FORMALDEHYDE

This substance was considered by previous working groups, in October 1981 (IARC, 1982) and March 1987 (IARC, 1987a). Since that time, new data have become available, and these have been incorporated in the monograph and taken into consideration in the evaluation.

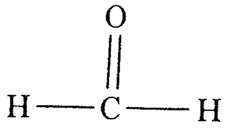
1. Exposure Data

1.1 Chemical and physical data

1.1.1 Nomenclature

Chem. Abstr. Serv. Reg. No.: 50-00-0
Deleted CAS Reg. Nos: 8005-38-7; 8006-07-3; 8013-13-6; 112068-71-0
Chem. Abstr. Name: Formaldehyde
IUPAC Systematic Name: Methanal
Synonyms: Formaldehyde, gas; formic aldehyde; methaldehyde; methyl aldehyde; methyl oxide; methylene oxide; oxomethane; oxymethylene

1.1.2 Structural and molecular formulae and relative molecular mass



$$H-\overset{\overset{\displaystyle O}{\|}}{C}-H$$

CH_2O

Relative molecular mass: 30.03

1.1.3 Chemical and physical properties of the pure substance

From Lide (1993), unless otherwise noted

(*a*) *Description*: Colourless gas with a pungent odour (Reuss *et al.*, 1988)
(*b*) *Boiling-point*: –21 °C
(*c*) *Melting-point*: –92 °C
(*d*) *Density*: 0.815 at 20 °C/4 °C
(*e*) *Spectroscopy data*: Infrared [prism, 2538], ultraviolet [3.1] and mass spectral data have been reported (Weast & Astle, 1985; Sadtler Research Laboratories, 1991).
(*f*) *Solubility*: Very soluble in water, ethanol and diethyl ether
(*g*) *Stability*: Commercial formaldehyde–alcohol solutions are stable; the gas is stable in absence of water; incompatible with oxidizers, alkalis, acids, phenols and urea

(Gerberich *et al.*, 1980; IARC, 1982; Cosmetic Ingredient Review Expert Panel, 1984; Reuss *et al.*, 1988).

(*h*) *Reactivity*: Reacts explosively with peroxide, nitrogen oxide and performic acid; can react with hydrogen chloride or other inorganic chlorides to form bis(chloromethyl) ether (see IARC, 1987b) (Gerberich *et al.*, 1980; IARC, 1982; Cosmetic Ingredient Review Expert Panel, 1984; Reuss *et al.*, 1988).

(*i*) Octanol/water partition coefficient (P): log P = 0.35 (Sangster, 1989)

(*j*) Conversion factor: $mg/m^3 = 1.23 \times ppm^a$

1.1.4 Technical products and impurities

Trade names: BFV; FA; Fannoform; Floguard 1015; FM 282; Formalin; Formalin 40; Formalith; Formol; Fyde; Hoch; Ivalon; Karsan; Lysoform; Morbicid; Paraform; Superlysoform

Formaldehyde is most commonly available commercially as a 30–50% (by weight) aqueous solution, commonly referred to as 'formalin'. In dilute aqueous solution, the predominant form of formaldehyde is its monomeric hydrate, methylene glycol. In more concentrated aqueous solutions, oligomers and polymers that are mainly polyoxymethylene glycol are formed and may predominate. Methanol and other substances (e.g. various amine derivatives) are usually added to the solutions as stabilizers, in order to reduce intrinsic polymerization. The concentration of methanol can be as high as 15%, while that of other stabilizers is of the order of several hundred milligrams per litre. Concentrated liquid formaldehyde–water systems containing up to 95% formaldehyde are also available, but the temperature necessary to maintain solution and to prevent separation of the polymer increases from room temperature to 120 °C, as the concentration in solution increases. Impurities include formic acid, iron and copper (Cosmetic Ingredient Review Expert Panel, 1984).

Formaldehyde is marketed in solid form as its cyclic trimer, trioxane $(CH_2O)_3$, and its polymer, paraformaldehyde, with 8–100 units of formaldehyde (Cosmetic Ingredient Review Expert Panel, 1984; Reuss *et al.*, 1988; WHO, 1991).

1.1.5 Analysis

The most widely used methods for the determination of formaldehyde are based on spectrophotometry, with which sensitivities of 0.01–0.03 mg/m^3 can be achieved. Other methods include colorimetry, fluorimetry, high-performance liquid chromatography, polarography, gas chromatography, infrared detection and gas detector tubes. High-performance liquid chromatography is the most sensitive method (limit of detection, 0.002 mg/m^3). In all of these methods, other organic and inorganic chemicals, such as sulfur dioxide, other aldehydes and amines, cause interference.

The method of sampling and the treatment of samples before analysis are important in the accuracy of the determination. Gas detector tubes (WHO, 1989) and infrared analysers are often

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[a] Calculated from: mg/m^3 = (relative molecular mass/24.45) × ppm, assuming normal temperature (25 °C) and pressure (103.5 kPa)

used for monitoring workplace atmospheres, with a sensitivity of about 0.4–0.5 mg/m^3 (Gollob & Wellons, 1980; Heck *et al.*, 1982; Kennedy *et al.*, 1985; Kennedy & Hull, 1986; Stewart *et al.*, 1987a; Bicking *et al.*, 1988; Greenblatt, 1988; WHO, 1989; United States Occupational Safety and Health Administration, 1991; WHO, 1991). Selected methods for the determination of formaldehyde in various matrices are presented in Table 1.

Four methods have been developed to measure formaldehyde emissions from wood products. The large-scale chamber test developed by the Wilhelm Klauditz Institute in Germany is the principal method used in Europe. A value of 0.1 mg/m^3 in this test, used for the German 'E-1' classification, is often applied for approval of the use of formaldehyde-emitting building products. The large-scale chamber formaldehyde test method 2 (FTM-2) is used to test wood panels in Canada and the United States (European Commission, 1989; American Society for Testing and Materials, 1990; Groah *et al.*, 1991; Jann, 1991). A 2-h desiccator test (FTM-1) is a small-scale method for determining formaldehyde emitted from wood products; formaldehyde, absorbed in distilled water, reacts specifically with a chromotropic acid–sulfuric acid solution (National Particleboard Association, 1983; Groah *et al.*, 1991).

In the perforator method for extracting formaldehyde, small samples are boiled in toluene, and the formaldehyde-laden toluene is distilled through distilled/deionized water, which absorbs the formaldehyde; a sample of the water is then analysed photometrically by the acetylacetone or pararosaniline method. In the iodometric method, formaldehyde in water is determined by adding sulfuric acid solution and an excess of iodine; the iodine oxidizes the formaldehyde, and the excess is back-titrated with sodium thiosulfate (British Standards Institution, 1989).

1.2 Production and use

1.2.1 Production

Since 1889 in Germany, formaldehyde has been produced commercially by the catalytic oxidation of methanol. Various methods were used in the past, but only two are widely used currently: the silver catalyst and metal oxide catalyst processes (Reuss *et al.*, 1988; Gerberich & Seaman, 1994).

The silver catalyst process is conducted in one of two ways: (i) partial oxidation and dehydrogenation with air in the presence of silver crystals, steam and excess methanol at 680–720 °C and atmospheric pressure (also called the BASF process; methanol conversion, 97–98%); and (ii) partial oxidation and dehydrogenation with air in the presence of crystalline silver or silver gauze, steam and excess methanol at 600–650 °C (primary conversion of methanol, 77–87%); the conversion is completed by distilling the product and recycling the unreacted methanol. Carbon monoxide, carbon dioxide, methyl formate and formic acid are by-products (Gerberich *et al.*, 1980; Reuss *et al.*, 1988; Gerberich & Seaman, 1994).

In the metal oxide (Formox) process, methanol is oxidized with excess air in the presence of a modified iron–molybdenum–vanadium oxide catalyst at 250–400 °C and atmospheric pressure (methanol conversion, 98–99%). By-products are carbon monoxide and dimethyl ether and small amounts of carbon dioxide and formic acid (Gerberich *et al.*, 1980; Reuss *et al.*, 1988; Gerberich & Seaman, 1994).

Table 1. Methods for the analysis of formaldehyde in air and food

Sample matrix	Sample preparation	Assay procedure	Limit of detection	Reference
Air	Draw air through impinger containing aqueous pararosaniline; treat with acidic pararosaniline and sodium sulfite	S	0.01 mg/m^3	Georghiou *et al.* (1993)
	Draw air through PTFE filter and impingers, each treated with sodium bisulfite solution; develop colour with chromotropic acid and sulfuric acid; read absorbance at 580 nm	S	0.03 mg/m^3	Eller (1989a) [Method 3500]
	Draw air through solid sorbent tube treated with 10% 2-(hydroxymethyl) piperidine on XAD-2; desorb with toluene	GC/FID	0.3 mg/m^3	Eller (1989b) [Method 2541]
		GC/NSD	0.02 mg/m^3	United States Occupational Safety and Health Administration (1990) [Method 52]
	Draw air through impinger containing hydrochloric acid/2,4-dinitrophenylhydrazine reagent and isooctane; extract with hexane/dichloromethane	HPLC/UV	0.002 mg/m^3	United States Environmental Protection Agency (1988a) [Method TO5]
	Draw air through silica gel coated with acidified 2,4-dinitrophenylhydrazine reagent	HPLC/UV	0.002 mg/m^3	United States Environmental Protection Agency (1988b) [Method TO11]
	Expose passive monitor (Du Pont Pro-Tek® Formaldehyde Badge) for at least 2 ppm-h. Analyse according to manufacturer's specifications	Chromotropic acid test	0.1 mg/m^3	Kennedy & Hull (1986); Stewart *et al.* (1987a)
Food	Distil sample; add 1,8-dihydroxy-naphthalene-3,6-disulfonic acid in H_2SO_4; purple colour indicates presence of formaldehyde	Chromotropic acid test	NR	Helrich (1990) [Method 931.08]
	Distil sample; add to cold H_2SO_4; add aldehyde-free milk; add bromine hydrate solution; purplish-pink colour indicates presence of formaldehyde	Hehner-Fulton test	NR	Helrich (1990) [Method 931.08]

S, spectrometry; PTFE, polytetrafluoroethylene; GC/FID, gas chromatography/flame ionization detection; GC/NSD, gas chromatography/nitrogen selective detection; HPLC/UV, high-performance liquid chromatography/-ultraviolet detection; NR, not reported

Paraformaldehyde, a solid polymer of formaldehyde, consists of a mixture of poly(oxymethylene) glycols [$HO-(CH_2O)_n-H$; $n = 8-100$]. The formaldehyde content is 90–99%, depending on the degree of polymerization, *n* and product specifications; the remainder is bound or free water. Paraformaldehyde, a convenient source of formaldehyde for certain applications, is prepared commercially by concentrating aqueous formaldehyde solutions under vacuum in the presence of small amounts of formic acid and metal formates. An alternative solid source of formaldehyde, 1,3,5-trioxane, is the cyclic trimer of formaldehyde and is prepared commercially by strong-acid-catalysed condensation of formaldehyde in a continuous process (Reuss *et al.*, 1988; Gerberich & Seaman, 1994).

Formaldehyde is reported to be produced by 11 companies in Japan, eight companies each in China and the United States, seven companies in Italy, six companies each in Brazil, Mexico, Spain and the United Kingdom, five companies in Germany, four companies in India, three companies each in Austria and Canada, two companies each in Argentina, Australia, Finland, France, Israel, the Republic of Korea, Sweden, Turkey and the former Yugoslavia and one company each in Bulgaria, Colombia, the former Czechoslovakia, Ecuador, Greece, Hungary, New Zealand, Norway, Pakistan, Peru, Philippines, Poland, Portugal, South Africa, Switzerland, the Russian Federation and Thailand. Paraformaldehyde is reported to be produced by three companies in Japan and China, two companies in Spain and one company each in Argentina, Brazil, France, Germany, Israel, Mexico, the United Kingdom and the United States. 1,3,5-Trioxane is produced by three companies Germany (Chemical Information Services Ltd, 1991).

Worldwide production of formaldehyde in 1992 was approximately 12 million tonnes (Smith, 1993). Production of formaldehyde in selected years and countries is shown in Table 2. In 1986, most of the worldwide production capacity was based on silver catalyst processes (Reuss *et al.*, 1988).

1.2.2 Use

The widest use of formaldehyde is in the production of resins with urea, phenol and melamine and, to a small extent, their derivatives. Formaldehyde-based resins are used as adhesives and impregnating resins in the manufacture of particle-board, plywood, furniture and other wood products. They are also used for the production of curable moulding materials (appliances, electric controls, telephones, wiring services) and as raw materials for surface coatings and controlled-release nitrogen fertilizers. They are used in the textile, leather, rubber and cement industries. Further uses are as binders for foundry sand, stonewool and glasswool mats in insulating materials, abrasive paper and brake linings. Smaller amounts of urea–formaldehyde resins are used in the manufacture of foamed resins for mining and for building insulation (Reuss *et al.*, 1988; WHO, 1989; Gerberich & Seaman, 1994).

Another major use of formaldehyde is as an intermediate for synthesizing other industrial chemical compounds, such as 1,4-butanediol, trimethylolpropane and neopentyl glycol, which are used in the manufacture of polyurethane and polyester plastics, synthetic resin coatings, synthetic lubricating oils and plasticizers. Other compounds produced from formaldehyde

Table 2. Production of formaldehyde in selected countries (thousand tonnes)

Country or region	1982	1986	1990
Brazil	152	226	NA
Canada	70	117	106
China	286	426	467
Former Czechoslovakia	254	274	NA
Denmark	NA	3	0.3
Finland	NA	5	48
France	79	80	100
Germany	630	714	680
Hungary	13	11	NA
Italy	125	135	114
Japan	NA	1188	1460
Mexico	83	93	NA
Poland	219	154	NA
Portugal	NA	70	NA
Republic of Korea	NA	122	NA
Spain	NA	91	136
Sweden	NA	223	244
Taiwan	NA	204	215
Turkey	NA	21	NA
United Kingdom	107	103	80
United States[a]	2185	2517	3048
Former Yugoslavia	108	99	88

From Anon. (1985, 1989); Japan Chemical Week (1991); Anon. (1993); China National Chemical Information Centre (1993); Anon. (1994); Data-Star/Dialog (1994)
NA, not available
[a] 37% by weight

include pentaerythritol, used primarily in raw materials for surface coatings and explosives, and hexamethylenetetramine, used as a cross-linking agent for phenol–formaldehyde resins and explosives. The complexing agents nitrilotriacetic acid (see IARC, 1990a) and ethylenediamine-tetraacetic acid are derived from formaldehyde and are components of some detergents. There is a steadily increasing demand for formaldehyde for the production of 4,4′-diphenylmethane diisocyanate (see IARC, 1979), which is a constituent of polyurethanes used in the production of soft and rigid foams and, more recently, as an adhesive and for bonding particle-board (Reuss *et al.*, 1988; WHO, 1989; Gerberich & Seaman, 1994).

Polyacetal plastics produced by polymerization of formaldehyde are incorporated into automobiles to reduce weight and fuel consumption, and are used to make functional components of audio and video electronics equipment. Formaldehyde is also the basis for products used to manufacture dyes, tanning agents, dispersion and plastics precursors, extraction agents, crop protection agents, animal feeds, perfumes, vitamins, flavourings and drugs (Reuss *et al.*, 1988; WHO, 1989).

Formaldehyde itself is used for preservation and disinfection, for example, in human and veterinary drugs and biological materials (viral vaccines contain 0.05% formalin as an inactivating agent), for disinfecting hospital wards and preserving and embalming biological specimens. It is used as an antimicrobial agent in many cosmetics products, including soaps, shampoos, hair preparations, deodorants, lotions, make-up, mouthwashes and nail products (Cosmetic Ingredient Review Expert Panel, 1984; Reuss *et al.*, 1988). Formaldehyde is also used directly to inhibit corrosion, in mirror finishing and electroplating, in the electrodeposition of printed circuits and in photographic film development (Reuss *et al.*, 1988).

Paraformaldehyde is used in place of aqueous formaldehyde solutions, especially when the presence of water interferes, e.g. in the plastics industry for the preparation of phenol, urea and melamine resins, varnish resins, thermosets and foundry resins. Other uses include the synthesis of chemical and pharmaceutical products (e.g. Prins reaction, chloromethylation, Mannich reaction), the production of textile products (e.g. for crease-resistant finishes), preparation of disinfectants and deodorants (Reuss *et al.*, 1988) and in selected pesticide applications (United States Environmental Protection Agency, 1993).

The pattern of use of formaldehyde in the United States in 1992 (3 million tonnes) was: urea–formaldehyde resins, 24%; phenolic resins, 21%; acetylenic chemicals (precursors to diol monomers), 11%; polyacetal resins, 9%; pentaerythritol, 6%; urea–formaldehyde concentrates, 5%; diphenylmethane diisocyanate, 5%; hexamethylenetetramine, 4%; melamine, 4%; other (including chelating agents, trimethylolpropane, pyridine chemicals), 10% (Anon., 1992). The pattern of use in Japan in 1992 (1.4 million tonnes) was: urea–melamine adhesive, 25.4%; polyacetal resins, 22.7%; pentaerythritol, 7.4%; phenolic resins, 7.3%; paraformaldehyde, 6.0%; diphenylmethane diisocyanate, 4.4%; urea–melamine resin, excluding adhesives, 3.3%; hexamethylenetetramine, 3.1%; other uses, 20.1% (Japan Chemical Week, 1993).

1.3 Occurrence

The natural and man-made sources of formaldehyde in the environment and environmental levels in indoor and outdoor air, water, soil and food have been reviewed (WHO, 1989; see also IARC, 1982). Information on sources and emissions of formaldehyde in the United States has been compiled by the Environmental Protection Agency (Vaught, 1991).

1.3.1 Natural occurrence

Formaldehyde is ubiquitous in the environment; it is an important endogenous chemical that occurs in most life forms, including humans. It is formed naturally in the troposphere during the oxidation of hydrocarbons, which react with hydroxyl radicals and ozone to form formaldehyde and other aldehydes, as intermediates in a series of reactions that ultimately lead to the formation of carbon monoxide and dioxide, hydrogen and water. Of the hydrocarbons found in the troposphere, methane is the single most important source of formaldehyde. Terpenes and isoprene, emitted by foliage, react with hydroxyl radicals, forming formaldehyde as an intermediate product. Because of their short half-life, these potentially important sources of formaldehyde are important only in the vicinity of vegetation. Formaldehyde is one of the volatile compounds formed in the early stages of decomposition of plant residues in the soil (WHO, 1989), and it occurs naturally in fruits and other foods (WHO, 1991).

1.3.2 Occupational exposure

(a) Extent of exposure

As nonoccupational exposure to formaldehyde is ubiquitous, all work, e.g. in offices, contributes to total human exposure. About 1 500 000 workers in the United States in 1981–83 were estimated in the National Occupational Exposure Survey to be exposed to formaldehyde all or part of the time, representing about 0.6% of the population of the country. Industries in which more than 50 000 workers were exposed included health services, business services, printing and publishing, manufacture of chemicals and allied products, apparel and allied products, paper and allied products, personal services, machinery except electrical, transport equipment and furniture and fixtures. The minimal exposure to formaldehyde was not specified in this survey (United States National Institute for Occupational Safety and Health, 1990). In Finland, 9000–10 000 workers, representing about 0.2% of the Finnish population, were estimated to have been exposed to an 8-h time-weighted concentration of at least 0.3 mg/m^3 during at least one day per year. If the minimal level considered is decreased to 0.15 mg/m^3 (0.12 ppm), the number of people exposed increases by many thousands (Heikkilä *et al.*, 1991). It is impossible to estimate accurately the number of people occupationally exposed to formaldehyde worldwide, but it is likely to be several millions in industrialized countries alone.

Formaldehyde occurs in occupational environments mainly as gas. Inhalation of formaldehyde-containing particulates may occur when paraformaldehyde or powdered resins are being used. For example, production of solid resins may include dust-forming operations, such as drying, crushing grinding and screening (Stewart *et al.*, 1987b). Formaldehyde-based resins may also occur in air attached to carrier agents, such as wood dust from sawing of plywood (Kauppinen, 1986). Dermal exposure to formaldehyde is possible when formalin solutions or liquid resins come into contact with the skin.

(b) Manufacture of formaldehyde, formaldehyde-based resins and other chemical products

The concentrations of formaldehyde measured in the 1980s during the manufacture of formaldehyde and formaldehyde-based resins are summarized in Table 3. The mean levels during manufacture were below 1 ppm (1.2 mg/m^3). The values are sometimes reported as geometric means, which give less weight to occasional heavy exposures than arithmetic means. The workers may also be exposed to methanol (raw material), carbon monoxide, carbon dioxide and hydrogen (process gases) (Stewart *et al.*, 1987b).

The reported mean concentrations in the air of factories producing formaldehyde-based resins vary from < 1 to > 10 ppm (< 1.23–> 12.3 mg/m^3) . There are obvious differences between the factories but no consistent seasonal variation. The earliest measurements are from 1979. The chemicals other than formaldehyde to which exposure may occur depend on the types of resins manufactured: Urea, phenol, melamine and furfural alcohol are the chemicals most commonly reacted with liquid formaldehyde (formalin) or hexamethylenetetramine. Some processes require addition of ammonia. Alcohols are used as solvents in the production of liquid resins (Stewart *et al.*, 1987b).

Some potential occupational exposures to formaldehyde

Agricultural workers
Anatomists
Beauticians
Biologists
Bookbinders
Botanists
Chemical production workers
Cosmetic formulators
Crease-resistant textile finishers
Disinfectant makers
Disinfectors
Dress-goods shop personnel
Electrical insulation makers
Embalmers
Embalming-fluid makers
Fireproofers
Formaldehyde production workers
Formaldehyde resin makers
Foundry employees (see IARC, 1984)
Fumigators (see IARC, 1991)
Fur processors (see IARC, 1981)
Furniture makers (see IARC, 1981)
Glue and adhesive makers
Hide preservers (see IARC, 1981)
Histology technicians (including necropsy and autopsy technicians)
Ink makers
Lacquerers and lacquer makers
Medical personnel (including pathologists)
Mirror manufacturers
Paper makers (see IARC, 1981)
Particle-board makers (see IARC, 1981)
Photographic film makers
Plastics workers
Plywood makers
Rubber makers (see IARC, 1982)
Taxidermists
Textile mordanters and printers
Textile waterproofers
Varnish workers (see IARC, 1981)
Wood preservers (see IARC, 1981)

From United States National Institute for Occupational Safety and Health (1976)

No measurements were available to the Working Group of exposure to formaldehyde in other chemical plants where it is used, e.g. in the production of pentaerythritol, hexamethylenetetramine or ethylene glycol.

(c) *Manufacture of wood products and paper*

Table 4 is a summary of the formaldehyde concentrations in wood and pulp and paper industries. Formaldehyde-based glues have been used in the assembly of plywood for over 30 years. The highest mean concentrations are usually measured in glueing departments, where the glue mixture is prepared, veneers are glued to form plywood and the plywood is cured in hot presses; the mean levels were usually > 1 ppm (1.2 mg/m^3) before the mid-1970s but have been below that level more recently. This decrease in levels is consistent in each operation and is due

Table 3. Concentrations of formaldehyde (in ppm [mg/m^3]) in the workroom air in formaldehyde and resin manufacturing plants

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Chemical factory producing formaldehyde and formaldehyde resins (Sweden)	62	0.2 [0.3]	0.04–0.4 [0.05–0.5]	1979–85	Holmström *et al.* (1989a)
Production of formaldehyde (Sweden)	9	0.3 [0.34]		1980s	Rosén *et al.* (1984)
Formaldehyde manufacture (USA)				1983	Stewart *et al.* (1987b)
Plant no. 2, summer	15	0.6[b] [0.7]	0.03–1.9 [0.04–2.3]		
Plant no. 10, summer	9	0.7[b] [0.9]	0.6–0.8 [0.7–1.0]		
Resin plant (Finland)					Heikkilä *et al.* (1991)
Furan resin production	3	2.3 [2.9]	1.0–3.4 [1.3–4.2]	1982	
Maintenance	4	2.9 [3.6]	1.4–5.5 [1.8–6.9]	1981	
Urea–formaldehyde resin production	7	0.7 [0.87]	0.6–0.8 [0.7–1.1]	1981	
Resin manufacture (Sweden)	22	0.5 [0.6]		1980s	Rosén *et al.* (1984)
Resin manufacture (USA)				1983–84	Stewart *et al.* (1987b)
Plant no. 1, summer	24	3.4[b] [4.2]	0.2–13.2 [0.3–16.2]		
Plant no. 6, summer	6	0.2[b,c] [0.3]	0.1–0.2 [0.1–0.3]		
Plant no. 7, summer	9	0.2[b] [0.3]	0.1–0.3 [0.1–0.4]		
Plant no. 7, winter	9	0.6[b] [0.7]	0.4–0.9 [0.5–1.1]		
Plant no. 8, summer	13	0.4[b–d] [0.7]	0.2–0.8 [0.3–1.0]		
Plant no. 8, winter	9	0.1[b–d] [0.1]	0.1–0.2 [0.1–0.3]		
Plant no. 9, summer	8	14.2[b–d] [17.5]	4.1–30.5 [5.0–37.5]		
Plant no. 9, winter	9	1.7[b] [2.1]	1.1–2.5 [1.4–3.1]		
Plant no. 10, summer	23	0.7[b,d] [0.9]	0.3–1.2 [0.4–1.5]		
Special chemical manufacturing plant (USA)	8		< 0.03–1.6 [0.04–2.0]		Blade (1983)

[a] Arithmetic mean unless otherwise specified

[b] Mean and range of geometric means

Some of the results were affected by the simultaneous occurrence in the samples (Stewart *et al.*, 1987b) of:

[c] phenol (leading to low values)

[d] particulates containing nascent formaldehyde (leading to high values).

Table 4. Concentrations of formaldehyde (in ppm [mg/m^3]) in the workroom air of plywood mills, particle-board mills, furniture factories, other wood product plants and paper mills

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Plywood mills					
Plywood factory (Italy)				NR	Ballarin *et al.* (1992)
Warehouse	3	O.3 [0.4]	0.1–0.5 [0.2–0.6]		
Shearing press	8	0.08 [0.1]	0.06–0.11 [0.08–0.14]		
Plywood mills (Finland)					Kauppinen (1986)
Glue preparation, short-term	15	2.2 [2.7]	0.6–5.0 [0.7–6.2]	1965–74	
Glue preparation, short-term	19	0.7 [0.9]	0.1–2.3 [0.1–2.8]	1975–84	
Assembling	32	1.5 [1.9]	<0.1–4.4 [< 0.1–5.4]	1965–74	
Assembling	55	0.6 [0.7]	0.02–6.8 [0.03–8.3]	1975–84	
Hot pressing	41	2.0 [2.5]	<0.1–7.7 [< 0.1–9.5]	1965–74	
Hot pressing	43	0.5 [0.6]	0.06–2.1 [0.07–2.6]	1975–84	
Sawing of plywood	5	0.5 [0.6]	0.3–0.8 [0.4–1.0]	1965–74	
Sawing of plywood	12	0.1 [0.1]	0.02–0.2 [0.03–0.3]	1975–84	
Coating of plywood	7	1.0 [1.2]	0.5–1.8 [0.6–2.2]	1965–74	
Coating of plywood	28	0.3 [0.4]	0.02–0.6 [0.03–0.7]	1975–84	
Plywood mill (Indonesia)	40	0.6 [0.8]	0.2–2.3 [0.3–2.8]	NR	Malaka & Kodama (1990)
Plywood production (Sweden)	47	0.3 [0.36]		1980s	Rosén *et al.* (1984
Plywood panelling manufacture (USA)				1983–84	Stewart *et al.* (1987b)
Plant no 3, winter	27	0.2[b] [0.3]	0.08–0.4 [1.0–0.5]		
Plant no 3, summer	26	0.1[b] [0.1]	0.01–0.5 [0.01–0.6]		
Particle-board mills					
Particle-board mills (Finland)					Kauppinen & Niemelä (1985)
Glue preparation	10	2.2 [2.7]	0.3–4.9 [0.4–6.0]	1975–84	
Blending	10	1.0 [1.2]	0.1–2.0 [0.1–2.5]	1965–74	
Blending	8	0.7 [0.9]	<0.1–1.4 [< 0.1–1.7]	1975–84	
Forming	26	1.7 [2.1]	<0.5–4.6 [< 0.6–5.7]	1965–74	

Table 4 (contd)

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Particle-board mills (contd)					
Particle-board mills (Finland) (contd)					
Forming	32	1.4 [1.7]	0.1–4.8 [0.1–5.9]	1975–84	
Hot pressing	35	3.4 [4.2]	1.1–9.5 [1.4–11.7]	1965–74	
Hot pressing	61	1.7 [2.1]	0.2–4.6 [0.25–5.7]	1975–84	
Sawing	17	4.8 [5.9]	0.7–9.2 [0.9–11.3]	1965–74	
Sawing	36	1.0 [1.2]	< 0.1–3.3 [< 0.1–4.1]	1975–84	
Coating	7	1.0 [1.2]	0.5–1.8 [0.6–2.2]	1965–74	
Coating	12	0.4 [0.5]	0.1–1.2 [0.1–1.5]	1975–84	
Particle-board mill (Indonesia)	9	2.4 [3.0]	1.2–3.5 [1.5–4.3]	NR	Malaka & Kodama (1990)
Particle-board production (Sweden)	21	0.3 [0.4]		1980s	Rosén *et al.* (1984)
Chip-board production (Germany)	24	1.5 [1.9]	< 0.01–8.4 [< 0.01–10]	1980–88	Triebig *et al.* (1989)
Block-board mill (Indonesia)	6	0.5 [0.6]	0.4–0.6 [0.5–0.7]	NR	Malaka & Kodama (1990)
Medium-density fibre-board production (Sweden)	19	0.2 [0.3]		1980s	Rosén *et al.* (1984)
Furniture factories					
Furniture factories, surface finishing with acid curing paints (Sweden)				NR	Alexandersson & Hedenstierna (1988)
Paint mixer/supervisor	6	0.2 [0.3]	0.1–0.4 [0.2–0.5]		
Mixed duties on the line	5	0.4 [0.5]	0.3–0.5 [0.3–0.6]		
Assistant painters	3	0.5 [0.6]	0.2–0.7 [0.2–0.9]		
Spray painters	10	0.4 [0.5]	0.1–1.1 [0.2–1.3]		
Feeder/receiver	13	0.2 [0.3]	0.1–0.8 [0.1–0.9]		
Furniture factories (Finland)				1981–86	Heikkilä *et al.* (1991)
Glueing	73	0.3 [0.4]	0.07–1.0 [0.09–1.2]		
Machining in finishing department	9	0.3 [0.5]	0.1–0.9 [0.1–1.1]		
Varnishing	150	1.1 [1.4]	0.1–6.3 [0.1–7.9]		

Table 4 (contd)

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Furniture factories (contd)					
Furniture factories (Finland) (contd)				1975–84	Priha *et al.* (1986)
Feeding painting machine	14	1.1 [1.4]	0.3–2.7 [0.4–3.3]		
Spray painting	60	1.0 [1.2]	0.2–4.0 [0.3–5.0]		
Spray painting assistance	10	1.0 [1.2]	0.2–1.6 [0.3–2.0]		
Curtain painting	18	1.1 [1.4]	0.2–6.1 [0.3–7.5]		
Before drying of varnished furniture	34	1.5 [1.8]	0.1–4.2 [0.1–5.2]		
After drying of varnished furniture	14	1.4 [1.7]	0.2–5.4 [0.3–6.6]		
Furniture factories (Sweden)				1980s	Rosén *et al.* (1984)
Varnishing with acid-cured varnishes	32	0.7 [0.9]			
Manufacture of furniture (Denmark)				NR	Vinzents & Laursen (1993)
Painting	43	0.2 [0.3]	0.15–0.2 [0.2–0.24]		
Glueing	68	0.1 [0.2]	0.1–0.14 [0.1–0.2]		
Cabinet-making (Canada)	48		<0.1 [< 0.1]	NR	Sass-Kortsak *et al.* (1986)
Other wood product plants					
Match mill, impregnation of matchbox parts, short-term (Finland)	2	2.0 [2.5]	1.9–2.1 [2.3–2.6]	1963	FIOH (1994)
Wooden container mill, glueing and sawing (Finland)	6	0.3 [0.4]	0.2–0.4 [0.3–0.5]	1961	FIOH (1994)
Manufacture of wooden bars (Finland)				1983	Heikkilä *et al.* (1991)
Glueing	33	0.6 [0.7]	0.16–1.9 [0.2–2.4]		
Machining	7	1.2 [1.5]	0.2–2.2 [0.3–2.7]		
Parquet plant (Finland)				1981	Heikkilä *et al.* (1991)
Machining	3	0.3 [0.4]	0.16–0.5 [0.2–0.6]		
Varnishing	5	0.8 [1.0]	0.2–1.4 [0.3–1.7]		
Production of wooden structures (Finland)				1981–86	Heikkilä *et al.* (1991)
Glueing	36	0.7 [0.8]	0.07–1.8 [0.1–2.2]		
Machining	19	0.4 [0.44]	0.1–0.8 [0.1–0.9]		
Glueing in wood industry (Sweden)	65	0.2 [0.26]		1980s	Rosén *et al.* (1984)

Table 4 (contd)

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Paper mills					
Paper mill (Finland)					Finnish Institute of Occupational Health (1994)
Glueing, hardening, lamination and rolling of special paper	12	0.9 [1.1]	0.3–2.5 [0.4–3.1]	1971–73	
Impregnation of paper with phenol resin, partly short-term	38	7.4 [9.1]	< 1.0–33.0 [< 1.1–40.6]	1968–69	
Paper storage, diesel truck traffic	5	0.3 [0.4]	0.2–0.4 [0.25–0.5]	1969	
Paper mill (Finland)				1975–84	Heikkilä *et al.* (1991)
Coating of paper	30	0.7 [0.9]	0.4–31 [0.5–39]		
Gum paper production	4	0.4 [0.5]	0.3–0.6 [0.3–0.8]		
Impregnation of paper with amino resin	6	3.1 [3.9]	0.5–13 [0.6–16]		
Impregnation of paper with phenol resin	20	0.1 [0.1]	0.05–0.3 [0.06–0.4]		
Laminated paper production (Sweden)	23	0.3 [0.39]		1980s	Rosén *et al.* (1984)
Manufacture of offset paper (Sweden)	8	0.2 [0.21]		1980s	Rosén *et al.* (1984)
Lamination and impregnation of paper with melamine and phenol resins (USA)				1983	Stewart *et al.* (1987b)
Plant no 6, summer	53	0.7[b–d] [0.9]	< 0.01–7.4 [< 0.01–9.1]		
Plant no 6, winter	39	0.3[b,d] [0.4]	0.05–0.7 [0.06–0.9]		

NR, not reported

[a] Arithmetic mean unless otherwise specified

[b] Mean and range of geometric means

Some of the results were affected by the simultaneous occurrence in the samples (Stewart *et al.*, 1987) of:

[c] phenol (leading to low values)

[d] particulates containing nascent formaldehyde (leading to high values).

mainly to the introduction of glues that release less formaldehyde (Kauppinen, 1986). Other exposures in plywood mills include wood dust (see monograph, p. 74), phenol (see IARC, 1989a), pesticides (see IARC, 1991), heating products from coniferous veneers, solvents from coating materials and engine exhaust from forklift trucks (see IARC, 1989b). These exposures are described in more detail in the monograph on wood dust.

Particle-board mills, which started operating in many countries in the 1950s, use urea–formaldehyde resins, which are mixed with wood particles to form particle-board and then cured in hot presses. Phenol–, melamine– and resorcinol–formaldehyde resins are less commonly used in particle-board mills than in plywood mills, mainly for economic reasons. The levels of formaldehyde measured in particle-board mills before the mid-1970s were high—often well over 2 ppm (2.5 mg/m^3)—but the development of glues with a lower formaldehyde content and ventilation systems have decreased the levels to about 1 ppm (1.2 mg/m^3) or below (Kauppinen & Niemelä, 1985). Other exposures in particle-board and other reconstituted-board mills are usually similar to those in plywood mills. Exposure to wood dust is described in detail in the monograph on wood dust.

Furniture varnishes may contain urea–formaldehyde (carbamide) resins dissolved in organic solvents. Finnish workers varnishing, lacquering or painting wooden furniture in 1975–84 were continuously exposed to an average level of about 1 ppm (1.2 mg/m^3) formaldehyde (Priha *et al.*, 1986), but the levels decreased slightly during this period. The levels in Sweden in the 1980s were somewhat lower (Rosén *et al.*, 1984; Alexandersson & Hedenstierna, 1988). Formaldehyde-based glues are also used occasionally in veneering wood-based boards, but the levels associated with glueing are generally lower, 0.1–0.3 ppm [0.12–0.37 mg/m^3] (Heikkilä *et al.*, 1991; Vinzents & Laursen, 1993). Other exposures in furniture factories are to wood dust, organic solvents and pigments, described in detail in the monograph on wood dust.

Some paper mills produce special products coated with formaldehyde-based phenol or amino (urea or melamine) resins. Coating agents and other chemicals used in paper mills may also contain formaldehyde as a bactericide. The average levels related to lamination and impregnation of paper in a mill in the United States in the 1980s were below 1 ppm (Stewart *et al.*, 1987b). In Sweden and Finland, the levels of formaldehyde are also usually below 1 ppm, but there is considerable variation, depending on the resin used and the product manufactured. The earliest measurements, from the late 1960s, suggest that much higher exposure may occur in some circumstances (Table 4). Other exposures in paper-coating mills include phenol, urea, melamine, paper dust, solvents and engine exhaust from factory trucks.

(d) *Manufacture of textiles and garments*

The use of formaldehyde-based resins to produce crease-resistant fabrics started in the 1950s. The early resins contained substantial amounts of extractable formaldehyde: over 0.4% by weight of fabric. Introduction of dimethyloldihydroxyethyleneurea resins in 1970 reduced the levels of free formaldehyde in fabrics to 0.15–0.2%. Since then, methylation of dimethyloldihydroxyethyleneurea and other modifications of the resin have decreased the level of formaldehyde gradually to 0.01–0.02% (Elliott *et al.*, 1987). Some flame-retardants, such as Pyrovatex CP, however, contain agents that release formaldehyde (Heikkilä *et al.*, 1991).

Measurements of formaldehyde in the air of textile mills in the late 1970s and 1980s show average levels of 0.2–2 ppm (0.25–2.5 mg/m^3) (Table 5). Levels were probably higher in the 1950s and 1960s because the content of free formaldehyde in resins was higher (Elliott *et al.*, 1987). Finishing workers in textile mills may also be exposed to textile dyes, flame retardants, carrier agents, textile finishing agents and solvents. The exposures of textile workers are described in an earlier monograph (IARC, 1990b).

Measurements from the 1980s indicated that the formaldehyde levels in the garment industry were relatively low, usually averaging 0.1–0.2 ppm (0.12–0.25 mg/m^3) (Table 5). Exposures in the past were probably higher owing to the higher content of formaldehyde in fabrics. For example, the mean formaldehyde concentration in air increased from 0.1 to 1.0 ppm (0.12–1.23 mg/m^3) in a study in the United States when the formaldehyde content of the fabric increased from 0.015 to 0.04% (Luker & Van Houten, 1990). The concentration of formaldehyde was reported to have been 0.9–2.7 ppm (1.1–3.3 mg/m^3) in a post-cure garment manufacturing plant and 0.3–2.7 ppm (0.4–3.3 mg/m^3) in eight other garment plants in the United States in 1966. Few chemicals other than formaldehyde are used in garment factories. Cutting and sewing of fabrics release low levels of textile dust, and small amounts of chlorinated organic solvents are used in cleaning spots. Pattern copying machines may emit ammonia and dimethylthiourea in some plants (Elliott *et al.*, 1987).

(e) Manufacture of metal products, mineral wool and other products

Formaldehyde-based resins are commonly used as core binders in foundries. Urea–formaldehyde resin is usually blended with oleoresin or phenol–formaldehyde resin and mixed with sand to form a core, which is then cured by baking in an oven or by heating from inside the core box (hot box method). The original hot box binder was a mixture of urea–formaldehyde resin and furfuryl alcohol, commonly referred to as furan resin. The furan resins were then modified with phenol to produce urea–formaldehyde/furfuryl alcohol, phenol–formaldehyde/-furfuryl alcohol and phenol–formaldehyde/urea–formaldehyde resins. The mean levels of formaldehyde measured in core-making and operations following core-making in the 1980s in Sweden and Finland were usually below 1 ppm (Table 6); however, measurements made before 1975 suggest that past exposures may have been considerably higher (Heikkilä *et al.*, 1991). Many other chemicals occur in foundries, e.g. silica (IARC, 1987c) and other mineral dusts, polynuclear aromatic hydrocarbons (IARC, 1983), asbestos (IARC, 1987d), metal fumes and dusts, carbon monoxide, isocyanates (IARC, 1986a), phenols (IARC, 1989a), organic solvents and amines. These have been described in a previous monograph (IARC, 1984).

Phenol–formaldehyde resins are commonly used to bind man-made mineral fibre products. Measurements in glass-wool and stone-wool plants in the 1980s showed mean concentrations of 0.1–0.2 ppm (0.12–0.25 mg/m^3) formaldehyde (Table 6). Highest levels were measured occasionally in Finnish factories close to cupola ovens and hardening chambers (Heikkilä *et al.*, 1991). Other exposures in man-made mineral fibre production were described in a previous monograph (IARC, 1988).

Formaldehyde-based plastics are used in the production of electrical parts, dishware and various other plastic products. The concentrations of formaldehyde measured in such industries

Table 5. Concentrations of formaldehyde (in ppm [mg/m^3]) in the workroom air of textile mills and garment factories

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Textile mills					
Textile plants (Finland)				1975–78	Nousiainen & Lindqvist (1979)
Finishing department, mixing	8	0.8 [1.1]	< 0.2–>5 [< 0.2–> 6]		
Crease-resistant treatment	52	0.4 [0.5]	< 0.2–>3 [< 0.2–> 4]		
Finishing department (excluding crease-resistant and flame-retardant treatment)	17	0.3 [0.4]	< 1.3 [< 1.5]		
Flame-retardant treatment	67	1.9 [2.5]	< 0.2–>10 [< 0.2–> 11]		
Fabric store	6	0.8 [1.1]	0.1–1.3 [0.1–1.6]		
Textile mills (Sweden)				1980s	Rosén *et al.* (1984)
Crease-resistant treatment	29	0.2 [0.23]			
Flame-retardant treatment	2	1.2 [1.5]			
Garment factories					
Manufacture from crease-resistant cloth (USA)	181		< 0.1–0.9 [< 0.1–1.1]		Blade (1983)
Manufacture of shirts from fabric treated with formaldehyde-based resins (USA)	326	~0.2 [~0.25]	< 0.1–0.4 [< 0.1–0.5]	1980s	Elliott *et al.* (1987)
Garment industry (Finland)				1981–86	Heikkilä *et al.* (1991)
Handling of leather	3	0.1 [0.1]	0.02–0.1 [0.03–0.13]		
Pressing	32	0.2 [0.3]	0.02–0.7 [0.03–0.86]		
Sewing	15	0.1 [0.1]	0.02–0.3 [0.05–0.34]		
Sewing plant (USA)				NR	Luker & Van Houten (1990)
Processing of 0.04% formaldehyde fabric	9	1.0 [1.2]	0.5–1.1 [0.6–1.4]		
Processing of 0.016% formaldehyde fabric	9	0.1 [0.1]	< 0.1–0.2 [< 0.1–0.25]		

NR, not reported

Table 6. Concentrations of formaldehyde (in ppm [mg/m^3]) in the workroom air of foundries and other industrial facilities

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Foundries					
Foundries (Finland)					Heikkilä *et al.* (1991)
Coremaking	43	2.8 [3.4]	< 0.1–> 10 [< 0.1–> 11]	Before 1975	
Coremaking	17	0.3 [0.4]	0.02–1.4 [0.03–1.8]	1981–86	
Casting	10	0.15 [0.19]	0.02–0.2 [0.03–0.8]	1981–86	
Moulding	25	0.3 [0.39]	0.04–2.0 [0.05–2.5]	1981–86	
Foundries (Sweden)					Åhman *et al.* (1991)
Moulders and coremaker handling furan resin sand (8-h TWA)	36	0.1 [0.1]	0.02–0.2 [0.02–0.27]	NR	
Foundry (Sweden)				1980s	Rosén *et al.* (1984)
Hotbox method	5	1.5 [1.9]			
Moulding	17	0.1 [0.12]			
Man-made mineral fibre plants					
(Finland)				1981–86	Heikkilä *et al.* (1991)
Production	36	0.2 [0.25]	0.02–1.5 [0.03–1.7]		
Form pressing	24	0.1 [0.11]	0.01–0.3 [0.01–0.44]		
(Sweden)				1980s	Rosén *et al.* (1984)
Production	16	0.15 [0.19]			
Form pressing	4	0.16 [0.20]			
Plastics production					
Plastics production (Finland)				1981–86	Heikkilä *et al.* (1991)
Casting of polyacetal resin	10	0.3 [0.36]	0.06–0.7 [0.08–0.82]		
Casting of urea–formaldehyde resin	4	0.4 [0.46]	0.2–0.5 [0.27–0.59]		
Casting of other plastics	29	< 0.1	< 0.1–0.2 [< 0.1–0.3]		

Table 6 (contd)

Industry and operation	No. of measurements	Mean[a]	Range	Year	Reference
Plastics production (contd)					
Production of moulded plastic products (USA)				1983–84	Stewart *et al.* (1987b)
Plant no. 8, phenol resin, summer	10	0.5[b] [0.6]	0.1–0.9 [0.1–1.1]		
Plant no. 9, melamine resin, summer	13	9.2[b] [11.3]	< 0.01–26.5 [< 0.01–32.6]		
Moulding compound manufacture (USA)				1983–84	Stewart *et al.* (1987b)
Plant no. 9, winter	9	2.8[b] [3.4]	0.04–6.7 [0.05–8.2]		
Plant no. 9, summer	18	38.2[b,c] [45]	9.5–60.8 [11.7–74.8]		
Plant no. 1, winter	12	1.5[b] [1.8]	0.9–2.0 [1.1–2.1]		
Plant no. 1, summer	24	9.7[b] [11.9]	3.8–14.4 [4.7–17.7]		
Plant no. 8, winter	13	0.3[b] [0.4]	0.07–0.7 [0.09–0.9]		
Plant no. 7, summer	43	0.3[b] [0.4]	0.05–0.6 [0.06–0.8]		
Plant no. 2, summer	15	6.5[b] [8.0]	0.3–20.6 [0.4–25.3]		
Metalware plant, bake painting (Finland)	18	0.3 [0.4]	0.03–0.7 [0.04–0.9]	1981–86	Heikkilä *et al.* (1991)
Electrical machinery manufacture (Finland)				1977–79	Niemelä & Vainio (1981)
Soldering	47	< 0.1			
Lacquering and treatment of melamine plastics	8	0.35 [0.4]			
Painting with bake-drying paints (Sweden)	13	< 0.1		1980s	Rosén *et al.* (1984)
Miscellaneous					
Photographic film manufacture (USA)				1983–84	Stewart *et al.* (1987b)
Plants no. 4 and 5, summer	49	0.1[b]	< 0.01–0.4 [< 0.01–0.5]		
Plants no. 4 and 5, winter	29	0.3[b] [0.4]	0.02–0.9 [0.03–1.1]		
Print (Finland)				1981–86	Heikkilä *et al.* (1991)
Development of photographs	11	0.04 [0.05]	0.02–0.1 [0.03–0.13]		

Table 6 (contd)

Industry and operation	No. of measurements	Mean[a]	Range	Year	
Miscellaneous (contd)					
Photographic laboratories (Finland)	10	0.07 [0.09]	0.02–0.3 [0.03–0.40]	1981–86	Heikkilä *et al.* (1991)
Abrasive production (Sweden)	20	0.2 [0.3]		1980s	Rosén *et al.* (1984)
Coal coking plant (former Czechoslovakia)	NR	0.05[d] [0.06]	< 0.01–0.25 [< 0.01–0.3]	NR	Mašek (1972)
Pitch coking plant (former Czechoslovakia)	NR	0.4[d] [0.5]	0.05–1.6 [0.07–2.0]	NR	Mašek (1972)
Rubber processing (USA)	NR	NR	0.4–0.8 [0.5–0.98]	1975	IARC (1982)
Sugar mill (Sweden)				1980s	Rosén *et al.* (1984)
Preservation of sugar beets	26	0.4 [0.5]	NR		
Malt barley production (Finland)				1981	Heikkilä *et al.* (1991)
Preservation of malt barley	6	0.7 [0.9]	0.4–1.5 [0.5–1.8]		

[a] Arithmetic mean unless otherwise specified

[b] Mean of geometric mean

[c] Some of the results were affected by the simultaneous occurrence in the samples (Stewart *et al.*, 1987b) of particulates containing formaldehyde (leading to high values)

[d] Mean of arithmetic means

have usually been < 1 ppm, but much higher exposures may occur (Table 6). Plastic dust and fumes may be present in the atmospheres of moulded plastics product plants, and exposures in these facilities are usually considerably higher than those in facilities where the products are used. The mean concentration of formaldehyde was > 1 ppm in many plants in the United States where moulding compounds were used. Some workers may be exposed to pigments, lubricants and fillers (e.g. asbestos and wood flour) used as constituents of moulding compounds (Stewart *et al.*, 1987b).

Heating of bake-drying paints and soldering may release some formaldehyde in plants where metalware and electrical equipment are produced, but the measured levels are usually well below 1 ppm (Table 6).

The mean concentrations of formaldehyde measured during coating of photographic films and during development of photographs are usually well below 1 ppm (Table 6). Methanol, ethanol, acetone and ammonia are other volatile agents that may occur in film manufacturing facilities (Stewart *et al.*, 1987b). Skin contact with numerous photographic chemicals occurs occasionally in photographic laboratories.

Formaldehyde is also used or formed during many other industrial operations, such as preservation of fur, leather, barley and sugar beets, coal and pitch coking, rubber processing and abrasive production. Some of these activities may entail heavy exposure. For example, treatment of furs with formaldehyde resulted in the highest exposure to formaldehyde of all jobs and industries studied in a large Swedish survey in the early 1980s. The 8-h time-weighted average concentration of formaldehyde was assessed to be 0.8–1.6 ppm (1.0–2.0 mg/m^3), and high peak exposures occurred many times per day (Rosén *et al.*, 1984).

(f) Mortuaries, hospitals and laboratories

Formaldehyde is used as a tissue preservative and disinfectant in embalming fluids. Some parts of bodies to be embalmed are also cauterized and sealed with a hardening compound that contains paraformaldehyde powder. The concentration of formaldehyde in the air during embalming depends on the content of embalming fluid, type of the body, ventilation and work practices; the mean level is about 1 ppm (Table 7). Embalming of a normal intact body usually takes about 1 h. A survey in West Virginia (United States of America) in 1979 showed that undertakers prepare an average of 75 bodies per year, 15 of which have been autopsied; the 8-h time-weighted average exposure is therefore likely to be 0.1–0.4 ppm (0.1–0.5 mg/m^3). Disinfectant sprays are occasionally used which may release small amounts of solvents, such as isopropanol (Williams *et al.*, 1984). Methanol is used as a stabilizer in embalming fluids, and levels of 0.5–22 ppm (0.7–28.4 mg/m^3) have been measured during embalming. Low levels of phenol have also been detected in embalming rooms (Stewart *et al.*, 1992).

Formaldehyde is widely used in hospitals for disinfection. The mean concentrations, summarized in Table 7, range from 0.1 to 0.8 ppm (0.1–1.0 mg/m^3), but many of the measurements were made during disinfection, which usually takes a relatively short time. Low levels are found when detergents are used for cleaning; higher levels, which may occasionally exceed 1 ppm, occur when more concentrated formalin solutions are used, e.g. during the disinfection of operating theatres and dialysers (Salisbury, 1983).

Table 7. Concentrations of formaldehyde (in ppm [mg/m^3]) in the workroom air of mortuaries, hospitals and laboratories

Industry and operation (type of sample)	No. of measurements	Mean[a]	Range	Year	Reference
Embalming, six funeral homes (USA)	NR	0.7 [0.9]	0.09–5.3 [0.1–6.5]	NR	Kerfoot & Mooney (1975)
Embalming, 23 mortuaries (USA)	NR	1.1 [1.4]	0.03–3.15 [0.04–3.9]	NR	Lamont Moore & Ogrodnik (1986)
8-h TWA		0.16 [0.2]	0.01–0.49 [0.01–0.6]		
Embalming, seven funeral homes				1980	Williams *et al.* (1984)
Intact bodies (personal samples)	8	0.3 [0.4]	0.18–0.3 [0.2–0.4]		
Autopsied bodies (personal samples)	15	0.9 [1.1]	2.1 [0–2.6]		
Embalming (USA)				NR	Stewart *et al.* (1992)
Personal samples	25	2.58 [3.2]	0.31–8.72 [0.4–10.7]		
Area 1	25	2.03 [3.0]	0.23–7.52 [0.3–9.2]		
Area 2	25	2.16 [2.7]	0.28–8.15 [0.3–10.0]		
Embalming (Canada)				NR	Korczynski (1994)
Intact bodies (personal samples)	24	0.6 [0.8]	0.10–4.57 [0.12–5.64]		
Autopsied bodies (personal samples)	24	0.6 [0.8]	0.09–3.35 [0.11–4.13]		
Area samples	72	0.5 [0.6]	0.04–6.79 [0.05–8.37]		
Autopsy service (USA)[b]				NR	Coldiron *et al.* (1983)
Personal samples	27	1.3[c] [1.66]	0.4–3.28 [0.5–4.0]		
Area samples	23	4.2 [5]	0.1-13.6 [0.1-16.7]		
Autopsy (Finland)	5	0.7 [0.8]	< 0.1–1.4 [< 0.1–1.7]	1981–86	Heikkilä *et al.* (1991)
Anatomical theatre (Germany)	29	1.1[d] [1.4]	0.7–1.7 [0.9–2.2]	1980–88	Triebig *et al.* (1989)
Cleaning hospital floors with detergent containing formaldehyde (38–74 min) (Italy) (personal)	4	0.18 [0.22]	0.15–0.21 [0.18–0.26]		Bernardini *et al.* (1983)
Disinfecting operating theatres (Germany)[b]				NR	Binding & Witting (1990)
3% cleaning solution	43	0.8 [1.1]	0.01–5.1 [0.01–6.3]		
0.5 % cleaning solution	26	0.2 [0.22]	0.01–0.43 [0.01–0.53]		
Disinfecting operating theatres (Germany)	43	0.4[c] [0.5]	0.04–1.4 [0.05–1.7]	NR	Elias (1987)

Table 7 contd

Industry and operation (type of sample)	No. of measurements	Mean[a]	Range	Year	Reference
Disinfection of dialysis clinic (USA), personal samples (37–63 min)	7	0.6 [0.8]	0.09–1.8 [0.12–2.2]	1983	Salisbury (1983)
Disinfection in hospitals (Finland)	18	0.1 [0.14]	0.03–0.2 [0.04–0.3]	1981–86	Heikkilä *et al.* (1991)
Bedrooms in hospital (Germany)	14	0.05 [0.06]	< 0.01–0.7 [< 0.01–0.9]	1980–88	Triebig *et al.* (1989)
Pathology laboratory (Sweden)	13	0.5 [0.66]	NR	1980s	Rosén *et al.* (1984)
Pathology laboratories (Germany)	21	0.5[d] [0.6]	< 0.01–1.2 [< 0.01–1.6]	1980–88	Triebig *et al.* (1989)
Hospital laboratories (Finland)	80	0.5 [0.6]	0.01–7.3 [0.01–9.1]	1981–86	Heikkilä *et al.* (1991)

[a] Arithmetic means unless otherwise specified
[b] Mean is 8-h time-weighted average
[c] Mean of arithmetic means
[d] Median

Formalin solution is commonly used to preserve tissue samples in histopathology laboratories. The concentrations of formaldehyde are sometimes high, e.g. during tissue disposal, formalin preparation and changing of tissue processor solutions (Belanger & Kilburn, 1981). The mean level during exposure is usually about 0.5 ppm (0.6 mg/m^3) (Table 7). Other agents to which pathologists and histology technicians may be exposed include xylene (see IARC, 1989c), toluene (see IARC, 1989d), chloroform (see IARC, 1987e) and methyl methacrylate (see IARC, 1994). The 8-h time-weighted average concentrations were from nondetectable to 22 ppm (95.5 mg/m^3) for xylene, 9–13 ppm (34–49 mg/m^3) for toluene and 0.4–7 ppm (2.0–34.3 mg/m^3) for chloroform in a study of the exposure and symptoms of histology laboratory technicians in the United States (Belanger & Kilburn, 1981).

(g) Building, agriculture, forestry and other activities

Exposure to formaldehyde may also occur in the construction industry, agriculture, forestry and the service sector. Specialized construction workers who varnish wooden parquet floors may have relatively high exposure. The mean levels of formaldehyde in the air during varnishing with urea–formaldehyde varnishes were 2–5 ppm (2.5–6.2 mg/m^3) (Table 8). One coat of varnish takes only about 30 min to apply (Riala & Riihimäki, 1991), but the same worker may apply five or even 10 coats per day. Use of water-based polyurethane varnishes that do not release formaldehyde reduces exposure. Other chemical agents to which parquetry workers are usually exposed include wood dust from sanding (see the monograph on wood dust) and solvent vapours from varnishes, putties and adhesives. The concentrations of solvents measured during varnishing were 6.5 times the exposure limit of the solvent mixture during nitrocellulose varnishing and 3.4 times the exposure limit during urea–formaldehyde varnishing in a Finnish study. The main solvents released from nitrocellulose varnishes were acetone, ethyl alcohol, ethyl acetate, hexane and other aliphatic hydrocarbons. The solvents in the urea–formaldehyde varnishes were mainly ethanol, acetone, isobutyl alcohol, ethyl acetate and propylene glycol monomethyl ether (Riala & Riihimäki, 1991). Other operations that may result in exposure to formaldehyde in the building trades are insulation with urea–formaldehyde foam and machining of particle-board. Various levels of formaldehyde have been measured during insulation with urea–formaldehyde foam, but exposure during handling and sawing of particle-board seems to be consistently low (Table 8).

Formaldehyde is used in agriculture as a preservative for fodder and as a disinfectant. For example, fodder was preserved with a 2% formalin solution for several days per year from the late 1960s until the early 1980s on farms in Finland. As the concentration during preservation was < 0.5 ppm (0.6 mg/m^3), the annual mean exposure is probably very low. Formaldehyde gas is also used 5–10 times a year to disinfect eggs in brooding houses. The concentration of formaldehyde in front of the disinfection chamber immediately after disinfection was as high as 7–8 ppm (8.6–9.8 mg/m^3), but annual exposure from this source probably remains very low (Heikkilä *et al.*, 1991).

Engine exhausts contain a small amount of formaldehyde (see section 1.3.3). The average exposure of lumberjacks using chainsaws in Sweden and Finland was, however, < 0.1 ppm (Table 8).

Table 8. Concentrations of formaldehyde (in ppm [mg/m^3]) in the workroom air in building sites, agriculture, forestry and miscellaneous other activities

Industry and operation	No. of measurements	Mean^a	Range	Year	Reference
Varnishing parquet with urea–formaldehyde varnish (Finland)	10	2.9 [3.6]	0.3–6.6 [0.4–8.1]	1976	Heikkilä *et al.* (1991)
Varnishing parquet with urea–formaldehyde varnish (Finland)	6	4.3 [5.3]	2.6–6.1 [3.2–7.5]	1987	Riala & Riihimäki (1991)
Insulating buildings with urea–formaldehyde foam (USA)	66	1.3^b [1.6]	0.3–3.1 [0.4–3.8]	NR	WHO (1989)
Insulating buildings with urea–formaldehyde foam (Sweden)	6	0.1 [0.18]	NR	1980s	Rosén *et al.* (1984)
Sawing particle-board at construction site (Finland)	5	< 0.5 [< 0.6]	NR	1967	Finnish Institute of Occupational Health (1994)
Agriculture (Finland)				1982	Heikkilä *et al.* (1991)
Handling of fodder	NR	NR	0.02–0.4 [0.03–0.46]		
Disinfection of eggs	11	2.6 [3.2]	0.2–7.8 [0.3–9.6]	1981–86	
Chain-sawing (Sweden)	NR	0.05 [0.06]	0.02–0.1 [0.03–0.13]	NR	Hagberg *et al.* (1985)
Chain-sawing (Finland) (8-h TWA)	NR	< 0.1	< 0.1–0.5 [0.1–0.6]	NR	Heikkilä *et al.* (1991)
Retail dress shops (USA)	NR	NR	0.1–0.5 [0.15–0.6]	1959	Elliott *et al.* (1987)
Fabric shops (Finland)	3	0.16 [0.2]	0.1–0.2 [0.15–0.3]	1985–87	Priha *et al.* (1988)
Fire-fighting (USA)	30	0.1 [0.16]	0.04–0.3 [0.05–0.4]	1989	Materna *et al.* (1992)
Museum, taxidermy (Sweden)	8	0.2 [0.3]	NR	1980s	Rosén *et al.* (1984)

NR, not reported; TWA, time-weighted average

[a] Arithmetic mean unless otherwise specified

[b] Mean of arithmetic means

The use of formaldehyde-based resin in finishing textiles and some garments may also result in exposure in retail shops. Measurements in dress shops in the United States of America in the 1950s showed levels up to 0.5 ppm [0.62 mg/m^3]. The air in three Finnish fabric shops in the 1980s contained 0.1–0.2 ppm [0.12–0.25 mg/m^3] formaldehyde (Table 8).

Low concentrations of formaldehyde may occur also during firefighting and taxidermy (Table 8).

1.3.3 Ambient air

Although formaldehyde is a natural component of ambient air, anthropogenic sources usually contribute the most formaldehyde in populated regions, since the ambient levels are generally < 1 μg/m^3 in remote areas. For example, in the unpopulated Eniwetok Atoll in the Pacific Ocean, a mean of 0.5 μg/m^3 and a maximum of 1.0 μg/m^3 formaldehyde were measured in outdoor air (Preuss *et al.*, 1985). Other authors have reported similar levels in remote, unpopulated areas (Gammage & Travis, 1989; WHO, 1989).

Outdoor air concentrations in urban environments are more variable and depend on local conditions. They are usually 1–20 μg/m^3 (United States National Research Council, 1980, 1981; Preuss *et al.*, 1985; Gammage & Travis, 1989; WHO, 1989). A major source of formaldehyde in urban air is incomplete combustion of hydrocarbon fuels, especially from vehicle emissions (Sittig, 1985; WHO, 1989; Vaught, 1991). Urban air concentrations in heavy traffic or during severe inversions can range up to 100 μg/m^3 (United States National Research Council, 1980, 1981; Preuss *et al.*, 1985; WHO, 1989).

1.3.4 Residential indoor air

The levels of formaldehyde in indoor air are often higher than those outside (Gammage & Gupta, 1984). The concentrations in dwellings depend on the sources of formaldehyde that are present, the age of the source materials, ventilation, temperature and humidity. Major sources of formaldehyde in some dwellings have been reported to be off-gassing of urea–formaldehyde foam insulation and particle-board. In studies summarized by Preuss *et al.* (1985), the mean levels in conventional homes with no urea–formaldehyde foam insulation were 25–60 μg/m^3.

Many studies have been reported since the late 1970s of formaldehyde levels in 'mobile homes' (caravans) (see, for example, the review of Gammage & Travis, 1989). The levels appear to decrease as the mobile home (and its formaldehyde-based resins) age, with a half-life of four to five years (Preuss *et al.*, 1985). In the early 1980s, a mean levels of 0.4 ppm [0.49 mg/m^3] and individual measurements as high as several parts per million were measured in new mobile homes. As a result of new standards set in the mid-1980s for building materials used in mobile homes and voluntary reductions by the manufacturers, formaldehyde levels in mobile homes are now typically around 0.1 ppm [0.12 mg/m^3] or less (Gammage & Travis, 1989; Sexton *et al.*, 1989; Gylseth & Digernes, 1992; Lehmann & Roffael, 1992).

1.3.5 Other exposures

Several studies have been conducted to determine exposures of students in laboratories. Skisak (1983) measured formaldehyde in the breathing zone at dissecting tables and in the ambient air in a medical school in the United States for 12 weeks. Concentrations > 1.2 mg/m^3 were found in 44% of the breathing zone samples and 11 ambient air samples; 50% of the breathing zone samples contained 0.7–1.2 mg/m^3, with a range of 0.4–3.2 mg/m^3. Korky *et al.* (1987) studied the dissecting facilities at a university in the United States during the 1982–83 academic year. The airborne concentration of formaldehyde was 7–16.5 ppm (8.6–20.3 mg/m^3) in the laboratory, 1.97–2.62 ppm (2.4–3.2 mg/m^3) in the stockroom and < 1 ppm (< 1.2 mg/m^3) in the public hallway. In another study, of 253 samples of air taken during laboratory dissection classes at a university in the United States, 97 contained concentrations above the detection limit of 0.01 mg/m^3; all but four samples had levels < 1.2 mg/m^3. The average concentration detected was 0.5 mg/m^3 (Poslusny *et al.*, 1992).

Cigarette smoke has been reported to contain levels of a few micrograms to several milligrams of formaldehyde per cigarette. A ‘pack-a-day’ smoker may inhale as much as 0.4–2.0 mg formaldehyde (IARC, 1986b; WHO, 1989; American Conference of Governmental Industrial Hygienists, 1991).

Cosmetic products containing formaldehyde, formalin and/or paraformaldehyde may come into contact with hair (e.g. shampoos and hair preparations), skin (deodorants, bath products, skin preparations and lotions), eyes (mascara and eye make-up), oral mucosa (mouthwashes and breath fresheners), vaginal mucosa (vaginal deodorants) and nails (cuticle softeners and nail creams and lotions). Aerosol products (e.g. shaving creams) result in potential inhalation of formaldehyde (Cosmetic Ingredient Review Expert Panel, 1984).

Formaldehyde occurs naturally in foods, and foods may be contaminated as a result of fumigation (of e.g. grain), cooking (as a combustion product) and release from formaldehyde resin-based tableware (WHO, 1989). It has been used as a bacteriostatic agent in some foods, such as cheese (Restani *et al.*, 1992). Fruits and vegetables typically contain 3–60 mg/kg, milk and milk products about 1 mg/kg, meat and fish 6–20 mg/kg and shellfish 1–100 mg/kg. Drinking-water normally contains < 0.1 mg/L (WHO, 1989).

Other exposures to formaldehyde are reviewed by IARC (1982) and WHO (1989).

1.4 Regulations and guidelines

Occupational exposure limits and guidelines for formaldehyde are presented in Table 9. International regulations and guidelines related to emissions of and exposures to formaldehyde in occupational settings, indoor air and building materials have been reviewed (Scheuplein, 1985; Sundin, 1985; Coutrot, 1986; Meyer, 1986; McCredie, 1988; Gylseth & Digernes, 1992; Halligan, 1992; Lehmann & Roffael, 1992; McCredie, 1992).

Table 9. Occupational exposure limits and guidelines for formaldehyde

Country or region	Year	Concentration (mg/m^3)	Interpretation
Australia	1991	1.5	TWA; probable human carcinogen, sensitizer
		3	STEL
Austria	1982	1.2	TWA
Brazil	1978	2.3	TWA
Belgium	1991	1.2	TWA; probable human carcinogen
		2.5	STEL
Bulgaria	1984	1	TWA
Chile	1983	2.4	Ceiling
China	1982	3	TWA
Czech Republic	1991	0.5	TWA
		1	STEL
Denmark	1991	0.4	STEL; suspected carcinoegn
Egypt	1959	6.2	TWA
Finland	1993	1.3	STEL, 15 min; significant absorption through skin
France	1991	3	STEL
Germany	1993	0.6	TWA; suspected carcinogenic potential; local irritant; sensitizer
Hungary	1991	0.6	Ceiling; probable human carcinogen; irritant; sensitizer
India	1983	3	Ceiling
Indonesia	1978	6	Ceiling
Italy	1978	1.2	TWA
Japan	1991	0.61	TWA; suspected carcinogenic potential
Mexico	1983	3	TWA
Netherlands	1986	1.5	TWA
		3	Ceiling, 15 min
Norway	1990	0.6	TWA; allergen; suspected carcinogen
		1.2	Ceiling
Poland	1991	2	TWA
Romania	1975	4	MAX
Russian Federation	1991	0.5	STEL; significant absorption through skin; allergen
Sweden	1991	0.6	TWA; sensitizer
		1.2	Ceiling
Switzerland	1991	0.6	TWA; sensitizer
		1.2	STEL
Taiwan	1981	6	TWA; significant absorption through skin
United Kingdom	1992	2.5	TWA; maximum exposure limit
		2.5	STEL, 10 min
USA			
ACGIH	1993	0.37	Ceiling; suspected human carcinogen
NIOSH	1992	0.02	TWA; potential human carcinogen
		0.12	Ceiling, 15 min
OSHA	1993	0.9	TWA
		2.5	STEL

Table 9 (contd)

Country or region	Year	Concentration (mg/m^3)	Interpretation
Venezuela	1978	3	TWA, ceiling
Former Yugoslavia	1971	1	TWA

From Arbeidsinspectie (1986); Cook (1987); Direktoratet for Arbeidstilsynet (1990); International Labour Office (1991); United Kingdom Health and Safety Executive (1992); United States National Institute for Occupational Safety and Health (NIOSH) (1992); American Conference of Governmental Industrial Hygienists (ACGIH) (1993); Deutsche Forschungsgemeinschaft (1993); Työministeriö (1993); United States Occupational Safety and Health Administration (OSHA) (1993)

TWA, time-weighted average; STEL, short-term exposure limit; MAX, maximum

The European Union has adopted a Directive that imposes concentration limits for formaldehyde and paraformaldehyde in cosmetics. These substances are permitted at a maximal concentration of 0.2% (expressed as free formaldehyde) in all cosmetic formulations except nail hardeners, oral hygiene products and aerosol dispensers. Nail hardeners and oral hygiene products may contain maximal concentrations of 5 and 0.1%, respectively, whereas formaldehyde and paraformaldehyde are prohibited for use in aerosol dispensers (except for foams). Cosmetic product labels are required to list formaldehyde and paraformaldehyde as ingredients when the concentration of either exceeds 0.05% (Cosmetic Ingredient Review Expert Panel, 1984; European Commission, 1990).

Guidelines for ambient air levels of formaldehyde in living spaces have been set in several countries and range from 0.05–0.4 ppm (0.06–0.5 mg/m^3), with a preference for 0.1 ppm (0.12 mg/m^3) (Lehmann & Roffael, 1992).

In the United States, all plywood and particle-board materials bonded with a resin system or coated with a surface finish containing formaldehyde cannot exceed the following formaldehyde emission levels when installed in manufactured homes: plywood materials and particle-board flooring products (including urea–formaldehyde bonded particle-board) cannot emit more than 0.25 mg/m^3 formaldehyde, and particle-board materials and medium-density fibre-board cannot emit more than 0.37 mg/m^3 (National Particleboard Association, 1992, 1993; National Particleboard Association, 1994; United States Department of Housing and Urban Development, 1994). Several other countries have similar regulations (Lehmann & Roffael, 1992).