-lymphocytic leukaemia (ANLL) among children (Buckley *et al.*, 1989a). A total of 262 cases were identified during 1980–1984, and both mothers (n = 204) and fathers (n = 154) of the cases were interviewed. Controls were selected by random-digit dialling using the area code and first five digits of the case's telephone number, and were matched to cases by date of birth and race. If the selected control family would not participate, a second control was selected. Second controls were used for 23 cases. Interviews gathered information on a variety of potential risk factors, including lifetime occupational history for each job held for 6 months or more, and self-reported exposures. The OR for paternal occupation as a painter was 7.00 ($P = 0.02$). The ORs for maternal exposure to paints and pigments as inferred from the job titles were 1.5 (95% CI: 0.6–3.3; 15 cases) for durations of up to 1000 days, and 2.2 (95% CI: 0.9–5.4; 15 cases) for durations of more than 1000 days (P for trend, 0.05). The timing of maternal exposure to paints and pigments resulted in ORs of 2.3 ($P < 0.05$) before the pregnancy, 1.5 during the pregnancy, and 0.9 after the pregnancy. In a multivariate stepwise regression analysis, self-reported paint and pigment exposure did not reach statistical significance for entry, but was the most significant of the remaining unselected variables ($P = 0.06$).

Shu *et al.* (1999) conducted a case–control study of childhood acute lymphocytic leukaemia (ALL) and parental occupational exposure. Cases (n = 1842) were diagnosed during 1989–1993 by a member of the Children's Cancer Group in the USA. Controls (n = 1987) were selected by random-digit dialling and individually matched to cases by age, race, and telephone area code and exchange.

Figure 2.4. Funnel plot to assess publication bias in case-control studies of bladder cancer in painters

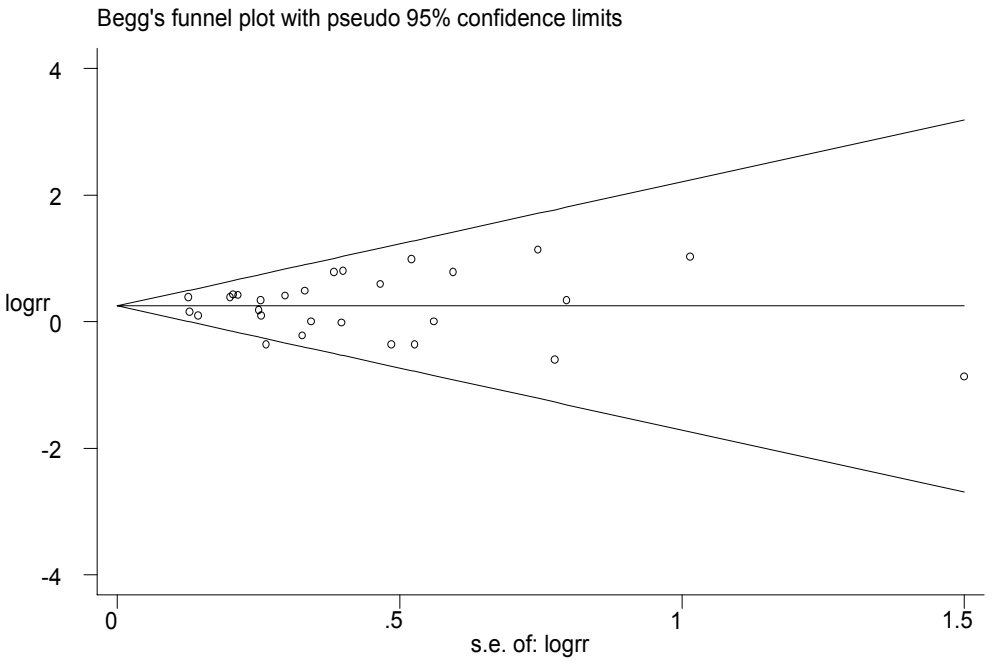


Table 2.7 Studies of childhood cancers and parental occupational exposure to paints

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Childhood leukaemia								
Buckley *et al*. (1989a) 100 institutions in USA and Canada, 1980–84 Case–control study	204 cases aged <18 years from the CCSG cooperative clinical trial group 262 population controls selected by RDD, matched by date of birth and race	Parental lifetime work history obtained through interviews with each parent	ANLL	Father painters Maternal paint and pigment exposure *Duration (days)* 1 to 1000 >1000 *P* for trend *Period of use in relation to pregnancy* Before During After Maternal use of spray paints (prolonged exposure)	7 15 15 NG NG NG NG	7.0 (P=0.02) 1.5 (0.6–3.3) 2.2 (0.9–5.4) 0.05 2.3 (P<0.05) 1.5 0.9 3.0 (P<0.03)	Unclear	

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Shu *et al*. (1999) 100 institutions in USA, 1989–93 Case–control study	1842 cases from CCG hospitals; aged <15 years 1987 population controls selected by RDD, individually matched by age, race, telephone area code and exchange	Detailed lifetime parental occupational history from telephone interview: all jobs held 6 months (father since age 18; mother for two years prior to pregnancy); assessment of specific exposures by an industrial hygenist	ALL	Maternal occupational exposure *Spray paints (time period)* Anytime Preconception During pregnancy Postnatal	 53 27 27 38	 1.0 (0.7–1.5) 1.3 (0.7–2.3) 1.4 (0.8–2.6) 1.2 (0.7–1.9)	Maternal education, race and family income	Evaluation of maternal exposures to paints and thinners by duration found a slightly larger OR for the shorter duration category.

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Shu *et al*. (1999) (contd)				*Other paints (time period)*				
				Anytime	87	1.3 (0.9–1.7)		
				Preconception	44	1.9 (1.2–3.1)		
				During pregnancy	37	2.0 (1.2–3.5)		
				Postnatal	51	1.3 (0.9–2.0)		
				Paternal occupational exposure			Paternal education, race, family income, age and sex of index child	
				Spray paints (time period)				
				Anytime	364	0.9 (0.7–1.1)		
				Preconception	272	1.0 (0.8–1.3)		
				During pregnancy	157	1.0 (0.8–1.3)		
				Postnatal	208	1.0 (0.8–1.2)		
				Other paints (time period)				
				Anytime	315	0.9 (0.7–1.1)		
				Preconception	226	0.9 (0.7–1.1)		
				During pregnancy	117	1.0 (0.7–1.3)		
				Postnatal	163	0.9 (0.7–1.2)		

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Schüz *et al*. (2000) Germany, LSP Study 1992–96; NIP and WGP 1993–97 Pooled analysis of three case–control studies	1138 cases from the German Childhood Cancer Registry; age <15 years. 2962 population controls from population registration files; matched on gender, year of birth and community (NIP study)	Self-reported parental occupational chemical exposures	ALL	Paints or lacquers *Fathers* Any time Preconception During pregnancy Postnatal *Mothers* Any time Preconception During pregnancy Postnatal	 157 147 129 115 54 45 32 18	 1.1 (0.9–1.4) 1.1 (0.9–1.4) 1.1 (0.9–1.4) 1.0 (0.8–1.3) 1.8 (1.2–2.6) 1.6 (1.1–2.4) 2.0 (1.2–3.3) 1.0 (0.6–1.8)	Age, gender, year of birth, urbanization, and SES	

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Freedman *et al*. (2001) USA (9 midwestern and mid-Atlantic states), 1989–93 Case–control study	640 cases from CCG hospitals; age <15 years. 640 population controls selected by RDD; individually matched by age, race, first 8 digits of telephone number	Household exposures of mothers During the interview mothers provided information on household activities that could result in chemical exposure, including painting	ALL	Ever Painted *Mother painted* *Other people painted* *Number of rooms painted* 1–2 3–4 ≤4 *P* for trend In homes painted after birth: >4 rooms painted >5 times painted	289 160 128 161 62 64 NG NG	1.2 (0.9–1.5) 1.1 (0.9–1.5) 1.3 (0.9–1.7) 1.0 (0.8–1.3) 1.4 (0.9–2.1) 1.7 (1.1–2.7) 0.01 1.6 (1.2–2.2) 1.8 (1.1–2.8)	Age, income, sex, maternal education, painting during other periods	
McKinney *et al*. (2003) England, Scotland, Wales 1991–96	1737 leukaemia cases (1461 ALL); age ≤14 years 2 controls per case randomly selected from population registries; individually matched by sex, age, geographic area	Complete occupational history from in-person interview	Leukaemia ALL	Paternal occupational exposure to paint Leukaemia ALL	 25 21	 1.22 (0.76–1.85) 1.22 (0.73–1.91)	Age, sex, region of residence	

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Central nervous system tumours								
Peters *et al.* (1981) Los Angeles, USA, 1972–77 Case–control study	92 cases from the Los Angeles County Surveillance Program; <10 years of age. 92 friend and neighbour controls individually matched by sex, race, year of birth and social class	Detailed parental occupational history before conception, during pregnancy and at the time of diagnosis was obtained through telephone interview	Brain tumours	Father exposed occupationally to paints	7	7.0 (P=0.04)	Matching factors were accounted for in a matched-pairs analysis	

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Olshan *et al*. (1999) USA and Canada, 1992–96 Case–control study	504 cases under the age of 19 from 139 hospitals in the CCG and POG collaborative clinical trials 504 controls selected by RDD; individually matched to cases on date of birth	Telephone interviews obtained all maternal and paternal occupations held since age 18 until the reference date	Neuro-blastoma	Paternal painters	18	2.1 (0.9–4.8)	Mother's race, age, and education; household income in year of birth	No OR for maternal painters. 18 discordant pairs with case exposed and control unexposed.

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
De Roos *et al.* (2001) 139 hospitals in USA and Canada, 1992–94 Case–control study	538 cases aged <19 years from 139 hospitals in the CCG and POG collaborative clinical trials 504 population controls selected by RDD and individually matched to cases on date of birth	Telephone interviews obtained parental occupational history. For the 2 years before child's birth, parents were asked about occupational exposure to 65 specific chemicals and responses were reviewed by an industrial hygienist.	Neuro-blastoma	Maternal *Paints, inks, pigments* Self-reported IH-based *Oil-based paints* Self-reported IH-based *Water-based paints* Self-reported IH-based	 21 7 15 2 13 5	 1.0 (0.5–1.9) 0.6 (0.2–1.4) 1.1 (0.5–2.4) 0.2 (0.1–1.1) 1.2 (0.5–2.7) 1.2 (0.3–4.7)	Child's age, maternal race, maternal age, maternal education	

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
De Roos *et al.* (2001) (contd)				Paternal				
				Paints, inks, pigments				
				Self-reported	52	0.8 (0.5–1.3)		
				IH-based	35	0.9 (0.5–1.6):		
				Oil-based paints				
				Self-reported	40	1.0 (0.6–1.7)		
				IH-based	27	1.4 (0.7–2.8);		
				Water-based paints				
				Self-reported	34	0.9 (0.5–1.5)		
				IH-based	24	1.1 (0.6–2.2)		

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Feychting *et al*. (2001) Sweden, 1976–93 Cohort study	Cohort of 235,635 children, born to married couples in 1976–1977 and 1981–1982, followed from birth until the age of 15 or 1993 through linkage with the Swedish Death and Cancer Registries. 522 childhood cancer cases (162 nervous system, 161 leukaemia, 40 lymphoma) observed	Occupational hygienists used a JEM to assess exposure through the 1975 or 1980 census reports of paternal occupation and industry	Nervous system cancers	Paternal occupation as a painter before conception	7	3.65 (1.71–7.80)	Census year, gender, maternal age, and SES (for 1981–1982 birth cohort)	

Table 2.7 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Tsai *et al*. (2006) USA (6 states), 1992–95 Case–control study	303 cases that were <9 years of age 575 population controls selected by RDD; frequency-matched by age and race	Telephone interview to obtain maternal occupational history 2 years before child's birth and abbreviated information on paternal occupational history	Wilms' tumour	Paints and paint strippers *During pregnancy* *2 year study period*	 16 17	**OR (90% CI)** 1.09 (0.64–1.86) 1.04 (0.62–1.74)	SES, parental occupation and hobbies	
Other cancers								
Buckley *et al*. (1989b) USA (100 institutions) and Canada 1980–83 Case–control study	75 cases registered with the CCSG. 75 age-matched population controls identified through RDD	Lifetime work history and a list of specific exposures for mothers and fathers obtained from interview	Hepato-blastoma	Paints or pigments: *Father* *Mother* *Mother*	 34 11 NG	 1.5 (P>0.10) 3.7 (P<0.05) 2.8 (P=0.11)	 Age-matched Age-matched Age-matched and adjusted for metal exposure	Multivariate models unclear but likely to be adjusted for exposure to oil and petroleum products and metal

ALL, Acute lymphocytic leukaemia; ANLL, Acute non-lymphocytic leukaemia; CCG, Children's Cancer Group; CCSG, Children's Cancer Study Group; IH, industrial hygienist; JEM, job–exposure matrix; NG, not given; POG, Pediatric Oncology Group; RDD, random-digit dialling; SES, socioeconomic status

Questionnaires were administered by telephone to obtain information on a variety of risk factors, including occupational histories, and potential environmental exposures. Specific exposures were assessed by industrial hygenists. ORs were estimated by logistic regression, adjusted for maternal education, race, and family income or paternal education, race, family income, age and sex of index child. ORs for ALL from maternal exposure to spray paints were 1.0 (95% CI: 0.7–1.5; 53 cases) for any exposure, 1.3 (95% CI: 0.7–2.3; 27 cases) at preconception, 1.4 (95% CI: 0.8–2.6; 27 cases) during pregnancy, and 1.2 (95% CI: 0.7–1.9; 38 cases) postnatally. ORs from maternal exposure to other paints were 1.3 (95% CI: 0.9–1.7; 87 cases) for any exposure, 1.9 (95% CI: 1.2–3.1; 44 cases) at preconception, 2.0 (95% CI: 1.2–3.5; 37 cases) during pregnancy, and 1.3 (95% CI: 0.9–2.0; 51 cases) postnatally. ORs for maternal exposure to paints or thinners with a cut-off at the median duration of time of exposure were 1.3 (95% CI: 0.9–1.8; 74 cases) below the median and 1.4 (95% CI: 1.0–1.9; 83 cases, P for trend = 0.04) above the median for any exposure, 1.8 (95% CI; 1.2–2.9; 54 cases) below the median and 1.4 (95% CI; 0.9–2.2; 43 cases; P for trend = 0.02) above the median at preconception, 1.8 (95% CI; 1.1–3.0; 45 cases) below the median and 1.5 (95% CI; 0.9–2.4; 43 cases; P for trend = 0.01) above the median during pregnancy, and 1.2 (95% CI; 0.8–1.8; 53 cases) below the median and 1.1 (95% CI; 0.7–1.6; 52 cases; P for trend = 0.56) above the median postnatally. ORs for paternal exposure to spray paints were 0.9 (95% CI: 0.7–1.1; 364 cases) for any exposure, 1.0 (95% CI: 0.8–1.2; 272 cases) at preconception, 1.0 (95% CI: 0.8–1.3; 157 cases) during pregnancy, and 1.0 (95% CI: 0.8–1.2; 208 cases) postnatally. ORs for paternal exposure to other paints were 0.9 (95% CI: 0.7–1.1; 315 cases) for any exposure, 0.9 (95% CI: 0.7–1.1; 226 cases) at preconception, 1.0 (95% CI: 0.7–1.3; 117 cases) during pregnancy, and 0.9 (95% CI: 0.7–1.2; 163 cases) postnatally. None of the ORs from the fathers' exposures to paints or thinners by duration of exposure exceeded 1.0.

Schüz *et al.* (2000) pooled data from three case–control studies of childhood leukaemia in Germany to evaluate risks from parental occupational exposures. The three studies were from north-western Germany (LSP study), near German nuclear installations (NIP study), and in west Germany (WGP only). All studies included childhood cases of leukaemia diagnosis before the age of 15 years. The time periods varied for each study, but overall ranged from 1992 up to 1997. Controls were drawn from population files and matched on gender, date of birth within one year and community (NIP study only). Self-administered questionnaires gathered information on potential occupational exposures among the parents. ORs were adjusted for gender, age, year of birth, urbanization and socioeconomic status. ORs for paternal exposure to paints or lacquers were 1.1 (95% CI: 0.9–1.4; 157 cases) for any exposure, 1.1 (95% CI: 0.9–1.4; 147 cases) at preconception, 1.1 (95% CI: 0.9–1.4; 129 cases) during pregnancy, and 1.0 (95% CI: 0.8–1.3; 115 cases) postnatally. ORs for maternal exposure to paints or lacquers were 1.8 (95% CI: 1.2–2.6; 54 cases) for any exposure, 1.6 (95% CI: 1.1–2.4; 45 cases) at preconception, 2.0 (95% CI: 1.2–3.3; 32 cases) during pregnancy, and 1.0 (95% CI: 0.6–1.8; 18 cases) postnatally.

Freedman *et al.* (2001) conducted a case–control study of children < 15 years old with ALL and potential exposure to household chemicals. Cases (n = 640) were diagnosed

during 1989–1993 and enrolled in the Children's Cancer Group in the USA. [Data from this study were used in the papers by Buckley *et al.* (1989a) and Shu *et al.* (1999) on parental occupational exposures.] Population controls ($n = 640$) were selected by random-digit dialling and matched to cases by age, race, first 8 digits of telephone number. During the interview, mothers provided information on household activities that could result in chemical exposure, including painting. ORs were adjusted for age, income, sex, maternal education, painting during other periods. ORs from engaging in artwork (using solvents) were 1.3 (95% CI: 0.9–1.8; 73 cases) for 'ever' use, 1.1 (95% CI: 0.7–1.8; 34 cases) for low exposure, 1.2 (95% CI: 0.7–2.0; 28 cases) for medium exposure, and 4.1 (95% CI: 1.1–15.1; 11 cases) for high exposure. ORs from painting in the house were 1.2 (95% CI: 0.9–1.5; 289 cases) for 'ever' painting, 1.0 (95% CI: 0.8–1.3; 161 cases) for painting 1 to 2 rooms, 1.4 (95% CI: 0.9–2.1; 62 cases) for 3 to 4 rooms, and 1.7 (95% CI: 1.1–2.7; 64 cases) for more than 4 rooms (*P* for trend, 0.01).

McKinney *et al.* (2003) conducted a case–control study among children < 14 years old; 1737 leukaemia cases ($n = 1461$ ALL cases) were enrolled along with two controls per case randomly selected from population registries and individually matched by sex, age, and geographic area. Complete occupational histories were obtained from in-person interviews. Paternal occupational exposure to paint was associated with an increased risk of childhood leukaemia in the offspring overall with ORs of 1.22 (95% CI, 0.76–1.85; 25 cases), and when restricted to ALL cases, 1.22 (95% CI, 0.73-1.91; 21 cases).

2.3.2 *Central nervous system tumours*

Peters *et al.* (1981) conducted a case–control study of brain tumours among children < 10 years old. Cases ($n = 92$) were identified from the Los Angeles County Cancer Surveillance Program during 1972–1977. Controls ($n = 92$) were matched to cases by sex, race, and year of birth, and selected from among friends or neighbours of the cases. Telephone interviews obtained information on occupational histories of fathers and mothers and other factors, including tobacco, alcohol, hair dyes, foods, and drugs. The OR from paternal occupational exposure to paints was 7.0 ($P = 0.04$).

Olshan *et al.* (1999) conducted a population-based case–control study of neuroblastoma and parental occupation. Cases ($n = 504$) were selected from 139 hospitals participating in the Children's Cancer Group or the Paediatric Oncology Group in 1992 and 1996 in the United States and Canada. Controls ($n = 504$) were selected by random-digit dialling and individually matched to cases by date of birth. Telephone interviews were conducted with mothers and fathers to obtain information on a variety of potential risk factors, including an occupational history on each parent since the age of 18 until the reference. Risk of neuroblastoma was 2.1 (95% CI: 0.9–4.8; 18 cases) among children whose fathers were painters. ORs were adjusted for the mothers' race, age and education and household income in the birth year. [No information was presented on risk among children whose mothers were painters.]

DeRoos *et al.* (2001) evaluated the risk of neuroblastoma from parental occupational exposures in a case–control study in the USA and Canada. The study was the same as that

described by Olshan *et al.* (1999). Cases ($n = 504$) were selected from the hospitals participating in the Children's Cancer Group or the Paediatric Oncology Group during 1992–1994. [The Working Group noted the time for collection of cases for Olshan *et al.* (1999) and De Roos *et al.* (2001) were different, but all other aspects were the same. This may have just been a typo.] Controls ($n = 504$) were selected by random-digit dialling and individually matched to case by date of birth. Telephone interviews were conducted with mothers and fathers o f cases to obtain information on a variety of potential risk factors, including an occupational history and information for occupational exposure to 65 predetermined chemicals or chemical groups 2 years before the index child's birth. These self-reports were also reviewed by an industrial hygienist so that improbable situations could be recorded as unexposed. ORs were adjusted for children's age, maternal race, maternal age, and maternal education. ORs from maternal exposure to paints, inks and pigments were 1.0 (95% CI: 0.5–1.9; 21 cases) for self-reports, and 0.6 (95% CI: 0.2–1.4; seven cases) for the corrected estimate by the industrial hygienist. ORs from maternal exposure to oil-based paints were 1.1 (95% CI: 0.5–2.4; 15 cases) for self-reports, and 0.2 (95% CI: 0.1–1.1; two cases) for the corrected estimate by the industrial hygienist. ORs for maternal exposure to water-based paints were 1.2 (95% CI: 0.5–2.7; 13 cases) for self-reports, and 1.2 (95% CI: 0.3–4.7; 5 exposed cases) for the corrected estimate by the industrial hygienist. ORs from paternal exposures to paints, inks, and pigments were 0.8 (95% CI: 0.5–1.3; 52 cases) for self-reports, and 0.9 (95% CI: 0.5–1.6; 35 cases) for the corrected estimate by the industrial hygienist. ORs from paternal exposure to oil-based paints were 1.0 (95% CI: 0.6–1.7; 40 cases) for self-reports, and 1.4 (95% CI: 0.7–2.8; 27 cases) for the corrected estimate by the industrial hygienist. ORs for paternal exposure to water-based paints were 0.9 (95% CI: 0.5–1.5; 34 cases) for self-reports, and 1.1 (95% CI: 0.6–2.2; 24 cases) for the corrected estimate by the industrial hygienist.

Feychting *et al.* (2001) conducted a cohort study of paternal occupational exposures and risk of childhood cancer. The cohort was composed of all children born to married parents in Sweden in 1976, 1977, 1981, and 1982. The 235 635 children were followed up until their 15th birthday, or through to 1993 by record linkage with the Swedish Cause of Death Registry and the Swedish Cancer Registry. A total of 522 cases of childhood cancer were identified (161 leukaemias, 162 nervous system tumours, and 40 lymphomas). The fathers' occupations were identified from census records in 1975 for the 1976 and 1977 births, and in the 1980 census for the 1981 and 1982 births. A job–exposure matrix using these occupations' titles was constructed for this study by two industrial hygienists. Relative risks were estimated using Cox proportional hazards modelling, adjusting for census year, gender, and maternal age. Control for socioeconomic status was performed for children born in 1981 and 1982. The RR for nervous system cancers was 3.65 (95% CI: 1.71–7.80; seven cases) for fathers occupationally exposed as painters.

Tsai *et al.* (2006) conducted a case–control study of Wilm tumour and residential and occupational exposures to chemicals. The study was located in six American states with toxic waste sites on the National Priorities List. Cases of Wilm tumour among children up

to the age of nine years diagnosed during 1992–1995 were obtained from the six states. A total of 303 cases and 575 age- and race-matched population controls that were selected by random-digit dialling were interviewed. A telephone interview obtained information on maternal occupational history 2 years before the child's birth, and an abbreviated questionnaire obtained information on paternal occupational history. ORs were calculated using unconditional logistic regression adjusting for socioeconomic status, parental occupation, and hobbies. ORs for occupational and household exposure to paint and paint strippers were 1.09 (95% CI: 0.64–1.86; 16 cases) during pregnancy, and 1.04 (95% CI: 0.62–1.74; 17 cases) during the 2-year study period.

2.3.3 *Other cancers*

Cases of hepatoblastoma were identified from the Children's Cancer Study Group in the USA (Buckley *et al.*, 1989b). This study has been described previously (Buckley *et al.*, 1989a; Freedman *et al.*, 2001; Shu *et al.*, 1999). A total of 75 cases were identified during 1980–1993. Age-matched population controls ($n = 75$) were selected by random-digit dialling. Interviews obtained information on a variety of factors including detailed parental occupational histories and 51 specific chemicals and substances. Conditional logistic regression was used to estimate ORs. The ORs from exposure to paints or pigments were 3.7 ($P < 0.05$) from mothers, and 1.5 ($P > 0.10$) for fathers. In a multivariate analysis, the OR for maternal and paternal exposure to paint and pigments was 2.8 ($P = 0.11$).

2.3.4 *Synthesis of studies assessing maternal paint exposure and childhood leukaemia* (See Table 2.8)

Eight population-based case-control studies reported on the association between maternal exposure to paints and childhood leukaemia (van Steensel-Moll *et al.*, 1985); Lowengart *et al.*, 1987; Buckley *et al.*, 1989a; Shu *et al.*, 1999, 2004; Schüz *et al.*, 2000; Freedman *et al.*, 2001; Alderton *et al.*, 2006). Most of the studies presented combined results for paints, stains, lacquers. One study presented a case-only analysis that examined if maternal paint exposure was associated with the development of *Ras* mutation in acute lymphocytic leukaemia cases compared to *Ras*-mutation-negative acute lymphocytic leukaemia cases (Shu *et al.*, 2004), and therefore was not directly relevant to the discussion of whether maternal paint exposure to paints increases the risk of childhood leukaemia compared to healthy controls. Two studies reported on acute leukaemias combined (van Steensel-Moll *et al.*, 1985; Lowengart *et al.*, 1987), four studies reported on acute lymphocytic leukaemia (Shu *et al.*, 1999; Schüz *et al.*, 2000; Freedman *et al.*, 2001; Alderton *et al.*, 2006), and two studies reported on acute myeloid leukaemia (Buckley *et al.*, 1989a; Alderton *et al.*, 2006).

Table 2.8. Studies of childhood leukaemia and maternal exposure to paints

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure Assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Van Steensel-Moll *et al.* (1985) Netherlands 1973–82 Case–control study	519 acute leukaemia cases from national cancer registry; <15 years old 507 controls from census lists; matched by region, date of birth, sex	Mailed questionnaire	Acute leukaemia	Paint, petroleum products, other chemicals during pregnancy	25	2.4 (1.2–4.6)	Social class, birth order, age, sex, region	Histological subtype not specified; estimated ~83% ALL cases; the category for paint exposure was combined with petroleum products and other chemicals
Lowengart *et al.* (1987) USA 1980–85 Case–control study	123 acute leukaemia cases ≤ 10 years old enrolled from population-based cancer registry 123 age-, sex-, race-, and Hispanic-ethnicity-matched controls selected from friends or by RDD	Telephone interview using a structured questionnaire	Acute leukaemia	Paint, lacquer exposure during pregnancy ≥ once/week	27 4	1.8 (p=0.03) 1.3 (p=0.30)	Age, sex, race, Hispanic ethnicity	Histological subtype not specified
Buckley *et al.* (1989a) 100 institutions in the USA and Canada 1980–84 Case–control study	204 cases aged <18 years from the CCSG cooperative clinical trial group 262 population controls selected by RDD, matched by date of birth and race	Parental lifetime work history obtained through interviews with each parent	ANLL	Paint & pigment exposure *Duration (days)* 1 to 1000 >1000 *P* for trend *Period of use* Before pregnancy During pregnancy After pregnancy Use of spray paints (prolonged exposure)	 15 15 NG NG NG NG	 1.5 (0.6–3.3) 2.2 (0.9–5.4) 0.05 2.3 (*P*<0.05) 1.5 0.9 3.0 (*P*<0.03)	Date of birth, race	

Table 2.8 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure Assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Shu *et al*. (1999) 100 institutions in USA 1989–93 Case–control study	1842 cases from CCG hospitals; <15 years old 1987 population controls selected by RDD, individually matched by age, race, telephone area code and exchange	Detailed lifetime parental occupational history from telephone interview: all jobs held 6 months (father since age 18; mother for two years prior to pregnancy); assessment of specific exposures by an industrial hygenist	ALL	Occupational exposure *Spray paints (time period)* Anytime Preconception During pregnancy Postnatal *Other paints (time period)* Anytime Preconception During pregnancy Postnatal	 53 27 27 38 87 44 37 51	 1.0 (0.7–1.5) 1.3 (0.7–2.3) 1.4 (0.8–2.6) 1.2 (0.7–1.9) 1.3 (0.9–1.7) 1.9 (1.2–3.1) 2.0 (1.2–3.5) 1.3 (0.9–2.0)	Maternal education, race, family income, age, area code	Evaluation of maternal exposures to paints and thinners by duration resulted in a slightly larger OR for the shorter duration category and significant duration–response relationships were observed
Schüz *et al*. (2000) Germany, LSP Study 1992–1996; NIP and WGP 1993–97 Pooled analysis of three case–control studies	1138 cases from the German Childhood Cancer Registry; <15 years old 2962 population controls from population registration files; matched by gender, year of birth and community (NIP study)	Self-reported parental occupational chemical exposures	ALL	Paints or lacquers Any time Preconception During pregnancy Postnatal	 54 45 32 18	 1.8 (1.2–2.6) 1.6 (1.1–2.4) 2.0 (1.2–3.3) 1.0 (0.6–1.8)	Age, gender, year of birth, urbanization, and SES	
Freedman *et al*. (2001) USA (9 midwestern and mid-Atlantic states), 1989–93 Case–control study	640 cases from CCG hospitals; <15 years old 640 population controls selected by RDD; individually matched by age, race, first 8 digits of telephone number	Household exposures of mothers During the interview, mothers provided information on household activities that could result in chemical exposure, including painting	ALL	Mother painted	160	1.1 (0.9–1.5)	Age, income, sex, maternal education, painting during other periods	

Table 2.8 (contd)

Reference, study location, period, study design	Characteristics of the cohort or of cases and controls	Exposure Assessment	Organ Site	Exposure categories	No.of exposed cases	RR (95% CI)	Adjustment for potential confounders	Comments
Shu *et al* (2004) USA and Canada 1989–93 Case–case analysis	837 cases identified from CCG institutions; <15 years old	Telephone interview using structured questionnaires	ALL	Paints or thinners			Maternal race, education, age, family income, age, sex	Case–case comparison to examine whether reported parental occupational exposure to hydrocarbons was related to *Ras* gene mutations
			K-*Ras* mutation positive	Any time	4	1.3 (0.4–3.9)		
				Before pregnancy	2	1.0 (0.2–4.6)		
				During pregnancy	2	1.0 (0.2–4.4)		
				After pregnancy	3	1.4 (0.4–4.9)		
			K-*Ras* mutation negative	Any time	7	1.0 (0.4–2.2)		
				Before pregnancy	6	1.6 (0.6–4.1)		
				During pregnancy	6	1.5 (0.6–3.6)		
				After pregnancy	6	1.1 (0.4–2.7)		
Alderton *et al* (2006) USA and Canada 1997–2002	158 children (≤19 years old) with Down syndrome and acute leukaemia (97 ALL, 61 AML) 173 age-matched control children with Down syndrome but without leukaemia	Interview using a structured, computer-assisted telephone questionnaire	ALL	Exposure to paints, stains, lacquers			Age, sex, mother's educational level	Information available for child's exposure to paints, stains, lacquers
				None	97	1.0 (ref)		
				Any	75	1.10 (0.65–1.86)		
				Low	40	1.26 (0.68–2.34)		
				High	35	0.92 (0.46–1.84)		
				P for trend		0.99		
			AML	None	34	1.0 (ref)		
				Any	27	1.23 (0.64–1.37)		
				Low	14	1.10 (0.49–2.44)		
				High	13	1.41 (0.61–3.23)		
				P for trend		0.44		

ALL, acute lymphocytic leukaemia; ANLL, acute non-lymphocytic leukaemia; CCG, Children's Cancer Group; CCSG, Children's Cancer Study Group; JEM, job exposure matrix; NG, not given; POG, Pediatric Oncology Group; RDD, random-digit dialling; SES, socioeconomic status

Five studies showed significant positive associations with maternal paint exposure either before or during pregnancy (van Steensel-Moll *et al.*, 1985; Lowengart *et al.*, 1987; Buckley *et al.*, 1989a; Shu *et al.*, 1999; Schüz *et al.*, 2000). All of these studies controlled for age and/or sex, race, social class (measured through income, socieoeconomic status, degree of urbanization) or other variables. Additionally, a borderline significant positive association (Freedman *et al.*, 2001) and non-significantly elevated ORs (Alderton *et al.*, 2006) were also observed in two studies. Furthermore, significant exposure–response relationships, according to duration of maternal paint exposure, were observed in two studies (Buckley *et al.*, 1989a; Shu *et al.*, 1999).

2.4 References

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3. Studies of Cancer in Experimental Animals

No data were available to the Working Group.

4. Mechanistic and Other Relevant Data

4.1 Toxicokinetics and metabolism

Painters and paint industry workers are exposed to complex mixtures of organic solvents (aliphatic, aromatic, chlorinated), metals (lead, chromium, cadmium) and many other compounds with potential mutagenic properties (IARC, 1989). It is not possible to provide information on the toxicokinetics and metabolism of all known components of paint or exposures related to painting activities (pyrolysis products of paint stripping, dust from sanding etc.). Selected chemicals profiled were chosen based on 1) their known carcinogenicity, and 2) relatively high frequency of exposure among populations exposed to paint that have been monitored. For a full overview of the main substances and the class of substances to which workers may have been exposed in painting trades, see Section 1.1, Table 1.1. [The Working Group recognized that exposure in paint trades is a complex mixture and that therefore the described toxicokinetics of single agents might be altered in the presence of other chemicals.]

4.1.1 *Aromatic hydrocarbons*

(a) Benzene

Inhalation exposure is probably the major route of human exposure to benzene, although oral and dermal exposure could be important. Benzene is readily absorbed following inhalation (70–80% in humans) or oral exposure (> 90% in rabbits and rodents). Although benzene is readily absorbed through the skin, a significant amount of a dermal application evaporates from the skin when not occluded or immersed (absorbed dose ~0.05%). Absorbed benzene is rapidly distributed throughout the body and tends to accumulate in fatty tissues (ATSDR, 2007a).

The liver serves an important function in benzene metabolism, which results in the production of several reactive metabolites (ATSDR, 2007a). Benzene is oxidized primarily by the cytochrome P450 (CYP) isozyme 2E1 to benzene oxide, which exists in equilibrium with its tautomer oxepin (Kim *et al.*, 2006, 2007). Spontaneous rearrangement of benzene oxide produces phenol that is either excreted or oxidized by CYPs to hydroquinone, which is in turn excreted or oxidized by myeloperoxidase in the bone marrow to 1,4-benzoquinone. Conversely, NAD(P)H quinone oxidoreductase 1

transforms 1,4-benzoquinone to hydroquinone. Hydroquinone and 1,4-benzoquinone are thought to be responsible for the toxic effects of benzene through their ability to inhibit topoisomerase II and microtubule function, induce oxidative stress, and damage DNA. Other major metabolites include catechol, representing the pathway involving hydrolysis of benzene oxide by epoxide hydrolases, and *E,E*-muconic acid, representing the pathway involving oxidation of oxepin and ring opening (ATSDR, 2007a). Reaction between benzene oxide and glutathione, possibly mediated by glutathione-*S*-transferases M1 and T1, can produce the minor metabolite *S*-phenylmercapturic acid (ATSDR, 2007a; Kim *et al.*, 2007). Although it is widely accepted that benzene toxicity is dependent on its metabolism, no single benzene metabolite has been found to be the major source of benzene haematopoietic and leukemogenic effects. At low exposure levels, benzene is rapidly metabolized and excreted predominantly as conjugated urinary metabolites. At higher exposure levels, metabolic pathways appear to become saturated and a large portion of an absorbed dose of benzene is excreted as parent compound in exhaled air. Benzene metabolism appears to be qualitatively similar among humans and various laboratory animal species. However, there are quantitative differences in the relative amounts of benzene metabolites (ATSDR, 2007a).

(b) Toluene

Toluene is readily absorbed from the respiratory (about 50%) and gastrointestinal tracts (> 95%) and, to a lesser extent, through the skin (ATSDR, 2000a; Baelum *et al.*, 1993).

The primary initial steps in toluene metabolism in humans and laboratory animals are side-chain hydroxylation (to form benzyl alcohol) catalysed predominantly by CYP2E1, followed by oxidation to benzoic acid. Most of the benzoic acid is then conjugated with glycine to form hippuric acid, but a small portion can be conjugated with UDP-glucuronate to form the acyl-glucuronide (ATSDR, 2000a). Studies with volunteers and human liver microsomes indicate that a very small portion (< 1–5%) of absorbed toluene can be converted by CYP1A2, CYP2B6, or CYP2E1 to *ortho*- or *para*-cresol, which are excreted in the urine as sulfate or glucuronate conjugates (ATSDR, 2000a; Nakajima *et al.*, 1997). In both humans and rats, up to about 75–80% of inhaled toluene that is absorbed can be accounted for as hippuric acid in the urine (Löf *et al.*, 1993; Wang & Nakajima, 1992). Much of the remaining toluene is exhaled unchanged. In humans exposed by inhalation, rates of urinary excretion of *ortho*-cresol were about 1000-fold lower than excretion rates for hippuric acid. The excretion of toluene and its metabolites is rapid, with the major portion occurring within 12 hours of exposure (Baelum *et al.*, 1993; Löf *et al.*, 1993).

(c) Xylenes

Xylenes (mixtures of *ortho*, *meta* and *para* isomers) are well absorbed by the inhalation and oral routes. Approximately 60% of inhaled xylene is retained, and approximately 90% of ingested xylene is absorbed. Absorption of xylene also occurs by

the dermal route, but to a much lesser extent than by the inhalation and oral routes. Following absorption, xylene is rapidly distributed throughout the body through systemic circulation. In the blood, xylene is primarily bound to serum proteins. Xylene accumulates essentially in adipose tissue (ATSDR, 2007b).

All three isomers of xylene are primarily metabolized in the liver by oxidation of a methyl group (mainly by CYP2E1) and conjugation with glycine to yield methylhippuric acid, excreted in urine. In humans exposed to xylene, > 90% of the absorbed xylene is excreted in the urine as the methylhippuric acid, about 5% as other metabolites, and the rest excreted unchanged in the exhaled air. Aromatic hydroxylation of xylene to xylenol occurs to only a limited extent in humans. Less than 2% of an absorbed dose is excreted in the urine as xylenol. Other minor metabolites found in urine include methylbenzyl alcohol and glucuronic acid conjugates of the oxidized xylene. Metabolism in animals is qualitatively similar, but glucuronide conjugates make up a larger proportion of the urinary excretion. In addition, methylbenzaldehyde (the product of the action of alcohol dehydrogenase on methylbenzyl alcohol) has been detected in animals, but its presence has not been confirmed in humans. Elimination from most tissue compartments is rapid, with slower elimination from muscle and adipose tissue (ATSDR, 2007b).

4.1.2 *Chlorinated solvents*

(a) Dichloromethane

Inhalation is the main route of exposure to dichloromethane for humans. Within the first few minutes of exposure, approximately 70–75% of inhaled vapour is absorbed (Environmental Protection Agency, 1994). Distribution data in humans are lacking, but dichloromethane has been found in human breast milk and blood. Dichloromethane is widely distributed in animal tissues after inhalation exposure. The highest concentrations are found in adipose tissue and liver. Dichloromethane has been found in blood from rats' fetuses. Distribution of dichloromethane does not seem to be route-dependent, and it does not bioaccumulate in tissues. After acute exposure, dichloromethane disappears rapidly from fat (ATSDR, 2000b).

There are two main competing metabolic pathways for dichloromethane; one initially catalysed by CYP2E1, and the other by a theta glutathione-*S*-transferase. The CYP pathway produces carbon monoxide and carbon dioxide via formyl chloride and the glutathione-*S*-transferase (GST) pathway produces carbon dioxide via a postulated glutathione conjugate (*S*-chloromethyl glutathione), and formaldehyde. Both pathways can give rise to toxic metabolites. The CYP pathway is preferred at lower exposure concentrations and becomes saturated as exposure levels increase. Oxidative biotransformation of dichloromethane is similar in rats and humans. In rats, the CYP pathway is high-affinity low capacity, whereas the GST pathway has lower affinity, but higher capacity. The GST pathway is more active in mice than in rats and less active in hamsters and humans than in rats. After inhalation exposure, humans eliminate dichloromethane mainly in exhaled air, but also in the urine (ATSDR, 2000b).

(b) Trichloroethylene

Inhalation, oral, and dermal studies in animals and humans indicate that trichloroethylene is rapidly absorbed into the bloodstream, regardless of the route, where it is then widely distributed to its target organs, which include the liver, kidney, and cardiovascular and nervous systems. Metabolism occurs fairly rapidly, and the resulting metabolites may be responsible for much of the toxic effect of trichloroethylene. Metabolites are excreted primarily in the urine, and unabsorbed or unmetabolized trichloroethylene is exhaled in the breath (ATSDR, 1997).

Trichloroethylene is metabolized by two pathways: oxidation by CYP (major pathway), and conjugation with glutathione (Davidson & Beliles, 1991; Lash *et al.*, 2000). Trichloroethylene metabolism through the CYP pathway leads to the formation of major metabolites such as chloral hydrate, trichloroethanol, and trichloroacetic acid. This step primarily takes place in the liver. Four CYP isoforms have been identified as playing a role in trichloroethylene metabolism: CYP2A1/2, CYP2B1/2, CYP2C11/6, CYP2E1 (Guengerich and Shimada, 1991; Koop *et al.*, 1985; Nakajima *et al.*, 1988; Lash *et al.*, 2000). Metabolites produced through this pathway are thought to be associated with liver toxicity and liver carcinogenesis in animals.

The glutathione conjugation pathway leads to the formation of dichlorovinyl glutathione and dichlorovinyl cysteine. Dichlorovinyl cysteine can be further metabolized by β-lyase to reactive species but only at relatively high levels of exposure. These are thought to play a role in trichloroethylene-associated proximal renal tubular toxicity, and renal carcinogenicity in animals (Lash *et al.*, 2000).

4.1.3 *Styrene*

Styrene is absorbed orally, by inhalation, and dermal transfer in both man and experimental animals. In man, 60–70% of inhaled styrene is absorbed. It is rapidly distributed throughout the body, with the highest concentrations found in adipose tissue (IARC, 1994, 2002).

A large percentage of absorbed styrene is excreted as urinary mandelic and phenylglyoxylic acids, following its oxidation to styrene-7,8-oxide. Glutathione conjugates represent a minor fraction of the metabolites of styrene-7,8-oxide. Saturation of metabolic activation of styrene becomes apparent at concentrations above 200–300 ppm (850–1280 mg/m^3) in rats and mice, and above 150–200 ppm (430–850 mg/m^3) in humans. The formation of styrene-7,8-oxide, the dominant first metabolite, appears to be catalysed in humans principally by CYP2E1 and CYP2F but also by CYP2B6. Isolated erythrocytes are also capable of non-enzymatic conversion of styrene to styrene-7,8-oxide. The amounts of styrene-7,8-oxide present in the blood of rats and mice exposed to styrene at concentrations below 100 ppm (430 mg/m^3) were about 5–20-fold greater than those in humans exposed to similar styrene concentrations (IARC, 1994, 2002).

4.1.4 *Metals*

(a) Cadmium

Cadmium enters the body mainly by inhalation, and by ingestion. Fractional intestinal absorption is influenced by dietary factors and increases with dietary cadmium concentration. Pulmonary fractional absorption depends partly on the solubility *in vivo* of the compound. Cadmium induces synthesis of metallothionein, a low molecular-weight protein that binds cadmium primarily in the liver and kidney. Metallothionein production can also be induced by other divalent metals, e.g. zinc. When metallothionein-bound cadmium is released into the blood, it is filtered through the renal glomeruli and then reabsorbed in the proximal tubules. In certain mammalian tissues, such as rat ventral prostate, hamster ovary, and rat, mouse and monkey testis, the concentrations of metallothionein are low and its synthesis is not induced by exposure to cadmium. Most of the body burden of cadmium is retained in the kidney, and the liver. The half-life of cadmium in human kidney is probably 10–20 years. Cadmium concentrations in whole blood are affected by both recent exposure and by body burden. Excretion occurs mainly via the urine. Urinary excretion of cadmium by individuals without renal dysfunction primarily reflects the amount of cadmium retained in the kidney (IARC, 1993).

(b) Chromium

The toxicokinetics of a given chromium compound depends on the valence state of the chromium atom and the nature of its ligands. Absorption of chromium (VI) compounds is higher than that of chromium (III) compounds. This is because the chromate anion CrO_4^{2-} can enter cells via diffusion through nonspecific anion channels (similarly to phosphate and sulfate anions). Absorption of chromium (III) compounds is via passive diffusion and phagocytosis. Absorption of inhaled chromium compounds takes place in the lung via transfer across cell membranes, and in the gastrointestinal tract from particles cleared from the lungs. Absorption after oral exposure in humans varies from essentially none for the highly insoluble chromium(III) compound chromic oxide, to 0.5–2.0% for chromium (III) compounds in the diet, to approximately 2–10% for chromium (VI) as potassium chromate. Dermal absorption depends on the physical and chemical properties of the compound, the vehicle, and the integrity of the skin. Once in the blood, chromium compounds are distributed to all organs of the body. Particles containing chromium can be retained in the lung for years after occupational exposure (ATSDR, 2000c).

Chromium (VI) is unstable in the body and is reduced to chromium (V), chromium (IV), and ultimately to chromium (III) by many substances including ascorbate and glutathione. It is believed that the toxicity of chromium (VI) compounds results from damage to cellular components during this process (e.g. generation of free radicals). There is also evidence in in-vitro experiments that chromium (III) can be reduced to chromium (II), and exert toxic effects (ATSDR, 2000c).

Absorbed chromium is excreted primarily in urine, the half-time for excretion of chromium administered as potassium chromate is estimated to be 35–40 hours in humans. Hair and nails are minor excretion pathways (ATSDR, 2000c).

(c) Inorganic lead

Lead absorption from the gastrointestinal tract in both humans and experimental animals is strongly influenced by age (neonates and the young absorb a larger fraction than adults), fasting/fed status (fasting humans and experimental animals absorb much larger fractions than their fed counterparts), nutrition (fat and caloric intakes; phosphorus, copper, zinc and especially iron and calcium status, all affect lead absorption), solubility (soluble lead compounds are better absorbed) and particle size (in controlled studies in rats, lead absorption from ingested mining wastes was shown to be inversely proportional to particle size). There are no data indicating that the fraction of lead absorbed from an inhalation exposure is dependent on the amount of lead in the lung. Patterns and rates of particle deposition are highly dependent on particle size and ventilation rate, but all lead deposited deep in the lung is eventually absorbed. Limited studies indicate that dermal absorption of inorganic lead is negligible, although slightly increased by high perspiration rates in humans. In both humans and experimental animals, absorbed lead is rapidly distributed from blood plasma simultaneously into erythrocytes, soft tissues, and bone. The half-life of lead in blood and soft tissues is 20–30 days in adult humans, and 3–5 days in adult rats. The majority of lead is stored in bone (in adults > 90%) and is partitioned mainly into trabecular and cortical bone. The higher rate of remodelling in trabecular bone is reflected in a shorter half-life of lead in trabecular bone (2–8 years) compared with that in cortical bone (> 20 years). Bone can be a significant source of endogenous lead, in particular when the bone resorption rate is increased, such as during pregnancy, lactation, and the period just after menopause. After oral ingestion, inorganic lead that has not been absorbed in the gastrointestinal tract is excreted in the faeces. Absorbed lead is primarily excreted in the urine and, via the bile, in the faeces (IARC, 2006).

4.1.5 *Polycyclic aromatic hydrocarbons (PAHs)*

PAH exposure in paint trades might occur due to use of paints containing PAHs or by pyrolysis of paint products at removal. There are more than 100 different PAHs. PAHs generally occur as complex mixtures and not as single compounds. The mixture of PAHs in paints or as a result of pyrolysis of paint residues during paint removal is unknown. Therefore, the toxicokinetics is discussed in broad general terms.

Absorption of benzo[*a*]pyrene following ingestion is low in humans, while oral absorption in animals varies among the PAH compounds depending on their lipophilicity. Oral absorption increases with more lipophilic compounds or in the presence of oils in the gastrointestinal tract. Percutaneous absorption of PAHs appears to be rapid for both humans and animals, but the extent of absorption is variable among these compounds, and may be affected by the vehicle used for administration. Absorption of inhaled PAHs appears to occur through the mucous lining of bronchi, while ingested PAHs are taken up

by the gastrointestinal tract in fat-soluble compounds. Percutaneous absorption is through passive diffusion. PAHs appear to be widely distributed in tissues of animals following oral and inhalation exposure; peak tissue concentrations occur earlier with higher exposure levels. Placental transfer of PAHs appears to be limited, and therefore, fetal levels are not as high as maternal levels (ATSDR, 1995).

Metabolism of PAHs occurs in all tissues and involves several possible pathways. Metabolism products include epoxide intermediates, dihydrodiols, phenols, quinones, and their various combinations. The phenols, quinones, and dihydrodiols can all be conjugated to glucuronides and sulfate esters; the quinones also form glutathione conjugates (ATSDR, 1995; see also Section 4.2.2 (j)).

Quantitative data on the excretion of PAHs in humans are lacking. In general, elimination via faeces is the major route of excretion of PAHs in animals following inhalation exposure. Excretion of benzo[*a*]pyrene appears to be high following low-level exposure in rats but low in dogs and monkeys. PAHs are eliminated to a large extent within 2 days following low- and high-level oral exposure in rats. Following dermal exposure, elimination of PAHs occurs rapidly in the urine and feces of guinea-pigs and rats (ATSDR, 1995).

The mechanism of action of most PAHs involves covalent binding to DNA by PAH metabolites. The bay region diol epoxide intermediates of PAHs are currently considered to be the ultimate carcinogen for alternant PAHs. Once the reactive bay region epoxide is formed, it may covalently bind to DNA and other cellular macromolecules, and presumably initiate mutagenesis and carcinogenesis (ATSDR, 1995; see also 4.2.2 (j)).

4.2 Genetic and related effects

4.2.1 *Direct genotoxicity*

Several studies have evaluated genotoxic effects in painters (Table 4.1). Results of these studies are discussed by genotoxic end-point in chronological order. Paints as a compound have not been tested in experimental systems.

(a) Chromosomal aberrations

Haglund *et al.* (1980) were the first to report on cytogenetic effects among 17 workers exposed to paints (average employment > 10 years). Median exposure levels of xylene, toluene, isobutanol, ethylacetate, *n*-butylacetate, ethanol, *n*-butanol, methylacetate, methylene chloride, white spirit and isopropanol were all below the corresponding exposure limits except for methylene chloride (719 mg/m^3). Five heavily exposed workers in paint manufacturing were compared to an unexposed referent group (factory workers working in: store room, paint grinders, electricians, drivers, carpenters) matched by age, sex, place of residence (rural/urban), and smoking habits. No difference in the frequency of aberrant cells (i.e. presence of a structural and/or numerical chromosomal aberrations) were observed between the exposed workers and their matched reference group (3.4% versus 3.7%, respectively, $0.90 < P < 0.95$).

Table 4.1. Genotoxicity studies of painters

Study Population	Industry	Assay conditions	Result	Reference
Chromosomal Aberrations				
5 workers in paint manufacturing and 5 unexposed controls	Paint industry	Lymphocytes/72 h culture/100 metaphases	– (Individually matched on smoking status)	Haglund *et al.* (1980)
13 painters and 12 unexposed controls	Metallurgy	Lymphocytes/72 h culture/100 metaphases	+ (Frequency matched on smoking status)	Capomazza & Botta (1990)
25 male railroad and underground railroad car painters and 25 unexposed controls	Railroad car construction industry	Lymphocytes/48 h culture/100 metaphases	+	Piña-Calva *et al.* (1991)
13 painters (6 with abnormal blood cell counts) and 4 unexposed controls	Shipyard	Bone marrow precursor cells/10–20 cells	+/–	Cullen *et al.* (1992)
25 male car painters and 20 unexposed controls	Automobile body and painting shops	Lymphocytes/48 h culture/200 metaphases	+	Silva & Santos-Mello (1996)
25 male public building painters and 25 unexposed controls		Lymphocytes/48 h culture/100 metaphases	+	Pinto *et al.* (2000)
104 spray painters employed in 64 workshops and 50 controls	Automobile repainting, steel furniture making and refrigerator painting	Lymphocytes/48 and 72 h culture/100 metaphases	+ (+ S, +/– NS)	Gajalakshmi *et al.* (2002)

Table 4.1. Genotoxicity studies of painters

Study Population	Industry	Assay conditions	Result	Reference
25 car painters and 37 unexposed controls	8 Italian automobile paint shops	Lymphocytes/48 h culture/200 metaphases	+ (+ S, + NS)	Testa *et al.* (2005)
Sister Chromatid Exchanges				
17 workers in paint manufacturing and 17 unexposed controls	Paint industry	72 h culture/20–25 cells	–	Haglund *et al.* (1980)
106 painters of which 21 with minimal or no exposure (controls)	2 union locals	72 h culture/50 cells	+/– (+/– S; – NS)	Kelsey *et al*. (1988, 1989)
13 painters (6 with abnormal blood cell counts) and 4 unexposed controls	Shipyard	Unknown	– (Adjusted for smoking)	Cullen *et al*. (1992)
22 spray painters and 22 unexposed controls	3 automotive workshops	72 h culture/30 cells	+ (Individually matched on smoking status)	Sardas *et al*. (1994)
6 painters (individuals serve as their own controls)	Aircraft maintenance personnel	68–70 h culture/50 cells	+ (Adjusted for smoking)	Lemasters *et al*. (1997, 1999)
25 male public building painters and 25 unexposed controls		72 h culture/30 cells	+	Pinto *et al*. (2000)

Table 4.1. Genotoxicity studies of painters

Study Population	Industry	Assay conditions	Result	Reference
25 car painters and 37 unexposed controls	8 Italian automobile paint shops	72 h culture/100 cells	+ (+ NS, – S)	Testa *et al*. (2005)
Micronuclei				
21 male workers and 19 unexposed controls	2 paint factories	Lymphocytes/72 h culture/1000 binucleated cells Buccal cells/3000 cells	+ (Similar frequency of smoking among exposed and unexposed)	Diaz *et al.* (1990)
33 industrial painters and 200 subjects from the general population	Plastics industry	Lymphocytes/44 h culture/500 binucleated cells	+ (+ NS, + S)	Di Giorgio *et al.* (1994)
6 painters (individuals serve as their own controls)	Aircraft maintenance personnel	Lymphocytes/44 h culture/100 binucleated cells	– (Adjusted for smoking)	Lemasters *et al.* (1997, 1999)
25 public male building painters and 25 unexposed controls		Buccal cells/3000 cells	+	Pinto *et al.* (2000)
10 car painters and 10 unexposed controls	Automobile industry	Buccal cells/2000 cells	+ (Not adjusted for smoking)	Martino-Roth *et al.* (2003)
25 car painters and 37 unexposed controls	8 Italian automobile paint shops	Lymphocytes/72 h culture/1000 binucleated cells	+ + NS (no effect among smokers)	Testa *et al.* (2005)

Table 4.1. Genotoxicity studies of painters

Study Population	Industry	Assay conditions	Result	Reference
DNA strand breaks				
39 spray painters and 39 unexposed controls	14 automotive body repair shops	Non-fractionated alkaline elution method	+ + NS (no effect among smokers)	Fuchs *et al.* (1996a); Oesch *et al.* (1994)
9 bitumen painters and 34 unexposed controls		Non-fractionated alkaline elution method	–	Fuchs *et al.* (1996b)
80 painters and 45 auxiliary workers and two control groups (managerial n=29; assembly workers n=18)	Bus manufacturing factory	COMET	+ + NS	Zhu *et al.* (2001)
10 car painters and 10 unexposed controls	Automobile industry	COMET	+	Martino-Roth *et al.* (2003)
Other genotoxicity assays				
181 painters and 27 unexposed controls	Shipyard	Aromatic-DNA adducts (Bulky DNA adducts) Glycophorin A	+ –	Lee *et al.* (2003)

+, increase; -, no significant increase; NS, non-smokers; S, smokers

In a subsequent study by Capomazza & Botta (1990), frequency of chromosomal aberrations was assessed in 13 painters (30–55 years old), and 12 occupationally unexposed subjects (30–50 years old). Groups were frequency-matched on smoking habits. The results showed a significant increase ($P < 0.001$) of chromosomal aberrations level (chromatid breaks and chromatid gaps) in painters (1.77 ± 1.30), compared to the referent group (0.33 ± 0.45).

In a study among railroad car painters in Mexico, increased levels of chromosomal aberrations were found among 25 exposed individuals when compared to 25 unexposed controls (teachers and students at a college). Total chromosomal aberrations levels were 1.92 ± 6.89 and 12.2 ± 2.9 ($P < 0.01$) for controls and painters, respectively. The mean duration of employment as a painter for the study subjects was 5.2 years (Piña-Calva *et al.*, 1991). [Although solvent exposures were measured, no individual results were reported except that all measurements were below the PELs. The Working Group noted that although the study was not adjusted for smoking, the likelihood of confounding is low as no relation was observed between smoking and chromosomal aberrations].

Cullen *et al.* (1992) reviewed chromosomal aberrations in bone marrow precursor cells obtained from six painters with abnormal blood cell counts, seven painters with normal blood cell counts and four unexposed controls. Between 10 and 20 banded cells per subject were reviewed for chromosomal and chromatid breaks. A single chromatid break was noted in only two painters with normal blood cell counts.

Silva & Santos-Mello (1996) studied 25 male car painters aged 20–56 years in Brasil, who had been working for a period of 1–39 years in this occupation. The control group consisted of 20 unexposed individuals aged 20–47 years. Painters had a higher frequency of individuals with at least one chromosomal aberration in 200 metaphases when compared with controls (96% versus 55%, respectively, $P < 0.05$). This difference was mostly driven by the difference in frequency of chromosomal deletions (60% and 20% for exposed versus unexposed, respectively, $P < 0.05$). However, no association was found between years at work and chromosomal deletion frequency. An association between years at work and aneuploidy was however reported (Kendall coefficient, $\tau = 0.25$, $P < 0.05$). [The Working Group noted that smoking status was not taken into account in the analyses. However, smoking habits among the exposed did not seem to be related to chromosomal aberrations and is therefore unlikely to have confounded the results.]

In a study among 25 male public building painters aged 18–62 years in Mexico, increased chromosomal aberration levels were found when compared to the same number of sex- and age-matched unexposed controls (0.188 ± 0.026 versus 0.037 ± 0.004, respectively, $P < 0.0001$). Individual blood lead levels did not correlate with the observed cytogenetic damage. A strong correlation ($r^2 = 0.73$, $P < 0.001$) was observed between years of employment and chromosomal aberrations (Pinto *et al.*, 2000). [The Working Group noted that the study was not adjusted for smoking habits. However, all controls were non-smokers while seven out of the 25 exposed subjects smoked up to four cigarettes a day. Re-analyses of the data showed that the reported difference was present when comparison was made with non-smokers only ($P < 0.0001$; Wilcoxon).]

In a study of spray painters ($n = 104$) aged 18–61 years, from Chennai, India, Gajalakshmi *et al.* (2002) found that frequency of chromosomal aberrations were significantly higher among painters (3.29 ± 0.29) when compared to 50 age- and sex-matched controls (1.52 ± 0.21, $P < 0.001$). Results were comparable among smokers and non-smokers although statistical significance was only reached with the smokers. Duration of employment was on average 14 years (range, 2–40 years) and was found to be positively associated with chromosomal aberrations ($P = 0.03$).

Chromosomal aberrations were evaluated in 25 car painters working in different automobile paint shops in Italy and 37 unexposed control subjects (healthy blood donors). Air sampling in the workplaces showed that exposures to ethyl acetate, ethyl benzene, xylene, dichloropropane and *n*-butylacetate were below the PELs. Conversely, mean values of benzene and toluene were 9.99 mg/m^3 (range, 1.5–53.2) and 212.4 mg/m^3 (range, 15–938), respectively. Exposed workers had higher frequencies of chromosomal aberrations when compared to controls (2.52 ± 1.58 versus 1.08 ± 0.81, respectively, $P \leq 0.001$). This difference was observed for chromosome and chromatid-type aberrations, and was consistent among smokers and non-smokers (Testa *et al.*, 2005).

Overall, six of the eight published papers on chromosomal aberrations among painters or workers in paint manufacturing showed statistically significant elevated frequencies of chromosomal aberrations. Of these six positive studies, three reported an association with years of employment while the other studies did not report analyses on duration of employment. In the two studies that reported results stratified by smoking status, no marked difference in the association between exposure to paint and chromosomal aberrations was observed. Noteworthy is the negative study by Cullen *et al.* (1992) on bone marrow precursor cells. However, given the small number of exposed subjects ($n = 13$) and the limited number of scored cells (between 10 and 20), no firm conclusions could be drawn from this observation. Exposures in the different studies most likely differed and included among other organic solvents, glycol ethers, and lead (as reported by the authors). However, due to the limited exposure assessment in the studies, no meaningful dose–response analyses could be performed and therefore, none of the studies was able to associate a specific exposure to the observed effects. [The Working Group noted that, overall, the studies were small (generally less than 25 exposed subjects) and that the potential for publication bias (unpublished small negative studies) could not be ruled out.]

(b) Sister chromatid exchanges

Haglund *et al.* (1980) studied 17 workers (average duration of employment > 10 years) in the Swedish paint industry. No difference in the frequency of sister chromatid exchanges (SCEs) was observed between the exposed workers (0.193 SCE/chromosome) and a reference group ($n = 17$) (0.192 SCE/chromosome) matched by age, sex, place of residence (rural/urban), and smoking habits. In addition, no correlation was observed between xylene or toluene exposure and SCE frequency or between total solvent exposure and SCE frequency. SCE frequency was different between

smokers (0.202 SCE/chromosome) and non-smokers regardless of solvent exposure or matching (0.175 SCE/chromosome, $P = 0.02$).

Kelsey *et al.* (1988, 1989) studied 106 painters who were recruited from two union locals of the International Brotherhood of Painters and Allied Tradesman. Of these 106 subjects, eight workers reported no exposure to solvents/paints, and 13 workers (including drywall tapers, wallpaper hangers) reported minimal exposure to solvent/paints. Cumulative exposure based on interviewer questionnaire data was estimated for the working lifetimes of the remaining 85 painters (mean duration of employment 18.9 years). No difference in SCE frequency was observed between the 21 unexposed control subjects (existing out of the unexposed and minimal exposed subgroups), and painters for both the non-smokers (5.73 ± 0.89 and 5.90 ± 0.76, for exposed and controls, respectively) and smokers (6.75 ± 1.17 and 6.84 ± 0.27, for exposed and controls, respectively). In addition, neither lifetime solvent exposure intensity nor cumulative years of painting was associated with an elevation in SCE level. The difference between smokers and non-smokers by exposure status was significantly different ($P < 0.01$) (Kelsey *et al.*, 1988). However, in a subsequent analysis focusing on stratified analyses by smoking and using days worked in the last month before venipuncture as a measure of recent exposure, an association with days worked and increased SCE levels among current smokers was reported ($P < 0.006$) (Kelsey *et al.*, 1989).

Cullen *et al.* (1992) analysed SCEs in lymphocytes from 13 painters (of whom six had been diagnosed with abnormal cell counts and found no difference in SCEs between the painters with low blood cell counts (8.22 ± 1.04), painters with normal counts (8.56 ± 1.56) and four unexposed controls (9.59 ± 2.17). Adjustment for smoking habits did not change the results. Current smoking was, however, strongly associated with SCE levels, smokers having a mean SCE level 1.8 times greater than former or non-smokers ($P = 0.006$).

In a study of 22 spray painters from Turkey aged between 18–56 years, a significant increase in mean SCE levels in spray painters (7.81 ± 1.50) versus 22 unexposed healthy controls matched by age and smoking status (4.92 ± 0.10, $P < 0.001$) was reported. The number of SCEs seemed to increase by duration of exposure although formal significance was only reached among smokers ($P < 0.001$) (Sardas *et al.*, 1994).

In a prospective repeated measures design, SCEs were assessed at baseline, after 15 weeks of exposure, and after 30 weeks of exposure among six aircraft painters. These painters were primarily exposed to solvents and paints. Mean total solvent exposure as measured by industrial hygiene sampling was 2.4 ppm; fuel, 1.4 ppm; and benzene, 0.0 ppm. SCE frequency increased with duration of exposure (5.9 ± 0.7, $P > 0.05$; 6.2 ± 1.0, $P > 0.05$; 6.7 ± 1.0, $P = 0.05$ at baseline, 15 weeks of exposure, and 30 weeks of exposure, respectively) (Lemasters *et al.*, 1997, 1999).

In a study among 25 male public building painters aged between 18–62 years in Mexico, increased SCE levels in lymphocytes were found when compared to the same number of sex- and age-matched unexposed controls (6.60 ± 1.58 versus 5.07 ± 0.90, respectively, $P < 0.05$). Blood lead levels did, however, not correlate with the observed

cytogenetic damage. A correlation ($r^2 = 0.32$, $P = 0.0001$) was observed between years of exposure and SCE (Pinto *et al.*, 2000). [The Working Group noted that the study was not adjusted for smoking habits. However, all controls were non-smokers while seven out of the 25 exposed subjects smoked up to four cigarettes a day. Re-analyses of the data showed that the reported difference was present when comparison was made with non-smokers only ($P < 0.0031$; Wilcoxon).]

SCEs were evaluated in 25 car painters working in different automobile paint shops in Italy and 37 unexposed control subjects (healthy blood donors). Air sampling in the workplaces showed that exposures to ethyl acetate, ethyl benzene, xylene, dichloropropane and *n*-butylacetate were below the PELs. Conversely, mean values of benzene and toluene were 9.99 mg/m^3 (range, 1.5–53.2) and 212.4 (range, 15–938), respectively. The exposed workers had higher frequencies of SCEs than controls (7.55 ± 1.18 versus 6.44 ± 1.32, respectively, $P < 0.05$). This difference was however only observed among non-smokers (7.45 ± 1.14 and 5.25 ± 0.37, for exposed and controls, respectively, $P \leq 0.001$) and not among current smokers (7.61 ± 1.27 versus 7.96 ± 0.84, for exposed and controls, respectively) (Testa *et al.*, 2005).

The results of the cytogenetic studies among painters or workers in the paint industry using sister chromatid exchanges as the biological outcome are less clear than those observed for chromosomal aberrations. Four out of seven published studies reported increased SCEs levels among painters. The negative studies tended to be the older studies. Results among smokers and non-smokers were not always consistent. Exposure–response relationships with duration of exposure were reported in three studies of which the prospective study of Lemasters *et al.* (1997, 1999) showed the clearest association with duration due to the prospective nature of the study. No direct associations with any specific exposures were reported.

(c) Micronuclei

In a study among 21 Cuban paint industry workers aged 21–59 years, elevated levels of micronuclei in lymphocytes and oral mucosal cells were found when compared to 19 controls (5.5 ± 0.5 versus 4.0 ± 0.5, $P < 0.05$, and 0.9 ± 0.2 versus 0.5 ± 0.1, $P < 0.05$ for lymphocytes and oral mucosal cells, respectively). Controls were recruited from the blood bank and were slightly younger than the exposed subjects. Frequency of smoking was similar between exposed subjects and controls. Adjustment for age or smoking did not change the significance of the results. Exposure of the subjects was not measured but the authors stated that benzene should not have been present (Diaz *et al.*, 1990).

Di Giorgio *et al.* (1994) studied 33 male industrial painters in a plastics factory and compared those to an unexposed group of 200 male and female individuals of mixed social class, not occupationally exposed to mutagens or aneugens. Among smokers, micronucleated cell rates observed in painters were 19.1 ± 8.57 while levels in controls were 11.8 ± 3.47, per 1000 binucleated cells ($P < 0.0001$). Among non-smokers, a similar effect was observed with micronucleated cell rates, which were 17.95 ± 8.01 and 8.9 ± 2.53, per 1000 binucleated cells ($P < 0.0001$), for painters and controls, respectively.

In a prospective repeated measures design, micronuclei were assessed at baseline, after 15 weeks of exposure, and after 30 weeks of exposure among six aircraft painters. These painters were primarily exposed to solvents and paints. Mean total solvent exposure as measured by industrial hygiene sampling was 2.4 ppm; fuel, 1.4 ppm; and benzene, 0.0 ppm. Micronuclei frequency increased non-significantly with duration of exposure 15.8 ± 5.6, 16.3 ± 11.4, 20.5 ± 7.0 at baseline, 15 weeks of exposure, and 30 weeks of exposure, respectively (Lemasters *et al.*, 1997, 1999).

In a study among 25 public building painters aged 18–62 years in Mexico, increased micronuclei levels in buccal cells (MN/1000) were found when compared to the same number of sex- and age-matched unexposed controls (0.32 ± 0.01 versus 1.19 ± 0.02, respectively, $P < 0.001$). Blood lead levels did not correlate with the observed cytogenetic damage. A correlation ($r^2 = 0.30$, $P < 0.0001$) was observed between years of exposure and micronuclei frequency (Pinto *et al.*, 2000). [The Working Group noted that the study was not adjusted for smoking habits. However, all controls were non-smokers while seven out of the 25 exposed subjects smoked up to four cigarettes a day. Re-analyses of the data showed that the reported difference was present when comparison was made with non-smokers only, although formal statistical significance was not reached ($P = 0.0580$; Wilcoxon).]

In a study among ten car painters in Brasil, a significant increase in micronuclei frequency in buccal cells was observed when compared to ten individually age- matched unexposed controls (6.9 ± 2.92 versus 2.2 ± 1.75, respectively, $P < 0.0001$). No information about specific exposures was available (Martino-Roth *et al.*, 2003). [The Working Group noted that the study was not adjusted for smoking habits. However, three out of ten controls were smokers while among the painters, five out of ten were smokers.]

Micronuclei were evaluated in 25 car painters working in different automobile paint shops in Italy and 37 unexposed control subjects (healthy blood donors). Air sampling in the workplaces showed that exposures to ethyl acetate, ethyl benzene, xylene, dichloropropane and *n*-butylacetate were below the PELs. Conversely, mean values of benzene and toluene were 9.99 mg/m^3 (range, 1.5–53.2) and 212.4 (range, 15–938), respectively. Exposed workers had higher frequencies of binucleated cells with micronucleus than controls (6.68 ± 3.27 versus 3.00 ± 2.50, respectively, $P \leq 0.001$),. However, this difference was observed only among the non-smokers (for exposed and control subjects, 7.57 ± 2.56 versus 3.00 ± 1.21, respectively, $P \leq 0.001$), and not among smokers (for exposed and control subjects, 5.54 ± 3.83 versus 5.93 ± 2.95, respectively) (Testa *et al.*, 2005).

Five out of six published studies reported increased micronuclei frequencies among painters ($n = 4$), and subjects employed in paint manufacturing ($n = 1$). Although not all studies controlled for smoking, elevated levels of micronuclei frequency was seen among both smokers and non-smokers. Genotoxic effects were found both in cultured lymphocytes and buccal cells. Two studies reported a dose–gradient with years or weeks worked and micronuclei frequency levels.

(d) DNA strand breaks

In a study of 39 (38 male and one female) German spray painters aged 16–62 years, Fuchs *et al.* (1996a) found that spray painters had a significantly higher mean level of single DNA strand breaks using the alkaline elution method in Friday samples (2.05 ± 0.17) compared to their respective Monday samples (1.38 ± 0.07, $P < 0.001$). This effect was observed among smokers and non-smokers, but reached statistical significance only among the non-smokers (Oesch *et al.*, 1994). DNA damage seemed to be reversible as no difference was observed in the level of DNA strand breaks between 39 unexposed controls (1.41 ± 0.62) and the Monday samples of the spray painters (Fuchs *et al.*, 1996a).

In a study of workers exposed to bitumen-based products, nine bitumen painters were assayed for DNA strand breaks using an alkaline elution method. For these nine bitumen painters, mean DNA strand break level was 1.34 ± 0.17 on Mondays and 1.09 ± 0.10 on Fridays. Levels of single DNA strand breaks were also comparable to a control group of 34 office employees and students (1.13 ± 0.05). The authors noted that non-smokers were overrepresented in the control group (Fuchs *et al.*, 1996b).

A study on lymphocyte DNA damage using the COMET assay among 346 male and female employees from a bus-manufacturing factory in Guangzhou, China, included 80 painters and 45 auxiliary workers who took up duties from the painters whenever necessary. Cells of painters (3.25 μm; 95% CI: 2.97–3.55) and auxiliary workers (3.13 μm; 95% CI: 2.82–3.48) had larger tail moments than 29 managerial workers (2.54 μm; 95% CI: 2.22–2.90) or 18 assembling workers (2.32 μm; 95% CI: 2.02–2.67) who were thought not to be exposed to obvious occupational exposures. Stratified analyses of non-smokers showed similar results. Although it is impossible to link the observed effects to any putative chemicals, it is worth noting that exposure levels of benzene ranged from 0.1–138.5 mg/m^3 in painting workshops (Zhu *et al.*, 2001).

In a study among ten car painters in Brasil, a significant increase in comet tail length (COMET assay) in lymphocytes was observed when compared to ten individually matched unexposed controls (33.85 ± 0.51 versus 30.73 ± 0.16, respectively, $P < 0.001$). No information about specific exposures was available (Martino-Roth *et al.*, 2003). [The Working Group noted that the study was not corrected for smoking habits. However, three out of ten controls were smokers while among the exposed, five out of 10 were smokers.]

Three of the four studies that investigated single DNA strand breaks revealed elevated levels of strand breaks among painters. These effects were also present among non-smokers only.

(e) Other genotoxicity assays

In a study in the Republic of Korea among 208 workers (191 male and 17 female) in a shipyard, DNA adducts by ^{32}P-postlabelling and glycophorin A variant frequencies in red blood cells were assessed. The glycophorin A assay is a somatic mutation assay that measures the number of red blood cells that have a change in the M- or N-form of the glycophorin A gene. Employees were grouped into three groups: 111 painters using coal-

tar paints, 70 painters using general paints, and 27 on-site controls. Aromatic-DNA adduct levels (adducts/10^8 nucleotides) tended to be higher in coal-tar paint users (0.38 ± 0.23, $P = 0.07$) and general paint users (0.38 ± 0.24, $P = 0.06$) compared to on-site controls (0.26 ± 0.13). When both groups of painters were combined, they showed greater adduct levels than on-site controls ($P < 0.05$). Glycophorin A mutation frequencies measured in 55 individuals with MN heterozygote genotypes were not significantly different among the three job groups (Lee *et al.*, 2003).

Several chromosomal abnormalities could be detected in the bone marrow of most patients with acute myeloid leukaemia. In a study by Crane *et al.* (1996), routine cytogenetic data from 213 patients (129 enrolled in the period 1976–1983, and 84 enrolled in the period 1986–1990) with acute myeloid leukaemia were correlated with environmental exposures to organic chemicals (eg., benzene), paints, pesticides, and other substances such as dyes, glues, or varnishes. A suggestive effect was found between exposure to paints and the –7/7q chromosomal abnormality (odds ratio, 7.50) but this was non-significant and only observed in the set of patients enrolled between 1986–1990.

In summary, most cytogenetic studies among painters measuring a variety of cytogenetic end-points and markers of genotoxicity showed elevated levels of genetic damage. These effects were by and large similar for smokers and non-smokers. In addition, several studies have shown a dose–gradient with years or weeks worked and the cytogenetic end-point. These studies support that painters have increased levels of DNA damage. However, the number and size of the studies is generally small. Furthermore, as no comprehensive exposure assessment has been done in any of these studies, it is difficult to relate the observed genotoxic effects to any specific component(s) of paint.

4.2.2 *Genotoxicity information for individual constituents of paints*

It is not possible to provide information on the genotoxicity and mechanism of action of all known components of paint or exposures related to painting activities (for an overview of main substances to which workers may be exposed in painting trades, see Section 1.1). We therefore limit this overview to selected chemicals as described in section 4.1.

(a) Benzene

Chromosomal aberrations in human peripheral lymphocytes have been associated with occupational exposure to benzene and include hypo- and hyperdiploidy, deletions, breaks, and gaps (ATSDR, 2007a). SCE was not found to be a significant effect of benzene exposure in humans. In-vivo animal studies provide convincing evidence of the genotoxicity of benzene. Benzene induced chromosomal aberrations, micronuclei and SCEs in bone marrow cells of mice, chromosomal aberrations in bone marrow cells of rats and Chinese hamsters and sperm-head anomalies in mice treated *in vivo* (IARC, 1987). It induced chromosomal aberrations and mutation in human cells *in vitro*. In-vitro studies strongly imply that benzene's genotoxicity is derived primarily from its metabolites hydroquinone and 1,4-benzoquinone through their ability to inhibit

topoisomerase II and microtubule function, induce oxidative stress, and break DNA (ATSDR, 2007a).

(b) Toluene

Toluene is mainly converted to benzyl alcohol and excreted as hippurate. Human data are inconclusive with regard to the genotoxicity of toluene. Studies of exposed workers are limited by concurrent exposure to other chemicals, small cohort size, and a lack of historical exposure monitoring, and it is likely that they are not sufficiently sensitive to detect small, but significant, manifestations of genetic toxicity in workers exposed to toluene (ATSDR, 2000a). Toluene toxicity is most prominent in the central nervous system after acute and chronic exposure in exposed humans and experimental animals. Reproductive toxicity has been observed in exposed humans and rats. Genotoxicity testing of laboratory animals *in vivo* has been limited, and has produced mostly negative results. In some cytogenetic studies in occupationally exposed populations, increases in chromosomal aberrations (two studies), micronuclei (one study), and of DNA strand breaks (one study) have been described. These effects have also been observed in rats and mice in some studies and in cultured mammalian cells. DNA adducts have not been detected (IARC, 1999).

(c) Xylenes

Genotoxicity studies on mixed xylenes and the individual isomers of xylene have provided consistently negative results in a variety of in-vitro and in-vivo assays and test systems (bacteria, yeast, cultured mammalian cells, mice, rats, and humans). Xylenes may cause DNA fragmentation at cytotoxic concentrations because of nucleases released from lysosomes in moribund cells. There is also limited evidence from bacterial test systems that suggests that xylene metabolites, specifically *meta*-xylenol, *para*-xylenol, 2,4-dimethylphenol, and *ortho*-methylbenzyl alcohol, are also non-mutagenic (ATSDR, 2007b). Renal and hepatic toxicity has been described following human accidental poisonings and experimental exposure of rats and mice. In rats, hepatic CYP content, particularly of CYP2B1, and the activities of certain conjugation enzymes are increased upon inhalation exposure to *meta*-xylene (IARC, 1999).

(d) Dichloromethane

Two dose-dependent alternative pathways involving CYP2E1 and GSTT1–1 are responsible for the metabolism of dichloromethane in human and rodent cells (IARC, 1999; ATSDR, 2000b). Dichloromethane is consistently mutagenic in microorganisms. Weaker and less consistent responses are seen in mammalian systems, predominantly in mice, both *in vitro* and *in vivo*. It induces SCEs, chromosome breakage, and chromosome loss *in vitro* in human cells. In-vitro results in rodent cells have been inconclusive or negative. Dichloromethane-induced DNA single-strand breaks in mammalian cell cultures, but inconclusive or negative effects, have been reported for induction of gene mutations. It has not induced unscheduled DNA synthesis either *in vivo* in rodents or in

human fibroblast cultures. It is genotoxic in fungi but not in *Drosophila* in the sex-linked recessive lethal assay (IARC, 1999).

Mechanistic studies have established a link between GST-mediated metabolism of dichloromethane and its genotoxicity and carcinogenicity in mice. The GST responsible for the metabolism of dichloromethane is expressed to significantly greater extents in mouse tissues than in rat, hamster or human tissues. The available data suggest a plausible mechanism for the development of liver and lung tumours which occur in mice but not in rats exposed to dichloromethane (IARC, 1999).

(e) Trichloroethylene

In rodents, trichloroethylene is rapidly absorbed from the gastrointestinal tract and through the lungs, whereas absorption of the vapour through the skin is negligible. The major pathway is oxidative metabolism leading to the formation of chloroacetic acids. Mice have shown consistently higher rates of oxidative biotransformation than rats. A minor pathway in rodents and humans involves the formation of mercapturic acids (IARC, 1995).

The acute toxicity of trichloroethylene in rodents and humans is low. After high doses of trichloroethylene are administered repeatedly to rodents, damage is seen in the liver and kidney (in mice and rats), and in the lung (in mice only). Repeated exposure of humans in the workplace appears to have no marked toxic effects on the kidney or liver. Trichloroethylene is a more potent peroxisome proliferator in the livers of mice than the livers of rats. The available studies have shown no consistent effect of trichloroethylene on the human reproductive system. Trichloroethylene is metabolized to trichloroacetic acid in the placenta or fetus of many species. There is little evidence of toxic effects in developing rats or mice. Studies of structural chromosomal aberrations, aneuploidy and SCE in peripheral lymphocytes of workers exposed to trichloroethylene were inconclusive but are suggestive of clastogenic effects (IARC, 1995; ATSDR, 1997). Pure trichloroethylene did not induce chromosomal aberrations, dominant lethal mutations, SCE or unscheduled DNA synthesis in rodents, whereas an increased induction of micronuclei and DNA single-strand breaks/alkaline labile sites was observed. In single studies with human cells *in vitro*, trichloroethylene of low purity slightly increased the frequencies of SCE and unscheduled DNA synthesis. Pure trichloroethylene did not induce gene mutation in human cells. In mammalian cells *in vitro*, pure trichloroethylene-induced cell transformation, SCE and gene mutation, but not chromosomal aberrations (IARC, 1995). Although trichloroethylene itself may not be genotoxic, several of its metabolites are reactive and potentially genotoxic compounds. Several isomers of 1,2-dichlorovinyl-cysteine, a product of trichloroethylene metabolism in the kidney, are mutagenic in the in-vitro Ames assay. These products have been identified in the urine of workers exposed to trichloroethylene. Although trichloroethylene itself may not be genotoxic, the evidence that some of its metabolites are genotoxic suggests that genotoxic effects may be a concern for some persons exposed to trichloroethylene (ATSDR, 1997).

(f) Styrene

Exposure to styrene leads to the formation of both protein and DNA adducts in humans, rats, and mice. The levels of the *N*-terminal valine adduct of haemoglobin, *N*-(1-hydroxy-2-phenylethyl)valine, have been found to be four times higher in styrene-exposed workers than in controls, and the levels of the DNA adduct, O^6-(2-hydroxy-1-phenylethyl)-2′-deoxyguanosine-3′-monophosphate, have been found to be about five times higher than in controls. *N*7-deoxyguanosine adducts have also been detected (IARC, 1994).

Inconsistent results have been reported for chromosomal aberrations, micronuclei and SCE in approximately 30 studies of workers exposed to styrene in various industries. These studies were predominantly from the reinforced plastics industry where styrene exposure is high, but there was no indication of a dose–response relationship in any of the studies reporting positive results. Induction of chromosomal aberrations was reported in 12 of 25 studies, sister chromatid exchange in six of 16 studies, and micronuclei in three of 14 studies (IARC, 2002).

SCE and to a lesser degree chromosomal aberrations were induced in rodents *in vivo*, and consistently in human lymphocytes *in vitro*. Styrene was predominantly inactive in assays for gene mutations in bacteria, although some studies reported mutations in the presence of a metabolic activation system (IARC, 2002).

Data from both laboratory (*in vitro* and *in vivo*) and human studies indicate that styrene exposure can result in low levels of DNA adducts and DNA damage in individuals who possess the capacity to activate styrene metabolically to styrene-7,8-oxide. However, as noted above, mice, but not rats, develop lung tumours following exposure to styrene, even though both species form DNA adducts. DNA adducts are also found in organs other than the lung. Circulating styrene-7,8-oxide may also play a role. However, the concentration in rat blood is two orders of magnitude higher than in the mouse. The lung tumours in mice probably develop as a result of in-situ formation of styrene-7,8-oxide which causes cytotoxicity and increased cell proliferation, but the roles of circulating styrene-7,8-oxide and of DNA adducts cannot be discounted. Based on metabolic considerations, it is likely that the proposed mechanism involving metabolism of styrene to styrene-7,8-oxide in mouse Clara cells is not operative in human lungs to a biologically significant extent. However, based on the observations in human workers regarding blood styrene-7,8-oxide, DNA adducts and chromosomal damage, it cannot be excluded that this and other mechanisms are important for other organs (IARC, 2002).

(g) Cadmium

In several studies, the frequencies of chromosomal aberration were increased in peripheral blood lymphocytes of workers exposed to cadmium in the metal industry, where they were usually also exposed to other metals. No effect of cadmium was observed in a limited study of workers from a Swedish alkaline battery factory. In two studies of cadmium pigment plant workers, no increase in the frequency of chromosomal aberrations was observed. No increase in the frequency of SCE was seen in one study of

workers exposed to cadmium. In one study of *itai-itai* disease patients, increased frequency and severity of chromosomal aberrations were observed but these results were not replicated in another study. In one study, no increase in SCE frequency was observed in people living in a cadmium-polluted region of Japan. In a study of subjects living in a cadmium-polluted region of China, there were small but significant increases in chromosomal aberration frequency. A significant dose–effect relationship between urinary levels of cadmium and chromosomal aberration frequency was also observed, and more severe aberration types were observed in individuals with high urinary levels of cadmium. In those studies in which significant responses were observed, the chromosomal aberrations tended to occur in the more heavily exposed groups and were of more complex types (IARC, 1993).

Chromosomal aberrations and aneuploidy were observed in animals exposed to cadmium chloride *in vivo*. Dominant lethal mutations were generally not induced in mice. Cadmium chloride damaged DNA of human cells *in vitro*. In the few studies available, chromosomal aberrations were observed in human cells treated with cadmium sulfide but not in those treated with cadmium chloride. Indications of aneuploidy were observed in human fibroblasts after treatment with cadmium chloride. Studies using cultured animal cells show that exposure to cadmium compounds damages genetic material. DNA strand breaks, mutations, chromosomal damage and cell transformation have been observed *in vitro*. Cadmium compounds inhibit the repair of DNA damaged by other agents, thereby enhancing their genotoxicity. Mutations have generally not been observed in *Drosophila* or bacteria; however, a weak response was observed in some studies in bacteria and there is evidence for cadmium-induced DNA damage in bacteria (IARC, 1993).

Overall, cadmium appears to have the capability of altering genetic material, particularly chromosomes in mammalian cells, but germ cells appear to be protected except at high acute parenteral doses (ATSDR, 1999).

(h) Chromium

Chromium(VI) compounds may cause adverse effects to the skin, the respiratory tract and, to a lesser degree, the kidneys in humans, while chromium(III) is less toxic. Elevated levels of SCE were observed in workers exposed to chromium(VI) compounds in electroplating factories in some but not all studies. Similarly, chromosomal aberrations were found in several studies of exposed workers but not all. The studies on chromium(III) were inadequate to evaluate its cytogenetic effect in humans (IARC, 1990; ATSDR, 2000c).

Chromates, which are chromium(VI) compounds, enter cells more readily than chromium(III) compounds, and are reduced ultimately to chromium(III). The reduction process and the subsequent intracellular activity of reduced chromium species are important for the mechanism of toxicity and carcinogenicity of chromium(VI). Particulate chromium(III) compounds can also enter cells by phagocytosis. Chromium(VI) compounds cross the placental barrier in greater amounts than chromium(III) compounds (IARC, 1990).

Chromium(VI) compounds of various solubilities in water were consistently active in numerous studies covering a wide range of tests for genetic and related effects. In particular, potassium dichromate, sodium dichromate, ammonium dichromate, potassium chromate, sodium chromate, ammonium chromate, chromium trioxide, calcium chromate, strontium chromate, and zinc yellow induced a variety of effects (including DNA damage, gene mutation, SCE, chromosomal aberrations, cell transformation and dominant lethal mutation) in several targets, including animal cells *in vivo*, and animal and human cells *in vitro*. Potassium chromate induced aneuploidy in insects, while chromium trioxide did not; various compounds induced gene mutation in insects. Potassium dichromate produced recombination, gene mutation and aneuploidy in fungi. All of these chromium(VI) compounds induced DNA damage and gene mutation in bacteria. Similar patterns were observed with zinc chromate, barium chromate, lead chromate and the derived pigments chromium orange, chromium yellow and molybdenum orange, which, however, often required preliminary dissolution in alkali or acids. A liquid chromium(VI) compound (chromyl chloride) and its vapours induced gene mutation in bacteria (IARC, 1990).

Although chromium(III) compounds were generally even more reactive than chromium(VI) compounds with purified DNA and isolated nuclei, 12 compounds of various solubilities (chromic chloride, chromic acetate, chromic nitrate, chromic sulfate, chromic potassium sulfate, chromium alum, neochromium, chromic hydroxide, chromic phosphate, chromic oxide, chromite ore, and cupric chromite) gave positive results in only a minority of studies using cellular test systems. This was often under particular treatment conditions or at very high concentrations, which were generally orders of magnitude higher than those needed to obtain the same effects with chromium(VI) compounds. Some of the positive results could be ascribed to contamination with traces of chromium(VI) compounds. In particular, no DNA damage was observed in cells of animals treated *in vivo* with chromic chloride, and no micronuclei were seen in cells of animals given chromic nitrate. The chromium(III) compounds tested did not generally produce DNA damage, gene mutation, SCE or cell transformation in cultured animal and human cells. Chromosomal aberrations were often observed with high concentrations of chromium (III) compounds. Weak effects on gene mutation and mitotic gene conversion were observed in fungi. Negative results were obtained in the large majority of tests for DNA damage and gene mutation in bacteria. Certain complexes of chromium (III) with organic ligands, which favour the penetration of chromium (III) into cells, were reported to induce DNA damage and gene mutation in bacteria and in cultured mammalian cells (IARC, 1990).

A chromium (II) compound (chromous chloride) gave negative results in in-vitro tests with animal cells (DNA damage, chromosomal aberrations and aneuploidy). A water-insoluble chromium (0) compound (chromium carbonyl) did not induce DNA damage in bacteria (IARC, 1990).

(i) Inorganic lead

Evidence of genotoxicity has been shown in humans occupationally exposed to lead, as measured in a variety of assays. In some studies, these effects were correlated with blood lead concentrations. However, all the human genotoxicity studies involved co-exposure to lead and other compounds, making it difficult to attribute genetic and other effects to lead alone. In a limited number of studies on non-occupationally exposed individuals, no genotoxic effects were found that were correlated with blood lead concentrations (IARC, 2006).

Mutations were not induced in bacteria by either lead acetate or lead chloride, but were induced by both lead chromate and lead bromide. In these last two cases, however, the activity appeared to be due to the anions. In cultures of various mammalian cells, lead acetate, lead chromate and lead nitrate induced DNA strand breaks. Furthermore, most studies revealed positive mutagenic responses even though the extent of mutagenicity and the lead concentrations at which the responses were observed varied considerably, depending on cell type and experimental conditions. Tests for SCE and chromosomal aberrations showed variable responses. Micronucleus formation has been shown to occur at low concentrations of lead. In a single study, lead sulfide induced micronuclei, gene mutations, and SCE. Organo-lead compounds do not appear to have been tested *in vitro* (IARC, 2006).

Studies of genetic toxicity in animals have been conducted by the oral, inhalation, subcutaneous, intraperitoneal, and intravenous routes. It should be noted that blood lead concentrations were not available in these studies, except in a single study in cynomolgus monkeys, and that the exposure concentrations were generally far higher than those reported in human occupational studies. DNA strand breakage has been demonstrated in animals exposed to lead, and variable results have been found in tests for induction of SCE. Micronucleus induction in bone marrow cells of animals exposed to lead has been demonstrated in some studies. Most studies of chromosomal aberrations have demonstrated increased frequencies in mice, rats, and in the one study in cynomolgus monkeys. Aneuploidy has been demonstrated in rats and mice exposed to lead. Increases in the proportion of morphologically abnormal sperm have also been found in mice and cynomolgus monkeys, but not in rabbits. Dominant lethal effects were not observed in male mice exposed to lead in a single study (IARC, 2006).

In conclusion, lead is a toxic metal and one expression of this property is genetic toxicity. There is, however, little evidence that it interacts directly with DNA at normally encountered blood lead concentrations. The genetic toxicity of lead appears to be mediated in part by increases in, and modulation of, reactive oxygen species. In addition, lead interacts with proteins, including those involved in DNA repair. This latter mechanism might be responsible for enhancing the genotoxicity of other agents. These properties could result in mutation, changes in gene expression and cell proliferation, all of which would contribute to a carcinogenic response if exposure is sustained (IARC, 2006).

(j) Polycyclic aromatic hydrocarbons

Metabolic activation of lipophilic PAHs occurs primarily in the liver, but also in many other tissues, including the epithelial barriers. Although distribution through the circulatory system is widespread, slow absorption through most epithelia results in higher levels of enzymes that activate PAH substrates at the site of entry. This uneven distribution of dose is a factor that may contribute to the high propensity of PAHs to act as carcinogens at the sites where they enter the body (IARC, 2010).

PAHs are metabolized by phase I enzymes and peroxidases, which produce DNA-reactive metabolites, and phase II enzymes, which form polar conjugates. Phase I enzymes, such as CYPs, catalyse the mono-oxygenation of PAHs to form phenols and epoxides. Specific cytochrome P450 isozymes and epoxide hydrolase can form reactive diol epoxides that comprise one class of ultimate carcinogenic metabolites of many PAHs. Both cytochrome P450s and peroxidases can form radical cations by one-electron oxidation that comprise another class of ultimate carcinogenic metabolites. Further oxidation of PAH phenols leads to the formation of PAH quinones. The major cytochrome P450s that are involved in the formation of diol epoxides are CYP1A1, CYP1A2 and CYP1B1, while CYP2C9 and CPY3A4 play a minor role in the activation of PAHs. Additional enzymes that may play a role in the further activation of some PAH diols include members of the aldo-keto reductase (AKR1) family. NQO1 catalyses the reduction of PAH quinones to hydroquinones which may be re-oxidized and generate reactive oxygen species. The major phase II enzymes include the GSTs, uridine 5′-diphosphate glucuronosyltransferases and sulfotransferases. The major GSTs involved in the conjugation of PAH metabolites are GSTM1, GSTP1 and GSTT1 (IARC, 2010).

The current understanding of the carcinogenesis of PAHs in experimental animals is almost solely based on two complementary mechanisms: those of the diol epoxide and the radical cation. The diol epoxide mechanism features a sequence of metabolic transformations of PAHs, each of which leads to potentially reactive genotoxic forms. In general, PAHs are converted to epoxides and dihydrodiols, which are in turn oxidized to diol epoxides. Both epoxides and diol epoxides are ultimate DNA-reactive metabolites. PAH epoxides can form stable DNA adducts and diol epoxides can form stable and depurinating adducts with DNA through electrophilic carbonium ions, and induce mutations (e.g. in *ras* proto-oncogenes) that are strongly associated with the tumorigenic process. One-electron oxidation creates radical cations at a specific position on some PAHs, resulting in the formation of depurinating DNA adducts which generate apurinic sites that can induce mutations in *ras* proto-oncogenes, and are strongly associated with tumorigenesis (IARC, 2010).

The genotoxic effects of exposure to complex mixtures that contain PAHs have been studied in some populations exposed in industrial settings and in patients who undergo coal-tar therapy. Measured end-points include mutagenicity in urine and the presence of aromatic DNA adducts in the peripheral lymphocytes of exposed workers. In some studies, specific benzo[*a*]pyrene–DNA adducts have been measured. Cytogenetic effects such as micronucleus formation have also been reported. Other mechanisms of

carcinogenesis have been proposed for PAHs, but these are less well developed. They include generation of reactive oxygen species, activation of the aryl hydrocarbon receptor with regulation of phase I and II metabolism, lipid peroxidation, production of arachidonic acid-reactive metabolites, decreased levels of serum thyroxine and vitamin A, and persistent activation of the thyroid hormone receptor, as well as activation of mitogen-mediated protein kinase pathways, suppression of immunity by p53-dependent, and other, pathways (IARC, 2010).

4.2.3 *Indirect effects potentially related to genotoxicity*

(a) Haematological changes

Beving *et al.* (1991) studied haematological parameters, iso-transferrin ratio in plasma in ten men (age range, 21–54 years) with occupational long-term, low-level exposure to vapours from epoxy paints. The mean cellular volume of erythrocytes was significantly higher ($P < 0.05$) for house painters (90.6 fl ± 3.4) than for 10 unexposed healthy controls (86.9 fl ± 3.3). Plasma concentration of iso-transferrin, a major iron transport protein in the blood, and the ratio with total transferrin were significantly higher ($P < 0.05$) in the exposed group (median 51.8 mg/l and 2.12%, respectively) as compared to the controls (median, 33.4 mg/l and 1.55%, respectively).

Cullen *et al.* (1992) studied morphological and biochemical changes in the bone marrow and in circulating red blood cells and lymphocytes in painters exposed to glycol ethers. In a previous study, they reported that although the means of all blood cell counts were comparable between exposed and unexposed subjects, a significant proportion of painters were anaemic (10%) and granulocytopenic (5%); none of the controls were affected. Review of company records documented that most of these abnormalities were acquired during employment; pre-existing disease and other exposure could not explain the findings. In their subsequent follow-up study, the affected exposed painters ($n = 10$) were matched to two control groups: exposed painters without evidence of haematological abnormalities on the previous investigation ($n = 7$) and unexposed controls ($n = 7$). No differences were observed between the groups in terms of bone marrow morphology and cellularity, and stem cell growth kinetics. However, exposed subjects, when compared to unexposed controls, had significantly decreased saturation of glutathione reductase with flavine adenine dinucleotide (68.3% versus 80.3%, $P = 0.05$) suggesting riboflavin deficiency or impaired riboflavin metabolism. Riboflavin deficiency has been implicated as a risk factor for cancer, although this has not been satisfactorily established in humans.

A group of 60 male workers involved in applying lacquer to steel cans were investigated for haematological effects. The lacquer applied contained 3% xylene, 12% butanol, 35% cyclohexanol, 25% 2-ethoxyethanol acetate, and 25% 2-butoxyethanol. Environmental monitoring revealed benzene time-weighted average values between 0–12 ppm with a mean value of 6 ppm. The workplace air also contained toluene and xylene. A significant decrease in peripheral blood T-cell and NK-cell count was observed

among painters when compared to 79 unexposed male workers. In contrast, T-suppressor cell count was increased among exposed workers when compared to controls (Moszczyński *et al.*, 1996).

Kim *et al.* (1999) evaluated haematological effects among 57 shipyard painters exposed to ethylene glycol monoethyl ether acetate (EGEEA), a solvent widely used for paints. Painters were divided in two exposure groups (high/low). Mean EGEEA levels were 3.03 and 1.76 ppm, respectively. In addition, environmental monitoring revealed detectable levels of toluene, ethyl benzene, xylene, butanol, isopropanol, ethanol, ethyl acetate, butyl acetate, methyl isobutyl ketone, and nonane. No benzene or other glycol ethers could be detected in the bulk samples of some paints and thinners or air samples. Mean white blood cell counts in the high exposure group (6033 cells/μl ± 1433) were lower ($P < 0.05$) than in the control group of 41 unexposed workers in non-production areas of the same factory (7031 cells/μl ± 1400). Six (11%) of the 57 painters were leucopenic (leucocyte count < 4500 cells/μl) while none of the controls was affected ($P < 0.05$). Results indicate that EGEEA might be toxic to the bone marrow.

These studies on haematological effects among painters show consistently that peripheral blood cell counts and morphology of the cells are affected by the exposures encountered during the handling or making of paints. The relation between haematotoxicity and cancer are not directly clear except that in a study among subjects exposed to benzene, subjects with benzene poisoning (total white blood cell count < 4000/μl or white blood cell count between 4000 and 4500/μl and platelet count < 80 000/μl, with repeated confirmation of this count in a few months in a peripheral blood examination) had an increased risk for developing acute myeloid leukaemia (relative risk, 70.6; 95% CI: 11.4–439.3; Rothman *et al.*, 1997). However, it needs to be recognized that although this lends plausibility to a possible association between severe haematoxicity and acute myeloid leukaemia, it does not necessarily mean that the association is relevant for less severe, transient haematological effects.

(b) Immunological effects

Hexamethylene diisocyanate (HDI) is an aliphatic diisocyanate that is used almost exclusively in the manufacture of paints and surface coatings. HDI can induce occupational asthma (Vandenplas *et al.*, 1993), and HDI-specific IgE and IgG have been detected in selected patients with diisocyanate asthma or small populations of exposed workers (Grammer *et al.*, 1988; Cartier *et al.*, 1989; Baur *et al.*, 1996; Tee *et al.*, 1998; Redlich *et al.*, 2001). Besides specific Ig responses, increased proliferation of HDI-specific lymphocytes has been observed upon in-vitro cell stimulation with HDI (Redlich *et al.*, 2001). These results indicate that HDI-containing paints can trigger specific systemic immunological responses.

4.3 Susceptible populations

A few studies have addressed the interplay between genetic factors and biological and clinical end-points. Gene–environment interactions related to specific exposures and

metabolites are outside the scope of the current overview but some specific chemicals have been reviewed in previous monographs.

4.3.1 *Gene–environment interactions and clinical end-points*

Golka *et al.* (2001) studied the impact of *N*-acetyltransferase 2 phenotype in painters with bladder cancer and controls. Sixteen painters with bladder cancer and 26 healthy painters (controls) from the same geographic area in Germany were phenotyped for *N*-acetyltransferase 2 based on the molar ratio of two caffeine metabolites in the urine. Cases and controls had comparable smoking habits, similar age at first exposure, and comparable number of persons exposed to colorants before 1960 (at that time, some azo-dyes used by painters were based on carcinogenic aromatic amines, especially benzioline). The slow acetylation status was over-represented in the painters with bladder cancer (88%) compared to their healthy colleagues (65%). The odds ratio for bladder cancer of slow acetylators compared to rapid acetylators was 3.0 (95% CI: 0.64–14.04).

4.3.2 *Gene–environment interactions and biological end-points*

Testa *et al.* (2005) studied multiple cytogenetic effects among 25 car painters and 37 unexposed control subjects (healthy blood donors). The exposed subjects had higher frequencies of chromosomal aberrations, SCE and micronuclei than controls (see section 4.2). Subjects were also genotyped for *GSTM1* polymorphisms (controls, 49% *GSTM1* null; exposed, 48% *GSTM1* null) and *GSTT1* (controls 35% *GSTT1* null; exposed, 24% *GSTT1* null). No significant associations were detected between any of the biomarker responses and either the *GSTM1* or *GSTT1* genotype. However, as the authors indicate, the small size of the study does not allow definite conclusions on the relationship between the genetic polymorphisms and the biomarkers.

In a study by Lee *et al.* (2003) among 181 painters using coal-tar paints ($n = 111$) or general paints ($n = 70$) and 27 on-site controls, no gene–environment interactions between *GSTM1* (all workers, 51% *GSTM1* null), *GSTT1* (all workers, 54% *GSTT1* null) and aromatic-DNA adducts was found among all groups exposed.

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5. Summary of Data Reported

5.1 Exposure data

Thousands of chemical compounds are used in paint products as pigments, extenders, binders, solvents, and additives. The main organic solvents used are toluene, xylene, aliphatic compounds, ketones, alcohols, esters, and glycol ethers. Azo pigments that contain 3,3′-dichlorobenzidine are common, although free aromatic amines are not present in significant quantities. Asbestos was used as a filler in paints and decorative coatings until the early 1990s. Several hazardous chemicals including benzene, some other solvents, phthalates (plasticizers), chromium and lead oxides have been reduced or replaced in paint, although they are still used in some countries. The increasing use of water-based paints and powder coatings has promoted this trend. New formulations contain lower-toxicity solvents, neutralizing agents, such as amines, and biocides.

Workers in the painting industry are potentially exposed to the chemicals found in paint products during their application and removal. Exposure to dichloromethane occurs during paint stripping from wood and metal surfaces. Diisocyanate is present in some binders and is released during painting. Silica is used in the preparation of surfaces. Painters may also be exposed to asbestos or crystalline silica as bystanders during construction activities. During the application of paint, workers are exposed primarily to solvents whereas the mechanical removal of paint leads mainly to exposure to pigments and fillers. In the past, exposure to hazardous substances frequently exceeded current occupational exposure limits, but exposure levels have generally decreased over time.

Inhalation is the predominant route of exposure, followed by dermal absorption to a much lesser extent; higher inhalation exposures are frequently accompanied by higher dermal exposures. Appropriate selection and use of personal protective equipment can substantially reduce uptake, although painters do not generally wear respirators or gloves. Biomonitoring of exposure to paint products reveals elevated levels of paint compounds or their metabolites in blood and urine.

5.2 Human carcinogenicity data

Seventeen cohort and linkage studies of painters have shown consistent and significant, although moderate (36%), excesses of mortality from lung cancer. Three of these studies provided information on tobacco smoking which is strongly associated with this neoplasm. These excesses are consistent with case–control studies which largely controlled for smoking. Twenty-nine case–control studies of lung cancer in painters were evaluated. Although the results were heterogeneous, partially due to small numbers in

some studies, overall, a consistent excess risk of lung cancer was observed over time. Of the 29 studies, three had an odds ratio < 1 with large confidence intervals that included the null value, and the others had odds ratios > 1, 14 of which showed a statistically significant or borderline significant increase. When all independent studies that appropriately adjusted for potential confounders were used in a meta-analysis, a statistically significant excess risk of 35% was obtained. When the analysis and results from the above and from population-based studies were restricted to smoking-adjusted estimates, the statistically significant excess risks were 34% and 41%, respectively.

A borderline significant excess of mortality from mesothelioma was observed in cohort studies and positive results were obtained in two case–control studies of this tumour, which is consistent with the presence of asbestos at some sites where painters work.

The 11 cohort and linkage studies of painters showed consistent, although moderate (21%), excesses of mortality from urinary bladder cancer. Two of these studies provided information on tobacco smoking which is strongly associated with this neoplasm. These excesses are consistent with case–control studies of painters that controlled for smoking in which an excess risk for urinary bladder cancer was seen. Most of the studies that were evaluated had odds ratios > 1. When all independent studies that appropriately adjusted for confounding were used in a meta-analysis, a statistically significant excess risk of 28% was obtained. When the analysis and results from the above and from population-based studies were restricted to smoking-adjusted estimates, the statistically significant excess risks were 26% and 27%, respectively.

Other statistically significant excesses of mortality were observed in the cohort studies for cancers of the pharynx, oesophagus, and liver. Cancers at these sites are associated with tobacco smoking (pharynx and oesophagus) and alcoholic beverage consumption (pharynx, oesophagus, and liver), both of which have been shown to be increased among painters compared with the national populations typically used as referent groups; hence, these might act as positive confounders. However, there are inadequate supportive data from case–control studies of these cancers that control for these potential confounders to conclude that confounding can be excluded as a cause of these excesses. The data were insufficient for evaluation, but the Working Group noted some consistency between case–control and cohort studies for cancers of the pharynx and oesophagus.

More case–control studies evaluated the risk for lymphatic and haematopoietic cancers among painters than that for cancers at other sites. Although some excesses were observed, the data are inadequate to draw a conclusion because of inconsistency among results from these studies, and the lack of any excess mortality from these cancers in the cohort studies. A few case–control studies of cancers of the nose, nasopharynx, larynx, oesophagus, stomach, pancreas, small bowel, kidney, brain, prostate, ovary and breast, mesothelioma, melanoma, and soft–tissue sarcoma were conducted among painters.

Several case–control studies evaluated the risk for childhood cancer and parental occupation as a painter or parental exposure to paints. Seven studies focused on

leukaemia. Five showed significant excesses associated with occupational or non-occupational exposure to paints, primarly among mothers. Despite this relatively small amount of data, the Working Group considered that there was some evidence that maternal occupational or other exposure to paints is associated with childhood leukaemia. The risks tended to be greater when mothers were exposed before or during pregnancy rather than after birth of the child, and two studies showed some evidence of an exposure–response relationship with duration of exposure.

Overall, a weakness of both the cohort and case–control studies is the lack of information on exposure–response trends, and few studies included analyses by duration of work as a painter.

There is also little information on specific work settings. One cohort, one case–control and one proportionate mortality study of artistic painters all showed excess mortality from urinary bladder cancer. Insufficient information is available to judge whether trends for risk for cancer have decreased over time with the changes in components of paints; for example, the levels of solvents, such as benzene, and pigments, such as lead chromates in paints, have decreased over past years. Data from studies carried out since the previous evaluations of painters still involve primarily painters who were exposed in the 1960s and the 1970s before many changes in paint components had taken effect.

Nevertheless, when the cohort and case–control studies were taken together, the Working Group concluded that there is consistent evidence in humans that occupational exposure as a painter causes lung and urinary bladder cancer. It does not appear that the excess mortality from these cancers is caused by the principal potential confounder, which is tobacco smoking.

No particular agent can be identified from epidemiological studies as the cause of excess of lung and urinary bladder cancer. It is improbable that the presence of asbestos would completely explain the excess of lung cancer; if this had been the case, a more pronounced excess of mesothelioma would have been observed. There is little information from epidemiological studies on the risk associated with the use of paint pigments that are known lung carcinogens, such as chromium or cadmium.

5.3 Animal carcinogenicity data

No data were available to the Working Group.

5.4 Other relevant data

Painters and paint industry workers are exposed to solvents (such as benzene, toluene and dichloromethane), paint pigments (such as lead, cadmium and chromium compounds) and many other compounds. Solvents are absorbed by inhalation and through the skin, and are generally rapidly metabolized and excreted as conjugated metabolites. Metal compounds that are used as paint pigments are predominantly

absorbed in the lung. Dermal absorption is generally low and depends on the chemical properties of the compound, the vehicle, and the integrity of the skin. Absorbed metals are distributed to the organs and, in the case of lead, are concentrated in the bone. Elimination of metals varies from several days to several years.

Overall, six of the eight studies on chromosomal aberrations among painters showed consistent and significant elevated frequencies. Of these six positive studies, three reported an association with years of employment while the other studies did not report analyses on duration of employment. Five of six studies reported significant increases in the frequencies of micronucleus formation among painters. Two of these five studies reported a dose gradient with years or weeks worked and levels of micronuclei. Chromosomal aberrations and micronucleus formation were found in both cultured lymphocytes and buccal cells. Four of seven studies on sister chromatid exchange among painters reported significantly increased frequencies. Exposure–response relationships with duration of employment were reported in three of these four studies. Three of the four studies on DNA single-strand breaks reported increased levels among painters.

Haematological changes were observed in several studies of painters. These included decreased levels of total white blood cells, T-cells and natural killer cells. Furthermore, an increased prevalence of leucopenia, anaemia and granulocytopenia was observed among painters. Immunological changes were also observed among painters in several studies. These effects included specific immunoglobulin (G and E) responses to hexamethylene diisocyanate and increased proliferation of lymphocytes after in-vitro stimulation with hexamethylene diisocyanate.

Most cytogenetic studies among painters that measured a variety of cytogenetic end-points and markers of genotoxicity reported elevated levels of genetic damage. Several of these studies showed a dose-gradient with years or weeks worked and the cytogenetic end-point. Stratified analyses by tobacco smoking status generally showed consistent results among smokers and nonsmokers. These data strongly suggest that occupational exposures in painting lead to increased levels of DNA damage. Furthermore, mechanistic data reviewed by the Agency for Toxic Substances and Disease Registry and in previous evaluations by the IARC Monographs on selected specific chemicals that had been or still are prevalent in exposures encountered by painters indicate strong support for the induction of haematopoietic (benzene, trichloroethylene, 1,3-butadiene), liver (trichloroethylene), and lung (asbestos, cadmium, chromium) cancers.

6. Evaluation and Rationale

6.1 Cancer in humans

There is *sufficient evidence* in humans for the carcinogenicity of occupational exposure as a painter. Occupational exposure as a painter causes cancers of the lung, and of the urinary bladder.

There is *limited evidence* in humans, based primarily on studies of maternal exposure, that painting is associated with childhood leukaemia.

6.2 Cancer in experimental animals

There is *inadequate evidence* in experimental animals for the carcinogenicity of occupational exposure as a painter, since no data were available to the Working Group.

6.3 Overall evaluation

Occupational exposure as a painter is *carcinogenic to humans (Group 1)*.