2-BUTOXYETHANOL

1. Exposure Data

1.1 Chemical and physical data

1.1.1 *Nomenclature*

Chem. Abstr. Serv. Reg. No.: 111-76-2
Chem. Abstr. Name: 2-Butoxyethanol
IUPAC Systematic Name: 2-Butoxyethanol
Synonyms: Butoxyethanol; β-butoxyethanol; *n*-butoxyethanol; 2-*n*-butoxyethanol; 2-butoxy-1-ethanol; 2-*n*-butoxy-1-ethanol; O-butyl ethylene glycol; butylglycol; butyl monoether glycol; EGBE; ethylene glycol butyl ether; ethylene glycol *n*-butyl ether; ethylene glycol monobutyl ether; ethylene glycol mono-*n*-butyl ether; glycol butyl ether; glycol monobutyl ether; monobutyl ether of ethylene glycol; monobutyl glycol ether; 3-oxa-1-heptanol

1.1.2 *Structural and molecular formulae and relative molecular mass*

$$H_3C—CH_2—CH_2—CH_2—O—CH_2—CH_2—OH$$

$C_6H_{14}O_2$ Relative molecular mass: 118.17

1.1.3 *Chemical and physical properties of the pure substance*

From Lide (2004) unless otherwise specified

(*a*) *Description*: Liquid
(*b*) *Boiling-point*: 168.4 °C
(*c*) *Melting-point*: –74.8 °C
(*d*) *Density*: 0.9015 g/mL at 20 °C
(*e*) *Spectroscopy data*: Infrared and nuclear magnetic resonance (proton) spectral data have been reported (National Toxicology Program, 2000)

(*f*) *Solubility*: Miscible with water, ethanol and diethyl ether; slightly soluble in carbon tetrachloride; soluble in mineral oil and most organic solvents (National Toxicology Program, 2000)
(*g*) *Volatility*: Vapour pressure, 100 Pa or 0.6 mm Hg at 20 °C; relative vapour density (air = 1), 4.07 (Verschueren, 2001)
(*h*) *Octanol/water partition coefficient (P)*: log P, 0.83 (Hansch *et al.*, 1995)
(*i*) *Conversion factor*: $mg/m^3 = 4.873 \times ppm$[1]

1.1.4 *Technical products and impurities*

2-Butoxyethanol is commercially available with the following specifications: purity, 99% min.; acidity (as acetic acid, % wt), 0.005–0.01 max.; water (% wt), 0.1 max.; peroxides (as oxygen), 10 mg/kg max.; ethylene glycol (% wt), 0.2–0.3 max.; n-butyl alcohol (% wt), 0.1 max.; diethylene glycol monobutyl ether (% wt), 0.1 max.; stabilizer (butylated hydroxytoluene), 376 ppm target or 0.1% max. (Eastman Chemical Co., 2000a,b; Dow Chemical Co., 2001; Shell Chemicals, 2002; Eastman Chemical Co., 2003; Shell Chemicals, 2004).

Trade names for 2-butoxyethanol include: Butyl Cellosolve®; n-Butyl Cellosolve®; Butyl Cellosolve® Solvent; Butyl Cellu-Sol; O-Butyl Ethylene Glycol; Butyl Glysolv; Butyl Oxitol®; Butyl Oxital® EB; C4E1; Chimec NR; Dowanol® EB; Eastman® EB; Eastman® EB Solvent; Ektasolve EB; Ektasolve EB Solvent; Gafcol EB; Glycol EB; Glycol Ether EB; Jeffersol EB; Minex BDH; Poly-Solv EB.

1.1.5 *Analysis*

Analytical methods suitable for the determination of 2-butoxyethanol in environmental matrices have been reviewed (ATSDR, 1998). These methods rely principally on adsorption onto charcoal or other suitable material, followed by gas chromatographic (GC) analysis with flame ionization (FID) or mass spectrometric (MS) detection. Lower limits of detection generally range from 0.1 to 2 ppm, depending on the specific analytical method employed and on the sampling procedure used (Boatman & Knaak, 2001). Typical methods include those from the Deutsche Forschungsgemeinschaft (1991), the National Institute for Occupational Safety and Health (2003), the Occupational Safety and Health Administration (1990) and the Institut national de Recherche et de Sécurité (INRS, 2002). Yoshikawa and Tani (2003) reported a reversed-phase high-performance liquid chromatography (HPLC) method with fluorescence detection after derivatization by treatment with 1-anthroylnitrile; the method detects 2-butoxyethanol in workplace air in the low parts per billion range (1–3 pg).

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[1] Calculated from: $mg/m^3 = (\text{relative molecular mass}/24.45) \times ppm$, assuming normal temperature (25 °C) and pressure (103.5 kPa)

Preparation methods for water samples are based on purge-and-trap (Michael *et al.*, 1988, 1991), solvent extractions (Jungclaus *et al.*, 1976; Yasuhara *et al.*, 1981; Nguyen *et al.*, 1994) or direct injection (Beihoffer & Ferguson, 1994). Eckel *et al.* (1996) noted the inefficiency of the common purge-and-trap and solvent extraction methods for the isolation of low-molecular-weight glycol ethers, and recommended instead the use of direct aqueous injection, extractive alkylation or salting-out extraction with derivatization with pentafluorobenzoyl chloride.

Analytical methods for the determination of 2-butoxyethanol and its metabolites (2-butoxyacetic acid and conjugates) in biological matrices (blood and urine) have also been reviewed (Johanson, 1988; ATSDR, 1998). The methods generally involve extraction, derivatization and analysis by GC with FID, MS or electron capture detection (ECD), or HPLC with ultraviolet (UV) detection (Johanson *et al.*, 1986a; Begerow *et al.*, 1988; Johanson, 1989; Groeseneken *et al.*, 1989; Rettenmeier *et al.*, 1993; Sakai *et al.*, 1993, 1994; Bormett *et al.*, 1995). A more recent method (Shih *et al.*, 1999; Brown *et al.*, 2003) reported improved analysis of butoxyacetic acid in urine without derivatization.

Jones and Cocker (2003) reported that about half of the total 2-butoxyacetic acid in human urine is in the conjugated form, although the percentage is highly variable between and within individuals. The authors recommended total 2-butoxyacetic acid (after acid hydrolysis) in urine as the biomarker of choice to monitor exposure to 2-butoxyethanol.

1.2 Production and use

Glycol ethers began to be used in the 1930s and some have been in general use for nearly 50 years. They form a varied family of more than 30 solvents that commonly dissolve in both water and oil. Traditionally, a distinction is made between two main groups of glycol ethers: the E series and the P series, which derive from the name of the chemical substance that serves as a starting point for their production (ethylene and propylene, respectively). In each series, different derivatives have been developed to provide the properties of solubility, volatility, compatibility and inflammability that are required for different uses (Oxygenated Solvents Producers Association, 2004).

1.2.1 *Production*

Ethylene glycol ethers are manufactured in a closed, continuous process by reacting ethylene oxide with an anhydrous alcohol in the presence of a suitable catalyst. Depending on the molar ratios of the reactants and other process parameters, the mixtures obtained contain varying amounts of the monoethylene, diethylene, triethylene and higher glycol ethers. Typically, the products of these mixtures are separated and purified by fractional distillation (Boatman & Knaak, 2001).

Available information indicates that 2-butoxyethanol was produced by nine companies in China, seven companies in Germany, six companies in India, four companies in Japan, three companies in the USA, two companies each in Argentina, Mexico, Taiwan

(China) and the United Kingdom and one company each in Australia, Brazil, Poland, Russia, Slovakia and Spain (Chemical Information Services, 2004).

Since the early 1980s, 2-butoxyethanol has been the most widely produced and consumed glycol ether in the USA. Production estimates for 2-butoxyethanol in the USA from 1970 to 1999 are presented in Table 1.

Table 1. Production of 2-butoxyethanol in the USA from 1970 to 1999 (thousand tonnes)

1970	1975	1980	1985	1990	1995	1999
48.5	59.2	90.9	125.6	187.5	187.2	226.8

From Chinn *et al*. (2000)

1.2.2 *Use*

Because of their miscibility with water and with a large number of organic solvents, most ethylene glycol ethers are especially useful as solvents in oil–water compositions. This property, among others, leads to their use in numerous industrial (paints, pharmaceutical products, inks) and consumer (cosmetics, detergents) applications. Their relatively slow rate of evaporation also makes them useful as solvents and coalescing agents in paints. Other uses include inks, cleaning products, chemical intermediates, process solvents, brake fluids and de-icers (Boatman & Knaak, 2001).

Time trends in consumption of 2-butoxyethanol in the USA and western Europe are shown in Tables 2 and 3, respectively. In 1999, consumption in Japan was estimated at 27 600 tonnes (Chinn *et al*., 2000). Some data on typical uses in Canada, the European Union and the USA are shown in Table 4.

Table 2. Trends in consumption for 2-butoxyethanol in the USA — 1980–99 (thousand tonnes)

	1980	1985	1990	1995	1999
Paints, coatings and inks	36.3	42.6	63.1	68.5	76.7
Metal and liquid household cleaners	11.8	14.5	19.0	21.3	20.4
Other uses	16.8	18.1	25.4	26.8	29.9
Production of 2-butoxyethanol acetate	4.5	6.4	6.4	5.9	6.8
Other production	0.9	4.5	5.9	6.8	7.7
Total	70.3	86.1	119.8	129.3	141.5

From Chinn *et al*. (2000)

Table 3. Trend in consumption of 2-butoxyethanol in selected western European countries[a] from 1987 to 1999 (thousand tonnes)

Year	1987	1991	1993	1995	1997	1999
Consumption	72	90	92	98	104	114

From Chinn *et al*. (2000)

[a] Countries include, in order of relevance: Austria, Switzerland, Sweden, Norway, Portugal, Finland, Denmark, Ireland and Greece.

Table 4. Typical uses of 2-butoxyethanol in selected regions and countries

Region/country Year	European Union [2001]	Canada 2002	USA [1997]
Industrial use	**87.3%**	**78%**	**61%**
Paints and coatings	75.8%	85%	
Cleaners	3.8%	8%	
Inks	6.4%	5%	
Other[a]	14.0%	2%	
Consumer use	**12.7%**	**22%**	**39%**
Cleaners	8.8%	47%	46%
Paints and coatings	91.2%	32%	32%
Solvents			21.5%
Polishes			0.5%
Other[b]		21%	

From OECD (1997); Boatman & Knaak (2001); ToxEcology Environmental Consulting Ltd (2003)

[a] Includes chemicals used in synthesis and the electronic, rubber and oil industries, agricultural products, adhesives, oil spill dispersants, leather finishing, fire foams, pharmaceuticals and construction materials.

[b] Includes consumer solvents, pesticides and personal care products.

The largest use for 2-butoxyethanol is as a solvent in surface coatings, especially water-based paints and varnishes. Other coatings include spray lacquers, quick-dry lacquers, enamels, varnishes and latex paint. Approximately 80% of 2-butoxyethanol consumed in surface coatings is used for industrial and specialty coatings; the remainder is used in architectural coatings (Chinn *et al*., 2000).

2-Butoxyethanol also is used as a mutual solvent and coupling agent to stabilize and solubilize immiscible ingredients in emulsion metal and liquid household cleaners. Other solvent applications include printing inks, industrial cleaning fluids, nitrocellulose resins, dry-cleaning compounds, rust-removing liquids, varnish removers, textile and mineral oils, as a formulation solvent for insecticides and herbicides, as a co-solvent in diesel fuel, and use in cosmetic products such as hair dyes, nail polishes, nail polish removers and skin cleansers (Chinn *et al.*, 2000; Boatman & Knaak, 2001; Environment Canada/Health Canada, 2002).

2-Butoxyethanol has a number of important applications as a chemical intermediate, notably to form esters of acetic acid, phthalic anhydride, phosphoric acid, adipic acid and several specialty herbicide products (e.g. the glycol ether esters of 2,4-D and 2,4,5-T) (Chinn *et al.*, 2000; Boatman & Knaak, 2001). It is also used as a component in phthalate and stearate plasticizers.

In the 1980s, 2-butoxyethanol was used in certain automotive brake fluids, but it has mostly been replaced by higher-boiling glycol ethers (Chinn *et al.*, 2000).

2-Butoxyethanol has been replaced in some of its applications by the P-series of glycol ethers, such as propylene glycol mono-*n*-butyl ether, dipropylene glycol mono-*n*-butyl ether and propylene glycol mono-*tert*-butyl ether. Relative consumption of E- and P-series glycol ethers differs by geographical region, ranging in 1999 from 55% E/45% P in western Europe to about 75% E/25% P in the USA and Japan and 94% E/6% P in Mexico (Chinn *et al.*, 2000).

1.3 Occurrence

1.3.1 *Natural occurrence*

2-Butoxyethanol is not known to occur as a natural product.

1.3.2 *Occupational exposure*

Occupational exposure to 2-butoxyethanol may occur during its manufacture and use as an intermediate in the chemical industry, and during the formulation and use of its products. The major routes of exposure are inhalation and skin absorption. Because 2-butoxyethanol is readily absorbed through the skin and has a relatively low vapour pressure, the dermal route may be predominant or may contribute significantly to overall exposure.

Exposure to 2-butoxyethanol by inhalation is well documented; recent high-quality reports prepared by national or international bodies are available (NICNAS, 1996; OECD, 1997; ATSDR, 1998).

Environmental monitoring of air concentrations in the breathing zone or in the work area has been found to be inadequate to assess overall exposures; measurements of total exposure to 2-butoxyethanol should take into account the respiratory uptake of vapours and aerosols and the dermal absorption of 2-butoxyethanol in liquid, vapour and aerosol form (NICNAS, 1996). Biological monitoring of the common urinary metabolite, 2-butoxyacetic acid, is recommended for a complete assessment of exposure (Angerer *et al.*, 1990; Johanson & Johnsson, 1991; Söhnlein *et al.*, 1993; Vincent *et al.*, 1993; Jones

& Cocker, 2003). For workers in high-exposure occupations who do not wear protective gloves, environmental sampling probably underestimates the exposure, and biomonitoring of urinary butoxyacetic acid appears to be the best method for estimating overall exposure.

Data from the National Occupational Exposure Survey (NOES) conducted in the USA by the National Institute for Occupational Safety and Health from 1980 to 1983 indicate that an estimated 2 139 000 workers in 2260 industrial/occupational categories were potentially exposed to 2-butoxyethanol (National Institute for Occupational Safety and Health, 1989; ATSDR, 1998). The NOES database does not contain information on the frequency, level or duration of exposure of workers to any chemical listed therein and does not reflect recent changes in US production. The numbers also do not include workers who were potentially exposed to trade-name compounds (observed in the NOES survey) that contain 2-butoxyethanol.

In Australia, 82 companies were identified that formulate 2-butoxyethanol into cleaning products, some of which produced cleaning products at more than one site; at least 200 workers were involved in the formulation in each company (NICNAS, 1996).

(*a*) *Manufacture and use as an intermediate*

2-Butoxyethanol is manufactured continuously, either full-time during the year or within specific periods of several weeks or months. Workers may be exposed for approximately 8 h per day on 5 days per week during specific periods, but, typically, no personnel works constantly at the plant, and fitters, engineers and other technical staff visit the plant occasionally only. The process is enclosed as extensive precautions are taken to prevent and minimize exposure of workers to the toxicity of the ethylene oxide feedstock (ECETOC, 1994; NICNAS, 1996; OECD, 1996).

Exposure during transfer to tankers or drums is generally minimized by the use of automated filling, where the operator is outside of the area during transfer, and the use of local exhaust ventilation. Accidental exposure may occur when the process is breached or when spills occur. Exposure may also occur during maintenance and cleaning activities; however, the prior purging of equipment is generally standard practice (OECD, 1996).

Measurements of airborne concentrations of 2-butoxyethanol provided by manufacturers and collected for the OECD assessment are reported in Table 5.

Measurements in a manufacturing plant in the USA during drum filling operations, the most probable source of exposure, showed levels of 1.7 ppm during area monitoring. The highest personal monitoring reading was 0.1 ppm (Clapp *et al.*, 1984).

Eight-hour time-weighted average (TWA) personal exposures of 2-butoxyethanol in manufacturing plants in Europe were in the range of 0.01–0.4 ppm (production), 0.03–0.3 ppm (drum filling), 0.5–2.7 ppm (blending) and < 1.6 ppm (roadcar filling) (ECETOC, 1985).

Personal exposure measurements of 2-butoxyethanol at a number of production sites during 1988–93 showed concentrations in the range of 0.1–1.6 ppm and a mean of 0.13 ppm (ECETOC, 1994).

Table 5. Airborne concentrations[a] measured during the manufacture of 2-butoxyethanol

Plant location	Activity	No. of readings	Mean (ppm)	Maximum (ppm)
Australia	All (STEL and TWA, personal)		0.1	
	Maintenance (TWA, area)			1.8
European Union	Production	97	0.09	1.2
	Filling	66	1.3	5.3
	Technical unit	9	0.25	1.2
	Laboratory	14	1.3	11
	Various	8	0.5	2.7
European Union	All	311	< 0.1	1.6
European Union	Production	30	< 0.14	< 0.31
	Filling	10	< 0.14	0.22
	Laboratory sampling	20	< 0.38	1.1
USA	Production	16		< 0.04
	Tanker loading	11	< 0.25	1.8

From NICNAS (1996); OECD (1997)

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

[a] No indications were available as to whether they represent task measurements or 8-h time-weighted averages, except for the plant in Australia.

(*b*) *Formulation of products containing 2-butoxyethanol*

Exposure during formulation strongly depends on the mixing process, which may be enclosed or relatively open. Information obtained from the national assessment of exposure to 2-butoxyethanol in Australia indicated that approximately 50% of formulators of cleaning products that contain 2-butoxyethanol carry out mixing in open-top tanks that provide greater potential for exposure (NICNAS, 1996). Workers are potentially exposed to 2-butoxyethanol for an average of 3 h per week (56% for ≤ 1 h per week; range, 0.1–20 h). For most formulators, 2-butoxyethanol is an ingredient of only some of their products, and therefore exposure is not continuous on a daily or weekly basis.

Personal exposures of 2-butoxyethanol during the formulation of products are presented in Table 6.

(*c*) *Painting, printing and use of inks and varnishes*

Airborne concentrations of 2-butoxyethanol that were measured during painting and printing activities are summarized in Tables 7 and 8, respectively.

In a study performed from 1988 to 1993 (Vincent *et al*., 1996), exposure measurements were made in 55 companies that covered 18 sectors of activity, including the principal use category of products that contain glycol ethers: paints, inks, diluents and varnishes (Table 9). Exposure of workers was measured by 8-h individual atmospheric sampling and

Table 6. Eight-hour time-weighted average personal exposures to butoxyethanol during formulation of products

Product	No. of samples	Mean (ppm)	Range (ppm)	Reference
Printing ink	9	< 1	NR	Winchester (1985)
Varnish	12[a]	1.1	< 0.1–8.1	Angerer *et al.* (1990)
Varnish	12[a] pre-shift	0.5	< 0.1–1.4	Söhnlein *et al.* (1993)
	12[a] post-shift	0.6	< 0.1–1	
Paints	4	1.3	0.41–3.13	Foo *et al.* (1994)
Paints	328	0.4	< 0.1–44.7	Vincent *et al.* (1996)
Paints	179	0.1	0.0–1.4	Wesolowski & Gromiec (1997)

NR, not reported
[a] No. of workers [no. of samples not stated]

biological monitoring of urine at the beginning and at the end of the shift. The people most heavily exposed to 2-butoxyethanol were workers in the area of cataphoresis, where the mean atmospheric exposure was 0.8 ppm, whose concentration of urinary butoxyacetic acid reached 210 mg/g creatinine.

In a survey of industrial solvents conducted in 1994–96 in Japan in 95 different plants (196 unit work areas; 1176 samples), 2-butoxyethanol was detected in 59 samples (eight samples taken in printing areas and 51 samples taken in painting areas) with a median atmospheric concentration of 0.5 ppm and a maximum concentration of 1.3 ppm (Yasugi *et al.*, 1998).

Exposure measurements (sampling period, 60–480 min) registered between 1987 and 1998 in the COLCHIC database in France were analysed by Vincent (1999). Results related to painting and coating are presented in Table 10, and those for the printing industry are given in Table 11.

Referring to the same COLCHIC database, 45 atmospheric personal samples were taken between 1987 and 1998 in the printing industry and resulted in an arithmetic mean concentration of 0.6 ppm (range, 0.02–5.3 ppm; median, 0.04 ppm; 95th percentile, 2.7 ppm) (Vincent, 1999). It should be noted that exposure to 2-butoxyethanol in the printing industry in France has significantly decreased from 1987–92 to 1993–98; the arithmetic mean for personal samples in 1987–92 was 1.4 ppm (median, 1.3 ppm; range, 0.02–6.6 ppm; 68 samples) and that in 1993–98 was 0.3 ppm (median, 0.1 ppm; range, 0.02–2.6 ppm; 79 samples) ($p < 0.01$) (Vincent & Jeandel, 1999).

In another study in France (Delest & Desjeux, 1995), exposures of 54 house painters were assessed by biological monitoring. Only three painters had urinary concentrations of butoxyacetic acid higher than the limit of detection (2 mg/g creatinine) and the maximum concentration was 13.2 mg/g. The main reasons for the low figures observed were the application technique (brush or roller) and the low content of 2-butoxyethanol in the products used (< 5%).

Table 7. Time-weighted average[a] personal exposures to 2-butoxyethanol during painting

Activity	No. of samples (no. of workers)	Mean (ppm)	Max. or range (ppm)	Reference
Furniture production/finishing	64	1.5	0.07–9.9	Zaebst (1984, cited in ATSDR, 1998)
Staining/varnishing of parquet	9[b]	5	71.8	Denkhaus *et al.* (1986)
Car repair	1[b]	1.2	NA	Veulemans *et al.* (1987)
General painting	10[b]	3.9	0.7–19.2	Veulemans *et al.* (1987)
House painting (water-based paints < 1.4% 2-butoxyethanol)	15	NR	0.4–12	Hansen *et al.* (1987)
Wood cabinet finishing	6 (3)	NR	ND–0.4	Newman & Klein (1990)
Automobile spray painting	8 (8)	0.4	0.2–0.6	Winder & Turner (1992)
Painting (water-based paints < 5 % 2-butoxyethanol)	(54)[b]	< 0.1	< 0.1–0.2	Delest & Desjeux (1995)
Indoor house painting (water-based paints)	20[c]	0.02	< 0.01–0.15	Norbäck *et al.* (1996)
Painting of plastic material (two plants)	79 (19)	< 0.1	< 0.1–0.8	Vincent *et al.* (1996)
Cataphoresis (two plants)[d]	66 (12)	0.8	< 0.1–6.2	
Varnishing metallic containers (three plants)	168 (79)	0.2	< 0.1–2.4	
Painting new vehicles (one plant)	39 (20)	< 0.1	< 0.1–0.5	
Can coating (three plants)	261 (143)	0.1	< 0.1–1.0	
Painting of metal frame (two plants)	50 (23)	< 0.1	< 0.1–0.3	
Painting of buildings (11 plants)	63 (63)	< 0.1	< 0.1–0.2	
Printed circuit boards varnishing (two plants)	57 (13)	< 0.2	< 0.1–2.8	
Can coating				Haufroid *et al.* (1997)
External decoration	20	0.7	0.4–1.3	
Inner protection	11	0.5	0.2–0.7	

NA, not applicable; ND, not detected [limit of detection not reported]; NR, not reported

[a] Unless stated otherwise

[b] Type of sampling not stated

[c] 2-Butoxyethanol found in two samples

[d] Electro-deposition of water-based anticorrosive agent

Table 8. Personal exposures to 2-butoxyethanol during printing

Activity	No. of samples (no. of workers)	Mean (ppm)	Range (ppm)	Content of 2-butoxyethanol (%); comments	Reference
Printing press operators	3	< 0.2	< 0.04–0.49	2% in cleaning printing press rollers	Lewis & Thoburn (1981); ATSDR (1998)
Label printing/plate makers and pressmen	7	[2]	1–2		Apol (1981)
Silkscreen printing and cleaning	6	3.4	1.1–5.2		Boiano (1983)
Silkscreen printing					Baker *et al*. (1985)
Silk screeners	16	6.8			
Spray printer	5	2.6			
Controls	6	0.3			
Silkscreen printing	3	4	3–5		Apol (1986)
Printing (various)	25[a]	0.8	0.3–3.6		Veulemans *et al*. (1987)
Printing press operators	1	NA	8		Lee (1988)
Silkscreen clean-up and maintenance	5	5.2	1.7–9.8	10–50% in hydrocarbon-based cleaning solvent	Salisbury *et al.* (1987)
Printing press operators	2	< 0.33	ND–0.53	2% in cleaning printing press rollers	Kaiser & McManus (1990); ATSDR (1998)
General printing	9	0.64	0.4–0.8		Sakai *et al*. (1993)
Tampography (three workshops)	84 (29)	0.2	< 0.1–0.7		Vincent *et al.* (1996)
Silkscreen (six workshops)	295 (110)	0.2	< 0.1–1.6		
Screen printing					Auffarth *et al*. (1998)
Semi automatic	5	0.5	0.3–0.9		
75% automatic	14	0.6	0.3–1.0		
Fully automatic	3	0.5	0.3–0.9		
Screen cleaning	5	0.6	0.2–0.7		

NA, not applicable; ND, not detected

[a] Type of sampling not stated

Table 9. Biological monitoring during the use of paints, inks and varnishes

Activity	No. of samples		Arithmetic mean urinary excretion (mg/g creatinine) of butoxyacetic acid (range)	
	Pre-shift	Post-shift	Pre-shift	Post-shift
Cataphoresis	51	51	6.3 (< 2–88.3)	17.9 (< 2–210)
Painting new vehicles	40	40	ND	ND
Automobile repainting	8	8	ND	ND
Aircraft repainting	28	28	ND	ND
Silk-screen painting	116	154	ND	ND
Tampography	48	48	< 2[a] (< 2–4.1)	2.2 (< 2–7.1)
Offset printing	9	11	3.2 (< 2–11.0)	2.2 (< 2–3.8)
Can coating	85	213	< 2[a] (< 2–13.6)	2.3 (< 2–28.4)
Varnishing metallic containers for foods	79	79	3.0 (< 2–38.2)	5.0 (< 2–33.9)
Manufacture of paints	112	300	2.2 (< 2–5.2)	3.9 (< 2–59.6)
Painting metal frames	47	46	4.3 (< 2–30.7)	9.4 (< 2–63.0)
Painting buildings	63	63	< 2 (< 2–9.1)	< 2 (< 2–13.2)
Manufacture of printed circuit boards	56	56	< 2 (< 2–15.7)	4.6 (< 2–30.4)
Staining and varnishing furniture	50	50	ND	2.9 (< 2–31.2)
Painting plastic materials	19	19	ND	ND

From Vincent *et al.* (1996)
ND, not detected (< 2 mg/L)
[a] The arithmetic mean was < 2 when calculated by replacing data below the limit of detection by half of the limit of detection.

Table 10. Personal exposures (60–480 min) to 2-butoxyethanol during painting and coating activities in 1987–98

Type of work	No. of positive samples	Mean (ppm)	Median (ppm)	Range (ppm)
Pneumatic coating with paint or varnish	58	0.47	0.2	0.04–4.3
Varnishing (curtain)	19	0.14	0.1	0.02–0.6
Brush or roll coating with paint or varnish	21	0.18	0.1	0.04–0.6
Electrodeposition	3	0.21	NR	0–0.6

From Vincent (1999)
NR, not reported

Table 11. Personal exposures (60–480 min) to 2-butoxyethanol during printing activities in 1987–98

Activity	No. of results	Mean (ppm)	Range (ppm)	Median (ppm)
Manual or automated screen printing	92	1.1	0.02–6.6	0.4
Screen cleaning	9	0.4	0.04–1.6	NR
Offset printing	13	0.3	0.02–1.2	0.04
General cleaning with solvents	2	2.6	1.2–3.9	NR
Flexography	20	0.08	0.04–0.1	0.1
'Rotogravure'	7	0.04	0.02–0.1	NR

From Vincent (1999)
NR, not reported

Twelve workers in a varnish production facility in Germany were found to be exposed to an average concentration of 1.1 ppm 2-butoxyethanol, and individual TWA exposures ranged from < 0.1 to 8.1 ppm. Biological monitoring of 2-butoxyethanol in the blood and butoxyacetic acid in the urine showed average post-shift concentrations of 121.3 μg/L and 10.5 mg/L, respectively. A markedly lower pre-shift concentration of butoxyacetic acid in the urine (3.3 mg/L) was reported. Most of the exposure was attributed to dermal absorption (Angerer *et al*., 1990).

In another study in Germany, the occupational exposure to glycol ethers of 12 workers in the varnish production industry was evaluated. Urine samples of the workers were collected on the morning of the first day (pre-shift) and at the end of the second day (post-shift). Mean concentrations of 2-butoxyethanol from personal air samples were 0.5 ppm (range, < 0.1–1.4 ppm) on the first day and 0.6 ppm (range, < 0.1–1.0 ppm) on the second day. The mean urinary concentration of butoxyacetic acid was 0.2 mg/L (range, < 0.02–1.3 mg/L) on Monday pre-shift and 16.4 mg/L (range, 0.8–60.6 mg/L) on Tuesday post-shift (Söhnlein *et al*., 1993).

(*d*) *Cleaning*

Exposure during cleaning is extremely variable, due to differences in the frequency and duration of use of cleaning products, the strength of the solutions used, the method of application of the products and the precautions taken during their use. Monitoring data reported for cleaning activities are summarized in Table 12.

A study was conducted in France to evaluate the occupational exposure to 2-butoxyethanol of 16 office cleaners and 13 automobile cleaners who used window-cleaning agents (Vincent *et al*., 1993). Table 13 shows the atmospheric concentrations of 2-butoxyethanol and the urinary concentrations of butoxyacetic acid in pre-shift and end-shift samples by occupation. Average urinary concentrations of butoxyacetic acid correlated well with work practices, i.e. with duration of use and daily quantity of window-cleaning agent used.

Table 12. Personal exposures to 2-butoxyethanol during cleaning activities

Activity	No. of samples (no. of workers)	Mean (ppm)	Range (ppm)	% 2-Butoxyethanol; comments	Reference
Window cleaning in hospitals	(4)	< 0.2	< 0.2	Cleaner applied in spray	Apol & Cone (1983)
Cleaning in food plant	(1)		1.6	0.3%; mechanical floor scrubbing, 95-min sampling	Apol & Johnson (1979)
School cleaning	(4)[a]		< 0.7 < 0.2	0.25%; cleaner applied in liquid and spray form	Rhyder (1992), cited in NICNAS (1996)
Window cleaning					Vincent *et al.* (1993)
Cleaning cars					
Garage A	10 (2)	[0.5]	< 0.1–1.2	14.4%; 0.8–5-h exposure	
Garage B	10 (6)	[0.83]	< 0.1–2.8	21.2%; 0.3–4-h exposure	
Garage C	6 (3)	< 0.1	NR	5.7%; 0.7–2-h exposure	
Garage D	4 (2)	4.9	2.9–7.3	21.2%; 5.3-h exposure	
Office cleaners[b]					
Group A	32 (8)	0.32	< 0.3–0.73	9.8%; 15-min exposure	
Group B	8 (2)	< 0.3	NR	0.9%; 15-min exposure	

Adapted from NICNAS (1996)
NR, not reported
[a] Area monitoring
[b] Half-day shift air samples

Table 13. Results of air and biological sampling for 2-butoxyethanol during cleaning activities

Job category	Air concentration of 2-butoxyethanol (ppm)			Urinary concentration of butoxyacetic acid (mg/g creatinine)					
				Pre-shift			End of shift		
	No. of samples	AM	Range	No. of samples	AM	Range	No. of samples	AM	Range
Cleaner of new cars	15	2.33	< 0.10–7.33	14	17.9	< 2–98.6	12	111.3	12.7–371.0
Cleaner of used cars	15	0.36	< 0.10–1.52	12	4.8	< 2–33	11	6.3	< 2–24.4
Office cleaner	32	0.32	< 0.30–0.73	32	2.1	< 2–4.6	32	2.1	2–3.3

From Vincent *et al.* (1993)
AM, arithmetic mean

Among workers with the highest exposures, the average TWA concentration of 2-butoxyethanol was 2.33 ppm and the maximum urinary concentration of butoxyacetic acid reached 371 mg/g creatinine. Butoxyacetic acid was detected in only three of the 32 post-shift urine samples of the office cleaners. Pre-shift concentrations were generally < 10 mg/g creatinine; however, an isolated reading of 99 mg/g and a few readings of approximately 30 mg/g were obtained for car cleaners (Vincent *et al.*, 1993).

(*e*) *Offices*

2-Butoxyethanol was measured in indoor air samples at 70 office buildings across the USA in 1991. 2-Butoxyethanol was detected in 24% of the samples from 50 telecommunications offices at concentrations up to 33 μg/m³ [6.7 ppb] (geometric mean [GM], 0.1 μg/m³ [0.02 ppb]), in 44% of the samples from nine data centres at concentrations up to 16 μg/m³ (GM, 0.2 μg/m³ [0.04 ppb]) and in 73% of the samples from 11 administrative offices at concentrations up to 32 μg/m³ [6.6 ppb] (GM, 1.0 μg/m³ [0.2 ppb]). In contrast, 70 samples of outdoor air collected in the immediate vicinities of these office buildings were below the limit of detection of 0.05 μg/m³ [0.01 ppb] (Shields *et al.*, 1996).

Indoor air was sampled in 1990 in 12 office buildings in the San Francisco Bay area (USA). Concentrations of 2-butoxyethanol ranged from below the limit of detection (1.9 μg/m³ [0.39 ppb]) to 130 μg/m³ [26.6 ppb]. The GM concentration was 7.7 μg/m³ [1.6 ppb] in indoor air compared with < 1.9 μg/m³ [0.39 ppb] in the air outside these buildings (Daisey *et al.*, 1994).

(*f*) *Miscellaneous data*

From 1987 to 1998, the French COLCHIC database collected the results of 10 593 samplings of glycol ethers from 620 facilities. 2-Butoxyethanol was detected in 1195 samples; the arithmetic mean (AM) concentration of the 60–480-min personal samplings (347 results) was 0.64 ppm (median, 0.10 ppm; range, 0.02–22.6 ppm) (Vincent, 1999). It should be noted that, globally, personal exposure concentrations have significantly decreased from 1987–92 (147 samples; AM, 1.1 ppm; median, 0.6 ppm; range, 0.02–11.0 ppm) to 1993–98 (178 samples; AM, 0.3 ppm; median, 0.1 ppm; range, 0.02–3.9 ppm) (Vincent & Jeandel, 1999).

Exposure to 2-butoxyethanol was monitored in a 1983 survey of 336 industries and workshops in Belgium (Veulemans *et al.*, 1987). 2-Butoxyethanol was found in 25 of 94 air samples from sites that used printing pastes, in 10 of 81 samples where painting was carried out, in one of 20 samples from automobile repair shops and in 17 of 67 samples from various other industries (production and distribution of chemicals, production and sterilization of medical equipment and cleaning agents). The GM atmospheric concentrations and ranges of 2-butoxyethanol at various sites were: printing shops, 0.8 ppm (range, 0.3–3.6 ppm); painting areas, 3.9 ppm (range, 0.7–19.2 ppm); automobile repair shops, 1.2 ppm (one sample); various other industries, 1.7 ppm (range, < 0.1–367 ppm) (the data that relate to painting and printing activities are also presented in Tables 7 and 8, respectively).

Exposure of 53 hairdressers who worked in 10 workshops was evaluated. The composition of 43 products was analysed; 2-butoxyethanol was detected in eight products at concentrations of 0.5–5% by volume. No solvent was detected in the air samples (Vincent *et al.*, 1996).

Six personal exposure measurements made during the removal of mastic that contained asbestos showed 2-butoxyethanol concentrations in the range of 8–107 mg/m^3 [2–22 ppm] with a mean of 56.5 mg/m^3 [12 ppm] (Kelly, 1993).

Exposure levels of workers who used soluble cutting oils that contained 2-butoxyethanol were relatively low; the range of butoxyacetic acid concentrations in post-shift urine samples was in the order of < 2–8.3 mg/g creatinine (Vincent *et al.*, 1996).

1.3.3 *Environmental occurrence*

(*a*) *Air*

According to data reported under the CEPA Section 16 survey, 319 tonnes of 2-butoxyethanol were released into the air in Canada in 1996, while 63 tonnes were released as waste, 6.5 tonnes were released into landfills and 2 tonnes were released into water (Environment Canada, 1997, cited in Environment Canada/Health Canada, 2002).

Reported levels of 2-butoxyethanol in three samples of ambient air taken from a remote site in Nepal ranged from 0.1 to 1.6 µg/m^3; in forested areas in Germany (one sample) and Italy (one sample), concentrations were 1.3 µg/m^3 and 0.4 µg/m^3, respectively (Ciccioli *et al.*, 1993). In a later study (Ciccioli *et al.*, 1996), levels of 2-butoxyethanol in samples from six sites near the Italian base on Terra Nova Bay, Antartica, ranged from 1.3 to 14.9 µg/m^3. [The source of these unexpectedly high levels is unknown.]

The US Environmental Protection Agency's national volatile organic compounds database, which includes data on indoor air in non-industrial offices (residential and commercial), showed an average level of 0.214 ppb (median, 0.075 ppb) in 14 samples that contained 2-butoxyethanol (Shah & Singh, 1988).

Concentrations of 2-butoxyethanol were measured in the indoor air of flats in France (CSHPF, 2002; Gourdeau *et al.*, 2002; Kirchner, 2002; European Union, 2004). Preliminary results indicate that the 90th percentiles were 3 µg/m^3 in the bedroom of a flat that had a maximum value of 14 µg/m^3, and 3.5 µg/m^3 in the kitchen of a flat that had a maximum value of 23 µg/m^3. Releases from building materials were also evaluated. Simulations were made by installing new carpets or new floor coverings or by applying paints to the walls of reference rooms. After 24 h, the concentrations of 2-butoxyethanol in air ranged from below the limit of detection to 3.8 µg/m^3 (mean, 1.7 µg/m^3; standard deviation [SD], 1.5 µg/m^3) when release from carpets was tested. After 28 days, they ranged from undetectable to 23.3 µg/m^3 (mean, 6.1 µg/m^3; SD, 9.0 µg/m^3). With other categories of floor coverings, concentrations ranged from undetectable to 5.6 µg/m^3 (mean, 2.5 µg/m^3; SD, 2.7 µg/m^3) after 24 h and from undetectable to 59.6 µg/m^3 (mean, 27.5 µg/m^3; SD, 30.9 µg/m^3) after 28 days. Release by paint applied to the wall was at undetectable values after 24 h and reached 24 and 298 μg/m^3, respectively, for the two paints tested 28 days after application.

(*b*) *Drinking-water, groundwater and surface water*

2-Butoxyethanol was listed as a contaminant in drinking-water samples analysed between September 1974 and January 1980 in a survey of cities in the USA (Lucas, 1984, cited in ATSDR, 1998).

2-Butoxyethanol was detected in 68% of 50 drinking-water samples (limit of detection, 0.02 μg/L) collected from Ontario, Nova Scotia and Alberta, Canada, in 1997. Concentrations ranged from below the limit of detection to 0.94 μg/L, with a mean concentration of 0.21 μg/L. The authors mentioned that, due to limitations of the analytical methods involved, confidence in the results of this study is low (Environment Canada/Health Canada, 2002).

Leachate from municipal landfills and hazardous waste sites can release 2-butoxyethanol into groundwater (Brown & Donnelly, 1988). Concentrations of 2-butoxyethanol in aqueous samples from a municipal and an industrial landfill in the USA ranged from < 0.4 to 84 mg/L (Beihoffer & Ferguson, 1994). 2-Butoxyethanol was detected at a concentration of 23 μg/L in one of seven groundwater samples collected near the Valley of Drums, KY, USA, in February 1974 (Stonebreaker & Smith, 1980, cited in ATSDR, 1998).

Water samples taken from a polluted river in Japan (Hayashida River, where effluent enters the river from the leather industry) in 1980 contained 2-butoxyethanol at a concentration of 1310–5680 μg/L (Yasuhara *et al.*, 1981).

Environment Canada/Health Canada (2002) have estimated that the average daily intake of 2-butoxyethanol from air and drinking-water for the general Canadian population ranges from 5 to 15 μg/kg bw for various age groups, and that the major contributor is indoor air.

(*c*) *Occurrence in consumer products*

Typical percentage concentrations (ranges) of 2-butoxyethanol in various consumer products are summarized in Table 14.

Emissions of 2-butoxyethanol from 13 consumer products purchased in the Ottawa, Ontario, area were recently investigated by Health Canada (Cao, 1999; Zhu *et al.*, 2001). Products were selected on the basis of their likelihood to contain 2-butoxyethanol. 2-Butoxyethanol was detected in emissions from seven products, including cleaners, nail polish remover and hair colourant, at rates of up to 876 mg/m^2/h. Analyses of the products indicated that the cleaners contained 0.5–3.7% 2-butoxyethanol, while the nail polish remover and hair colourant contained 3.8% and 25%, respectively (Environment Canada/Health Canada, 2002).

In the Swedish product register (KEMI, 2002, cited in European Union, 2004), 882 products that contain 2-butoxyethanol have been identified, of which 58% are paints or inks, 16% are cleaning agents, 8% are antirust agents and 8% are polishing agents.

Table 14. Typical levels of 2-butoxyethanol in consumer products (%)

Paints and coatings	2–25
Surface cleaners	0.1–71
Polishes	5–10
Floor strippers	< 1–30.5
Glass and window cleaners	< 1–40
Degreasers	5–15
Carpet cleaners	< 1–30
Laundry detergent	< 1.5–30
Rust removers	< 10–60
Oven cleaners	< 1–30
Ink and resin removers	1–93
Other (including solvents, pesticides and personal care products)	0.1–94

From NICNAS (1996); Boatman & Knaak (2001); ToxEcology Environmental Consulting Ltd (2003)

In the Danish product register (Arbejdstilsynet, 2001), 1204 products that contain 2-butoxyethanol have been identified, of which 76 were private household products. The most common products were paints and varnishes (37%), cleaning/washing agents (20%), surface treatments (8%), corrosion inhibitors (6%), surface active agents (3%), adhesives/binding agents (3%) and solvents (2%).

Data extracted from the French product register SEPIA (INRS, 2003, cited in European Union, 2004) showed that 368 of the 10 345 products registered between 1997 and 2003 contained 2-butoxyethanol. The main use categories were paints, varnishes and inks (39%), cleaning agents (37%) and products for metallurgical and mechanical sectors, e.g. grease cleaners (14%).

Twenty-seven water-based paints and formulations used in the French automotive industry have been analysed (Jargot *et al.*, 1999). 2-Butoxyethanol was found in 18 samples at concentrations ranging from traces to 40%; in thinners, the concentration ranged from 0 to 24.7%.

Concentrations of 2-butoxyethanol in window-cleaning preparations used by car and office cleaners ranged from 0.9 to 21.2% by volume (Vincent *et al.*, 1993).

(*d*) *Miscellaneous*

Potential exposure has been linked to the stoppers of bottles used for perfusion in medicine that are made with natural or artificial rubber. Chemicals used in rubber formulations can leach from rubber stoppers during sterilization and enter the bloodstream of patients when the perfusion is administered. Results indicated a release of 70 and 65 μg/150 mL 2-butoxyethanol from two dextrose solutions and a release of 13 μg/500 mL 2-butoxyethanol from a sodium bicarbonate solution (Danielson, 1992).

1.4 Regulations and guidelines

Occupational exposure limits and guidelines for 2-butoxyethanol in workplace air are presented in Table 15.

Germany recommends a biological tolerance value for occupational exposure to 2-butoxyethanol of 100 mg/L butoxyacetic acid in urine, and recommends that butoxyacetic acid in urine collected for long-term exposures after several shifts be monitored as an indicator of exposure to 2-butoxyethanol (Deutsche Forschungsgemeinschaft, 2003).

The Health and Safety Executive (2002) in the United Kingdom recommends a biological monitoring guidance value for occupational exposure to 2-butoxyethanol of 240 mmol butoxyacetic acid/mol creatinine in urine [roughly equivalent to 200 mg/L butoxyacetic acid] measured after a shift.

In the European Union, 2-butoxyethanol is environmentally regulated as part of the Volatile Compounds Directive (European Union, 1999).

2. Studies of Cancer in Humans

In a case–control study at eight haematology departments in France, Hours *et al.* (1996) identified all locally resident patients aged 25–75 years who had acute myeloid leukaemia or myelodysplasia with an excess of blastoids that was newly diagnosed during January 1991–April 1993. The controls were patients from the same hospitals, matched for age (± 3 years), department of residence and nationality (French or other), who had never been hospitalized for cancer or an occupational disease. All subjects were interviewed in hospital by a trained investigator and were asked about their occupational history, including details of tasks and products handled. An occupational hygieniest who was blinded to the case/control status reviewed the information and classified the subject for exposure to each of four categories of glycol ethers, as well as to various potentially confounding substances. Analysis was by conditional logistic regression, and was based on 198 case–control pairs. After adjustment for level of education, exposure to the group of glycol ethers that included 2-butoxyethanol was associated with an odds ratio of 0.64 (95% confidence interval [CI], 0.31–1.29), based on 20 exposed cases and 27 exposed controls. [The Working Group noted that the exposure category analysed included propyl and butyl glycol ethers. Furthermore, the high prevalence of exposure among controls (27/191) suggests that the index of exposure used was relatively non-specific.]