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An Exposure Assessment of Industries using Ethylene Glycol Ethers

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Human case reports and animal experiments have shown that ethylene glycol ethers have the potential to cause adverse health effects. The National Institute for Occupational Safety and Health has completed an exposure assessment of industries to determine the extent of occupational exposure to 2-methoxyethanol, 2-ethoxyethanol, and their respective acetates (2-methoxyethyl acetate and 2-ethoxyethyl acetate). This information is useful for assessing the feasibility of additional health studies of glycol ether-exposed workers, and in addition, the results are of interest to the Occupational Safety and Health Administration (OSHA) which has announced its intent to revise the current permissible exposure limits for these four ethylene glycol ethers.

This study attempted to quantify human exposures in a variety of industries where these glycol ethers are produced or used as ingredients. Field surveys were conducted at eight different workplaces to collect industrial hygiene samples and obtain information concerning glycol ether usage, process operations, engineering controls, exposure levels, the size of the exposed workforce, and the industrial hygiene and safety programs.

A total of 151 samples were collected at 8 survey sites; less than half (40%) had detectable levels of glycol ethers. The range of detectable results was 0.04–2.77 ppm for long-term samples and 0.21–11.9 ppm for short-term samples. Most inhalation exposures at the sites surveyed were well within current OSHA and American Conference of Governmental Industrial Hygienists exposure guidelines. Engineering controls and work practices were commonly observed to minimize workers exposures effectively; respiratory and skin protective equipment were also frequently utilized. Sampling for airborne glycol ethers, using the OSHA recommended method, revealed a problem in adequately separating organic interferences. It is apparent that measurement results may be compromised if proper separation of organic compounds is not achieved. Also, considering that glycol ethers are relatively nonvolatile and can easily penetrate the skin, traditional air sampling may provide an incomplete assessment of total exposure. The application of biomonitoring techniques may permit more complete assessment of workers exposed to glycol ethers, especially at low concentrations. **Piacitelli, G.M.; Votaw, D.M.; Krishnan, E.R.: An Exposure Assessment of Industries using Ethylene Glycol Ethers. Appl. Occup. Environ. Hyg. 5:107–114; 1990.**

Introduction

Adverse central nervous system (encephalopathy) and hematotoxic (anemia, leukopenia) effects in workers exposed to 2-methoxyethanol (2-ME) were first noted in the late 1930s following its use for stiffening collars in shirt factories.[1, 2] The hematotoxic effects of exposure to 2-ME and other ethylene glycol ethers were later confirmed in animal studies.[3–5] In the late 1970s, studies reported adverse reproductive effects, including testicular atrophy, infertility, fetotoxicity, and fetal malformations in several species of laboratory animals exposed to different ethylene glycol ethers.[6–9]

In response to the toxicological findings, the National Institute for Occupational Safety and Health (NIOSH) published a Current Intelligence Bulletin (CIB) in which it recommended that 2-ME, 2-ethoxyethanol (2-EE), and structurally related glycol ethers be regarded in the workplace as having the potential to cause adverse reproductive effects in male and female workers and embryotoxic effects, including teratogenesis, in the offspring of exposed pregnant females.[10] NIOSH urged employees "to reduce workplace levels to the lowest extent possible"; this remains the current NIOSH recommended exposure limit (REL).

However, since publication of the CIB in 1983, additional toxicological and epidemiological data on the glycol ethers have been published.[8, 9, 11] These data are currently being evaluated by NIOSH during its development of a criteria document concerning glycol ethers. Also, NIOSH remains interested in identifying an adequate worker population for a possible study which could better describe the relationship between exposure and reproductive impairment. NIOSH has recently completed an exposure assessment of industries producing or using ethylene glycol ethers

Mention of company or product name in this article does not constitute endorsement by the National Institute for Occupational Safety and Health.

TABLE I. Physical and Chemical Properties of Four Ethylene Glycol Ethers[12]

Property	2-ME	2-MEA	2-EE	2-EEA
IUPAC Chemical Name	2-Methoxyethanol	2-Methoxyethyl acetate	2-Ethoxyethanol	2-Ethoxyethyl acetate
CAS No.	109-86-4	110-49-6	110-80-4	111-15-9
RTECS No.	KL5775000	KL5950000	KK8050000	KK8225000
Empirical formula	$C_3H_8O_2$	$C_5H_{10}O_3$	$C_4H_{10}O_2$	$C_6H_{12}O_3$
Molecular weight	76.1	118.1	90.1	132.1
Specific gravity	0.97	1.01	0.93	0.97
Density (lbs/gal)	8.04	8.37	7.75	8.10
Vapor pressure (mmHg) 25°C	9.7	2.0-3.7	5.7	2.8
20°C	6.0	2.0	4.0	2.0
Boiling point (°C)	124.5	145.0	135.0	156.0
Flash point (°F) open cup	115	140	120	138
1 ppm = mg/m³ (25°C, 760 mmHg)	3.11	4.83	3.69	5.41
1 mg/m³ = ppm (25°C, 760 mmHg)	0.32	0.21	0.27	0.19
Other identifiers:	Methyl Cellosolve; Ethylene glycol monomethyl ether; Dowanol EM	Methyl Cellosolve acetate; Ethylene glycol monomethyl ether acetate	Cellosolve; Ethylene glycol monoethyl ether; Dowanol EE	Cellosolve acetate; Ethylene glycol monoethyl ether acetate

and intends to use this information to help determine the feasibility of conducting any additional health studies of glycol ether-exposed workers.

Background

Physical and Chemical Properties

The glycol ethers 2-ME and 2-EE, and their respective acetates, are part of the family of ethylene glycol ethers; their chemical and physical properties are summarized in Table I.[12] The ethylene glycol monoalkyl ethers are generally manufactured by the reaction of ethylene oxide with the appropriate alcohol (e.g., ethanol, methanol); the glycol ethers are used to form acetates by their reaction with acetic acid. In general, glycol ethers and their acetates are colorless liquids with versatile solvent properties (e.g., miscible in water and most hydrocarbon solvents, low vapor pressure, even flow, and slow evaporation rate) which make them desirable in a wide variety of industrial applications.

Production and Usage

Domestic production of the ethylene glycol ethers regulated by the Occupational Safety and Health Administration (OHSA) is listed in Table II.[13] Glycol ethers have been used commercially for over 50 years, primarily as solvents in the manufacture of protective coatings such as paints, lacquers, metal coatings, enamels, varnishes, epoxy resin coatings, and stains; more than half are consumed by the surface coatings industry.[10] These chemicals are also used as solvents for printing inks, textile dyes and pigments, and leather finishes; as anti-icing additives in military jet fuels; and as a casting solvent for positive photoresist used for electronic parts.

Many of these uses require direct handling of the glycol ethers by workers during the formulation and/or evaporation stages, thus leading to the potential for exposure via inhalation and/or skin absorption.[14] Based on data obtained from the National Occupational Hazard Survey during 1972–1974, an estimated 850,000 men and women may be occupationally exposed to the four ethylene glycol ethers, as shown in Table II.[15] According to preliminary survey results recently collected by PEI Associates, the number of workers presently exposed is expected to be much lower due to the significantly reduced usage of these chemicals in industry today.

TABLE II. Domestic Production and Estimate of the Number of Workers Exposed to Four Ethylene Glycol Ethers[13,15]

Glycol Ether	1983 Production (pounds)	Number of Workers (1974)
2-ME	83,000,000	100,000
2-MEA	1,000,000	20,500
2-EE	187,000,000	407,000
2-EEA	153,000,000	321,000

Toxicology

The effects of 2-ME and 2-EE on reproduction and fetal development have been studied extensively in rats, rabbits, and mice. The results uniformly show developmental toxicity, including increased incidences of fetal malformations and resorptions. The embryo- and fetotoxicity and teratogenicity of 2-EE and 2-ethoxyethyl acetate (2-EEA) have been demonstrated in rats after these glycol ethers were applied cutaneously.[16] Some studies have indicated that behavioral teratogenic effects may occur in the offspring of rats treated with 2-ME and 2-EE.[17] Testicular damage has also been caused in rats after acute exposures to 2-ME.[6] In general, the evidence also suggests that the glycol ether acetates (i.e., 2-methoxyethyl acetate [2-MEA] and 2-EEA) have the same reproductive toxicity as their parent glycol ethers.[6,8,17,19]

Adverse effects on the bone marrow and thymus have been observed in rats and rabbits exposed to 2-ME which led to changes in the blood, such as lowered red and white blood cell counts (RBC and WBC, respectively).[3] Grant *et al.* have reported at least partial reversal of these effects in rats following short-term exposure to 2-ME.[18] Limited information suggests that 2-EE, 2-EEA, and 2-MEA also produce adverse effects in the peripheral blood of rats.[4,5,19]

Methoxyacetic acid (MAA) has been isolated and identified in urine as the major metabolite of 2-ME in rats.[3] Although not all of the glycol ethers are metabolized via a single pathway, it has been suggested that the major metabolites of 2-ME and 2-EE, which are MAA and ethyoxyacetic acid (EAA), respectively, act to cause the testicular, developmental, and hematotoxic effects observed in rats treated with 2-ME or 2-EE.[7–9]

Both neurologic and hematologic effects were observed in workers in the printing industry following inhalation and dermal exposure to 2-ME.[20,21] Worker exposures were 61–3960 ppm during various cleaning activities,[20] averaged 8 ppm for printers.[21] The adverse neurological effects included personality changes, ataxic gait, metal retardation, slurred speech, disorientation, stupor, and encephalopathy. The adverse hematologic effects included anemia, lowered WBC counts, and bone marrow depression. The acute toxic effects of 2-ME in humans also include irritation of the eyes, nose, and throat.[10]

A cross-sectional study assessing sterility, anemia, and leukopenia among men engaged in the production of 2-ME reported decreases in testicular size and decreased WBC counts and hemoglobin values. Eight-hour time-weighted average exposures among these workers ranged from zero to 9 ppm 2-ME.[22]

A cross-sectional evaluation of semen quality (sperm concentration, pH, motility, velocity, and morphology) was conducted among 37 men exposed to 2-EE, which was used as a solvent in a binder for ceramic parts. Full-shift, breathing-zone concentrations ranged from zero to 23.8 ppm 2-EE. The average sperm count per ejaculate was significantly lower than that of an unexposed group; no differences were observed with respect to the other characteristics of semen quality or testicular size.[23]

Another fertility study of 93 printers exposed to both 2-EE and 2-ME in a naval shipyard (full-shift exposures averaged 3 ppm 2-EE and 0.8 ppm 2-ME) found sperm abnormalities, including reduced sperm count and hematologic abnormalities (anemia and granulocytopenia).[24,25]

There is limited experimental and clinical information on the health effects of compounds structurally related to 2-ME and 2-EE. In general, the ethylene glycol ethers are more toxic than the propylene glycol ethers; observed differences in toxicologic properties are believed due to differences in routes of metabolism and type of metabolites. For instance, the adverse effects of 2-ME (a primary alcohol) probably are due to its primary metabolite MAA; propylene glycol ethers (secondary alcohols) are metabolized to propylene glycol which is reported to be relatively innocuous.[8]

Applicable Standards and Recommended Limits

The current OSHA permissible exposure limits (PELs) were established for glycol ethers in 1971 based upon the 1968 American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs).[26] These TLVs were based on the hematotoxic and neurotoxic effects and on exposure concentrations reported in the early case reports of human health effects.[27]

However, more recent information from experimental animal studies indicates that adverse hematotoxic, reproductive, and embryotoxic effects may occur at exposures below these early TLVs.[3, 6–9, 18] Accordingly, in 1985, the ACGIH TLVs for glycol ethers were reduced to levels lower than the PELs; the TLVs also bear a "skin" notation which refers to their potential contribution to the overall exposure by the cutaneous route.[28] OSHA, due in large part to the mounting concerns regarding the adequacy of its current PELs, published an advanced notice of proposed rulemaking (ANPR) to revise its regulations for these four ethylene glycol ethers.[29] OSHA is considering exposure levels ranging from 0.03–5.0 ppm; technical and economic feasibility must be demonstrated before final rulemaking. The current NIOSH RELs, OSHA PELs, and ACGIH TLVs established for the targeted glycol ethers are summarized in Table III.[10,26,28]

TABLE III. Applicable Standards and Recommended Limits for Selected Glycol Ethers[26,28]

	Exposure Limit[a] (ppm)		
Compound	NIOSH REL	OSHA PEL	ACGIH TLV
2-ME	*	25[s]	5[s]
2-MEA	*	25[s]	5[s]
2-EE	*	200[s]	5[s]
2-EEA	*	100[s]	5[s]

[a]8-hour time-weighted average (TWA_8).
[s]Skin notation.
*Reduce exposure to lowest feasible level.

Methods

This study attempted to quantify exposures in a variety of industries where glycol ethers are produced or used. An effort was made to select at least one facility within each of the major usage categories based upon industry profile information which describes the type of industry, size, location, etc., of glycol ether producers and users.[30] The survey sites included an aerospace equipment manufacturer (uses various glycol ether-containing coatings and positive photoresists); a glycol ethers formulator (produces 2-ME, 2-EE, and 2-EEA); an automotive assembly plant and an aircraft maintenance hangar (both use 2-EEA spray paints); a fuel terminal (distributes 2-ME-containing jet fuel); a coatings formulator (makes industrial coatings with 2-EEA); a paperboard manufacturer (applies a 2-ME ink); and an electronic parts manufacturer (uses a 2-EEA coating). Characteristics of each survey site are summa-

TABLE IV. Summary of Survey Site Information

Industry Surveyed	Total No. Site Employees	Activities Sampled for Exposure	No. Workers Exposed	Engineering Controls[A]	Personal Protect Equip.[B]	Dermal Exposure Potential[C]	Medical/IH Program[D]
Aerospace equipment manufacture	10,000	Spray painting	50	+ +	+ +	M	Plant IH with corporate support
		Paint blending	4	+	+	M	Regular IH sampling program
		Primer application	8	+	+	M	Annual medical exam
		Wafer Coating	20	+ + +	+ + +	L	
Electronics manufacture	450	Board marking	15	+ + +	+ + +	M	Plant engineer with corporate support Annual medical exam
Airline maintenance	6,000	Spray painting	20	+ +	+ + +	M	Plant engineer only Annual medical exam
Coating formulation	120	Ingredient mixing	8	+ +	+ + +	M	No plant IH staff
		Drum/tank filling	8	+	+	M	Corporate IH support only
		QC testing	6	+	+	M	Pre-employment exam only
Automotive assembly	4,500	Spray painting	32	+ +	+ +	M	No plant IH staff
		Paint bleeding	3	+	+	L	Corporate IH support only Annual medical exam
Jet fuel terminal	22	Barge unloading	3	+ +	+ +	M	No IH or medical
		Tanker loading	6	+ + +	+ +	L	
		QC testing	2	+	+	H	
Paperboard manufacture	60	Ink application	5	+	+	M	Plant safety manager Corporate IH support Biannual medical exam
Glycol ether production	100	Process engineer	15	+ + +	+ + +	L	Plant IH with corporate support
		Bulk loading	12	+ +	+ +	M	Regular IH sampling program
		QC testing	12	+ + +	+ +	L	Annual medical exam

[A]Degree to which engineering controls are utilized (wherever appropriate):
+ + + = frequent use of local exhaust ventilation, enclosures, dual mechanical seals, automation, etc.
+ + = some use of above
+ = little or no use of above

[B]Degree to which personal protective equipment are available and properly worn:
+ + + = frequent use of respirators, gloves, coveralls, safety glasses, etc.
+ + = some use of above
+ = little or no use of above

[C]Degree of potential for dermal exposure to occur:
H = high; M = medium; L = low

[D]Degree of any industrial hygiene and/or medical surveillance programs (including availability of plant IH staff, corporate support, regular IH sampling program, annual medical examination).

rized in Table IV.

Field surveys were conducted at these eight facilities during which personal breathing-zone and area long-term (about 5–8-hour) and short-term (about 15-minute) samples were collected. Full-shift personal samples were taken in work areas where significant usage of glycol ethers was anticipated during the survey period; additionally, short-term samples were occasionally collected when glycol ethers were actually handled. OSHA Method 53 was followed for sampling and analysis of all samples.[31] Airborne samples were collected on charcoal, desorbed with methylene chloride/methanol, and analyzed by gas chromatography using flame ionization detection (GC/FID). The analytical limit of detection (LOD) ranged from 0.01–0.03 mg/m^3. The sampling LOD, which varied with each individual sample volume, ranged from 0.02–0.10 ppm for long-term samples and from 0.12–0.64 ppm for short-term samples.

Results and Discussion

As seen in Table IV, the range of numbers of potentially exposed workers at the survey sites varied from less than 10 to over 80. Likewise, a wide spectrum of occupational health programs was represented by these same sites; company involvement varied from no existing medical or industrial hygiene programs to comprehensive annual medical examinations and exposure monitoring by in-plant, occupational health specialists. Also shown is an assessment of the utilization of engineering controls, the availability and use of personal protective equipment, and the dermal exposure potential at each survey site based upon personnel interviews and observations.

As shown in Tables V and VI, a total of 151 air samples (both personal and area) were collected at the 8 survey sites; 60 (40%) had detectable levels of glycol ethers. Each sample was analyzed for any of the four subject glycol ethers only if its presence was suspected based on product ingredient information (e.g., material safety data sheets [MSDS]). During the sampling surveys, 2-EEA was most commonly found; 2-MEA was not used in any of the areas sampled. Only 32 percent (37 of 117) of the long-term samples had detectable results for any of the four glycol ethers compared to 68 percent (23 of 34) of the short-term samples. The range of detectable results was 0.04–

2.69 ppm for long-term samples and 0.21–11.9 ppm for short-term samples; sample results were not time-weighted to 8-hour concentrations. Long-term samples were probably representative of 8-hour concentrations since sampling periods normally lasted 7–8 hours; however, short-term samples were generally collected for less than 15-minutes during worst case exposures and would, therefore, tend to overestimate actual 8-hour TWAs.

Job categories with the highest exposure potential were generally those involved with the transfer and manual handling of glycol ether compounds (such as the mixing of formulations [maximum short-term exposure of 0.7 ppm 2-EEA], drum- and tanker-filling [1.2 ppm 2-EEA], and quality control [QC] sampling and analyses [6.8 ppm 2-ME]). In particular, spray application of paints and coatings often resulted in significant potential for inhalation and dermal exposure. For instance, the samples collected during aircraft painting indicated detectable concentrations of 2-EEA for all samples collected, with short-term exposures up to 11.9 ppm. (In fact, actual inhalation dosages at this facility could be expected to be significantly lower than indicated by sampling due to the regular use of respirators during high exposure situations. In most facilities, however, respirators were rarely worn, although usually available.)

Monitoring results at several of the sites (particularly, aerospace, electronics, automotive, and glycol ether formulation) indicated that airborne concentrations of the glycol ethers were generally nondetectable in all or most areas. This was generally attributable to infrequent usage and handling of only small quantities of glycol ether materials (often present in low percentages); the effectiveness of engineering controls (which included local exhaust ventilation, enclosures, dual mechanical seals on pumps, automation, etc.); and conscientious work practices (including frequent cleaning/maintenance, proper chemical storage, et cetera).

TABLE V. Long-term Sampling Results for 2-Methoxyethanol (2-ME), 2-Ethoxyethanol (2-EE), and 2-Ethoxyethyl Acetate (2-EEA)

Industry	Glycol Ether(s) Sampled	No. Samples	No. < Limit of Detection	Concentration Range (ppm)[A]
Aerospace	2-ME	8	8 (100%)	all ≤0.27[B]
	2-EE	5	5 (100%)	all ≤0.22[B]
	2-EEA	15	15 (100%)	all ≤0.23[B]
Electronics	2-EEA	8	8 (100%)	all ≤0.02[C]
Airlines	2-EEA	13	0 (0%)	0.29 -2.69
Coating mfg.	2-EEA	6	0 (0%)	0.07[D]–0.35
Automotive	2-EEA	12	10 (83%)	≤0.02[C]–0.05[D]
Fuel distribution	2-ME	10	3 (34%)	≤0.03[C]–0.34
Paperboard mfg.	2-ME	9	6 (66%)	≤0.04[C]–1.06
Glycol Ether mfg.	2-EEA	31	25 (81%)	≤0.02[C]–0.44
Summary	2-ME	27	17 (63%)	≤0.02[C]–1.06
	2-EE	5	5 (100%)	all ≤0.22[B]
	2-EEA	85	58 (68%)	≤0.02[C]–2.69
TOTAL		117	80 (68%)	≤0.02[C]–2.69

[A]Samples were not time-weighted to 8-hour concentrations.
[B]Laboratory analysis was below limit of detection (0.03 mg/sample).
[C]Laboratory analysis was below limit of detection (0.01 mg/sample).
[D]Laboratory analysis was below limit of quantitation (0.3 mg/sample).

TABLE VI. Short-term Sampling Results for 2-Methoxyethanol (2-ME) and 2-Ethoxyethyl Acetate (2-EEA)

Industry	Glycol Ether(s) Sampled	No. Samples	No. < Limit of Detection	Concentration Range (ppm)[A]
Aerospace	2-ME	3	2 (66%)	≤0.65[B]–1.04[C]
	2-EEA	3	1 (33%)	≤0.33[B]–0.86[C]
Electronics	2-EEA	2	2 (100%)	all ≤0.12[D]
Airlines	2-EEA	5	0 (0%)	1.73–11.9
Coating mfg.	2-EEA	7	0 (0%)	0.41[E]–1.85
Automotive mfg.	2-EEA	2	2 (100%)	all ≤0.61[D]
Fuel distribution	2-ME	5	0 (0%)	0.21[E]–6.86
Paperboard mfg.	2-ME	3	2 (66%)	≤0.22[D]–5.25
Glycol ether mfg.	2-ME	2	1 (50%)	≤0.20[D]–2.45
	2-EEA	2	1 (50%)	≤0.12[D]–1.22[E]
Summary	2-ME	13	5 (38%)	≤0.20[D]–6.86
	2-EEA	21	6 (29%)	≤0.12[D]–11.9
TOTAL		34	11 (32%)	≤0.12[D]–11.9

[A]Samples were not time-weighted to 8-hour concentrations.
[B]Laboratory analysis was below limit of detection (0.03 mg/sample).
[C]Laboratory analysis was below limit of quantitation (0.08 mg/sample).
[D]Laboratory analysis was below limit of detection (0.01 mg/sample).
[E]Laboratory analysis was below limit of quantitation (0.03 mg/sample).

Most of the facilities, even those with low inhalation exposures, had the potential for dermal exposures. In many cases (such as during QC sampling and analyses), liquids containing glycol ethers were manually handled, often without gloves. While coveralls were supplied by several of the companies, they were typically made of cotton, providing only minimal protection from liquid penetration (and may actually increase dermal absorption because of reduced evaporation).

In a few cases, although personal exposures were either nondetectable or quite low, area samples indicated that glycol ether aerosols were indeed being generated. For instance, two long-term area samples collected in the near proximity of the ink rollers at the paperboard manufacturer had concentrations of 0.73 ppm and 1.06 ppm; the highest personal breathing-zone concentration at this site was only 0.08 ppm. Similarly, the only quantifiable results at the glycol ether formulator were from area samples. This generally meant that workers did not work in close proximity to the sources of exposures and/or did not spend much time in those areas. Some of the plants had effectively isolated areas with potential exposures (e.g., by chaining off areas or installing barriers/shields) to minimize the possibility of contact with the emissions.

The generally low results from the collected air samples might also be expected since the concentration of glycol ethers used in formulations was typically low (about 5–20% according to manufacturer's specifications; however, bulk analysis showed that many contained less than 1% glycol ethers). Additionally, because the glycol ethers have relatively low vapor pressures, these chemicals are not readily vaporized at typical room temperatures.

However, because glycol ethers can readily penetrate the skin, dermal absorption should be considered when evaluating total exposure. While our sampling results primarily address inhalation exposures, the air concentrations also provide a partial measure of the aerosol which may be potentially absorbed through any exposed skin. Survey observations also indicated that the potential for direct skin contact with liquid glycol ethers was frequent during many routine workplace activities such as the handling of QC samples, mixing, and filling, and also from accidental spills.

While traditional air sampling for glycol ethers, alone, provides an incomplete assessment of total exposure, methods for estimating total body burden (including dermal absorption) are not as well developed. There have been recent reports, however, indicating that sampling for the glycol ethers in blood or their metabolites in urine may help to quantify total exposure.[32,33] For example, procedures have been developed to measure oxidized acidic metabolites (i.e., MAA and EAA) in urine as indices of exposure.[34,35] Biomonitoring was considered but not attempted in this field study because of the lack of a proven method applicable for all four glycol ethers. Further, air sampling was the only method used for this study's exposure assessment due to the lack of a validated dermal absorption measurement technique and time constraints which prevented adequate methods development.

Finally, laboratory analyses of these survey results revealed an analytical artifact which may distort the results for glycol ethers when they are sampled by the OSHA method. During this study, incongruities between some analytical results and the expected absence of certain glycol ethers (i.e., based upon MSDS information) led to finding a problem with OSHA Method 53. In one case, while 2-EE was reported to be present in some samples collected at the automotive painting site, the MSDS data (and later confirmation with the product manufacturer) indicated that 2-EE was not an ingredient in any of the products used. Further investigation into this finding by the analytical laboratory indicated that the presence of other organic solvents may interfere with the proper identification and quantitation of the glycol ethers from the charcoal tubes. For instance, experimentation showed that the presence of isobutanol gives a higher quantification of 2-ME due to its coelution with 2-ME. This is, therefore, a particular problem whenever samples are collected in workplaces using complex organic mixtures (such as paints and coatings). This was the case in several of the NIOSH surveys.

The analytical problem can be minimized or corrected by 1) performing gas chromatography/mass spectroscopy (GS/MS) analysis to better identify the sample components; 2) reviewing any MSDS information prior to sample analysis to alert the chemists to potential interferences and the presence of any glycol ethers; and 3) modifying the OSHA Method 53 for glycol ethers to more efficiently separate solvent interferences (e.g., by changing to a different capillary column for elution).

While it is impossible to quantify the exact effect on each sample result accurately, in most cases the lack of complete separation of compounds may have resulted in an additive effect and artifactually high reported values for any of the glycol ethers. Considering the low (often nondetected) values reported, the overall conclusion formed by these investigators that inhalation exposures to the glycol ethers were minimal during the surveys remains unchanged.

Exposure Controls

Efforts to further minimize the potential for exposure in facilities with detectable concentrations of glycol ethers could focus on the following controls: improving local exhaust ventilation in work areas where glycol ethers are used (e.g., paint bays, QC laboratories); isolating emission sources from adjacent work areas; modifying work practices to minimize the manual handling of glycol ethers and encouraging conscientious handling by workers; substituting alternative materials with lower potential health risks; and providing personal protective equipment (e.g., respirators, impermeable coveralls and gloves) and actively encouraging its regular and proper use during high exposure situations (e.g., whenever manually handling liquids containing glycol ethers).

Although extremely complex, substitution for glycol ethers is well advanced and being implemented in some products (e.g., coatings) and is gradually becoming more available in others (e.g., photoresists). Boggs[36] has suggested a methodology for conducting a comparative risk assessment for identifying less toxic solvents than ethylene glycol ethers in positive photoresists; a similar rationale could be applicable when considering substitution for other uses. In fact, several of the companies visited have already successfully substituted less toxic substances for the ethylene glycol ethers (e.g., propylene glycol ethers or water-based solvents). In some cases, however, substitution results in inferior products which do not satisfy the consumer market. For example, reformulation of products currently made for the military may have difficulty in meeting the strict specifications required by the Department of Defense.

Conclusions

After glycol ethers were associated with reproductive and hematotoxic effects in the 1980s, many companies that use glycol ether-containing products voluntarily adopted exposure guidelines below the existing OSHA PELs. This has apparently helped to minimize workplace exposures. the monitoring data from the eight surveys suggest that inhalation exposures to glycol ethers, while widespread and diverse, were generally well below recommended exposure guidelines. All full-shift measurements were below quantifiable levels at the aerospace, electronics, and automotive facilities surveyed. The highest exposures, both long-term and peak, were measured for spray painters at the aircraft maintenance facility (up to 2.69 ppm 2-EEA [long.-term] and 11.9 ppm [short-term]). The jet fuel terminal had the highest potential for dermal exposure, primarily during QC testing of fuel samples.

Engineering controls, particularly local exhaust ventilation, and conscientious work practices, such as good housekeeping, were commonly observed to minimize worker exposures effectively. Proper respiratory and skin protective equipment, while observed to be worn sometimes, could have been more frequently utilized, especially during high exposure situations, e.g., QC sample collection and analysis, mixing and filling activities, and spray application of coatings. The glycol ether production facility utilized the highest degree of exposure controls (including both engineering controls and personal protective equipment) of the sites visited; the ink application process at the paperborad manufacturer was felt to be the least controlled.

Sample analysis by the current OSHA method for glycol ethers was found at times to give erroneous results for samples with other organic solvents present. Alerting the chemist to the possible presence of such interferences, and subsequently modifying the analysis, would help to quantify more reliability and accurately the glycol ethers from air samples.

Opportunities for future epidemiologic studies of glycol ether-exposed workers may be limited. Glycol ether exposures often are components of a mixed chemical exposure for workers, thus confounding the evaluation of observed adverse effects. Also, because glycol ethers are relatively nonvolatile and can easily penetrate the skin, traditional air sampling information may provide an incomplete assessment of total exposure and may, therefore, be of limited value for identifying significantly exposed study cohorts. Also, the small number of exposed workers distributed across many different industries and employers may prove impractical for a meaningful epidemiologic study. Finally, biomonitoring techniques may permit a more complete and accurate assessment of workers exposed to glycol ethers.

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