6. POTENTIAL FOR HUMAN EXPOSURE

6.1 OVERVIEW

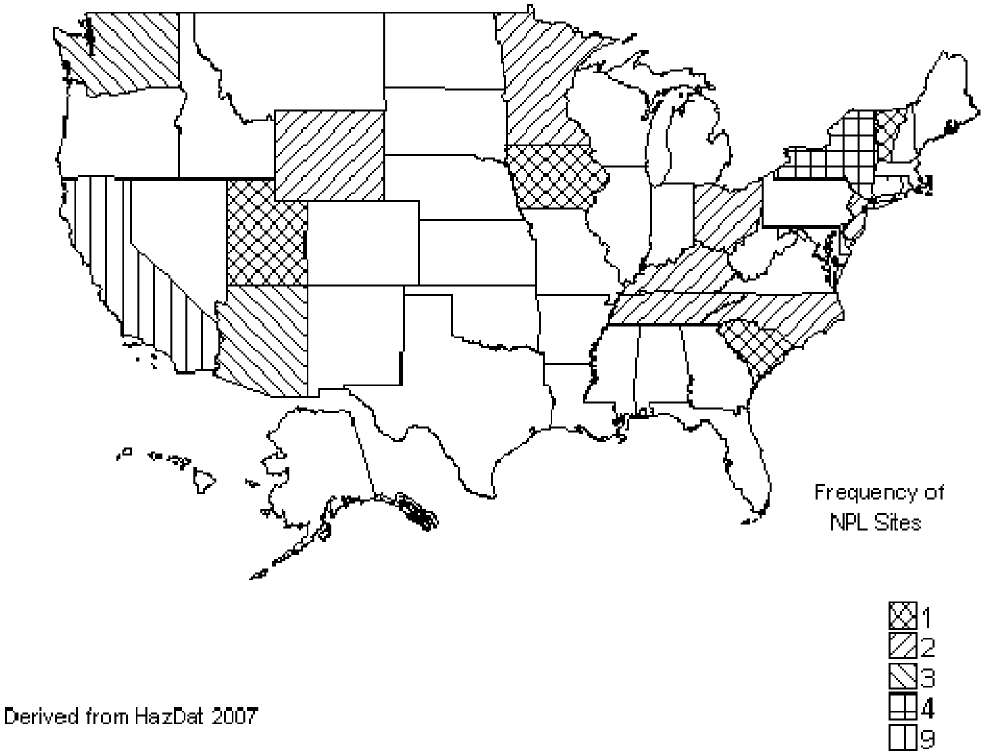
Ethylene glycol has been identified in at least 37 of the 1,689 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (HazDat 2007). However, the number of sites evaluated for ethylene glycol is not known. The frequency of these sites can be seen in Figure 6-1.

Two promising methods for the complete (>99%) destruction of ethylene glycol in waste water are ultraviolet (UV) light-catalyzed oxidation and supercritical oxidation. In the UV light-catalyzed oxidation method, ethylene glycol-containing waste water in the presence of 10% hydrogen peroxide is oxidized by UV irradiation (200–250 nm) with light from a mercury lamp (DOE 1993b). The UV/hydrogen peroxide undergoes photochemical decomposition to produce OH radicals that are strong oxidants capable of oxidizing most organic compounds stepwise to complete mineralization (e.g., carbon dioxide and water). In the supercritical water oxidation method, the waste water is subjected to oxidation at >550 °C and 4,000 psi pressure with a residence time of <30 seconds (DOE 1993a).

A new technology, *in situ* vitrification (a thermal treatment technology) (Drajun 1991), has shown potential for the remediation of soil contaminated with ethylene glycol. During the *in situ* vitrification process, contaminated soil is transformed into silicate glass using large amounts of electrical energy and a crystalline product similar to obsidian is formed. Another novel approach involving an encapsulated biooxidation method proposes that sodium percarbonate encapsulated in polyvinylidene chloride be inserted in subsurface soil by a method called hydraulic fracturing. Oxygen slowly released from the encapsulated sodium percarbonate increases the number of glycol-degrading organisms. This method is expected to remediate soils contaminated with glycols via enhanced aerobic biodegradation in subsurface soils (Vesper et al. 1994).

Distillation of used automobile and heavy duty engine coolant under reduced pressure has been assessed to be an acceptable technology for recycling ethylene glycol in terms of economic potential, waste reduction potential, and product quality that meets both American Society for Testing and Materials (ASTM) and SAE standards (EPA 1993d).

Figure 6-1. Frequency of NPL Sites with Ethylene Glycol Contamination



Derived from HazDat 2007

6.2 RELEASES TO THE ENVIRONMENT

The Toxics Release Inventory (TRI) data should be used with caution because only certain types of facilities are required to report (EPA 2005). This is not an exhaustive list. Manufacturing and processing facilities are required to report information to the TRI only if they employ 10 or more full-time employees; if their facility is included in Standard Industrial Classification (SIC) Codes 10 (except 1011, 1081, and 1094), 12 (except 1241), 20–39, 4911 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4931 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4939 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4953 (limited to facilities regulated under RCRA Subtitle C, 42 U.S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited to facilities primarily engaged in solvents recovery services on a contract or fee basis); and if their facility produces, imports, or processes ≥25,000 pounds of any TRI chemical or otherwise uses >10,000 pounds of a TRI chemical in a calendar year (EPA 2005).

6.2.1 Air

Estimated releases of 3.1 million pounds (1,400 metric tons) of ethylene glycol to the atmosphere from 1,454domestic manufacturing and processing facilities in 2006, accounted for about 41% of the estimated total environmental releases from facilities required to report to the TRI (TRI06 2008). These releases are summarized in Table 6-1.

During the application of de-icing solutions to aircraft, an estimated 49–80% of de-icing solutions containing ethylene glycol are released on airport runway aprons. The remainder is retained on the aircraft or is immediately dispersed to the air (Sills and Blakeslee 1992).

Ethylene glycol has been identified in air samples collected at 2 of the 37 NPL hazardous waste sites where it was detected in some environmental media (HazDat 2007).

Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Ethylene Glycol[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
AK	3	54	No data	0	0	0	54	0	54
AL	30	49,624	219	0	104,418	1,867	154,008	2,120	156,128
AR	9	11,603	40	9,931	1,030	0	21,624	980	22,604
AZ	12	19,755	No data	0	0	0	19,755	0	19,755
CA	85	65,434	8	237	97,403	1,148	144,114	20,115	164,229
CO	15	6,468	812	0	5	684	7,285	684	7,969
CT	10	1,492	5	0	0	0	1,497	0	1,497
DE	3	156	No data	0	0	250	156	250	406
FL	33	17,500	0	0	8,637	0	17,500	8,637	26,137
GA	59	10,273	1,705	0	8,437	1,189	14,113	7,491	21,604
IA	29	11,033	1,430	0	460	2,258	12,463	2,718	15,181
ID	3	9	No data	0	22,074	0	22,063	20	22,083
IL	87	56,055	8,704	0	57,990	244	64,825	58,168	122,993
IN	49	29,895	24,005	810	237,458	655	58,515	234,308	292,822
KS	17	10,438	0	0	0	0	10,438	0	10,438
KY	29	7,253	17,215	0	3,511	0	24,468	3,511	27,979
LA	48	56,501	17,324	21,687	238,430	0	315,521	18,421	333,942
MA	24	16,574	0	0	133	2,670	16,574	2,803	19,377
MD	16	3,299	No data	0	280	0	3,299	280	3,579
ME	2	1,370	2,300	0	750	0	3,670	750	4,420
MI	58	26,211	920	0	115,219	20,865	28,407	134,808	163,215
MN	34	10,629	7,492	0	4	13,205	18,121	13,209	31,330
MO	41	4,284	0	0	43	293	4,327	293	4,620
MS	11	55,647	30,005	0	1,643	0	85,652	1,643	87,296
MT	7	2,865	990	0	19,469	144	23,279	189	23,468
NC	59	438,298	15,741	0	83,059	9,130	454,469	91,759	546,228
ND	5	0	0	0	45,800	0	45,800	0	45,800
NE	11	3,018	0	0	1,316	32	3,268	1,098	4,366
NH	2	0	No data	0	0	0	0	0	0
NJ	42	10,196	2,663	0	2,192	4,463	12,983	6,531	19,514
NM	9	2,423	5	2,594	0	3,156	2,428	5,750	8,178
NV	6	6	No data	0	112,586	0	112,592	0	112,592
NY	28	3,098	4,780	0	20,087	6,400	27,383	6,982	34,365
OH	93	83,662	16,809	357,322	38,018	8,833	456,593	48,051	504,643

Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Ethylene Glycol[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
OK	32	94,801	0	750	31,193	819	125,987	1,576	127,563
OR	16	8,087	5	0	0	10	8,092	10	8,102
PA	68	55,282	3,388	0	16,751	138,419	67,409	146,430	213,840
PR	10	2,285	No data	0	100	321	2,285	421	2,706
RI	7	1,192	0	0	2,210	0	1,192	2,210	3,402
SC	52	511,500	39,405	0	736,820	42,112	550,905	778,932	1,329,837
SD	1	0	No data	0	0	0	0	0	0
TN	25	262,245	247,371	0	91,085	0	516,191	84,510	600,701
TX	158	454,959	50,198	914,240	114,001	1,905	924,881	610,422	1,535,303
UT	11	7,706	0	0	71,169	385	78,802	458	79,260
VA	28	459,257	455	0	28	2,700	459,712	2,728	462,440
VT	1	0	300	0	0	302	300	302	602
WA	14	8,305	0	0	468	2,589	8,305	3,057	11,362
WI	41	107,031	54	0	2,280	3,021	107,085	5,301	112,386
WV	15	97,225	96	0	87,843	80	148,388	36,856	185,244
WY	6	25	No data	13,836	32	0	13,861	32	13,893
Total	1,454	3,085,022	494,445	1,321,407	2,374,430	270,149	5,200,639	2,344,813	7,545,453

[a] The TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.
[b] Data in TRI are maximum amounts released by each facility.
[c] Post office state abbreviations are used.
[d] Number of reporting facilities.
[e] The sum of fugitive and point source releases are included in releases to air by a given facility.
[f] Surface water discharges, waste water treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).
[g] Class I wells, Class II-V wells, and underground injection.
[h] Resource Conservation and Recovery Act (RCRA) subtitle C landfills; other on-site landfills, land treatment, surface impoundments, other land disposal, other landfills.
[i] Storage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown
[j] The sum of all releases of the chemical to air, land, water, and underground injection wells.
[k] Total amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI06 2008 (Data are from 2006)

6.2.2 Water

Estimated releases of 0.5 million pounds (220 metric tons) of ethylene glycol to surface water from 1,454 domestic manufacturing and processing facilities in 2006, accounted for about 6.5% of the estimated total environmental releases from facilities required to report to the TRI (TRI06 2008).

Ethylene glycol is released to surface waters in waste water from production and processing facilities, from spills, in runoff (e.g., through the use of the compounds as de-icing fluids), and in the disposal of used antifreeze (Christian and Moorehead 1985; EPA 2000; Ware 1988). Ethylene and propylene glycol concentrations up to 19,000 mg/L (ppm) were detected in storm water runoff at the Salt Lake City Airport in Utah, and airport runoff was found to contain up to 3,100 mg/L (ppm) at the Toronto International Airport in Canada and up to 5,050 mg/L (ppm) at the Denver Airport in Colorado (Sills and Blakeslee 1992). Ethylene glycol was detected, but not quantified, in effluents from a chemical plant in Brandenburg, Kentucky (EPA 1976).

EPA (2000) estimated that 21 million gallons of aircraft deicing fluid (including both ethylene and propylene glycol-based fluids) are discharged to surface waters per year in the United States with an additional 2 million gallons discharged to publicly owned treatment works (POTWs). These releases are expected to decrease as source reduction technologies and recycling/recovery systems are improved. Airports that have updated equipment and collection systems have achieved a 70% collection efficiency on average.

Ethylene glycol that is released onto the ground when used in aircraft de-icing fluid may contaminate nearby groundwater (Corsi et al. 2001a). Groundwater samples collected from a perched water table at the Ottawa Airport in Canada contained 415 mg/L (ppm) of ethylene glycol (Sills and Blakeslee 1992).

Ethylene glycol has been identified in surface water and groundwater samples collected at 1 and 7 of the 37 NPL hazardous waste sites, respectively, where it was detected in some environmental media (HazDat 2007).

6.2.3 Soil

Estimated releases of 2.4 million pounds (1,080 metric tons) of ethylene glycol to soils from 1,454 domestic manufacturing and processing facilities in 2006, accounted for about 31% of the estimated total environmental releases from facilities required to report to the TRI (TRI06 2008). An additional

1.3 million pounds (600 metric tons), constituting about 17.5% of the total environmental emissions, were released via underground injection (TRI06 2008). These releases are summarized in Table 6-1.

The major sources of ethylene glycol release to soil are from the disposal of used antifreeze fluids and deicing fluids containing this compound (EPA 1979, 1987; Ware 1988). Ethylene glycol may also be released to soil via natural processes associated with the metabolism of ethylene by plants (Blomstrom and Beyer 1980).

Ethylene glycol has been identified in soil and sediment samples collected at 2 and 1 of the 37 NPL hazardous waste sites, respectively, where it was detected in some environmental media (HazDat 2007).

6.3 ENVIRONMENTAL FATE

6.3.1 Transport and Partitioning

Ethylene glycol has a low vapor pressure (0.089 mm Hg at 25 °C) and is miscible with water (see Table 4-2). If released to the atmosphere (e.g., as vapors generated at elevated temperatures), ethylene glycol should exist almost entirely in the vapor phase (Eisenreich et al. 1981). The high solubility of ethylene glycol in water ensures that at least partial removal of the compound will occur by wet deposition. The low Henry's law constant value for this compound (6.00×10^{-8} atm-m^3/mole, see Table 4-2) suggests that ethylene glycol released to surface water will not partition to the atmosphere via volatilization (Simmons et al. 1976; Thomas 1990). Ethylene glycol is not expected to adsorb to sediment or soil particulates based on an estimated K_{oc} value of 1 (see Table 4-2). Based on the low K_{oc} value (see Table 4-2), ethylene glycol is expected to have a very high mobility in soil and could leach into groundwater (Swann et al. 1983).

The low octanol/water partition coefficient (K_{ow}) value of -1.36 (see Table 4-2) suggests that bioconcentration and biomagnification of ethylene glycol are not likely to occur. Laboratory testing with this compound confirms insignificant bioconcentration in fish (Freitag et al. 1985). The bioconcentration factor (BCF) for ethylene glycol in fish (Golden ide) was 10 after 3 days of exposure.

Ethylene glycol is expected to be highly mobile, particularly in moist soils, and it may leach into groundwater upon release to surface soils. In laboratory studies, ethylene glycol was found to percolate rapidly through soil columns with little or no adsorption (LA DOTD 1989; Løkke 1984); however, rapid biodegradation is expected to limit the extent of leaching through soil (see Section 6.3.2.3). The compound may also volatilize from dry surface soils (EPA 1979, 1987; Hine and Mookerjee 1975). In dry soils, ethylene glycol liquid can enter the soil system and travel through the porous media before contacting free water. Amoozegar et al. (1986) reported that in dry soils (<1% water) the rate of ethylene glycol movement was the slowest of 6 organic liquids tested (toluene, xylene, kerosene, acetone, and isopropyl alcohol).

6.3.2 Transformation and Degradation

6.3.2.1 Air

Ethylene glycol released to the atmosphere is expected to undergo rapid photochemical oxidation via reaction with hydroxyl radicals. The half-life for the photochemical oxidation of ethylene glycol is 1.4 days calculated using a measured reaction rate constant of $7.7\text{x}10^{-12}$ cm^3/molecule-second at 25 °C, assuming a 12-hour day and an average day-light atmospheric hydroxyl radical concentration of $1.5\text{x}10^6$ radicals/cm^3 (Atkinson 1989; EPA 1993e). Direct photolysis of ethylene glycol is not expected since alcohols do not absorb UV light at environmental wavelengths (above 295 nm) (Boethling and Mackay 2000).

6.3.2.2 Water

Biodegradation is the most important transformation process for ethylene glycol in surface waters under both aerobic and anaerobic conditions (Staples et al. 2001). In screening tests using aerobic sewage sludge inocula, the incubation time for the majority of the biodegradation of ethylene glycol to take place ranges from within a day to a few weeks (Bridie et al. 1979; Conway et al. 1983; Ettinger 1956; Heukelekian and Rand 1955; Lamb and Jenkins 1952; Means and Anderson 1981; Pitter 1976; Price et al. 1974; Slave et al. 1974; Wagner 1976; Young et al. 1968). Evans and David (1974) performed river die-away tests in which ethylene glycol, added to river water at concentrations $\leq$10 mg/L (ppm), was completely biodegraded after 3 days at 20 °C and after 14 days at 8 °C.

Other reports of biotransformation of ethylene glycol include anaerobic metabolism (Battersby and Wilson 1989; Bieszkiewicz et al. 1979; Dwyer and Tiedje 1983; Hovious et al. 1973; Kameya et al. 1995; Watson and Jones 1977). Based on available data, ethylene glycol appears to be completely degraded within 1–2 weeks under anaerobic conditions (Battersby and Wilson 1989; Dwyer and Tiedje 1983; Kameya et al. 1995). Schoenberg et al. (2001) measured first-order biodegradation rate constants of 3.5–5.2 per day for ethylene glycol-based deicing fluids under anaerobic conditions, corresponding to half-lives of <1 day. Dwyer and Tiedje (1983) proposed that the methanogenic degradation pathway proceeds through formation of ethanol followed by acetate.

Waste water carrying ethylene glycol can be purified using the activated sludge method provided the concentration of ethylene glycol does not exceed 1,000 mg/L (ppm) (Bieszkiewicz et al. 1979). Similar results were observed for the degradation of ethylene glycol in groundwater (McGahey and Bouwer 1992). At an initial substrate concentration of 111 mg/L (ppm), naturally occurring microorganisms in groundwater biodegraded ethylene glycol with a calculated half-life of <1 day following a lag phase of <3 days.

Ethylene glycol is not expected to undergo significant abiotic transformation in surface waters via hydrolysis or oxidation (EPA 1979; Harris 1990). Glycols are resistant to hydrolysis (Harris 1990). Ethylene glycol is not expected to undergo direct photolysis in sunlit waters since alcohols do not absorb UV light at environmental wavelengths (above 295 nm) (Boethling and Mackay 2000). However, indirect photolysis of ethylene glycol sorbed to goethite (a common natural constituent of surface water sediments) by near ultraviolet radiation (300–400 nm) has been demonstrated in the laboratory. Formaldehyde and glycolaldehyde were detected as degradation products (Cunningham et al. 1985).

6.3.2.3 Sediment and Soil

Biodegradation under both aerobic and anaerobic conditions is also the most important transformation process for ethylene glycol in soils, with half-lives similar to or less than those measured in surface waters (EPA 1987).

The rate of biodegradation of ethylene glycol in simulated subsurface soils is dependent on substrate concentrations, soil types, and ambient soil temperatures (McGahey and Bouwer 1992). Greater than 95% removal was consistently accomplished in <5 days and 7 days at ethylene glycol concentrations of 100 and 1,000 ppm, respectively; however, substrate concentrations of 10,000 ppm showed negligible loss of ethylene glycol. The rate of degradation was higher in soils with high organic matter. A doubling in the degradation rate was also observed with a 10 °C increase in soil temperature. McGahey and Bouwer (1992) concluded that microorganisms naturally occurring in soils and groundwater are effective in biodegrading ethylene glycol with the half-life ranging from 0.2 to 0.9 days. Approximately 23–26% of ethylene glycol at 2.25 ppm was biodegraded in anaerobic sandy till soil grab sample tests run for 86 and 140 days (Løkke 1984).

Klecka et al. (1993) studied the biodegradation of aircraft de-icing fluids in soils adjacent to airport runways at various ethylene glycol concentrations and at various temperatures ranging from -2 to 25 °C. Generally, the rate of biodegradation of ethylene glycol was faster in soils with low glycol concentrations, high organic carbon content, and higher ambient soil temperatures. Ethylene glycol present in soils at concentrations <6,000 mg/kg (ppm) biodegraded at an average rate of 3.0 mg/kg (ppm) soil/day at -2 °C, at 19.7 mg/kg (ppm) soil/day at 8 °C, and at an average rate of 66.3 mg/kg (ppm) soil/day at 25 °C (Klecka et al. 1993). Based on these results, biodegradation is expected to play a major role in removing ethylene glycol residues from soils adjacent to airport runways and taxiways. Revitt and Worrall (2003) measured first-order biodegradation rate constants of 0.064 day^{-1} at 1 °C, 0.082 day^{-1} at 4 °C, and 0.091 day^{-1} at 8 °C for an ethylene glycol-diethylene glycol de-icing formulation on paving blocks taken from an airport. These rates correspond to half-lives of 10.8, 8.5, and 7.6 days, respectively.

As in surface waters, abiotic transformation of ethylene glycol in soil is not expected to be a significant process (EPA 1987).

6.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to ethylene glycol depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of ethylene glycol in unpolluted atmospheres and in pristine surface waters are often so low as to be near the limits of current analytical methods. In reviewing data on ethylene glycol levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable. The analytical methods available for monitoring ethylene glycol in a variety of environmental media are detailed in Chapter 7.

6.4.1 Air

Ethylene glycol was detected in ambient air samples, at time-weighted average (TWA) concentrations of <0.05–0.33 mg/m^3 as aerosol and <0.05–10.4 mg/m^3 as vapor, following spray application of de-icing fluids containing 50% solutions of the compound to the surfaces of bridges. The ambient air samples were collected above the sprayed bridges (LA DOTD 1989). Ethylene glycol was detected as a vapor above 2.5 mg/m^3 in 18 out of 154 air samples collected during de-icing operations at a Montreal airport (Gérin et al. 1997). The maximum concentration reported was 22.0 mg/m^3. Three of the air samples contained ethylene glycol as a mist at concentrations of 76, 91, and 190 mg/m^3.

Ethylene glycol was identified in air samples collected in four new manufactured houses and seven site-built houses (Hodgson et al. 2000). The range and geometric mean of ethylene glycol concentrations were <9.2–43.8 and 17.9 mg/m^3, respectively, in the manufactured houses and 20.7–491 and 2.7 mg/m^3, respectively, in the site-built houses. Latex paint was indicated as a source for ethylene glycol emissions in the new houses.

Background concentrations of ethylene glycol in ambient air are not available.

6.4.2 Water

Monitoring data from several contractor and airport authority reports reveal that storm water runoff from airports may contain several hundred to several thousand mg/L (ppm) glycols (Sills and Blakeslee 1992). Ethylene and propylene glycol levels up to 19,000 mg/L (ppm) were detected in storm water from the Salt Lake City International Airport. The concentration of ethylene glycol in runoff from runway apron areas at the Toronto International Airport ranged from 75.0 mg/L to 3,100 mg/L (ppm) and was up to 70 mg/L (ppm) in a stream that received runoff from the airport. Ethylene glycol concentrations ranged from 2 to 660 mg/L (ppm) and from 5 to 170 mg/L (ppm) in streams flowing through Winnipeg International Airport and St. John's International Airport (Newfoundland), respectively (Environment Canada 2000). Ethylene glycol concentrations were less than the detection limit (25 mg/L) in Etobicoke Creek, which receives storm water from Lester B. Pearson International Airport in Toronto. The concentration of ethylene glycol in storm water runoff from Stapleton International Airport in Denver, Colorado ranged from near zero to 5,050 mg/L (ppm) (Sills and Blakeslee 1992). Although the potential for groundwater contamination is quite low for many airports with predominantly heavy soil, the movement of glycols through unsaturated silty sand can be potentially high (Sills and Blakeslee 1992). Thus, although ethylene glycol was not detected even in shallow soils at the edge of the runway at the Stapleton International Airport, the groundwater in the perched water table at Ottawa International Airport in Canada, which contained sandy soil, was found to contain ethylene glycol at levels up to 415 mg/L (ppm). Peak concentrations occurred in June and declined to nondetectable levels by the fall.

No information was found regarding background concentrations of ethylene glycol in surface water, groundwater, or drinking water.

6.4.3 Sediment and Soil

No information was found regarding the concentrations of ethylene glycol in soil or sediment.

6.4.4 Other Environmental Media

Ethylene glycol has been found to migrate into a number of foods from regenerated cellulose films containing triethylene glycol and polyethylene glycol as softening agents. Ethylene glycol was detected in fruit cakes at 27–34 mg/kg (ppm) after 84–336 days of storage, in meat pies at <10 mg/kg (ppm) after 3–7 days of storage, in toffee at <10–22 mg/kg (ppm) after 168–450 days of storage, in madeira cake at <10–22 mg/kg (ppm) after 21–28 days storage, and in boiled sweets at 14–34 mg/kg (ppm) after 168–450 days storage (Castle et al. 1988a). According to Kashtock and Breder (1980), ethylene glycol can migrate into food simulants from polyethylene terephthalate (PET) bottles used in the packaging of carbonated beverages. The compound was detected at a concentration of about 100 ppb (0.1 ppm) in a 3% acetic acid solution used as a food simulant after 6 months of storage at 32 °C (Kashtock and Breder 1980). These authors stated that the source of ethylene glycol in this food simulant is the small amount of unreacted ethylene glycol in the polyethylene terephthalate polymer. More recent information regarding levels of ethylene glycol in food is not available.

Ethylene glycol has been identified in negligible amounts in the water-soluble component of cigarette smoke (Schumacher et al. 1977).

6.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Ethylene glycol concentrations in blood, urine, tissue, or breast milk are not available for the general population in the United States. The most common route of human exposure to ethylene glycol for members of the general population is dermal contact with ethylene glycol-based automobile antifreeze. However, intentional or accidental ingestion of antifreeze is the most serious type of exposure, resulting in thousands of ethylene glycol poisonings including several deaths reported each year in the United States (Fraser 2002; Leth and Gregersen 2005).

Exposure to ethylene glycol through consumption of foods or drinks stored in plastics made from this chemical may be possible if the plastic contains unreacted ethylene glycol that can migrate into the food (Kashtock and Breder 1980). However, current levels of ethylene glycol in food have not been located;

therefore, evidence is not available to indicate that this as an important route of human exposure to ethylene glycol.

Background concentrations of ethylene glycol in air, surface water, groundwater, drinking water, soil, and sediment are not available. Ethylene glycol is not expected to be found in the environment away from areas where it is released since this substance is degraded within days to a few weeks in air, water, and soil. Therefore, inhalation of ambient air, ingestion of drinking water, and dermal contact with water or soil are not expected to be important routes of exposure of the general population to ethylene glycol.

Contact with the skin and eyes is the most likely route of worker exposure to ethylene glycol. Inhalation may be an important route of human exposure under occupational conditions where the compound is heated or if mists are generated by heat or violent agitation (Rowe and Wolf 1982). Individuals involved in airport de-icing operations are exposed to ethylene glycol through inhalation since the de-icing formulation is sprayed through the air, generating ethylene glycol vapor and mist. Dermal exposure to ethylene glycol in deicing fluids may also be important, especially for workers who do not have adequate skin protection during or after application (Leggat and Smith 2006; Upadhyay et al. 2008).

Gérin et al. (1997) measured urinary ethylene glycol concentrations for 33 aviation workers exposed to de-icing fluid over a winter period of 2 months. Ethylene glycol was detected above 2.5 mg/m^3 (limit of quantification) as vapor in only 18 out of 154 air samples collected during spray operations. Reported concentrations ranged from 0.9 to 22 mg/m^3. Ethylene glycol was also detected as a mist in three of the air samples with concentrations of 76, 91, and 190 mg/m^3. Ethylene glycol quantities in post-shift and next-morning urine samples exceeded 5 mmol/mol creatinine in 16 of the 33 workers (5.2–129 mmol/mol creatinine). Exposure was greatest for basket operators and coordinators. Air samples taken from the breathing zones of workers applying de-icing fluids (50% ethylene glycol) to bridge surfaces contained the compound at concentrations of <0.05–2.33 mg/m^3 as aerosols and <0.05–3.37 mg/m^3 as vapors (LA DOTD 1989).

Laitinen et al. (1995) measured urinary ethylene glycol concentrations in 10 car mechanics frequently exposed to ethylene glycol and a control group of 10 male office workers. Levels were noticeably higher in the urine of the mechanics. Ethylene glycol and oxalic acid concentrations were 7.3 and 47 mmol/mol creatinine, respectively, in the urine of the car mechanics and 1.7 and 36 mmol/mol creatinine, respectively, in the urine of the controls. Ethylene glycol concentrations in the air of the mechanics' environment were negligible. A health hazard evaluation of a newspress facility in Buffalo, New York found that concentrations of ethylene glycol in air were below occupational exposure criteria (<0.50 mg/m^3); however, dermal exposure to ethylene-glycol-containing solvent washes was reported to be a significant route of exposure for employees (NIOSH 2006). Letzel et al. (2000) reported mean and median ethylene glycol concentrations of 0.31 and 0.23 mg/L, respectively, measured in the urine of 16 individuals living in Germany who had no known occupational exposure to glycols.

The National Occupational Exposure Survey (NOES) conducted by NIOSH during 1981–1983 estimated that 1.5 million workers are potentially exposed to ethylene glycol each year (NIOSH 1990).

6.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in Section 3.7, Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and spend more time outdoors. Children also are closer to the ground, and they do not use the judgment of adults to avoid hazards (NRC 1993).

Ethylene glycol antifreeze is a brightly-colored liquid and can be confused for a beverage, especially when it is not kept in its original container (Leth and Gregersen 2005). The sweet taste of ethylene glycol adds to this attraction. For this reason, some states have mandated that the bittering agent, denatonium benzoate, be added to ethylene glycol antifreeze formulations (Hogue 2006; White et al. 2008). Although the presence of a bittering agent is expected to deter children from accidentally ingesting ethylene glycol-based antifreeze, caution should still be used. Harry et al. (1998) reported a case of accidental ingestion of ethylene glycol antifreeze by a 4-year-old child even though the formulation contained denatonium benzoate.

Many ethylene glycol poisonings occur when an antifreeze bottle is in use (EPA 2004b; Leth and Gregersen 2005; Schwerk et al. 2007). Children may touch or ingest ethylene glycol from an opened container of antifreeze that an adult has placed within reach. Children may also play with a puddle of antifreeze that has been spilled onto the ground.

Children who live near facilities that manufacture or use ethylene glycol may be exposed to this substance through contact with contaminated soil or water. Children living near airports where ethylene glycol is used in de-icing operations may be exposed through ingestion of contaminated groundwater or inhalation of ethylene glycol vapor.

Biomonitoring data for children, including levels of ethylene glycol measured in breast milk, neonatal blood, cord blood, and meconium fluid have are not available. A 28-year-old woman who was 26 weeks pregnant was admitted to the hospital following ingestion of 400 mL ethylene glycol (Kralova et al. 2006; Kuczkowski 2006). The child was delivered immediately via cesarean section. Serum ethylene glycol levels measured in the mother and child were 2,480 and 2,206 mg/L, respectively (Kralova et al. 2006).

6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Workers in industries involved in the manufacture or use of products containing high concentrations of ethylene glycol (e.g., antifreeze, coolants, de-icing fluids, brakes fluids, solvents) may be exposed to concentrations of the compound at levels higher than the general population, particularly in operations involving heating or spraying of these materials.

Members of the general population who currently have potentially high exposures to ethylene glycol include individuals living near sites where ethylene glycol is manufactured or used and individuals living near waste disposal sites contaminated with ethylene glycol. Persons living near airports where large amounts of ethylene glycol are used for de-icing of aircraft or near hazardous waste sites are potentially at greater risk of exposure, particularly from consumption of contaminated groundwater.

6.8 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of ethylene glycol is available. Where adequate information is not available, ATSDR, in conjunction with NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of ethylene glycol.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.8.1 Identification of Data Needs

Physical and Chemical Properties. As seen in Table 4-2, the relevant physical and chemical properties of ethylene glycol are known (AIChE 1995; Forkner et al. 2004; Hansch et al. 1995; Hine and Mookerjee 1975; HSDB 2009; Lewis 2001; Lide 2005; O'Neil et al. 2001; Rebsdat and Mayer 2005) and predicting the environmental fate and transport of ethylene glycol based on these properties is possible. No further information is needed.

Production, Import/Export, Use, Release, and Disposal. According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit substance release and off-site transfer information to the EPA. The TRI, which contains this information for 2005, became available in February of 2007. This database is updated yearly and should provide a list of industrial production facilities and emissions.

Production, Import/Export, Use, Release, and Disposal. Knowledge of production and use data for a chemical is important in predicting its potential for environmental contamination and human exposure. Both recent and historical production data are available for ethylene glycol (Brown et al. 1980; CMR 1981, 1984, 1987, 1990, 1993, 1998, 2001, 2004; Forkner et al. 2004; McClelland and Rector 1951; Miller 1966; Rebsdat and Mayer 2005; SRI 2008). Similarly, data on the import/export volumes for ethylene glycol for the last several years are available (HSDB 2009; ITA 2007). Information on the various uses of this compound is also available (Browning 1965; CMR 2004; Forkner et al. 2004; Lewis 2001; O'Neil et al. 2001; Rebsdat and Mayer 2005; SRI 2008). Ethylene glycol enters the environment primarily during its use as a component of automotive antifreeze/coolants, as a de-icing fluid for aircraft, and as an intermediate in the synthesis of polyester fibers (Klecka et al. 1993; Lewis 2001; O'Neil et al. 2001; Rowe and Wolf 1982). Major sources of ethylene glycol releases to soils are from the disposal of used antifreeze and de-icing solutions in hazardous waste sites (EPA 1979, 1987; Ware 1988).

Information regarding the disposal of ethylene glycol-containing waste waters (DOE 1993a, 1993b) and for remediation of ethylene glycol contaminated soils (Drajun 1991; Vesper et al. 1994) is available.

Environmental Fate. Information regarding the fate of ethylene glycol in the air is available that suggests that the compound would be primarily found in the vapor phase and would likely be removed from the atmosphere via wet deposition (Eisenreich et al. 1981; EPA 1979). Ethylene glycol undergoes rapid photochemical oxidation via reaction with hydroxyl radicals with a half-life of 1.4 hours (Atkinson 1989; EPA 1993e). Because of its high solubility in water, the compound is expected to be transported primarily in aqueous media (EPA 1979) and will not partition to the atmosphere via volatilization from water (Thomas 1990). Adsorption to sediment or soil particles is not expected to be significant based on the low K_{oc} value; therefore, ethylene glycol is expected to have a high mobility in soil and the potential to leach into groundwater (Swann et al. 1983). Ethylene glycol is degraded in both water (Battersby and Wilson 1989; Bieszkiewicz et al. 1979; Bridie et al. 1979; Caskey and Taber 1981; Dwyer and Tiedje 1983; Evans and David 1974) and soil (Klecka et al. 1993; McGahey and Bouwer 1992; Revitt and Worrall 2003) primarily by biodegradation. Based on available data, ethylene glycol is biodegraded under both aerobic and anaerobic conditions from within a day to a few weeks. No additional information on degradation of ethylene glycol in air, water, or soil is required.

Bioavailability from Environmental Media. Available information regarding the rate of ethylene glycol absorption following inhalation, oral, or dermal contact has been discussed in the Toxicokinetics section (see Section 3.4). Although no data on ethylene glycol's bioavailability from contaminated air are available, the bioavailability from inhalation exposure is expected to be high because ethylene glycol is likely to be present in the vapor phase (Eisenreich et al. 1981) and not in the particulate phase in the adsorbed state. Similarly, no data on the bioavailability of ethylene glycol from water, soil, or plant material are available; however, ethylene glycol is miscible in water and does not adsorb readily to soil. Ethylene glycol, therefore, is expected to be readily bioavailable from soil and water. Information on the bioavailability of ethylene glycol from actual environmental media needs further development.

Food Chain Bioaccumulation. Based on its low K_{oc} value, ethylene glycol is not expected to bioconcentrate in aquatic food chains. Freitag et al. (1985) reported a BCF value of 10 measured in fish. Information is also lacking regarding the biomagnification potential of ethylene glycol through aquatic food chains, although biomagnification is probably a minor process because of the rapid degradation rate for the chemical in aquatic systems. No further information on the bioconcentration or biomagnification potential of ethylene glycol is needed.

Exposure Levels in Environmental Media. Reliable monitoring data for the levels of ethylene glycol in contaminated media at hazardous waste sites are needed so that the information obtained on levels of ethylene glycol in the environment can be used in combination with the known body burden of ethylene glycol to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Information on the number of hazardous waste sites on the NPL at which ethylene glycol was detected in air, surface water, groundwater, soil, and sediment is available (HazDat 2007). However, more specific information, such as concentrations in these media, is needed to give a better indication of the potential for human exposure to ethylene glycol in areas near hazardous waste sites.

No information was located on the concentration of ethylene glycol in ambient air. Time weighted average concentrations of the compound as both an aerosol and a vapor were measured following the spray application of de-icing fluids containing ethylene glycol on a bridge (LA DOTD 1989) and at an airport (Gérin et al. 1997). These data are not general enough to estimate inhalation exposure to ethylene glycol for the general population in the United States. No data on the level of ethylene glycol in drinking water were located, although ethylene glycol has been detected at up to 415 mg/L (ppm) in groundwater in the vicinity of an airport (Sills and Blakeslee 1992). No information on the background levels of ethylene glycol in soil, surface water, or groundwater was located. Additional information regarding the levels of ethylene glycol in ambient air, drinking water, surface water, groundwater, and soil is needed. Some older data on ethylene glycol levels in foods, particularly those stored in cellulose films or in PET bottles are available (Castle et al. 1988a; Kashtock and Breder 1980). Additional quantitative information on current levels of ethylene glycol in various environmental media and levels of contamination in foods would be helpful in assessing the health risks to the general population and in occupational settings.

Exposure Levels in Humans. Little quantitative information on ethylene glycol levels in various human tissues and body fluids of a control population, populations near hazardous waste sites, or occupationally exposed groups in the United States is available. Most information is available for oral exposures derived from intentional or accidental poisonings (Gabow et al. 1986; Hewlett et al. 1986; Jacobsen et al. 1988; Parry and Wallach 1974; Robinson and McCoy 1989; Vale 1979; Wiener and Richardson 1988). Some information is available on plasma glycolate levels for poisoning victims admitted to a hospital (Jacobsen et al. (1984), and on urine and other tissues (Cheng et al. 1987; Rothman et al. 1986; Winek et al. 1978). Data are needed on the levels of ethylene glycol and its metabolites in body tissues and fluids especially from dermal and inhalation studies. Two studies have been located that report urinary concentrations for airport de-icing workers and car mechanics (Gérin et al. 1997; Laitinen et al. 1995). Additional information on control populations, populations living in the vicinity of hazardous waste sites, and those who are occupationally exposed to ethylene glycol is needed.

This information is necessary for assessing the need to conduct health studies on these populations.

Exposures of Children. Information regarding the background exposure of children to ethylene glycol is not available. Body burden studies measuring the levels of ethylene glycol in the blood, urine, and body tissue of children would be helpful. Studies measuring the levels of this chemical in the neonatal blood, cord blood, and meconium fluid of infants would also be helpful. Levels of ethylene glycol in breastmilk have not been located. Children are considered to be more susceptible to accidental ingestion of ethylene glycol than adults (Leth and Gregersen 2005). Information is needed regarding how effective the use of a bittering agent has been in deterring accidental ingestion of ethylene glycol by children.

Child health data needs relating to susceptibility are discussed in Section 3.12.2, Identification of Data Needs: Children’s Susceptibility.

Exposure Registries. No exposure registries for ethylene glycol were located. This substance is not currently one of the compounds for which a sub-registry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for sub-registries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

6.8.2 Ongoing Studies

Ongoing studies related to the potential for human exposure to ethylene glycol were not located.