

5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Large amounts of toluene enter the environment each year, almost entirely as direct releases to the atmosphere. The largest source of toluene release is during the production, transport, and use of gasoline, which contains about 5–7% toluene by weight. Significant quantities are also released in association with the production, use, and disposal of industrial and consumer products that contain toluene. Small amounts are released in industrial waste water discharges and land disposal of sludges and petroleum wastes.

Toluene in the atmosphere is degraded by reaction with hydroxyl radicals, with a typical half-life of approximately 13 hours. Toluene in soil or water rapidly volatilizes to air, and that which remains is subject to microbial degradation. As a consequence of the volatilization and degradation occurring in air, soil, and water, there is little tendency for toluene levels to build up in the environment over time.

The concentrations of toluene in air have been found to be quite low in remote areas, but levels of 1.3–6.6 ppb are common in suburban and urban areas. The automobile emissions are the principal source of toluene in ambient air, with levels fluctuating in proportion to automobile traffic. Toluene is also a common indoor contaminant, and indoor air concentrations are often several times higher (averaging 8 ppb) than outside air. This is likely due to release of toluene from common household products (paints, paint thinners, adhesives, and nail polish in which it is used as a solvent) and from cigarette smoke.

Toluene is occasionally detected in drinking water supplies, but occurrence is not widespread and levels are generally below 3 ppb. In contrast, toluene is a very common contaminant of water and soil in the vicinity of hazardous waste sites, with average concentrations in water of 7–20 ppb, and average concentrations in soil of over 70 ppb.

The most likely pathway by which people may be exposed to toluene is by breathing contaminated air. Since most people spend a large fraction of the day indoors, indoor air levels are likely to be the dominant source. Moreover, indoor levels generally exceed outdoor levels because of volatilization of toluene from household products. Based on a typical concentration of 8 ppb in indoor air, inhalation of air at 20 m³/day, and absorption of 50% of the inhaled dose of toluene, a typical absorbed dose is about 300 µg/day. Intake from food and water may contribute substantially smaller amounts. By comparison,

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smoking may contribute 1,000 µg/day or more. Higher exposure levels might occur for individuals living near a hazardous waste site or an industrial source of toluene emissions, but these exposures can be estimated only on a site-by-site basis.

Toluene exposure may also occur in the workplace, especially in occupations such as printing or painting, where toluene is used as a solvent. A workplace air level of 100 ppm (equivalent to a dose of 3,750 mg/day) has been established by the Occupational Safety and Health Administration (OSHA) as the 8-hour TWA Permissible Exposure Limit (PEL) for toluene (OSHA 1989a). The American Conference of Governmental Industrial Hygienists (ACGIH 1999) recommends an 8-hour TWA concentration of 50 ppm as the Threshold Limit Value for workplace air to protect against central nervous system effects.

Toluene has been identified in at least 959 of the 1,591 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (HazDat 2000). However, the number of sites evaluated for toluene is not known. The frequency of these sites can be seen in Figure 5-1. Of these sites, 959 are located within the United States and none are located in the Commonwealth of Puerto Rico (not shown).

5.2 RELEASES TO THE ENVIRONMENT

According to the Toxics Release Inventory (TRI), in 1997 a total of 114 million pounds (251 million kg) of toluene was released to the environment from 3,118 manufacturing or processing facilities (TRI97 1999). Table 5-1 lists the amounts released from these facilities to air, water, land, and publicly owned treatment works (POTWs). Table 5-1 also shows that less than 1% of the total released was injected deep underground and that about 3.3 million pounds of toluene were transferred off-site (TRI97 1999). The relative proportions of the material transferred off-site that were recycled or entered environmental media are not stated. The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

Toluene has been identified in a variety of environmental media (air, surface water, groundwater, soil, and sediment) collected at 959 of the 1,591 NPL hazardous waste sites (HazDat 2000).

Figure 5-1. Frequency of NPL Sites with Toluene contamination

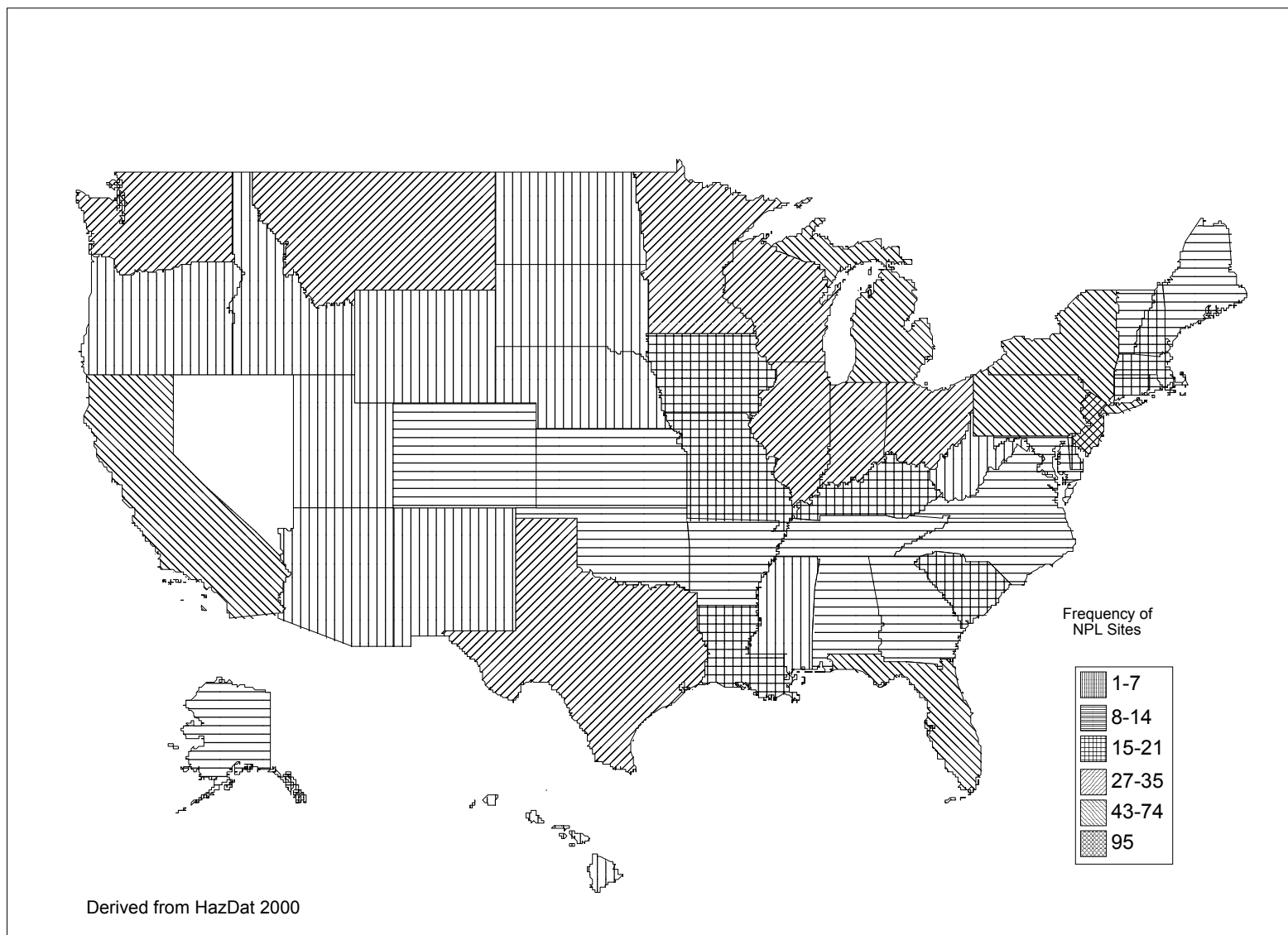


Table 5-1. Releases to the Environment from Facilities that Manufacture or Process Toluene

State ^b	Number of facilities	Range of reported amounts released in pounds per year ^a						POTW transfer	Off-site waste transfer
		Air ^c	Water	Land	Underground injection	Total environment ^d			
AK	2	88,176	0	265	0	88,441	0	66	
AL	75	3,001,377	1,331	0	5	3,002,713	1,046	21,433,270	
AR	59	2,209,387	68	3,250	106,107	2,318,812	5	1,755,909	
AZ	9	126,923	0	0	0	126,923	0	30,482	
CA	125	1,553,654	242	122	500	1,554,518	61,772	13,826,818	
CO	22	343,136	0	0	0	343,136	10	2,194,676	
CT	33	668,010	5	0	0	668,015	1,155	1,839,393	
DE	10	38,727	72	0	0	38,799	50,548	478,664	
FL	47	1,429,964	0	3,302	0	1,433,266	899	740,691	
GA	79	3,118,819	689	0	0	3,119,508	1,080	5,842,004	
HI	2	18,375	0	0	0	18,375	0	2,640	
IA	51	1,968,830	66	5	0	1,968,901	9	1,666,065	
ID	3	353,942	0	0	0	353,942	0	35,772	
IL	198	5,228,891	611	10,252	0	5,239,754	19,136	19,447,474	
IN	171	7,710,949	399	33,703	0	7,745,051	2,883	6,933,973	
KS	51	1,579,396	307	3,296	420	1,583,419	10	1,885,660	
KY	57	5,602,482	613	6,432	0	5,609,527	2,898	6,131,146	
LA	75	1,968,292	553	4,120	157,705	2,130,670	0	3,846,996	

Table 5-1. Releases to the Environment from Facilities that Manufacture or Process Toluene (continued)

State ^b	Number of facilities	Range of reported amounts released in pounds per year ^a						
		Air ^c	Water	Land	Underground injection	Total environment ^d	POTW transfer	Off-site waste transfer
MA	74	1,625,237	0	7	0	1,625,244	1	7,914,191
MD	20	403,263	3	0	0	403,266	79	2,795,379
ME	7	302,348	0	0	0	302,348	0	87,118
MI	150	6,770,172	387	3,022	6,142	6,779,723	13,541	34,965,822
MN	65	2,235,464	107	0	0	2,235,571	15	2,395,773
MO	81	1,990,918	48	911	0	1,991,877	27,917	23,510,623
MS	61	4,489,512	6,278	421	5,120	4,501,331	254	3,667,812
MT	6	104,600	16	255	0	104,871	5	2,025
NC	156	6,404,347	33	5	0	6,404,385	36,976	6,249,840
ND	3	80,337	0	1	0	80,338	0	28,880
NE	19	776,949	5	0	0	776,954	250	418,576
NH	12	186,830	0	0	0	186,830	5	144,415
NJ	107	1,110,539	85	4,616	0	1,115,240	63,040	14,837,724
NM	10	317,538	0	1,010	0	318,548	0	74,210
NV	2	619,855	0	0	0	619,855	11	137,181
NY	87	4,074,714	575	5	0	4,075,294	5,121	2,204,985
OH	203	3,400,247	3,598	760	0	3,404,605	4,579	18,091,777
OK	36	1,283,992	1,238	439	2,200	1,287,869	726	1,027,209
OR	32	663,051	0	0	0	663,051	171	582,455

Table 5-1. Releases to the Environment from Facilities that Manufacture or Process Toluene (continued)

State ^b	Number of facilities	Range of reported amounts released in pounds per year ^a						POTW transfer	Off-site waste transfer
		Air ^c	Water	Land	Underground injection	Total environment ^d			
PA	148	6,447,689	1,671	251	0	6,449,611	55,637	14,314,073	
PR	28	1,130,850	13	0	0	1,130,863	43,141	2,346,775	
RI	16	761,923	1	2,089	0	764,013	5	146,233	
SC	63	4,931,964	604	1,405	0	4,933,973	510	6,539,868	
SD	10	155,429	0	3	0	155,432	0	104,056	
TN	115	8,955,221	2,365	0	0	8,957,586	18,460	11,569,814	
TX	208	5,519,497	4,899	655,161	235,436	6,414,993	72,065	11,212,189	
UT	22	336,598	62	620	0	337,280	9,252	44,622	
VA	83	5,191,139	1,020	0	0	5,192,159	116,441	5,728,481	
VI	1	151,479	48	0	0	151,527	0	11,934	
VT	6	61,159	0	0	0	61,159	250	106,854	
WA	39	1,187,149	110	1,480	0	1,188,739	15	823,767	
WI	94	2,788,125	0	21	0	2,788,146	2,018	11,500,908	
WV	21	1,246,059	2,606	1,429	0–0	1,250,094	0	3,085,704	
WY	8	113,513	10	696	0–250	114,219	0	4,610	
Totals	3062	112,827,037	30,738	739,354	513,635	114,110,764	611,936	274,767,582	

Source: TRI97 1999

^aData in TRI are maximum amounts released by each facility

^bPost office state abbreviations used

^cThe sum of fugitive and stack releases are included in releases to air by a given facility

^dThe sum of all releases of the chemical to air, land, water, and underground injection wells

POTW = publicly owned treatment works

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5.2.1 Air

Nearly all toluene entering the environment is released directly to air. The largest source of emissions is gasoline, which typically contains 5–7% toluene by weight (Verschuere 1977). In 1978, air emissions associated with gasoline use were estimated to be 1.5 billion pounds (6.8×10^5 metric tons), the bulk of this (6.4×10^5 metric tons) was released through automobile exhaust (EPA 1981). Toluene used in paints, solvents, adhesives, inks, and similar products is also released to air upon use. The total release from these sources not associated with gasoline was estimated to be about 3.7×10^5 metric tons in 1978 (EPA 1981).

Toluene may also be released during disposal processes. Based on information from 40 medical waste incinerators in the United States and Canada, emission factors for toluene were reported to range from 37.3 to 178 (mean=113) ppb waste for uncontrolled emissions and 177–3,000 (mean=1,920) ppb waste for controlled emissions (Walker and Cooper 1992). Toluene emissions from coal-fired power stations ($119 \mu\text{g}/\text{Nm}^3$) were reported to be far less than toluene emissions from diesel engines ($167\text{--}287 \mu\text{g}/\text{Nm}^3$) and automobiles ($15,700\text{--}370,000 \mu\text{g}/\text{Nm}^3$, where N denotes 20 EC and 1 atmosphere pressure) (Garcia et al. 1992).

According to the Toxics Release Inventory, in 1997, the estimated releases of toluene of 113 million pounds (249 million kg) to air from 3,118 manufacturing or processing facilities accounted for about 50% of total environmental releases (TRI97 1999). Table 5-1 lists amounts released from these facilities. The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

Toluene has been identified in air samples collected at 187 of the 959 NPL hazardous waste sites where it was detected in some environmental media (HazDat 2000).

5.2.2 Water

Toluene may be released to water from industrial discharges and urban wastes, or by spills and leaks of gasoline. However, these releases are believed to comprise only a small fraction of the amount of toluene released to air (EPA 1981). In a survey of toluene levels in industrial waste waters, EPA (1982a) found values ranging from 1 to 2,000 ppb.

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According to the Toxics Release Inventory, in 1997, the estimated releases of toluene of 30,378 pounds (166,832 kg) to water from 3,062 manufacturing or processing facilities accounted for about 0.03% of total environmental releases (TRI97 1999). The majority of the releases to water are due to spills of gasoline and oil to surface water (TRI97 1999). Another 611,931 pounds were transferred to POTWs.

The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

Toluene has been identified in 243 surface water and 1,063 groundwater samples collected from 959 NPL hazardous waste sites, where it was detected in some environmental media (HazDat 2000).

5.2.3 Soil

Toluene has been identified in 807 soil and 220 sediment samples collected from 959 NPL hazardous waste sites, where it was detected in some environmental media (HazDat 2000).

Release of toluene to land may occur in association with gasoline spills, leaking underground gasoline storage tanks, or land disposal of municipal sludges or refinery wastes. Although, in some cases, releases might be significant on a local scale, the total amount of toluene released to the environment in soil is considered to be negligible (EPA 1981).

According to the Toxics Release Inventory, in 1997, the estimated releases of toluene of 739,354 pounds (1.6 million kg) to soil from 3,062 manufacturing or processing facilities accounted for about 0.65% of total environmental releases (TRI97 1999). Table 5-1 lists amounts released from these facilities. Another 3.3 million pounds were transferred off-site. The TRI data should be used with caution since only certain types of facilities are required to report.

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

Although toluene is a liquid at room temperature, it is sufficiently volatile (vapor pressure = 28.4 mmHg at 25 EC) that the majority of toluene released to the environment partitions to air. As discussed in Section 5.2, most toluene is released directly into air, and that which is released to surface water or soil

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tends to volatilize quickly. The rate of toluene volatilization from surface waters depends on whether the water is static (half-life of 1–16 days) or turbulent (half-life of 5–6 hours) (Mackay and Leinonen 1975; Wakeham et al. 1983). Laboratory studies indicate that surfactants can affect volatilization of toluene from water (Anderson 1992). The rate of volatilization from soils depends on temperature, humidity, and soil type, but under typical conditions, more than 90% of the toluene in the upper soil layer volatilizes to air within 24 hours (Balfour et al. 1984; Thibodeaux and Hwang 1982). Toluene present in deep soil deposits, however, is much less likely to volatilize. Calculations of toluene volatilization for deposits 1–1.3 m below the soil surface suggest that only 0.1–2.6% will volatilize over a 1-year period (Jury et al. 1990). The higher volatilization value allows for a soil water evaporation rate of 0.1 cm/day and the lower value assumes no water evaporation.

Because toluene is moderately soluble in water (534.8 ppm at 25 EC), it is likely that toluene is scrubbed from air by rainfall, but no quantitative estimate of the rate of this transport process was located. Toluene removed from the atmosphere by this process is likely to be rapidly volatilized.

The rate of toluene transport to groundwater depends on the degree of adsorption to soil. The log organic carbon-water partition coefficient is 2.25, which indicates that toluene will be moderately retarded by adsorption to soils rich in organic matter, but will be readily leached from soils with low organic content (Wilson et al. 1981). Soil desorption can be slow. Distilled water removed 9–40% of the toluene adsorbed to samples of five different soils of low organic content within 24 hours (Pavlostathis and Mathavan 1992), but after 7 days some of the toluene still remained adsorbed to the soil samples. Studies of the sorption mechanism when biological activity is minimized show that the primary, or partitioning process, is very fast, but the adsorption process is much slower (Wojtenko et al. 1996). A gravimetric method shows that adsorption of gas phase toluene on loam or clay occurs in two stages: fast diffusion and adsorption in macropores, followed by slower diffusion and adsorption in intragrain micropores (Arocha et al. 1996). Although the organic carbon content of aquifer materials is an important determinant of toluene migration in groundwater, other factors may be important as well (Larsen et al. 1992). For example, information from waste sites and U.S. coastal plain aquifers indicates that many site-specific hydro geologic factors can have unpredictable effects on toluene migration (Adams and Golden 1992). In addition, the presence of other gasoline components (benzene, xylene) can impact toluene migration. Competitive sorption between these gasoline components decreases the interaction between toluene and soil, thereby allowing it to move more quickly through the aquifer (Stuart et al. 1991).

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Based on its lipophilic properties, toluene is expected to have a low tendency to bioconcentrate in the fatty tissues of aquatic organisms (Franke et al. 1994). The bioconcentration factor was estimated to be about 10.7 in fish (EPA 1980a) and about 4.2 in mussels. The levels that accumulate in the flesh of aquatic species also depend on the degree to which the species metabolize toluene. The highest tissue levels of toluene tend to occur in species such as eels, crabs, and herring that have a low rate of toluene metabolism (EPA 1981). Metabolism of toluene limits its tendency to biomagnify in the food chain.

5.3.2 Transformation and Degradation

5.3.2.1 Air

Toluene in the atmosphere is rapidly degraded by reaction with hydroxyl radicals to yield cresol and benzaldehyde, which in turn undergo ring cleavage to yield simple hydrocarbons (Davis et al. 1979; Hoshino et al. 1978; Kenley et al. 1973). The estimated rate constant for this process is about $0.6\text{--}2.4 \times 10^{-5} \text{ sec}^{-1}$, which corresponds to an atmospheric half-life of around 13 hours. The actual half-life may range from 10 to 104 hours depending on atmospheric conditions (Howard et al. 1991). Toluene is also oxidized by reaction with nitrogen dioxide, oxygen, and ozone, but the rates of these reactions are two or more orders of magnitude less than for the hydroxyl radical (Altshuller et al. 1971; Dilling et al. 1976; Wei and Adelman 1969). Benzyl nitrate and nitrotoluene are formed through the reaction of atmospheric toluene with nitrogen oxides (Atkinson 1990). Photolysis is not a significant degradation pathway for toluene (EPA 1981). Smog chamber experiments with hydroxyl radical oxidation of toluene under simulated atmospheric conditions produce numerous carbonyl products.

5.3.2.2 Water

Although toluene may be oxidized in water by reactions similar to those that occur in air, the rates of these reactions in water are very slow (EPA 1979). The half-life for benzene in reaction with aqueous hydroxyl radicals has been estimated to range from 13 to 54 days (Howard et al. 1991). Degradation of toluene in water occurs primarily by microbial action. The rate of biodegradation is a function of many parameters (temperature, duration of microbial acclimation, etc.). The degradation half-life is less than 1 day under favorable conditions (Wakeham et al. 1983). In surface waters, the biodegradation half-life of toluene was estimated to range from 4 to 22 days, whereas the biodegradation half-life of toluene in groundwater was estimated to range from 7 to 28 days (Howard et al. 1991). The biodegradation of toluene in groundwater can be enhanced by the presence of sulfate, nitrate, potassium, and phosphate

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(Acton and Barker 1992; Armstrong et al. 1991; Hutchins 1991). Sulfate enhances toluene biodegradation by acting as an alternate electron acceptor (Acton and Barker 1992). The rate of toluene mineralization was estimated to range from 0.032 to 0.055 ppb hour (Armstrong et al. 1991). Rapid biodegradation (over 90% loss within 7 days) occurs in shallow groundwater (Wilson et al. 1983) and in sludge waste water (Davis et al. 1981). *In-situ* degradation is the most important sink for toluene in contaminated streams. Dilution, volatilization, and biodegradation account for 8, 26, and 66% of toluene loss in a small stream in Massachusetts (Kim et al. 1995). Laboratory studies of *in-situ* toluene biodegradation show results comparable to the stream studies and indicate that the streambed surfaces (sediments and rocks) are responsible for virtually all biodegradation (Cohen et al. 1995). Reduced, but still considerable, rates of toluene microbial degradation were reported in salt water, as compared to fresh water (Price et al. 1974). Bacteria are unable to degrade toluene in water when toluene concentration falls below a threshold value where the metabolism of the compound is too slow to provide cells with energy at a rate needed to maintain metabolism (Roch and Alexander 1997).

5.3.2.3 Sediment and Soil

Toluene can be degraded in soil by a number of bacterial species of the genera *Pseudomonas* and *Achromobacter* (Fewson 1981). The biodegradation process appears to occur in two phases. The first phase produces benzoic acid and is, in this respect, parallel to the metabolism of toluene by mammalian microsomes. In the second phase, the aromatic ring undergoes metabolic cleavage to produce the Krebs cycle intermediates, which are degraded to carbon dioxide or incorporated into bacterial biomolecules (Harayama et al. 1989). Addition of large numbers of bacterial cells to toluene-contaminated soils may have no benefit if the concentration of toluene is too low for the bacteria to maintain metabolic activity (Roch and Alexander 1997). Toluene degradation rates were proportional to the initial substrate concentration, and these rates reached a maximum at a concentration of 200 ppm (Davis and Madsen 1996). In aerobic soils, oxygen acts as the terminal electron acceptor in degradation of the ring cleavage products. Under anaerobic conditions, nitrogen or sulfate can act as the terminal electron acceptor (Beller et al. 1992a, 1992b; Dolfing et al. 1990; Evans et al. 1991). Under favorable conditions (presence of electron acceptors, nutrients, and oxidizable compounds), laboratory studies show that BTEX (benzene-toluene-ethylbenzene-xylene) compounds (which include toluene) are also degraded by bacteria in anaerobic (Langenhoff et al. 1996) or oxygen-limited environments (Lovley 1997; Olsen et al. 1995). Under sulfate-reducing conditions, less than 10% of the toluene carbon was metabolized to benzylsuccinic acid and benzylfumaric acid, whereas >80% was mineralized to carbon dioxide (Beller et al. 1992a). The half-life for biodegradation in soil under laboratory conditions may be as short as 1 hour

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(Claus and Walker 1964), whereas half-lives of 1–7 days are typical in the environment (API 1984). Based on data from the aerobic degradation of toluene in water, the biodegradation half-life of toluene in soils is expected to range from 4 to 22 days (Howard et al. 1991). Soil biodegradation is not impeded by adsorption (Robinson et al. 1990). The wood-degrading, white-rot fungus, *Phanerochaete chrysosporium*, mineralizes 50% of 2 ppm aqueous solutions of toluene or benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds to carbon dioxide within 5 days. Nonlignindytic conditions are favored (Yadav and Reddy 1993).

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to toluene depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. In reviewing data on toluene 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.

5.4.1 Air

The concentration of toluene in air has been measured in a number of studies. Table 5-2 summarizes the average concentration as a function of sampling location (EPA 1988b). Background levels of toluene in remote areas were found to be quite low (0.05 ppb), but levels of 0.27–7.98 ppb were observed in suburban and urban areas. Other studies have reported toluene concentrations of 0.9–70.1 ppb, 0.06–195 ppb, and 2.2–751.5 ppb in rural (Khalil and Rasmussen 1992), urban (Chan et al. 1991b; EPA 1991c; Evans et al. 1992; Kelly et al. 1993), and source dominated air samples (Guldberg 1992; Kelly et al. 1993). There are multiple sources of this atmospheric toluene, with vehicle emissions being a major contributor (Altshuller et al. 1971; EPA 1981; Garcia et al. 1992). The emission rate of toluene from motor vehicle traffic in a Los Angeles roadway tunnel was found to be 748 ppm (Fraser et al. 1998). Concentrations of toluene in air from the inside of vehicles have been reported to range from 0.56 to 42.0 ppb (Chan et al. 1991a; Lawryk and Weisel 1996; Weisel et al. 1992).

High air concentrations of toluene were nearly always found indoors (Lebret et al. 1986; Otson et al. 1983; Wallace et al. 1986). In several studies, indoor (home or office) toluene concentrations ranged from 0.7 to 24.2 ppb due mostly to infiltration from auto emissions (Chan et al. 1991b; Hodgson et al. 1991; Kelly et al. 1993; Michael et al. 1990b; Shields and Weschler 1992). Toluene was among the volatile organic compounds detected in the emissions from sponge rubber carpet cushions (Schaeffer et

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Table 5-2. Median Toluene Levels in Ambient Air

Sampling location	Number of samples	Daily mean concentration (ppb)	Concentration ($\mu\text{g}/\text{m}^3$)
Remote	225	0.049	0.18
Rural	248	0.35	1.3
Suburban	958	0.195	0.731
Urban	2,519	2.883	10.81
Source dominated	104	6.314	23.67
Indoor	101	8.4	31.5
Workplace	80	0.865	3.24
Personal	1,650	0.000	0.000

Adapted from EPA 1988b

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al. 1996). Indoor toluene can also originate from household products (paints, thinners, glues, etc.) and smoking. The indoor toluene concentrations in a household with smoking residents were found to be greater than those in a nonsmoking household (Montgomery and Kalman 1989).

Volatilization from contaminated tap water is another source of indoor toluene. Efficiencies of toluene volatilization have been estimated for sources such as the kitchen sink (13–26%), residential washing machines (8.2–99%), residential dishwashers (96–98%), and household showers (61–77%) (Howard and Corsi 1996, 1998; Howard-Reed et al. 1999; Moya et al. 1999). Toluene was found to be emitted at a rate of 40,000 ppb during the charbroiling of hamburger meat over a natural gas fired grill (Schauer et al. 1999a). Higher levels of toluene were detected in indoor air during the spring (4.8 ppb) than in the summer (7.70 ppb) (Mukerjee et al. 1997). Indoor and in-vehicle toluene levels appear to be affected by seasonal changes (Montgomery and Kalman 1989; Weisel et al. 1992).

Shields et al. (1996) compared volatile organic compounds measured in three types of commercial buildings (telecommunication offices, data centers, and administrative offices) across the United States. The highest amount of toluene was detected in the data centers with a geometric mean concentration of 2.68 ppb. Geometric mean concentrations of toluene measured in telecommunications offices, administrative offices, and outdoor air were 1.3, 1.5, and 0.7 ppb, respectively. The presence of aromatic compounds was found to be independent of occupant density and was attributed to presence of adhesives, building materials, floor and wall coverings, architectural coatings, and cleaning products.

Very high concentrations of toluene (53.2–38,038 ppb) were detected in gas from municipal landfills in Finland (Assmuth and Kalevi 1992). Toluene can enter nearby homes by diffusion and pressure-driven transport from soil (Hodgson et al. 1988).

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of 40,000 ppb during the charbroiling of hamburger meat over a natural gas fired grill (Schauer et al. 1999a). Higher levels of toluene were detected in indoor air during the spring (4.8 ppb) than in the summer (7.70 ppb) (Mukerjee et al. 1997). Indoor and in-vehicle toluene levels appear to be affected by seasonal changes (Montgomery and Kalman 1989; Weisel et al. 1992).

Shields et al. (1996) compared volatile organic compounds measured in three types of commercial buildings (telecommunication offices, data centers, and administrative offices) across the United States. The highest amount of toluene was detected in the data centers with a geometric mean concentration of 2.68 ppb. Geometric mean concentrations of toluene measured in telecommunications offices, administrative offices, and outdoor air were 1.3, 1.5, and 0.7 ppb, respectively. The presence of aromatic compounds was found to be independent of occupant density and was attributed to presence of adhesives, building materials, floor and wall coverings, architectural coatings, and cleaning products.

Very high concentrations of toluene (53.2–38,038 ppb) were detected in gas from municipal landfills in Finland (Assmuth and Kalevi 1992). Toluene can enter nearby homes by diffusion and pressure-driven transport from soil (Hodgson et al. 1988).

5.4.2 Water

A number of surveys have been conducted to investigate the occurrence of toluene in water. Although there is wide variation from location to location, toluene appears to be a relatively infrequent contaminant of drinking water, especially for systems utilizing groundwater sources. For example, in 2 surveys performed between 1977 and 1981, toluene was detected in only 2 of 289 and 11 of 929 samples, at concentrations ranging from 0.5 to 2.9 ppb (EPA 1981). The frequency of detection of toluene in drinking water drawn from surface water sources was somewhat higher (3 of 97 and 20 of 99, respectively), although concentration ranges were similar (0.1–1.6 ppb). Toluene was detected in less than 20% of the samples of groundwater taken from alluvial aquifers beneath Denver, Colorado, a major urban center, at a maximum concentration of 1 ppb (Bruce and McMahon 1996).

Toluene was found in 60 water samples in 48 private wells in the state of Rhode Island. The total number of wells sampled and the number of samples taken was not provided. The concentrations detected ranged from 1 to 3,500 ppb (RIDH 1989). Characteristics of the well sites, such as proximity to a waste site, were not described. Toluene was detected at concentrations of 6,400 and 6,900 ppb in two groundwater sampling wells at a hazardous waste site (Armstrong et al. 1991).

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5.4.3 Sediment and Soil

No studies were located regarding levels of toluene in typical urban, suburban, or rural soils. Toluene has been occasionally detected in sediments of surface waters at concentrations averaging 5 ppb (Staples et al. 1985). Toluene was detected in the sediment of lower Passaic River, New Jersey, in the vicinity of combined sewer overflow outfalls (Iannuzzi et al. 1997). The concentrations ranged from 4.0 to 250 ppb. In the absence of continuous releases from a waste site, it is expected that toluene would not persist for long periods in soil, due to its volatility, susceptibility to biodegradation, and water solubility.

5.4.4 Other Environmental Media

Toluene was detected at average levels of 20 ppb in 23% of 150 samples of aquatic biota recorded in the STORET data base (Staples et al. 1985). The concentration of toluene in commercial foodstuffs has not been thoroughly studied. Although the data are limited, the levels of toluene in food are not likely to be significant (EPA 1981). Toluene was detected in eggs stored in polystyrene containers that contained toluene (Matiella and Hsieh 1991). Cigarette smoke is a significant source of toluene, estimated to be about 80 µg/cigarette (Grob 1965). Toluene was detected in a variety of household items including automotive products, household cleaners/polishes, paint-related products, fabric and leather treatments, lubricants and adhesives (Sack et al. 1992). The levels of toluene in these products varied from 1.8 to 23.3% by weight.

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Available data indicate that for the general population, inhalation of toluene is likely to be the main route of exposure. Assuming an average concentration in indoor and outdoor air of 2.12 ppb (EPA 1988b), and assuming inhalation of 20 m³/day and 50% absorption of inhaled toluene (EPA 1981), the typical dose by this route would be about 300 µg/day. Exposure could be higher near heavily traveled roadways or point sources of toluene, and could also be increased by frequent use of home products containing toluene. For example, in an industry-sponsored study, personal inhalation exposures to toluene during the application of nail lacquers in residences ranged from approximately 1,030 to 2,820 µg/person/day (Curry et al. 1994). The mean toluene levels measured in air during the nail laquer application ranged from 0.85 to 2.45 ppm, while the post-application concentrations ranged from 0.05 to 0.27 ppm. No toluene was detected in air prior to the nail laquer application.

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Blood concentrations of toluene have been measured in 604 non-occupationally exposed people in the United States who participated in the Third National Health and Nutrition Examination Survey (NHANES III). Participants were selected on the basis of age, race, gender, and region of residence. Toluene was detected in 75% or more of the blood samples and was present at a mean concentration of 0.52 ppb, a median concentration of 0.28 ppb, a 5th percentile concentration of 0.11 ppb, and a 95th percentile concentration of 1.5 ppb (Ashley et al. 1994). Buckley et al. (1997) compared the amount of toluene detected in the blood samples of residents of the Lower Rio Grande Valley to that detected in the NHANES III study. Toluene was found in 81% of the blood samples. The amount of toluene was found to be lower than that observed in NHANES III, the median concentration being 0.17 ppb.

Cigarette smoking may also significantly increase exposure. Assuming inhalation of about 80–100 µg of toluene per cigarette and 50% absorption (EPA 1981; Grob 1965), smoking one pack per day would contribute an absorbed dose of about 1,000 µg/day.

Toluene is a volatile component of wood smoke. Emission rates of toluene during wood combustion in home heating units have been reported in the range of 0.15–1 g/kg of wood (Larson and Koenig 1994).

Based on average values of toluene in water, exposure by ingestion of contaminated drinking water is likely to be relatively small compared to inhalation. The concentration of toluene in drinking water drawn from surface water sources is 0.15–0.25 ppb (EPA 1981), and daily intake by this route (based on ingestion of 2 L/day) would be approximately 0.3–0.5 µg/day. In a survey of bottled drinking water sold in Canada, only 20 (or 11%) of 182 samples analyzed contained measurable amounts of toluene, with an average concentration of 6.92 ppb and a range of 0.5–63 ppb (Page et al. 1993). Toluene is also known to volatilize from various household sources of water such as the kitchen sink, dishwashers, washing machines, and showers water into air; thus, its presence in tap water may ultimately result in inhalation exposure (Howard and Corsi 1996, 1998; Howard-Reed et al. 1999; Moya et al. 1999).

Exposure to gasoline (which contains toluene) has been estimated for a household using gasoline-contaminated water (Beavers et al. 1996). In this house, 694 ppb of toluene was found in the water, 664 ppb in shower air, and 14.9 ppb in non-shower air. Dermal absorption during shower-related activities accounted for 30% of the total dose. Inhalation during shower-related activities represented 25%. Ingestion represented 30%, and non-shower household inhalation 16%. The authors note that personal habits limit the general applicability of these results (Beavers et al. 1996).

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Data are not available to estimate intake of toluene from ingestion of food, but these routes are likely to be minor (EPA 1981). A number of studies have indicated significant accumulations of toluene in products for human consumption. For example, escaping gasoline vapors from internal combustion engines used or stored near olives during the growing, harvesting, storage, and processing steps in the production of virgin olive oil can cause significant contamination of the product with toluene and other hydrocarbons (Biedermann et al. 1996). Significant concentrations of toluene have also been measured in 8 of 10 species of fruit tested in a European study, which showed higher concentrations of toluene in the peel than in the pulp of the fruit (Górna-Binkul et al. 1996). Dermal absorption of toluene is not a significant route of exposure. Uptake of toluene via skin has been estimated to contribute 1–2% of the body burden received following whole body (including inhalation) exposure (Brooke et al. 1998).

Although toluene has been found to be a common contaminant at hazardous waste sites, it is not possible to estimate human exposure levels that might occur near waste sites without detailed site-specific information on concentration values in air, water, and soil, and on human intake of these media. Pathways that might be of significance include inhalation of toluene vapors, ingestion of toluene-contaminated water (surface water and/or groundwater), volatilization and inhalation from contaminated water, and dermal contact with toluene-contaminated soil.

Based on average (0.19–0.7 ppm) and maximum (0.26–2.4 ppm) concentrations of toluene in air at service stations, inhalation exposures of self-serve customers, gas station attendants, and downwind residents were estimated to be 0.057 to 0.49, 38, and 0.062 to 0.29 ppb/day, respectively (Guldberg 1992). An Alaskan study compared the concentration of toluene in blood before and after pumping of regular and oxygenated gasoline in February (Backer et al. 1997). The median concentration of toluene in blood before pumping gasoline was found to be 0.38 ppb. A greater increase was detected in the blood concentration of toluene after pumping oxygenated gasoline (0.85 ppb) than after pumping regular gasoline (0.74 ppb). Other transportation-related toluene exposure pathways include: inhalation of volatile organic compounds from contaminated air in aircraft cabins (2–135 ppb for toluene) (Dechow et al. 1997), and breathing air in long road tunnels (97–167.6 ppb) (Barrefors 1996).

Toluene exposure may also occur in the work place, especially in the printing industry where toluene is used as a solvent for inks and dyes. Occupational exposure may also occur during paint stripping operations (Vincent et al. 1994). Concentrations of 5–50 ppm are common in the workplace with some values as high as 250 ppm (1,000 mg/m³) (NCI 1985). Assuming that a worker inhales 10 m³ of air while on the job, and that 50% of the inhaled toluene is absorbed, a workplace concentration of 53.2 ppm would

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correspond to an exposure level of 1,000 mg/day. The toluene burden of rotogravure workers measured with personal monitoring tubes was found to be higher (ranging from 14.9 to 120 ppm, median=60.9 ppm) than the air concentration in the workplace (ranging from 37.5 to 87.2 ppm, median=62.8 ppm) (Hammer et al. 1998). In another study, the blood of rotogravure workers was tested before and after the use of toluene to clean containers for the primary printing colors (Muttray et al. 1999). The concentration of toluene in their blood was found to increase from 0.87 to 4.9 ppm. In addition, dermal exposure might also occur from contact with toluene-containing materials, contributing perhaps 20 mg/use (EPA 1981). Personnel working with various types of fuel may be at a risk of toluene exposure. A Finnish study determined the exposure of gasoline tanker drivers to toluene during loading and delivery to be 0.4–2.9 ppm (Hakkola and Saarinen 1996; Saarinen et al. 1998). The exposure level of aircraft maintenance personnel to toluene in raw JP-8 jet fuel vapor was found to be 6.3 ± 1.6 ppm (Smith et al. 1997).

Art materials, especially painting supplies, represent another potential source for exposure to toluene for people of all ages and to people who spend time near an artist's work area or studio, which for about 50% of professional artists is in the home (McCann 1992). Case reports on acute toluene poisoning of workers installing a parquet floor in Singapore (Tan and Seow 1997) and on excessive exposure to toluene in a wood furniture manufacturing facility in the U.S. (Paulson and Kilens 1996) have also been reported. A group of Dutch carpet-layers using water-based adhesives were exposed to an 8-hour average concentration of toluene in the range of 0.27–76.87 ppm, while carpet-layers using contact adhesives were exposed to an 8-hour average concentration of 4.25–161.2 ppm (Muijser et al. 1996). Measurement data for fire-fighters occupationally exposed to combustion products in three separate building fires indicated they were exposed to an average concentration of 0.23 ppm toluene during the time they were fighting the fires (McDiarmid et al. 1991).

Workplace exposure to toluene and other volatiles is associated with the plastics industry (Socie et al. 1997), emissions from waste waters in municipal sewage treatment plants (Bianchi and Varney 1997), with sculptured nail manicure salons (Hiipakka and Samimi 1987), and with hair salons (Hollund and Moen 1998). Combinations of solvents can enhance the dermal penetration of toluene. Methanol enhances the skin absorption of toluene. Special precautions need to be taken against the skin absorption of toluene when handling paint thinners that contain methanol (Tsuruta 1996).

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5.6 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 2.7 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, and 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, they put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and they spend more time outdoors. Children also are closer to the ground, and they do not have the judgment of adults to avoid hazards (NRC 1993).

Exposures of the embryo or fetus to volatile organic compounds such as toluene may occur if the expectant mother is exposed to high levels that overwhelm maternal protective mechanisms including metabolic detoxification and disposition of toluene and possible preferential distribution of toluene to maternal adipose tissues (see Sections 2.3 and 2.5). A newborn infant may be exposed by breathing contaminated air and through ingestion of mother's milk that can contain small amounts of toluene. Children may be exposed through accidental ingestion of products containing toluene. Older children and adolescents may be exposed to toluene in their jobs or hobbies, or through deliberate solvent abuse by "sniffing." Human epidemiological studies and case reports discussing reproductive and/or developmental toxicity of toluene in humans have been reviewed. Exposure routes included occupational duties and sniffing of paints, paint reducers, and paint thinners (Donald et al. 1991b). Inhalant abuse during pregnancy poses significant risks to the pregnancy and endangers both the mother and the fetus. Solvent abuse of toluene for euphoric effects results in exposure levels that equal or exceed those producing adverse effects in animals.

Transfer of toluene to nursing infants from breast milk of currently exposed mothers is expected to be a possibility because of the lipophilicity of toluene and the relatively high lipid content of breast milk. Mobilization during pregnancy or lactation of stored toluene from pre-conception exposure, however, does not appear to be a major concern because most toluene is rapidly eliminated from the body (see Sections 2.3.4 and 2.7). There is also a risk for an adverse effect on the lactation process itself and the

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nutritional content of the milk. Women should be counseled about the effects of workplace exposure while breast-feeding (Byczkowski et al. 1994). A physiologically based pharmacokinetic model (PBPK) has been developed to estimate the amount of chemical that an infant ingests for a given nursing schedule and daily maternal occupational exposure to 50 ppm toluene for 8 hours (Fisher et al. 1997). This PBPK model predicted an ingestion rate of 0.460 mg/day for such an infant.

Young children often play close to the ground and frequently play in dirt, which increases their dermal exposure to toxicants in dust and soil. They also tend to ingest soil, either intentionally through pica or unintentionally through hand-to-mouth activity. Children may be orally and dermally exposed to toluene present as a contaminant in soil and dust, but toluene is not expected to persist for long periods in soil (in the absence of continuous release) due to its volatility, susceptibility to bacterial degradation, and water solubility. It has been demonstrated that the toluene adsorbed on soil is absorbed by the body (Turkall et al. 1991). Toluene in both aqueous solution and vapor phase has also been shown to be absorbed through the human skin, albeit slowly (Brooke et al. 1998; Dutkiewicz and Tyras 1968; Tsuruta 1989). Toluene has a log organic carbon-water partition coefficient of 2.25, indicating moderate adsorption to soil, especially to soil with high organic matter (Wilson et al. 1981). Most of the toluene present in the upper layers of the soil is volatilized to air within 24 hours (vapor pressure=28.4 mmHg at 25 EC) (Balfour et al. 1984; Thibodeaux and Hwang 1982). The degradation half-life of toluene is 1–7 days in soil (API 1984). Loss of toluene from the soil decreases the potential of dermal and oral exposure to children, but its rapid volatilization results in inhalation being the most likely route of exposure.

Children breathe in more air per kilogram of body weight than an adult. Therefore, a child in the same micro-environment as an adult may be exposed to more toluene from ambient air. Young children are closer to the ground or floor because of their height. The toluene vapors being heavier than air (vapor density=3.14 g/mL) tend to concentrate near the ground. The children, therefore, may be at greater risk of exposure than adults during accidental spills of toluene.

Children may also be exposed to fumes of toluene and other hydrocarbons by working with or playing near sources of gasoline. Children's exposure also occurs through accidental ingestion and inspiration of the chemicals into the lungs. Asthma, pneumonia, pulmonary damage, and death can result. Most accident victims are one- and two-year olds and are about evenly divided between males and females. Most incidents occur in the children's homes and the products are in their normal storage areas. Child-resistant packaging is recommended (Journal of Environmental Health 1997). Children are also exposed to higher concentrations of toluene in central urban areas with high traffic density, where children's blood

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toluene concentrations are, on average, 56% higher than those of children living in rural areas (Jermann et al. 1989; Raaschou-Nielson et al. 1997).

Children are also exposed through hobbies and art activities involving glues, adhesives, and paints (McCann 1992). Abuse of toluene-containing products among young people by inhalation (“sniffing”) is a social and clinical concern (Young 1987).

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

In addition to individuals who are occupationally exposed to toluene (see Section 5.5), there are several groups within the general population that have potentially high exposures (higher than background levels) to toluene. These populations include individuals living in proximity to sites where toluene was produced or sites where toluene was disposed, and individuals living near one of the 959 NPL hazardous waste sites where toluene has been detected in some environmental media (HazDat 2000).

The population most likely to experience high levels of exposure to toluene are workers in the printing industry or other industries employing toluene as a solvent. In addition, workers exposed to gasoline vapors are also likely to have higher than average exposure to toluene. Individuals may also be exposed to high levels at home in association with the use of toluene-containing consumer products. Smokers have a considerably higher exposure to toluene than nonsmokers.

Toluene has been frequently identified as a water contaminant in the proximity of hazardous waste sites. Drinking water sources for populations living near a hazardous waste site containing toluene should be evaluated for toluene. If groundwater wells are contaminated, exposure to toluene can occur when the well-water is used for showering, cleaning, cooking, and drinking purposes. Exposure can also occur through contact with contaminated soil.

A troublesome route of exposure to toluene is through deliberate inhalation of fumes from paint thinners, gasoline, glues contact adhesives, and aromatic solvents. Inhalant abuse can affect pregnancy outcome (Jones and Balster 1998). Inhalant abuse is an urgent health care problem among youth, including American Indians (Young 1987). Contact adhesives often contain toluene, heptane, and methyl ethyl ketone. Although toluene is more toxic than the other ingredients, it evaporates more slowly. Thus the vapors inhaled when “sniffing” such adhesives will contain less toluene and should be less toxic than would be expected from its liquid composition (Midford et al. 1993).

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5.8 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 toluene is available. Where adequate information is not available, ATSDR, in conjunction with the National Toxicology Program (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 toluene.

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.

5.8.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of toluene that are needed to evaluate its behavior in the environment are available (Table 3-2). It does not appear that further research in this area is essential.

Production, Import/Export, Use, Release, and Disposal. As of October 1, 1996, the International Trade Commission ceased to collect or publish annual synthetic organic chemicals data. The National Petroleum Refiners Association, which currently collects such data, does not include toluene on its list of organic chemicals. The available production data of toluene are out of date. It is essential that these data be updated regularly to allow a more accurate determination of the potential for human exposure.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. This database, Toxic chemical Release Inventory (TRI), will be updated yearly and should provide a list of industrial production facilities and emissions. Available information appears to be adequate for assessing industrial production and the potential for release of toluene at this time. Additional information concerning home-use products containing toluene and their disposal are needed. Household

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hazardous waste disposal programs are in their infancy and there are few data on the amounts of waste processed through these programs.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1996, became available in May of 1998. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Environmental Fate. Existing information indicates that volatilization, followed by reaction with hydroxyl radicals in air, is the principal fate process for toluene in the environment (Davis et al. 1979; Hoshino et al. 1978; Howard et al. 1991; Kenley et al. 1973). The rate constants for this process have been established, although further refinements would improve the ability to model the fate of toluene emissions. Although toluene is not a common contaminant in water, it has been found to occur in both groundwater and surface water near waste sites (HazDat 2000). Additional studies on the rate of volatilization, degradation, and transport of toluene in groundwater, surface water, and soils would be useful for assessing potential human exposure near hazardous waste sites.

Considerable data are available concerning the genetics of toluene-degrading microorganisms (Fewson 1981; Harayama et al. 1989), but distinctions need to be made between the activities of microorganisms found naturally in the soil and water, and those that are genetically engineered for use in bioremediation projects. Quantitative characterization of the end products of biodegradation and information concerning this fate would also be helpful.

Bioavailability from Environmental Media. On the basis of the available data, toluene appears to be highly bioavailable when it is released to the environment. Inhalation, oral, and dermal absorption occur due to toluene solubility in the lipid matrix of the cell membrane (Alcorn et al. 1991). Absorption is rapid and virtually complete at low exposure concentrations when exposures are oral or respiratory (Alcorn et al. 1991; Carlsson and Ljungqvist 1982; Hjelm et al. 1988). Adsorption also occurs through contact with the skin (Dutkiewicz and Tyras 1968). Additional research on bioavailability of toluene from the environment does not appear to be needed.

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Food Chain Bioaccumulation. Very little information was identified pertaining to the bioaccumulation of toluene in the food chain. Despite its lipid solubility, the bioconcentration factor for toluene is expected to be relatively low due to its rapid metabolism to more polar molecules with a lower affinity for lipids, and it has little tendency to bind to biomolecules. Additional research efforts pertaining to bioaccumulation of toluene would be justified for cold water fish with relatively high fat content and for plants used as a source of vegetable oils. It would be helpful to know if toluene becomes incorporated in the lipid deposits of these organisms. Although there has been little data collected concerning the tendency for toluene to biomagnify in the environment, available data on bioconcentration suggest that research on this topic is not needed.

Exposure Levels in Environmental Media. The concentration of toluene in ambient air and in drinking water has been the subject of numerous studies (Bruce and McMahon 1996; EPA 1981, 1988b, 1991c; HazDat 2000; Kelly et al. 1993; Lebret et al. 1986; Michael et al. 1990b; Montgomery and Kalman 1989; Otson et al. 1983; RIDH 1989), but there is a need to maintain the currency of the data. Further studies on toluene levels in food and soil would be useful, since quantitative data for these media are limited. The potential exists for toluene to be present in human and bovine milk due to its lipid solubility, but studies of exposure through these media were not identified. In view of the observation that the highest levels of toluene likely to be encountered by an average citizen occur in the home, studies that identify the sources of toluene in indoor air would be valuable in reducing or eliminating this pathway of exposure.

Reliable monitoring data for the levels of toluene in contaminated media at hazardous waste sites are needed. The information thus obtained on levels of toluene in the environment can be used in combination with the known body burdens of toluene to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites.

Exposure Levels in Humans. Data from the Total Exposure Assessment Methodology study (EPA 1987c) provide information on the concentration of toluene in the expired air of humans in relation to levels in the air breathed by the individual. Exposure of the general population to toluene in air has been monitored for a variety of scenarios (Backer et al. 1997; Beavers et al. 1996; Biedermann et al. 1996; Curry et al. 1994; EPA 1981; Grob 1965; Guldeberg 1992; Larson and Koenig 1994; Page et al. 1993). Amounts of toluene volatilizing from the household sources such as the kitchen sink, dishwashers, washing machines, and showers have also been estimated (Howard and Corsi 1996, 1998; Howard-Reed et al. 1999; Moya 1999). Combination of this data with appropriate toxicokinetic models of toluene

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absorption, distribution, and excretion in humans would allow for improved estimates of exposure levels in humans. Toluene exposure in the workplace is well documented (Hammer et al. 1998; Hiipakka and Samimi 1987; McCann 1992; McDiarmid et al. 1991; Muijser et al. 1996; Muttray et al. 1999; NCI 1985; Paulson and Kilens 1996; Smith et al. 1997; Tan and Seow 1997; Vincent et al. 1994). Continued monitoring will help to minimize exposure of workers. A study of toluene in human milk of occupationally exposed women may be useful in evaluating the risks to this population of mothers and infants. This information would be useful to assess the desirability of conducting health studies on exposed populations.

Exposures of Children. A study on the usefulness of intervention methods in cases of inhalant abuse by pregnant women may help to develop better means of preventing high-level exposure to toluene and other solvents. More research is needed to rule out concomitant risk factors and to identify specific chemicals and patterns of use associated with adverse effects.

Children may be at a greater risk of inhalation exposure to toluene as they breathe in more air per kilogram of body weight than an adult. They also spend more time closer to ground because of their height. Toluene vapors, being heavier than air, tend to concentrate closer to the ground, thereby increasing the risk of exposure for children. No data are available on the exposure of the children to toluene present in the air.

Means of protecting young children from ingestion of home products containing toluene need study and action. Child-proof containers and clearer warnings to parents should be considered to avoid unwanted exposure.

Child health data needs relating to susceptibility are discussed in Section 2.12.2, Identification of Data Needs: Children's Susceptibility.

Exposure Registries. No exposure registries for toluene were located. This substance is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for subregistries 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.

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5.8.2 Ongoing Studies

As part of the Third National Health and Nutrition Evaluation Survey (NHANES III), the Environmental Health Laboratory Sciences Division of the National Center for Environmental Health, Centers for Disease Control and Prevention, will be analyzing human blood samples for toluene and other volatile organic compounds. These data will give an indication of the frequency of occurrence and background levels of these compounds in the general population.

A number of ongoing research efforts will provide data regarding the potential for human exposure to toluene. These projects are summarized in Table 5-3. The EPA is also sponsoring the National Human Adipose Tissue Survey (NHATS), and this will provide additional data on the range of concentrations of toluene found in human fat samples taken during surgery or autopsy.

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Table 5-3. Ongoing Studies on the Potential for Human Exposure to Toluene

Investigator	Affiliation	Research description	Sponsor
Christiani, D.C.	Harvard School of Public Health	Effects on reproductive outcome of occupational exposure to aromatic solvents in the oil industry	NIOSH
Alexander, M.	Cornell University	Effects of aging of pollutants for soil on bioavailability	NIEHS
Rappaport, S.M.	University of North Carolina, Chapel Hill	Development and application of biomarkers of exposure	NIEHS
Abroila, L.M.	Michigan State University	Persistence of NAPL contaminants in natural subsurface systems	NIEHS
Balster, R.L.	Texas Tech University	Behavioral pharmacology of abused solvents	NIDA
Spormann, A.M.	Stanford University	Enzymatic studies on the initial steps of anaerobic toluene and xylene metabolism	NSF

NIDA = National Institute of Drug Abuse; NIEHS = National Institutes of Health Science; NIOSH = National Institute for Occupational Safety and Health; NSF = Nation Science Foundation