

## 6. POTENTIAL FOR HUMAN EXPOSURE

### 6.1 OVERVIEW

Toluene has been identified in at least 990 of the 1,832 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (ATSDR 2015). However, the number of sites in which toluene has been evaluated is not known. The frequency of these sites can be seen in Figure 6-1. Of these sites, 983 are located within the United States, 5 are located in the Commonwealth of Puerto Rico, and 2 are located in the Virgin Islands.

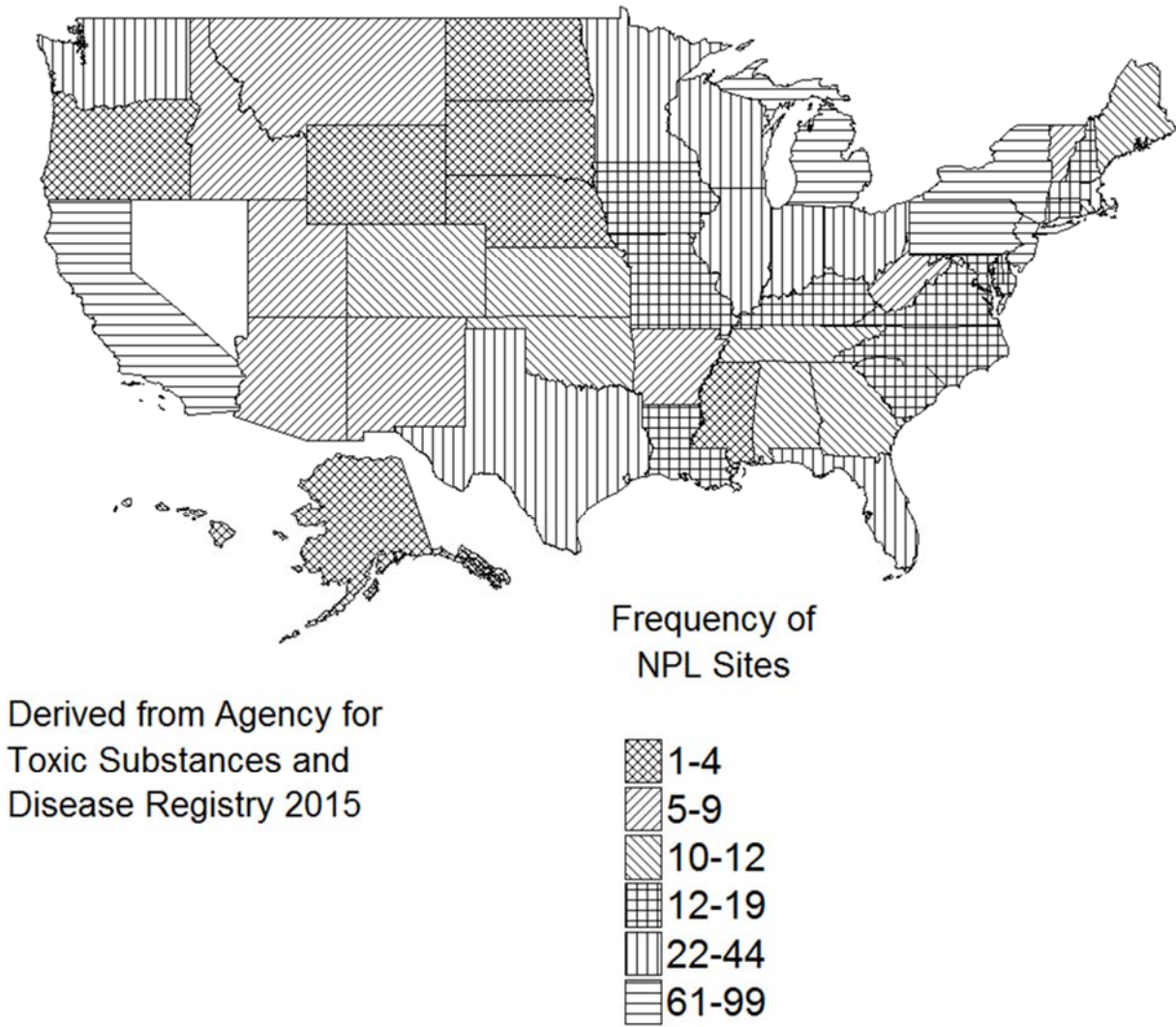
The majority of toluene released to the environment partitions to air. Large amounts of toluene enter the environment each year from production, use, and disposal of industrial and consumer products that contain toluene. The largest source of toluene emissions occurs during the production, transport, and use of gasoline. 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 (Howard et al. 1991). Toluene in soil or water rapidly volatilizes to air, and that which remains is subject to microbial degradation. As a result of volatilization and degradation occurring in air, soil, and water, toluene levels are not expected 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 are higher 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. Levels of toluene in the air are usually higher in urban areas that are heavily congested with traffic (21.4–98.1 ppbv or 80.5–368.9  $\mu\text{g}/\text{m}^3$ ). Levels in the same study were much lower in the outdoor air in less-congested urban areas (1.95 ppbv or 7.3  $\mu\text{g}/\text{m}^3$ ) (Baltrenas et al. 2011). Toluene is also a common indoor contaminant, and indoor air concentrations are often several times higher 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.

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**Figure 6-1. Frequency of NPL Sites with Toluene Contamination**



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Toluene is occasionally detected in drinking water supplies due to industrial water discharges or from contaminated surface water, but occurrence is not widespread and levels are generally much lower than levels found in the air. In contrast, toluene is a very common contaminant of water and soil in the vicinity of hazardous waste sites.

The most likely pathway by which the general population 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. 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. Gas service station workers can be exposed to toluene from the gasoline. Petroleum and coke plant workers may also be exposed to higher levels of toluene than the general population.

## 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  $\geq 25,000$  pounds of any TRI chemical or otherwise uses  $>10,000$  pounds of a TRI chemical in a calendar year (EPA 2005b).

According to the Toxics Release Inventory (TRI), in 2015 approximately 25 million pounds (11 million kg) of toluene was released to the environment from 2,198 manufacturing or processing facilities in the

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United States (TRI15 2016). The most recent TRI data continues to reflect a decline in the total amount of toluene released from facilities required to report to the TRI. Total on- and off-site releases of toluene were approximately 57, 48, 42, 36, 30, 32, 29, 27, and 25 million pounds in 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2015, respectively (TRI15 2016). Table 6-1 lists the amounts released from these facilities to air, water, land, and publicly owned treatment works (POTWs). Table 6-1 also shows that ~1% of the total released was injected deep underground and that ~1.1 million pounds of toluene were transferred off-site (TRI15 2016). The relative proportions of the material transferred off-site that were recycled or entered environmental media are not stated. Releases of toluene to the environment have decreased when compared to data from 1997.

**6.2.1 Air**

Estimated releases of 22 million pounds (~10,000 metric tons) of toluene to the atmosphere from 2,198 domestic manufacturing and processing facilities in 2015, accounted for nearly 90% of the estimated total environmental releases from facilities required to report to the TRI (TRI15 2016). These releases are summarized in Table 6-1.

EPA's National Emission Inventory (NEI) database contains data regarding sources that emit criteria air pollutants and their precursors, and hazardous air pollutants (HAPs) for the 50 United States, Washington DC, Puerto Rico, and the U.S. Virgin Islands. The NEI database derives emission data from multiple sources, including state and local environmental agencies, the TRI database, computer models for on-road and off-road emissions, and databases related to EPA's Maximum Achievable Control Technology (MACT) programs to reduce emissions of HAPs. Data downloaded from the 2011 NEI (see Table 6-2) indicated that the total emission of toluene was approximately 1,730,000,000 pounds (785,000 tons), with the biggest contribution arising from consumer and commercial solvent use (EPA 2013a). Nearly all toluene entering the environment is released directly to air or partitions to the atmosphere due to its relatively high vapor pressure (EC 2003). A major source of toluene emissions arises from gasoline use, which typically includes emissions from motor vehicle exhaust, gasoline storage tanks, filling stations, petroleum spills, etc. (EC 2003; Verschueren 1977). The emission rate of toluene from motor vehicle traffic in a Los Angeles roadway tunnel was found to be 748 mg/L of gasoline consumed (Fraser et al. 1998). In addition, the global release from automobile exhaust is estimated to be around 3–8 metric tons per year, and the emission factors from gasoline were  $2.22 \times 10^{-5}$ – $8.46 \times 10^{-4}$  lb/vehicle mile traveled for evaporation from automobile fuel tanks and automobile exhaust emissions (EPA 1994).

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**Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Toluene<sup>a</sup>**

State <sup>c</sup>	RF <sup>d</sup>	Reported amounts released in pounds per year <sup>b</sup>							Total release	
		Air <sup>e</sup>	Water <sup>f</sup>	UI <sup>g</sup>	Land <sup>h</sup>	Other <sup>i</sup>	On-site <sup>j</sup>	Off-site <sup>k</sup>	On- and off-site	
AK	7	11,916	8	0	162	0	12,087	0	12,087	
AL	47	400,857	3	0	767	19,877	400,861	20,643	421,504	
AR	18	99,591	45	2,051	1	351	101,687	352	102,038	
AZ	23	86,726	0	0	384	926	86,976	1,060	88,036	
CA	112	197,493	49	20	837,096	5,629	1,032,978	7,309	1,040,287	
CO	23	88,923	0	0	342	0	89,173	92	89,265	
CT	25	55,484	59	0	59	0	55,543	59	55,602	
DE	7	12,944	5	0	0	0	12,949	0	12,950	
FL	43	212,880	27	0	200	23,975	212,907	24,175	237,082	
GA	50	618,693	45,625	0	1,003	5,260	664,318	6,263	670,581	
GU	2	5,418	0	0	13	0	5,418	13	5,431	
HI	10	24,888	20	1	10	0	24,909	10	24,919	
IA	44	325,450	2	0	135	1,321	325,452	1,456	326,908	
ID	4	11,862	0	0	5,412	0	11,862	5,412	17,274	
IL	118	615,479	662	2,537	1,989	9,312	616,345	13,634	629,979	
IN	90	1,368,943	481	0	118,177	222,875	1,461,549	248,927	1,710,476	
KS	39	543,168	115	494	8,235	262	544,198	8,076	552,275	
KY	47	1,302,536	1,725	0	931	10,526	1,304,528	11,190	1,315,718	
LA	80	1,086,098	794	4,228	85,957	1,833	1,165,289	13,621	1,178,909	
MA	49	235,372	5	0	48	34,534	235,377	34,582	269,959	
MD	13	8,754	27	0	1	500	8,781	501	9,282	
ME	5	3,530	1	0	22	685	3,532	707	4,239	
MI	98	1,169,092	68	50	34,769	15,358	1,169,372	49,965	1,219,337	
MN	34	436,827	12	0	3,357	0	436,838	3,357	440,195	
MO	52	180,166	51	0	1,160	3,811	180,227	4,961	185,188	
MP	2	1,108	0	0	0	0	1,108		1,108	
MS	32	342,669	411	0	2,710	47	343,080	2,757	345,837	
MT	5	50,563	3	0	4,714	3,238	50,568	7,950	58,518	
NC	63	1,049,367	6	0	3,756	47,278	1,049,373	51,034	1,100,407	
ND	14	39,787	1	1	19	3	39,792	19	39,811	
NE	21	20,843	0	0	18,685	20,838	20,843	39,523	60,366	
NH	5	9,796	0	0	0	3	9,796	3	9,799	
NJ	48	124,496	619	110	1,251	11,771	125,115	13,133	138,248	
NM	9	41,455	0	0	227	2,887	41,455	3,114	44,569	
NV	12	308,684	0	0	24,711	0	333,395	No data	333,395	
NY	68	355,382	21	0	733	3,247	355,405	3,978	359,382	
OH	150	633,201	41	1,699	22,455	63,229	633,601	87,024	720,626	
OK	32	858,559	522	762	308	9,897	859,474	10,574	870,048	
OR	26	95,837	9	0	36,643	889	129,378	4,000	133,378	

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**Table 6-1. Releases to the Environment from Facilities that Produce, Process, or Use Toluene<sup>a</sup>**

State <sup>c</sup>	RF <sup>d</sup>	Reported amounts released in pounds per year <sup>b</sup>							
		Air <sup>e</sup>	Water <sup>f</sup>	UI <sup>g</sup>	Land <sup>h</sup>	Other <sup>i</sup>	Total release		On- and off-site
							On-site <sup>j</sup>	Off-site <sup>k</sup>	
PA	93	1,507,854	415	0	14,884	12,556	1,508,269	27,440	1,535,709
PR	13	31,776	0	0	0	0	31,776	No data	31,776
RI	10	15,433	12	0	0	7,277	15,445	7,277	22,722
SC	44	2,330,401	260	8	43	24,855	2,330,688	24,879	2,355,567
SD	9	61,382	0	0	0	0	61,382	No data	61,382
TN	66	1,124,815	87	0	1,126	2,444	1,124,978	3,494	1,128,472
TX	259	1,604,315	1,219	246,601	34,441	66,292	1,862,139	90,730	1,952,869
UT	16	75,632	5	0	161	598	75,692	704	76,396
VA	46	814,544	160	0	44,429	6,847	814,704	51,276	865,980
VI	2	11,352	0	0	91	0	11,441	1	11,442
VT	2	1,790	0	0	0	0	1,790	No data	1,790
WA	24	237,705	13	0	1,875	15	238,356	1,252	239,608
WI	60	948,096	0	0	8,121	228,570	951,876	232,911	1,184,786
WV	16	273,150	324	0	1,694	1,346	273,488	3,026	276,513
WY	11	40,531	5	0	391	0	40,549	378	40,927
Total	2,198	22,113,612	53,918	258,562	1,323,699	871,163	23,498,112	1,122,841	24,620,953

<sup>a</sup>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.

<sup>b</sup>Data in TRI are maximum amounts released by each facility.

<sup>c</sup>Post office state abbreviations are used.

<sup>d</sup>Number of reporting facilities.

<sup>e</sup>The sum of fugitive and point source releases are included in releases to air by a given facility.

<sup>f</sup>Surface water discharges, waste water treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).

<sup>g</sup>Class I wells, Class II-V wells, and underground injection.

<sup>h</sup>Resource Conservation and Recovery Act (RCRA) subtitle C landfills; other onsite landfills, land treatment, surface impoundments, other land disposal, other landfills.

<sup>i</sup>Storage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown

<sup>j</sup>The sum of all releases of the chemical to air, land, water, and underground injection wells.

<sup>k</sup>Total amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI15 2016 (Data are from 2015)

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**Table 6-2. 2011 NEI Total National Emissions of Toluene**

Emission source	Emissions in tons
Agriculture, livestock waste	2.566
Bulk gasoline terminals	1,989.817
Commercial cooking	646.584
Dust, construction dust	0.149
Fires, agricultural field burning	5,788.053
Fires, prescribed fires	24,784.188
Fires, wildfires	30,548.719
Fuel combustion, commercial/institutional, biomass	4.724
Fuel combustion, commercial/institutional, coal	0.230
Fuel combustion, commercial/institutional, natural gas	75.153
Fuel combustion, commercial/institutional, oil	4.905
Fuel combustion, commercial/institutional, other	3.239
Fuel combustion, electric generation, biomass	509.470
Fuel combustion, electric generation, coal	92.209
Fuel combustion, electric generation, natural gas	325.570
Fuel combustion, electric generation, oil	10.029
Fuel combustion, electric generation, other	17.986
Fuel combustion, Industrial boilers, ices, biomass	157.859
Fuel combustion, Industrial boilers, ices, coal	3.036
Fuel combustion, Industrial boilers, ices, natural gas	407.576
Fuel combustion, Industrial boilers, ices, oil	19.987
Fuel combustion, Industrial boilers, ices, other	31.980
Fuel combustion, residential, natural gas	52.243
Fuel combustion, residential, oil	1.146
Fuel combustion, residential, other	0.038
Fuel combustion, residential, wood	4,118.312
Gas stations	31,251.987
Industrial processes, cement manuf	26.102
Industrial processes, chemical manuf	2,094.087
Industrial processes, ferrous metals	58.466
Industrial processes, mining	6.779
Industrial processes, NEC	2,533.374
Industrial processes, non-ferrous metals	39.259
Industrial processes, oil and gas production	9,281.628
Industrial processes, petroleum refineries	710.439
Industrial processes, pulp and paper	111.692
Industrial processes, storage and transfer	2,487.106
Miscellaneous non-industrial NEC	7,290.227

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**Table 6-2. 2011 NEI Total National Emissions of Toluene**

Emission source	Emissions in tons
Mobile, aircraft	463.492
Mobile, commercial marine vessels	39.694
Mobile, locomotives	187.259
Mobile, non-road equipment, diesel	1,857.913
Mobile, non-road equipment, gasoline	144,745.874
Mobile, non-road equipment, other	4.067
Mobile, on-road diesel heavy duty vehicles	1,567.312
Mobile, on-road diesel light duty vehicles	44.951
Mobile, on-road gasoline heavy duty vehicles	10,911.517
Mobile, on-road gasoline light duty vehicles	194,777.346
Solvent, consumer and commercial solvent use	282,997.039
Solvent, degreasing	365.751
Solvent, dry cleaning	0.330
Solvent, graphic arts	4,271.392
Solvent, industrial surface coating and solvent use	58,964.001
Solvent, non-industrial surface coating	37,149.628
Waste disposal	3,232.753
<b>Sum</b>	<b>867,067.23</b>

NEC = not elsewhere classified; NEI = National Emission Inventory

Source: EPA 2013a



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BTEX emissions are primarily due to incomplete combustion of petroleum fuels from gasoline and volatilization of BTEX-based solvents and thinners. BTEX is often studied together because these chemicals comprise 60% of the water-soluble fraction of gasoline (CCME 2004). Toluene, along with the other aromatic hydrocarbons, is added to gasoline to raise the octane rating (Ozokwelu 2006).

Toluene is used in paints, solvents, adhesives, inks, and similar products and is also released to air upon use. Toluene is also emitted from building and finishing materials in newly constructed apartments. Indoor air exposure to a chemical that is generated at the source (from paints, varnishes, and adhesives) can be of a greater risk than ambient air exposure. Toluene was found at mean concentrations of 63.03  $\mu\text{g}/\text{m}^3$  (lower floor), 66.06  $\mu\text{g}/\text{m}^3$  (middle floor), and 27.16  $\mu\text{g}/\text{m}^3$  (highest floor) in newly constructed apartment buildings in Korea that had been finished with vinyl wallpaper and plywood. The outdoor concentration of toluene in the same study was 11.05  $\mu\text{g}/\text{m}^3$ . Calculated mean emission rates for toluene were 4,168  $\mu\text{g}/\text{hour}$  (lower floor), 4,171  $\mu\text{g}/\text{hour}$  (middle floor), and 7,356  $\mu\text{g}/\text{hour}$  (highest floor). The authors suggest that an increase in the ventilation on the highest floor may lead to an increase in emissions from the inner surfaces (Sim et al. 2010).

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)  $\mu\text{g}/\text{kg}$  waste for uncontrolled emissions and 177–3,000 (mean=1,920)  $\mu\text{g}/\text{kg}$  waste for controlled emissions (Walker and Cooper 1992). Toluene emissions from coal-fired power stations (119  $\mu\text{g}/\text{m}^3$ ) were reported to be far less than toluene emissions from diesel engines (167–287  $\mu\text{g}/\text{m}^3$ ) and automobiles (15,700–370,000  $\mu\text{g}/\text{m}^3$ ); all measurements were obtained at standard temperature and pressure (20°C and 1 atmosphere pressure) (Garcia et al. 1992).

### 6.2.2 Water

Estimated releases of ~54,000 pounds (~245 metric tons) of toluene to surface water from 2,198 domestic manufacturing and processing facilities in 2015, accounted for about 0.2% of the estimated total environmental releases from facilities required to report to the TRI (TRI15 2016). These releases are summarized in Table 6-1.

Toluene may be released to water from industrial discharges and urban wastes, or by spills and leakage of gasoline. However, these releases are believed to comprise only a small fraction of the amount of toluene

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released to air (EPA 1983b). Emissions into the water and soil sometimes lead to re-emission of toluene into the air (EC 2003).

Toluene can be released to groundwater following large surface spills of BTEX-containing components such as diesel fuel or conventional gasoline. For example, Gross et al. (2013) analyzed groundwater data following surface spills associated with hydraulic fracturing operations in the state of Colorado. The mean concentration of toluene in 218 groundwater samples associated with surface spills was 750 µg/L and the 95<sup>th</sup> percentile concentration was 1,900 µg/L. Some individual samples inside the excavation areas of the spill sites had levels as high as 10,000 µg/L.

### 6.2.3 Soil

Estimated releases of 1.3 million pounds (~590 metric tons) of toluene to soils from 2,198 domestic manufacturing and processing facilities in 2015, accounted for about 5% of the estimated total environmental releases from facilities required to report to the TRI (TRI15 2016). An additional ~258,500 pounds (~117 metric tons), constituting ~1% of the total environmental emissions, were released via underground injection (TRI15 2016). These releases are summarized in Table 6-1.

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. Releases of BTEX to the soil also occur from accidents and spills during transportation and pesticide applications (CCME 2004). In some cases, releases might be significant on a local scale; however, the total amount of toluene released to the environment in soil is considered to be negligible (EPA 1983b).

## 6.3 ENVIRONMENTAL FATE

### 6.3.1 Transport and Partitioning

Toluene is a volatile liquid at room temperature. Due to its high vapor pressure (28.4 mmHg at 25°C), the majority of toluene released to the environment partitions to air. As discussed in Section 6.2, most toluene is released directly into air, and that which is released to surface water or soil tends to volatilize quickly (EC 2003). Toluene rapidly volatilizes from surface water to air, with a half-life on the order of a few hours at 25°C; however, the volatilization rate is dependent upon conditions of the water body (e.g., depth, current) and the atmosphere (e.g., wind speeds). Laboratory studies also indicate that surfactants can affect volatilization of toluene from water (Anderson 1992).

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The rate of volatilization from soils depends on temperature, humidity, and soil type; however, under typical conditions, toluene rapidly volatilizes from soils based on its Henry's Law constant and vapor pressure (CCME 2004; HSDB 2010).

Toluene is expected to have high to moderate mobility in soil; the soil adsorption coefficient ( $K_{oc}$ ) values of 37–178 indicate that toluene is not expected to be strongly bound to the soil (HSDB 2010). Humidity interferes with the adsorption of toluene vapors into soils, with sorption primarily occurring with water vapor rather than toluene in low humidity (Chen and Wu 1998).

Adsorption of toluene to soil is possible under certain conditions. Distilled water removed 9–40% of the toluene adsorbed to samples of five different soils of low organic content within 24 hours, but after 7 days, some of the toluene still remained adsorbed to the soil samples (Pavlostathis and Mathavan 1992). Sorption of toluene can also be dependent on the size of the particles in soils. BTEX was adsorbed more in montmorillonite or illite clays, and less in kaolinite (Site 2001). A gravimetric method indicated 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). Temperature is also inversely related to adsorption (Site 2001).

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).

Toluene is expected to have a low tendency to bioconcentrate in the fatty tissues of aquatic organisms based on its measured BCF values (Franke et al. 1994). The bioconcentration factor (BCF) values were reported to be 8, 13, and 90 in herring, eels, and golden ide fish, respectively (EC 2003).

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**6.3.2 Transformation and Degradation****6.3.2.1 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). Secondary organic aerosol products from the photooxidation of toluene include carbonyl products (Cao and Jang 2008).

Processes for removing toluene from the air include adsorption, thermal and catalytic combustion, photocatalytic combustion, and biological methods. Biological methods include biotrickling filters, which are filters that move the polluted air and a recycled liquid through a packed bed for the creation of a biofilm. These biofilms facilitate the degradation of toluene in the air for pollution control (Cox et al. 2000). Experiments have been conducted in which *Acinetobacter* genospecies, a toluene-degrading bacteria, was isolated from a trickle bed air biofilter (TBAB). This newer bacteria showed excellent degradation capabilities. Biofilters are a relatively inexpensive way to eliminate toluene in the air (Hori et al. 2001).

Recently, non-thermal plasma techniques have become prevalent innovative techniques in removing volatile organic compounds from the air. Toluene was removed in a non-thermal reactor at room temperature with a 93% removal efficiency. The experiment yielded decomposition products that included ozone, carbon dioxide, nitric oxide, and nitrogen dioxide (Mista and Kacprzyk 2008).

**6.3.2.2 Water**

There is potential for rapid degradation of toluene in water, especially if there is an electron acceptor available for oxidation (Evans et al. 1991). In surface waters, the biodegradation half-life of toluene was estimated to range from 4 to 22 days and the biodegradation half-life of toluene in groundwater was estimated to range from 7 to 28 days (Howard et al. 1991).

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However, groundwater sometimes contains low amounts of dissolved oxygen. Anaerobic degradation of toluene, in this case, is an important fate process in the water (Evans et al. 1991). The biodegradation of toluene in groundwater can be enhanced by the presence of alternative electron acceptors, such as sulfate, nitrate, potassium, bicarbonate, and phosphate (Acton and Barker 1992; Armstrong et al. 1991; Hutchins 1991, Evans et al. 1991). Complete mineralization is possible under the right conditions. Edwards et al. (1992) found that toluene was completely mineralized to carbon dioxide and biomass by an aquifer-derived microorganism that used sulfate as a terminal electron acceptor. The authors found that toluene degradation stopped when the sulfate was removed, and started back up again once the sulfate was added again.

Microbial degradation in contaminated groundwater is also dependent on the depth and placement of the contamination. For instance, toluene degraders, related to *Geobacter* spp., *Desulfocapsa* spp., and *Sedimentibacter* spp. exist primarily in the biogeochemical gradient zone underneath contaminated plume cores. BTEX was found to exist with sulfate and those anaerobic toluene degraders in that gradient zone in a contaminated tar oil plume (Winderl et al. 2007).

Toluene can also be removed in aerobic conditions. In a laboratory study, toluene was removed from waste water by being stripped in an air stripping tank and subsequently degraded by *Pseudomonas putida* in a bioreactor (Dahlan et al. 1999). In a modified closed bottle study (OECD method 301D) referred to as a BOD<sub>28</sub> study (the biochemical oxygen demand after a 28-day incubation period), toluene degradation was observed at 93% after 14 days at a concentration of 50 mg/L and was reported to be readily biodegradable (Lapertot and Pulgarin 2006).

### 6.3.2.3 Sediment and Soil

Biodegradation of BTEX in soils can be affected by pH, temperature, and salinity. The bacteria responsible for degrading BTEX have a reduced growth rate at highly acidic and alkaline conditions, low and high temperatures, and salty conditions (You et al. 2013). Soils contaminated specifically with toluene can be effectively remediated with a combination of soil vapor extraction and bioremediation. Soils are required to have an organic matter content <14% in order for soil vapor extraction to be effective (Soares et al. 2013).

## 6. POTENTIAL FOR HUMAN EXPOSURE

It was discovered that the concentration of toluene in bioremediation practices has an effect on microbial compositions (Hubert et al. 1999). 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). Likewise, toluene degradation by bacterial cells is dependent on the types of bacteria. Growth of one strain exposed to a small concentration of toluene (0.01%) was negligible when compared to another strain (Hubert et al. 1999).

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 compounds 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 (Claus and Walker 1964). 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 BTEX compounds to carbon dioxide within 5 days. Non-ligninolytic conditions are favored (Yadav and Reddy 1993).

#### 6.4 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. Concentrations of toluene 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 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. The analytical methods available for monitoring toluene in a variety of environmental media are detailed in Chapter 7.

## 6. POTENTIAL FOR HUMAN EXPOSURE

**6.4.1 Air**

Ambient air levels of toluene are typically reported as micrograms per cubic meter of air ( $\mu\text{g}/\text{m}^3$ ) or part per billion by volume (ppbv);  $3.76 \mu\text{g}/\text{m}^3$  of toluene is equivalent to 1.00 ppbv (see Chapter 4).

Occasionally, monitoring data will be reported as parts per billion of carbon (ppbC). The unit ppbC is equivalent to ppbv multiplied by the number of carbons of the analyte.

The EPA Air Quality System (AQS) contains monitoring data of criteria air pollutants and HAPs.

Detailed air monitoring data for toluene in various cities/counties in the United States for 2015 are shown in Table 6-3. Table 6-4 summarizes the annual mean percentile distributions of toluene for years 2010–2015 (EPA 2016). Daily arithmetic mean concentrations of toluene ranged from 0.29 to 45.9 ppbC (0.041–6.56 ppbv) in 2015, which were similar to the concentrations measured in a study that analyzed the levels of toluene and 87 other volatile substances during a 1997–2001 sampling period from 13 semi-rural to urban locations in the United States. The states included Maine, Massachusetts, New Jersey, Pennsylvania, Ohio, Illinois, and California (Pankow et al. 2003). The arithmetic mean and median concentrations at these 13 locations were 0.22–2.7 and 0.10–2.4 ppbv ( $0.83$ – $10.2$  and  $0.38$ – $9.0 \mu\text{g}/\text{m}^3$ ), respectively. The measured concentrations exhibited seasonal trends, with the highest levels typically observed during the winter months, particularly in the more urban sampling locations. Older studies have reported toluene levels of 0.9–70.1, 0.06–195, and 2.2–751.5 ppbv ( $3.4$ – $263.6$ ,  $0.23$ – $733.2$ , and  $8.3$ – $2,825.6 \mu\text{g}/\text{m}^3$ ) in rural (Khalil and Rasmussen 1992), urban (Armstrong et al. 1991; Chan et al. 1991b; Evans et al. 1992; Kelly et al. 1993), and source-dominated air samples, respectively (Guldberg 1992; Kelly et al. 1993).

In a study conducted by Iovino et al. (2009), the authors found that the average toluene concentration in the Naples, Italy metropolitan area was  $35.0 \mu\text{g}/\text{m}^3$  (9.31 ppbv). The average concentration near suburban areas was  $16.2 \mu\text{g}/\text{m}^3$  (4.31 ppbv) and the average concentration far from suburban areas was  $15.3 \mu\text{g}/\text{m}^3$  (4.07 ppbv). Higher toluene levels in the outdoor air can be due to location and proximity to urban areas.

Toluene was detected at 1.95 ppbv ( $7.33 \mu\text{g}/\text{m}^3$ ) in the outdoor air of the urban zone near a crude oil refinery located in Lithuania. This level was similar to the levels of toluene found in urban areas of European cities; however, there were much higher levels of toluene (21.4–98.1 ppbv or  $80.5$ – $369 \mu\text{g}/\text{m}^3$ ) in the traffic congested areas in those same cities (Baltrenas et al. 2011).

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Phoenix-Mesa-Scottsdale, AZ	32	1.13	0.86	0.88
Phoenix-Mesa-Scottsdale, AZ	57	0.91	0.80	0.64
Phoenix-Mesa-Scottsdale, AZ	6	0.84	0.52	0.86
Phoenix-Mesa-Scottsdale, AZ	15	0.57	0.22	0.53
Phoenix-Mesa-Scottsdale, AZ	1	0.45	0.00	0.45
Phoenix-Mesa-Scottsdale, AZ	14	0.08	0.03	0.08
Phoenix-Mesa-Scottsdale, AZ	45	0.06	0.04	0.05
San Francisco-Oakland-Hayward, CA	29	0.51	0.40	0.46
San Francisco-Oakland-Hayward, CA	5,473	0.37	0.53	0.19
San Francisco-Oakland-Hayward, CA	30	0.67	0.47	0.58
San Francisco-Oakland-Hayward, CA	30	0.75	0.86	0.34
San Francisco-Oakland-Hayward, CA	30	0.49	0.41	0.31
San Francisco-Oakland-Hayward, CA	4,197	0.10	0.06	0.08
Chico, CA	30	0.41	0.27	0.42
San Francisco-Oakland-Hayward, CA	30	0.21	0.17	0.16
San Francisco-Oakland-Hayward, CA	29	0.36	0.33	0.28
San Francisco-Oakland-Hayward, CA	29	0.14	0.08	0.14
San Francisco-Oakland-Hayward, CA	30	0.18	0.17	0.11
San Francisco-Oakland-Hayward, CA	29	0.68	0.76	0.55
San Francisco-Oakland-Hayward, CA	30	0.26	0.22	0.22
San Francisco-Oakland-Hayward, CA	5,318	0.21	0.22	0.14
Fresno, CA	30	0.43	0.42	0.25
Fresno, CA	144	0.09	0.08	0.06
Fresno, CA	144	0.12	0.12	0.09
El Centro, CA	30	0.98	1.06	0.61
Bakersfield, CA	30	0.72	0.63	0.63
Bakersfield, CA	29	0.72	0.58	0.57
Bakersfield, CA	140	0.31	0.26	0.20
Bakersfield, CA	24	0.23	0.18	0.17
Los Angeles-Long Beach-Anaheim, CA	56	0.77	0.48	0.66
Los Angeles-Long Beach-Anaheim, CA	30	0.81	0.61	0.74
Los Angeles-Long Beach-Anaheim, CA	40	0.65	0.44	0.57
Los Angeles-Long Beach-Anaheim, CA	26	0.79	0.47	0.66
Los Angeles-Long Beach-Anaheim, CA	59	0.87	0.56	0.72
Los Angeles-Long Beach-Anaheim, CA	30	0.84	0.62	0.60
Los Angeles-Long Beach-Anaheim, CA	57	0.85	0.60	0.63
Los Angeles-Long Beach-Anaheim, CA	58	0.43	0.45	0.29
Los Angeles-Long Beach-Anaheim, CA	52	0.46	0.20	0.49



## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Madera, CA	32	0.09	0.10	0.04
San Francisco-Oakland-Hayward, CA	28	0.47	0.34	0.50
San Francisco-Oakland-Hayward, CA	30	0.07	0.12	0.04
Napa, CA	29	0.48	0.39	0.37
Sacramento-Roseville-Arden-Arcade, CA	30	0.26	0.19	0.22
Riverside-San Bernardino-Ontario, CA	43	0.50	0.42	0.43
Riverside-San Bernardino-Ontario, CA	25	0.82	0.58	0.73
Riverside-San Bernardino-Ontario, CA	57	0.73	0.50	0.63
Sacramento-Roseville-Arden-Arcade, CA	136	0.27	0.47	0.09
Sacramento-Roseville-Arden-Arcade, CA	16	0.13	0.08	0.10
Sacramento-Roseville-Arden-Arcade, CA	77	0.31	1.17	0.09
San Diego-Carlsbad, CA	31	0.45	0.37	0.32
San Diego-Carlsbad, CA	32	0.81	0.97	0.51
San Francisco-Oakland-Hayward, CA	28	0.35	0.27	0.34
San Francisco-Oakland-Hayward, CA	5	0.51	0.37	0.48
San Francisco-Oakland-Hayward, CA	30	0.37	0.29	0.30
Stockton-Lodi, CA	30	0.45	0.40	0.34
San Francisco-Oakland-Hayward, CA	29	0.85	0.69	0.48
San Jose-Sunnyvale-Santa Clara, CA	60	1.04	0.66	0.90
San Jose-Sunnyvale-Santa Clara, CA	30	0.65	0.62	0.45
San Jose-Sunnyvale-Santa Clara, CA	27	0.82	0.72	0.57
Vallejo-Fairfield, CA	30	0.41	0.42	0.26
Santa Rosa, CA	30	0.25	0.18	0.21
Oxnard-Thousand Oaks-Ventura, CA	81	0.21	0.19	0.13
Oxnard-Thousand Oaks-Ventura, CA	28	0.73	2.41	0.28
Oxnard-Thousand Oaks-Ventura, CA	140	0.11	0.11	0.09
Denver-Aurora-Lakewood, CO	42	1.22	0.71	1.15
Glenwood Springs, CO	54	0.76	0.33	0.72
Glenwood Springs, CO	46	0.92	1.44	0.65
Glenwood Springs, CO	52	0.61	0.61	0.40
Glenwood Springs, CO	26	4.53	10.24	0.79
Glenwood Springs, CO	20	5.25	10.48	1.20
Glenwood Springs, CO	6	0.59	0.20	0.55
Glenwood Springs, CO	51	0.58	0.38	0.46
Glenwood Springs, CO	2	0.40	0.12	0.48
Grand Junction, CO	50	0.81	0.56	0.71
Greeley, CO	40	1.01	0.60	0.99
Hartford-West Hartford-East Hartford, CT	1,962	0.32	0.27	0.22

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
New Haven-Milford, CT	2,012	0.76	1.12	0.36
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	36	0.32	0.68	0.19
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	54	0.54	0.36	0.37
Washington-Arlington-Alexandria, DC-VA-MD-WV	2,043	0.25	0.31	0.15
Washington-Arlington-Alexandria, DC-VA-MD-WV	59	0.35	0.19	0.31
Washington-Arlington-Alexandria, DC-VA-MD-WV	31	0.41	0.13	0.37
Washington-Arlington-Alexandria, DC-VA-MD-WV	60	0.28	0.38	0.21
Miami-Fort Lauderdale-West Palm Beach, FL	50	1.61	1.96	1.33
Miami-Fort Lauderdale-West Palm Beach, FL	46	0.95	0.47	0.93
Miami-Fort Lauderdale-West Palm Beach, FL	31	0.69	1.19	0.43
Miami-Fort Lauderdale-West Palm Beach, FL	47	1.50	0.66	1.45
Tampa-St. Petersburg-Clearwater, FL	59	0.19	0.06	0.18
Orlando-Kissimmee-Sanford, FL	29	0.28	0.13	0.25
Tampa-St. Petersburg-Clearwater, FL	59	0.25	0.18	0.19
Tampa-St. Petersburg-Clearwater, FL	57	0.34	0.18	0.31
Tampa-St. Petersburg-Clearwater, FL	17	0.34	0.19	0.29
Macon, GA	22	0.08	0.04	0.09
Savannah, GA	20	0.12	0.08	0.11
Douglas, GA	29	0.05	0.12	0.03
Atlanta-Sandy Springs-Roswell, GA	21	0.07	0.03	0.07
Atlanta-Sandy Springs-Roswell, GA	33	0.38	0.23	0.31
Atlanta-Sandy Springs-Roswell, GA	44	0.28	0.21	0.27
Atlanta-Sandy Springs-Roswell, GA	29	0.35	0.23	0.39
Atlanta-Sandy Springs-Roswell, GA	22	0.46	0.26	0.46
Atlanta-Sandy Springs-Roswell, GA	25	0.09	0.08	0.09
Atlanta-Sandy Springs-Roswell, GA	29	0.06	0.03	0.06
Atlanta-Sandy Springs-Roswell, GA	24	0.22	0.11	0.20
Chicago-Naperville-Elgin, IL-IN-WI	60	0.34	0.26	0.28
Chicago-Naperville-Elgin, IL-IN-WI	54	0.33	0.16	0.30
Chicago-Naperville-Elgin, IL-IN-WI	54	0.45	0.22	0.40
St. Louis, MO-IL	32	0.43	0.38	0.35
Louisville/Jefferson County, KY-IN	48	6.56	10.11	2.01
Chicago-Naperville-Elgin, IL-IN-WI	6,900	0.22	0.67	0.15
Chicago-Naperville-Elgin, IL-IN-WI	52	0.26	0.24	0.19
Chicago-Naperville-Elgin, IL-IN-WI	55	0.18	0.21	0.13
Chicago-Naperville-Elgin, IL-IN-WI	54	0.39	0.41	0.26
Chicago-Naperville-Elgin, IL-IN-WI	41	0.35	0.32	0.29
Chicago-Naperville-Elgin, IL-IN-WI	56	0.49	0.40	0.31

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Indianapolis-Carmel-Anderson, IN	57	0.66	0.71	0.33
Indianapolis-Carmel-Anderson, IN	7,862	0.41	0.66	0.19
Chicago-Naperville-Elgin, IL-IN-WI	57	0.14	0.15	0.09
Evansville, IN-KY	57	0.34	0.34	0.21
Terre Haute, IN	57	0.19	0.11	0.16
Cedar Rapids, IA	30	0.29	0.20	0.22
Cedar Rapids, IA	30	0.32	0.24	0.23
Des Moines-West Des Moines, IA	30	0.28	0.19	0.21
Des Moines-West Des Moines, IA	30	0.32	0.23	0.26
Davenport-Moline-Rock Island, IA-IL	30	0.29	0.39	0.21
Davenport-Moline-Rock Island, IA-IL	30	0.29	0.24	0.24
Huntington-Ashland, WV-KY-OH	60	0.30	0.17	0.29
Carter, KY	60	0.10	0.03	0.10
Lexington-Fayette, KY	53	0.26	0.19	0.20
Paducah, KY-IL	59	0.11	0.05	0.10
Paducah, KY-IL	60	0.09	0.03	0.08
Paducah, KY-IL	29	0.10	0.05	0.09
Paducah, KY-IL	59	0.14	0.10	0.12
Baton Rouge, LA	463	0.25	0.21	0.16
Baton Rouge, LA	59	0.24	0.13	0.21
Baton Rouge, LA	1,480	0.36	0.37	0.26
Baton Rouge, LA	48	0.42	0.28	0.36
Baton Rouge, LA	473	0.11	0.07	0.10
Baton Rouge, LA	55	0.11	0.04	0.10
Baton Rouge, LA	853	0.18	0.13	0.14
Baton Rouge, LA	56	0.18	0.09	0.16
Portland-South Portland, ME	3,415	0.08	0.06	0.06
Baltimore-Columbia-Towson, MD	1,948	0.42	0.43	0.28
Baltimore-Columbia-Towson, MD	60	0.55	0.53	0.41
Baltimore-Columbia-Towson, MD	59	0.67	0.55	0.54
Baltimore-Columbia-Towson, MD	54	0.23	0.09	0.20
Washington-Arlington-Alexandria, DC-VA-MD-WV	222	0.35	0.28	0.30
Washington-Arlington-Alexandria, DC-VA-MD-WV	59	0.37	0.16	0.34
Washington-Arlington-Alexandria, DC-VA-MD-WV	59	0.28	0.15	0.26
Baltimore-Columbia-Towson, MD	53	0.31	0.21	0.26
Boston-Cambridge-Newton, MA-NH	59	0.21	0.13	0.17
Boston-Cambridge-Newton, MA-NH	15	0.21	0.12	0.24
Boston-Cambridge-Newton, MA-NH	59	0.36	0.19	0.31

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Boston-Cambridge-Newton, MA-NH	29	0.33	0.15	0.31
Midland, MI	60	0.83	0.98	0.53
Midland, MI	59	0.48	0.65	0.29
Midland, MI	59	0.41	0.75	0.24
Midland, MI	57	0.57	0.38	0.50
Detroit-Warren-Dearborn, MI	30	0.33	0.19	0.31
Detroit-Warren-Dearborn, MI	60	0.37	0.28	0.30
Detroit-Warren-Dearborn, MI	45	0.08	0.08	0.08
Detroit-Warren-Dearborn, MI	10	0.08	0.07	0.09
Detroit-Warren-Dearborn, MI	55	0.74	0.36	0.65
Detroit-Warren-Dearborn, MI	53	1.12	0.56	0.96
Detroit-Warren-Dearborn, MI	49	0.68	0.40	0.57
St. Louis, MO-IL	60	0.35	0.25	0.27
Manchester-Nashua, NH	2,479	0.07	0.05	0.06
Manchester-Nashua, NH	15	0.09	0.02	0.09
Boston-Cambridge-Newton, MA-NH	2,579	0.12	0.09	0.10
Boston-Cambridge-Newton, MA-NH	15	0.19	0.08	0.17
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	61	1.63	1.10	1.43
New York-Newark-Jersey City, NY-NJ-PA	59	0.22	0.10	0.19
New York-Newark-Jersey City, NY-NJ-PA	563	0.18	0.18	0.11
New York-Newark-Jersey City, NY-NJ-PA	55	0.13	0.07	0.11
New York-Newark-Jersey City, NY-NJ-PA	60	0.49	0.22	0.46
Gallup, NM	13	0.15	0.11	0.12
Albany-Schenectady-Troy, NY	46	0.47	0.33	0.39
New York-Newark-Jersey City, NY-NJ-PA	56	0.40	0.22	0.31
New York-Newark-Jersey City, NY-NJ-PA	49	0.38	0.19	0.30
New York-Newark-Jersey City, NY-NJ-PA	54	0.40	0.22	0.30
New York-Newark-Jersey City, NY-NJ-PA	60	0.29	0.17	0.24
Buffalo-Cheektowaga-Niagara Falls, NY	50	0.30	0.17	0.27
Buffalo-Cheektowaga-Niagara Falls, NY	56	0.30	0.23	0.26
Buffalo-Cheektowaga-Niagara Falls, NY	55	0.32	0.23	0.27
Buffalo-Cheektowaga-Niagara Falls, NY	50	0.28	0.16	0.24
Buffalo-Cheektowaga-Niagara Falls, NY	58	0.31	0.25	0.26
Camden, NJ	56	0.08	0.15	0.04
New York-Newark-Jersey City, NY-NJ-PA	51	0.45	0.26	0.36
Rochester, NY	54	0.22	0.16	0.20
New York-Newark-Jersey City, NY-NJ-PA	57	0.37	0.21	0.33
New York-Newark-Jersey City, NY-NJ-PA	57	0.42	0.31	0.31

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Corning, NY	30	0.08	0.06	0.06
Asheville, NC	55	0.46	0.35	0.31
Asheville, NC	15	0.60	0.42	0.49
Winston-Salem, NC	58	0.34	0.27	0.30
Winston-Salem, NC	9	0.24	0.11	0.20
Sanford, NC	57	0.14	0.08	0.13
Sanford, NC	55	0.14	0.08	0.13
Charlotte-Concord-Gastonia, NC-SC	57	0.43	0.34	0.34
Charlotte-Concord-Gastonia, NC-SC	13	0.46	0.34	0.33
Montgomery, NC	58	0.12	0.10	0.09
Montgomery, NC	9	0.08	0.02	0.09
Wilmington, NC	57	0.18	0.15	0.16
Wilmington, NC	5	0.28	0.08	0.26
Raleigh, NC	57	0.32	0.26	0.23
Cincinnati, OH-KY-IN	27	0.31	0.22	0.36
Cincinnati, OH-KY-IN	29	0.59	0.85	0.33
Cincinnati, OH-KY-IN	30	0.38	0.23	0.30
Cincinnati, OH-KY-IN	30	1.18	0.90	1.00
Cincinnati, OH-KY-IN	56	0.46	0.33	0.39
Oklahoma City, OK	59	0.24	0.11	0.22
Oklahoma City, OK	39	0.32	0.17	0.29
Oklahoma City, OK	39	0.41	0.19	0.37
Oklahoma City, OK	60	0.35	0.20	0.28
Tulsa, OK	60	0.64	0.35	0.62
Tulsa, OK	59	0.94	1.05	0.67
Tulsa, OK	60	0.53	0.30	0.47
Portland-Vancouver-Hillsboro, OR-WA	52	0.82	0.90	0.59
Portland-Vancouver-Hillsboro, OR-WA	27	0.74	0.62	0.56
Portland-Vancouver-Hillsboro, OR-WA	54	0.53	0.36	0.40
La Grande, OR	42	0.29	0.18	0.24
Portland-Vancouver-Hillsboro, OR-WA	15	0.67	0.38	0.52
Gettysburg, PA	42	0.12	0.08	0.09
Pittsburgh, PA	34	0.37	0.14	0.36
Reading, PA	26	0.24	0.14	0.24
Pittsburgh, PA	39	0.19	0.14	0.11
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	42	0.58	0.49	0.42
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	42	0.36	0.24	0.28
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	42	0.51	0.28	0.44

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**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Erie, PA	38	0.16	0.11	0.14
Lancaster, PA	40	0.85	0.46	0.75
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	41	0.23	0.14	0.18
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	44	0.37	0.20	0.33
Allentown-Bethlehem-Easton, PA-NJ	41	0.32	0.15	0.31
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	679	0.26	0.18	0.22
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	20	0.38	0.24	0.33
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	59	0.43	0.29	0.36
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	13	0.30	0.35	0.21
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	32	0.33	0.22	0.27
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	59	0.21	0.18	0.17
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	45	0.32	0.20	0.31
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	59	0.52	0.44	0.40
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	59	0.34	0.24	0.29
Springville, PA	39	4.01	3.16	4.20
Lewisburg, PA	33	0.19	0.08	0.18
Pittsburgh, PA	43	0.34	0.20	0.32
Pittsburgh, PA	39	0.20	0.10	0.18
Pittsburgh, PA	39	0.33	0.15	0.33
Scranton-Wilkes-Barre-Hazleton, PA	29	0.28	0.93	0.09
York-Hanover, PA	45	0.34	0.14	0.32
Providence-Warwick, RI-MA	58	0.08	0.04	0.07
Providence-Warwick, RI-MA	58	0.38	0.23	0.33
Providence-Warwick, RI-MA	56	0.53	0.26	0.47
Providence-Warwick, RI-MA	546	0.26	0.26	0.17
Providence-Warwick, RI-MA	59	0.27	0.16	0.23
Providence-Warwick, RI-MA	56	0.26	0.16	0.24
Dallas-Fort Worth-Arlington, TX	7,607	0.39	0.62	0.23
Dallas-Fort Worth-Arlington, TX	57	0.28	0.24	0.20
Dallas-Fort Worth-Arlington, TX	55	0.21	0.19	0.16
Odessa, TX	2,273	0.54	0.77	0.30
Dallas-Fort Worth-Arlington, TX	59	0.07	0.05	0.06
El Paso, TX	7,118	0.91	1.71	0.39
Houston-The Woodlands-Sugar Land, TX	7,551	0.59	0.95	0.30
Houston-The Woodlands-Sugar Land, TX	7,082	0.71	1.50	0.34
Houston-The Woodlands-Sugar Land, TX	7,280	0.44	0.94	0.23
Houston-The Woodlands-Sugar Land, TX	59	0.32	0.23	0.28
Houston-The Woodlands-Sugar Land, TX	55	0.30	0.22	0.28

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-3. Toluene Levels in Ambient Air<sup>a</sup>**

Sampling location <sup>b</sup>	Number of samples	Daily arithmetic mean concentration (ppbv)	Standard deviation (ppbv)	Median (ppbv)
Marshall, TX	57	0.12	0.05	0.12
Beaumont-Port Arthur, TX	7,662	0.35	0.51	0.21
Beaumont-Port Arthur, TX	7,494	0.27	0.38	0.17
Dallas-Fort Worth-Arlington, TX	52	0.11	0.06	0.10
Corpus Christi, TX	60	0.16	0.11	0.14
Dallas-Fort Worth-Arlington, TX	7,289	0.40	0.47	0.24
Dallas-Fort Worth-Arlington, TX	57	0.24	0.12	0.20
Dallas-Fort Worth-Arlington, TX	59	0.14	0.08	0.12
Laredo, TX	49	0.67	0.34	0.55
Ogden-Clearfield, UT	50	0.58	0.42	0.49
Ogden-Clearfield, UT	49	0.70	0.43	0.59
Burlington-South Burlington, VT	60	0.04	0.03	0.04
Burlington-South Burlington, VT	30	0.35	0.14	0.35
Burlington-South Burlington, VT	29	0.36	0.15	0.34
Rutland, VT	30	0.42	0.23	0.36
Washington-Arlington-Alexandria, DC-VA-MD-WV	57	0.16	0.10	0.13
Richmond, VA	60	0.33	0.18	0.28
Richmond, VA	60	0.25	0.17	0.21
Richmond, VA	30	0.31	0.28	0.21
Richmond, VA	59	0.21	0.18	0.14
Virginia Beach-Norfolk-Newport News, VA-NC	57	0.22	0.15	0.19
Seattle-Tacoma-Bellevue, WA	56	0.31	0.22	0.24
Beaver Dam, WI	59	0.05	0.07	0.01
Milwaukee-Waukesha-West Allis, WI	27	0.39	0.20	0.37
Milwaukee-Waukesha-West Allis, WI	55	0.29	0.13	0.26

<sup>a</sup>Data were originally reported in units of parts per billion carbon, but converted to parts per billion volume to facilitate comparison with other data.

<sup>b</sup>State post office abbreviations used.

ppbC = parts per billion (carbon) = ppbv multiplied by the number of carbons in the analyte

Source: EPA 2016

## 6. POTENTIAL FOR HUMAN EXPOSURE

**Table 6-4. Percentile Distribution of Annual Mean Toluene Concentrations (ppbv) Measured in Ambient Air at Locations Across the United States<sup>a</sup>**

Year	Number of U.S. locations	25th	50th	75th	95th	Maximum
2010	430	0.26	0.41	0.65	1.28	8.14
2011	399	0.23	0.36	0.55	1.14	2.55
2012	391	0.24	0.37	0.57	1.31	32.05
2013	362	0.22	0.33	0.52	1.07	4.67
2014	345	0.19	0.30	0.86	0.96	3.87
2015	291	0.22	0.34	0.51	0.95	6.56

<sup>a</sup>Data were originally reported in units of parts per billion carbon, but converted to parts per billion volume to facilitate comparison with other data.

ppbC = parts per billion (carbon) = ppbv multiplied by the number of carbons in the analyte

Source: EPA 2016



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BTEX vehicle emissions from motor exhaust and emissions from the handling, distribution and storage of petrol are a major contributor of atmospheric toluene. Toluene concentrations in India were found to range from 3.26 to 13.68  $\mu\text{g}/\text{m}^3$  (0.867–3.64 ppbv) in air samples collected from busy traffic sites (Deole et al. 2004). Toluene levels near an airport were found to be comparable to the atmospheric toluene levels of the neighborhoods near the airport; however, levels were about 70% lower for areas further from the airport. Toluene is generated from kerosene evaporation and combustion from the jet fuel in airplanes (Jung et al. 2011).

In Rome, Italy, the annual average concentrations of toluene in the air decreased from 100  $\mu\text{g}/\text{m}^3$  (26.6 ppbv) in 1997 to 10.2  $\mu\text{g}/\text{m}^3$  (2.71 ppbv) in 2008. This reduction of toluene in the air was attributed to the decrease of total aromatic hydrocarbons in gasoline, the prevalence of low emission cars, and the increase in refilling stations with closed-loop gasoline vapor systems (Ciarrocca et al. 2012). Concentrations of toluene in air from the inside of vehicles have been reported to range from 0.56 to 42.0 ppbv (2.1–157.9  $\mu\text{g}/\text{m}^3$ ) (Chan et al. 1991a; Lawryk and Weisel 1996; Weisel et al. 1992).

Levels of toluene can be much greater in indoor air as compared to outdoor air depending upon the presence of potential exposure sources. For example, Curry et al. (1994) measured the indoor air concentrations of toluene during normal in home use of nail lacquer products at five different residences in California. The mean toluene levels measured in air during the nail lacquer application ranged from 3,200 to 9,200  $\mu\text{g}/\text{m}^3$  (850–2,400 ppbv), while the post-application concentrations ranged from 200 to 1,700  $\mu\text{g}/\text{m}^3$  (50–450 ppbv). Toluene was not detected in any of the air samples above the detection limits of 200  $\mu\text{g}/\text{m}^3$  (50 ppbv) in air prior to the nail lacquer application.

Hamidin et al. (2013) reported that toluene concentrations in the internal garages and residential indoor air of 32 homes in Brisbane, Australia were much higher than toluene concentrations in the outdoor ambient air. The average toluene concentration in residential indoor air was 10.7  $\mu\text{g}/\text{m}^3$  (2.84 ppbv), 25.5  $\mu\text{g}/\text{m}^3$  (6.78 ppbv) in internal garages, and 2.3  $\mu\text{g}/\text{m}^3$  (0.61 ppbv) in outdoor ambient air.

Toluene levels in indoor air from 16 newspaper stands located in Bari, Italy were shown to be substantially higher than the corresponding outdoor air levels (Caselli et al. 2009). The weekly mean concentrations of toluene in indoor air and outdoor air at these 16 stands are provided in Table 6-5, along with the indoor/outdoor (I/O) ratio of these levels at each site. The authors concluded that toluene levels were much higher inside the newspaper stands than outside because of the ink used to print the newspapers (Caselli et al. 2009).

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**Table 6-5. Weekly Mean Toluene Concentrations ( $\mu\text{g}/\text{m}^3$ ) in Indoor Air at 16 Newspaper Stands and the Corresponding Outdoor Air Levels<sup>a</sup>**

Newspaper stand	Mean indoor air level ( $\mu\text{g}/\text{m}^3$ )	Mean outdoor air level ( $\mu\text{g}/\text{m}^3$ )	I/O ratio
1	1,485.6	11.6	128
2	366.6	7.6	48
3	766.9	17.8	43.1
4	644.3	8.5	76
5	455.8	11.1	41.1
6	1,170.7	11.9	88.0
7	614.7	13.3	46.2
8	444.6	16.7	26.6
9	703.6	7.8	90
10	913.9	20.5	44.6
11	935.2	16.4	57.0
12	729.8	14.4	50.7
13	585.8	10.4	56.3
14	1,055.5	14.2	74.3
15	693.3	12.9	53.7
16	858.4	8.6	100

<sup>a</sup>The first eight sites are enclosed environments, with sites 2, 5, and 8 possessing air conditioning systems. The final eight sites closely resemble partially enclosed kiosks.

I/O = indoor/outdoor

Source: Caselli et al. 2009

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Massolo et al. (2010) analyzed toluene levels in indoor versus outdoor air at different locations in La Plata, Argentina. The ratio of I/O toluene levels were 1.10, 1.79, 3.11, and 3.45 for industrial, urban, semi-rural, and residential locations, respectively. Both indoor and outdoor levels were highest for the industrialized locations characterized by petrochemical plants and urban locations with heavy vehicular traffic.

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 indoor and outdoor levels of volatile organic compounds (VOCs) measured in three types of commercial buildings (telecommunication offices, data centers, and administrative offices) across the United States. The averaged I/O ratios for toluene were 1.6, 4.9, and 2.2 for telecommunication offices, data centers, and administrative offices, respectively.

Ventilation differences between the types of buildings were shown to be a major factor in differences between I/O ratios for toluene and other VOCs at these facilities. Mukerjee et al. (1997) reported the variation of toluene levels in indoor and outdoor air by season of the year in the Lower Rio Grande Valley. Median indoor air levels were  $4.80 \mu\text{g}/\text{m}^3$  (1.28 ppbv) and median outdoor levels were  $3.10 \mu\text{g}/\text{m}^3$  (0.824 ppbv) during the spring months. The median levels were reported as  $7.70 \mu\text{g}/\text{m}^3$  (2.05 ppbv) for indoor air and  $1.15 \mu\text{g}/\text{m}^3$  (0.306 ppbv) for outdoor air during the summer months.

In several studies, indoor (home or office) toluene concentrations ranged from 0.7 to 24.2 ppbv ( $3\text{--}91.0 \mu\text{g}/\text{m}^3$ ) due mostly to infiltration from auto emissions (Chan et al. 1991b; Hodgson et al. 1991; Kelly et al. 1993; Michael et al. 1990; Shields and Weschler 1992). Toluene was among the volatile organic compounds detected in the emissions from sponge rubber carpet cushions (Schaeffer et 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 (24–99%), 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. 1999).

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Very high concentrations of toluene (53.2–38,038 ppbv or  $2.00 \times 10^2$ – $143 \times 10^5$   $\mu\text{g}/\text{m}^3$ ) 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).

**6.4.2 Water**

Toluene was one of the most frequently detected volatile organic compounds in a comprehensive survey conducted by the United States Geological Survey (USGS) from 1985 to 2001 of private and public groundwater wells used for drinking water (USGS 2006). Toluene was detected in about 10% of 1,676 aquifer samples analyzed at an assessment level of 0.02 ppb. It was detected in about 2% of 3,457 samples analyzed at an assessment level of 0.2 ppb (Carter et al. 2008; USGS 2006). The median concentration of toluene was 0.032 ppb for all of the samples having positive detections. 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 detected in 10 out of 931 samples collected from May 1999 to October 2000 in the USGS National Survey of volatile organic compound contaminants of groundwater and surface water sources used for drinking water supplies (USGS 2003). It was more often detected in surface water sources (1.9% detection frequency) as compared to groundwater sources (0.53% detection frequency) and reservoirs (1.0% detection frequency) at the minimum reporting level of 0.2 ppb.

In addition to the groundwater in the United States, toluene was also found in the groundwater near the Tehran Automobile Industry waste water treatment plant. Toluene was detected with trichloroethylene, tetrachloroethylene, and other volatile organic compounds. The concentration of toluene in the groundwater was not provided (Dobaradaran et al. 2010). 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).

The USGS sampled storm water runoff from 16 cities and metropolitan areas from 11 different states during the period of 1991–1995 (USGS 2000). Toluene and total xylenes were the most frequently detected compounds in the collected samples. Toluene was identified in 137 out of 592 samples at levels ranging from 0.2 to 6.6 ppb.

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**6.4.3 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.

**6.4.4 Other Environmental Media**

The concentration of toluene in commercial foodstuffs has not been thoroughly studied. Although the data are limited, toluene is not likely to be found in food (CEPA 1999). Toluene was detected in eggs stored in polystyrene containers that contained toluene (Matiella and Hsieh 1991). Cigarette smoke releases toluene. Grob (1965) estimated that about 80 µg of toluene is released per cigarette. 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.

**6.5 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. Likewise, the main source of toluene is from vehicle exhaust, although the use of paints, varnishes, lacquers, shoe polishes, and cigarette smoke can contribute to levels indoors and personal exposures (Alexopoulos et al. 2006). The geometric mean and selected percentiles of toluene in whole-blood concentrations (in ng/mL) for the U.S. population from the National Health and Nutrition Examination Survey (NHANES) for 2001–2002, 2003–2004, and 2005–2006 are provided in Table 6-6 (CDC 2013). In addition, toluene was found in 91% of adipose tissue samples from the National Human Adipose Tissue survey. The maximum concentration of toluene in the samples was 250 ppb (HSDB 2010).

The total daily exposure of office workers to volatile organic compounds, including toluene, was analyzed in a study conducted in Milan, Italy. Personal pollutant exposure levels of workers to toluene were 30.9 µg/m<sup>3</sup> (8.22 ppbv) from the home, 32.5 µg/m<sup>3</sup> (8.64 ppbv) from the office, and 43.6 µg/m<sup>3</sup> (11.6 ppbv) from commuting. It was found that the levels of toluene in the workers in the summer (21.5–

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**Table 6-6. Geometric Mean and Selected Percentiles of Blood Toluene in Whole Blood Concentrations (in ng/L) for the U.S. Population from NHANES**

	Survey	Geometric mean (95% CI)	50 <sup>th</sup> percentile	75 <sup>th</sup> percentile	90 <sup>th</sup> percentile	95 <sup>th</sup> percentile	Sample size
Total	2001–2002	0.156 (0.122–0.198)	0.160 (0.120–0.220)	0.340 (0.260–0.430)	0.670 (0.480–0.950)	10.06 (0.700–10.43)	954
	2003–2004	0.114 (0.100–0.129)	0.096 (0.087–0.110)	0.220 (0.180–0.260)	0.430 (0.380–0.550)	0.680 (0.560–0.880)	1,336
	2005–2006	0.137 (0.123–0.152)	0.120 (0.110–0.130)	0.230 (0.200–0.262)	0.550 (0.481–0.640)	0.814 (0.702–0.937)	3,050
12–19 Years age	2005–2006	0.110 (0.098–0.122)	0.100 (0.094–0.120)	0.170 (0.150–0.180)	0.280 (0.240–0.310)	0.400 (0.300–0.610)	907
20–59 Years age	2001–2002	0.156 (0.122–0.198)	0.160 (0.120–0.220)	0.340 (0.260–0.430)	0.670 (0.480–0.950)	10.06 (0.700–10.43)	954
20–59 Years age	2003–2004	0.114 (0.100–0.129)	0.096 (0.087–0.110)	0.220 (0.180–0.260)	0.430 (0.380–0.550)	0.680 (0.560–0.880)	1,336
20–59 Years age	2005–2006	0.147 (0.133–0.163)	0.120 (0.110–0.137)	0.260 (0.210–0.340)	0.594 (0.505–0.720)	0.900 (0.730–10.10)	1,505
≥60 Years age	2005–2006	0.124 (0.100–0.154)	0.114 (0.097–0.138)	0.190 (0.167–0.230)	0.520 (0.370–0.600)	0.720 (0.600–0.814)	638
Males	2001–2002	0.165 (0.130–0.209)	0.170 (0.120–0.230)	0.360 (0.260–0.520)	0.780 (0.580–10.06)	10.22 (0.850–10.43)	450
Males	2003–2004	0.128 (0.112–0.148)	0.110 (0.096–0.130)	0.250 (0.190–0.310)	0.500 (0.380–0.660)	0.730 (0.590–10.10)	647
Males	2005–2006	0.152 (0.139–0.166)	0.130 (0.120–0.140)	0.280 (0.240–0.330)	0.640 (0.550–0.720)	0.920 (0.790–10.10)	1,441
Females	2001–2002	0.147 (0.114–0.190)	0.150 (0.110–0.220)	0.320 (0.240–0.390)	0.550 (0.400–0.740)	0.810 (0.530–10.63)	504
Females	2003–2004	0.101 (0.086–0.118)	0.085 (0.070–0.100)	0.190 (0.150–0.230)	0.410 (0.340–0.500)	0.580 (0.480–0.750)	689
Females	2005–2006	0.124 (0.107–0.144)	0.110 (0.097–0.130)	0.190 (0.170–0.230)	0.470 (0.380–0.550)	0.690 (0.550–0.880)	1,609
Mexican/American	2001–2002	0.136 (0.106–0.176)	0.140 (0.080–0.210)	0.270 (0.210–0.340)	0.550 (0.400–0.980)	0.990 (0.500–10.30)	219
Mexican/American	2003–2004	0.084 (0.074–0.096)	0.076 (0.064–0.091)	0.120 (0.100–0.170)	0.280 (0.170–0.410)	0.400 (0.310–0.620)	253
Mexican/American	2005–2006	0.110 (0.097–0.125)	0.110 (0.096–0.120)	0.160 (0.140–0.170)	0.240 (0.220–0.290)	0.340 (0.290–0.460)	737
Non-Hispanic blacks	2001–2002	0.137 (0.089–0.210)	0.150 (0.070–0.200)	0.310 (0.200–0.460)	0.690 (0.390–10.19)	10.15 (0.660–10.69)	194
Non-Hispanic blacks	2003–2004	0.105 (0.077–0.144)	0.095 (0.070–0.130)	0.200 (0.130–0.330)	0.440 (0.290–0.620)	0.620 (0.480–0.710)	297
Non-Hispanic blacks	2005–2006	0.139 (0.120–0.161)	0.120 (0.099–0.140)	0.230 (0.190–0.290)	0.450 (0.370–0.550)	0.670 (0.550–0.830)	796
Non-Hispanic whites	2001–2002	0.165 (0.125–0.217)	0.170 (0.120–0.240)	0.350 (0.270–0.450)	0.710 (0.450–10.12)	10.14 (0.710–10.63)	467

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**Table 6-6. Geometric Mean and Selected Percentiles of Blood Toluene in Whole Blood Concentrations (in ng/L) for the U.S. Population from NHANES**

	Survey	Geometric mean (95% CI)	50 <sup>th</sup> percentile	75 <sup>th</sup> percentile	90 <sup>th</sup> percentile	95 <sup>th</sup> percentile	Sample size
Non-Hispanic whites	2003–2004	0.123 (0.110–0.139)	0.100 (0.092–0.120)	0.240 (0.210–0.280)	0.500 (0.400–0.590)	0.750 (0.590–0.940)	685
Non-Hispanic whites	2005–2006	0.144 (0.125–0.166)	0.130 (0.110–0.140)	0.260 (0.210–0.330)	0.600 (0.510–0.710)	0.880 (0.760–0.990)	1,291

CI = confidence interval; NHANES = National Health and Nutrition Examination Survey

Source: CDC 2009

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34.3  $\mu\text{g}/\text{m}^3$ ; 5.72–9.12 ppbv) were lower than levels of toluene in the winter (37.6–53.7  $\mu\text{g}/\text{m}^3$ ; 10.0–14.3 ppbv). Toluene levels in nonsmokers, as compared to smokers, were about the same. In addition, personal exposure levels to toluene were much higher from cars (145.7  $\mu\text{g}/\text{m}^3$ ; 38.8 ppbv) than subways (39.3  $\mu\text{g}/\text{m}^3$ ; 10.4) and buses (44.1  $\mu\text{g}/\text{m}^3$ ; 11.7 ppbv) (Carrer et al. 2000). In a similar study, the personal exposures of traffic police officers in Milan, Italy to toluene were found to be 42.5  $\mu\text{g}/\text{m}^3$  (11.3 ppbv). Mean toluene and BTEX levels were higher in the afternoon shifts (Cattaneo et al. 2010).

Personal exposure was the highest when a vehicle was used as the main source of transportation, when a vehicle was used in work, when the participants had a roommate who smoked, in cities, near gas stations, and near busy roads. Levels were 71.6  $\mu\text{g}/\text{m}^3$  (19.0 ppbv), 72.5  $\mu\text{g}/\text{m}^3$  (19.3 ppbv), 64.0  $\mu\text{g}/\text{m}^3$  (17.0 ppbv), 64.0  $\mu\text{g}/\text{m}^3$  (17.0 ppbv), 91.9  $\mu\text{g}/\text{m}^3$  (24.4 ppbv), and 65.5  $\mu\text{g}/\text{m}^3$  (17.4 ppbv), respectively (Alexopoulos et al. 2006). Other transportation-related toluene exposure pathways include inhalation of volatile organic compounds from contaminated air in aircraft cabins (2–135 ppbv for toluene) (Dechow et al. 1997) and breathing air in long road tunnels (97–167.6 ppbv) (Barrefors 1996).

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  $\mu\text{g}/\text{person}/\text{day}$  (Curry et al. 1994). The mean toluene levels measured in the breathing zone during the nail lacquer application ranged from 3,200 to 9,200  $\mu\text{g}/\text{m}^3$  (850–2,400 ppbv), while the post-application concentrations ranged from below the detection limits of 200  $\mu\text{g}/\text{m}^3$  to 1,700  $\mu\text{g}/\text{m}^3$  (50–450 ppbv). Toluene concentrations were monitored 1 hour before application; no toluene was detected in air prior to the nail lacquer application. During application, sampling started with the first application and ended when the nails were dry. Post-application sampling started 1 hour after the nails were dry for the post-application sample group I, and 2 hours after the nails were dry for the post-application sample group II.

In an occupational study, workers from gasoline service stations had a geometric mean personal exposure level of 153.1 ppbv (576  $\mu\text{g}/\text{m}^3$ ), and the geometric mean concentration in the workplace air was reported as 99.3 ppbv (373  $\mu\text{g}/\text{m}^3$ ). Toluene exposure may also occur in 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), coke plant operations (Bieniek et al. 2004), and commercial painting (Burstyn and Kromout 2002). Assuming that a worker inhales 10  $\text{m}^3$  of air while on the job, and that 50% of the inhaled toluene is absorbed, a workplace concentration of 53.2 ppmv would correspond to an exposure level of 1,000 mg/day. The toluene burden of rotogravure (printing process) workers measured with



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personal monitoring tubes was found to be higher, ranging from 56 to 451 mg/m<sup>3</sup> (15–120 ppmv) than air concentrations monitored during the workday (Hammer et al. 1998).

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. Runners who exercise near highways may be exposed to higher levels of BTEX. Concentrations of toluene in the blood were significantly increased post-exercise in a running study near a roadway. The runners ran for 20 minutes. The mean blood concentrations were 1.4 ng/mL (1.4 ppb) pre-exercise and 2.8 ng/mL (2.8 ppb) post-exercise with a mean increase of 1.4 ng/mL (1.4 ppb). The concentration of toluene in the air was measured as 52 µg/m<sup>3</sup> (13.8 ppbv) at the start of the route, 60 µg/m<sup>3</sup> (16 ppbv) at the middle of the route, and 52 µg/m<sup>3</sup> (13.8 ppbv) at the distant end of the route (Blair et al. 2010). 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 (ng/mL). 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). 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. The concentration of toluene in their blood was found to increase from 0.87 to 4.9 mg/L (Muttray et al. 1999). The average levels of toluene measured in personal air samples of these workers ranged from 1,115 to 1,358 mg/m<sup>3</sup> (296–361 ppmv).

Toluene concentrations in the blood after rotogravure industry workers shifts were measured in a study conducted by Neubert et al. (2001). Concentrations were the highest from printing and assistance (266.3 µg/L or 266.3 ppb), followed by preparation of printing forms (67.7 µg/L or 67.7 ppb), processing of printed materials (67.7 µg/L for men, 53.2 µg/L for women or 67.7 ppb, 53.2 ppb), and other areas (78.1 µg/L or 78.1 ppb for men, 28.0 µg/L or 28.0 ppb for women).

Cigarette smoking may also significantly increase exposure. In a NHANES 2003–2004 study, levels of toluene among daily smokers were higher than levels of toluene among smokers who smoked less than daily. The levels were 0.327 ng/mL (0.327 ppb) for daily smokers and 0.082 ng/mL (0.082 ppb) for nondaily smokers (Chambers et al. 2011). Assuming inhalation of about 80–100 µg of toluene per cigarette and 50% absorption (EPA 1983b; Grob 1965), smoking one pack per day would contribute an absorbed dose of about 1,000 µg/day.

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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). Exposure to toluene can also occur from the combustion of solid biomass fuels. The fuels are used as a source of domestic energy in developing countries for cooking, etc. Toluene concentrations were much higher from dung ( $1.4 \mu\text{g}/\text{m}^3$  or 0.37 ppbv) than from mixed fuel ( $0.5 \mu\text{g}/\text{m}^3$  or 0.1 ppbv) (Sinha et al. 2006).

Based on average values of toluene in water, exposure by ingestion of contaminated drinking water is likely to be relatively small compared to inhalation. 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; 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  $\mu\text{g}/\text{L}$  of toluene was found in the water, which resulted in a level of 664 ppbv in shower air, and 14.9 ppbv in non-shower air. The total daily dose for the exposed subject in this household was estimated as 2,273  $\mu\text{g}$ . Approximately 61% of the dose was due to ingestion and 39% resulted from inhalation from showering and non-showering activities. Personnel working with various types of fuel may be at a risk of toluene exposure. A Finnish study determined the mean exposure of gasoline tanker drivers to toluene during loading and delivery to be 0.63–1.9  $\text{mg}/\text{m}^3$  (2.4–7.1 ppmv) (Saarinen et al. 1998). The exposure level of aircraft maintenance personnel to toluene in raw JP-8 jet fuel vapor was found to be  $6.1 \pm 1.5$  ppmv ( $6,100 \pm 1,560$  ppbv) (Smith et al. 1997).

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

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whole body (including inhalation) exposure (Brooke et al. 1998). Combinations of solvents, however, 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).

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.

## 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 than adults. 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 may spend more time outdoors. Children also are generally closer to the ground and have not yet developed the adult capacity to judge and take actions 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 Chapter 2 and Section 3.3). 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 inhalational solvent

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abuse using behaviors that may include “sniffing”, “bagging”, and/or “huffing” (NIDA 2012; 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).

Human epidemiological studies and case reports discussing reproductive and/or developmental toxicity of toluene in humans have been reviewed. Occupational exposures can occur when workers inhale materials containing toluene such as 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.

Toluene was detected in breast milk samples obtained from three mothers residing in the Baltimore, Maryland area at a median concentration of 0.46 ng/L (Kim et al. 2007). Transfer of toluene to nursing infants from breast milk is a possible source of toluene exposure; however, since most toluene is rapidly eliminated from the body (see Sections 3.4.4 and 3.7), this exposure route is expected to be low. Kim et al. (2007) used indoor air concentrations of toluene and other volatile organic compounds (VOCs) to estimate the relative exposure dose of these VOCs from inhalation of indoor air as compared to milk ingestion. Infant exposure from inhalation of air was estimated as 4,550 ng/kg body weight/day, which was 55 times greater than the estimated dose from milk ingestion (89 ng/kg body weight/day). A PBPK model 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 and dusts, 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  $K_{oc}$  range of 37–178, indicating high mobility in soil (HSDB 2010; Wilson et al.

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1981). Most of the toluene present in the upper layers of the soil is volatilized to air within 24 hours (vapor pressure of 28.4 mmHg at 25°C) (Balfour et al. 1984; HSDB 2010; Thibodeaux and Hwang 1982). 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, developmental stage (crawling, etc.), and/or play behavior. The toluene vapors being heavier than air (vapor density=3.1 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 toluene vapors 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. Most accident victims are 1- and 2-year-old children and are about evenly divided between males and females. Most incidents occur in the children's homes when 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 toluene concentrations are, on average, 56% higher than those of children living in rural areas (Jermann et al. 1989; Raaschou-Nielsen 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 intentional inhalation (e.g., "sniffing", "huffing", etc.) is a social and clinical concern (NIDA 2012; Young 1987). Inhalation exposure via "vaping" of e-cigarettes is also possible, and ongoing research may clarify the extent to which toluene exposure may occur by this route (CDC 2015; Chatam-Stephens et al. 2014)

### 6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

In addition to individuals who are occupationally exposed to toluene (see Section 6.5), 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 1,012 NPL hazardous waste sites where toluene has been detected in some environmental media (HazDat 2007).

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The population most likely to experience high levels of exposure to toluene includes 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. 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 containing toluene. Inhalant abuse can affect pregnancy outcome (Jones and Balster 1998). Inhalant abuse continues to be a health care problem among young people (NIDA 2012; Young 1987). Toluene abuse can affect driving (Capron and Logan 2009) and inhibit gap junction currents in human embryonic kidney cells (Del Re and Woodward 2005).

### 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 toluene 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 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.

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**6.8.1 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 4-2). It does not appear that further research in this area is necessary.

**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 2015, became available in 2016. This database is updated yearly and should provide a list of industrial production facilities and emissions.

The available production data of toluene are up to date; however, it is essential that these data be updated regularly to allow a more accurate determination of the potential for human exposure.

**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; EC 2003; Hoshino et al. 1978; Howard et al. 1991; Kenley et al. 1973). 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 2007). 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.

**Bioavailability from Environmental Media.** On the basis of the available data, toluene appears to be 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). Absorption 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.

**Food Chain Bioaccumulation.** The bioconcentration factor for toluene is relatively low due to its rapid metabolism to more polar molecules with a lower affinity for lipids, and it has little tendency to

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bind to biomolecules (EC 2003; Franke et al. 1994). Bioaccumulation in the food chain is expected to be low. No data needs are identified.

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

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. 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.

**Exposure Levels in Humans.** Exposure of the general population to toluene in air has been monitored for a variety of scenarios (Baltrenas et al. 2011; Bratveit et al. 2004; Ciarrocca et al. 2012; Deole et al. 2004; EPA 2016; Hamidin et al. 2013; Iovino et al. 2009; Massolo et al. 2010). 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). Combining these data with appropriate toxicokinetic models of toluene absorption, distribution, and excretion in humans would allow for improved estimates of exposure levels in humans. Likewise, more recent data on the ingestion of contaminated drinking water may be useful.

Toluene exposure levels in the workplace is well documented (Bieniek et al. 2004; Burstyn and Kromout 2002; Chen et al. 2002; Guldberg 1992; Hammer et al. 1998; Hiipakka and Samimi 1987; McCann 1992; McDiarmid et al. 1991; Muijser et al. 1996; Muttray et al. 1999; NCI 1985; Neubert et al. 2001; 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.

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

**Exposures of Children.** 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



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ground because of their height, developmental stage, and play behaviors. Toluene vapors, being heavier than air, tend to concentrate closer to the ground, thereby increasing the risk of exposure for children.

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. Studies of other possible sources and routes of exposure to toluene, such as e-cigarettes, may help to better characterize exposures of children, as well as adults.

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

**Exposure Registries.** The information 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; however, no exposure registries for toluene were located. Toluene is not currently one of the compounds for which a sub-registry has been established in the National Exposure Registry. Toluene will be considered in the future when chemical selection is made for sub-registries to be established.

### 6.8.2 Ongoing Studies

As part of the Fourth National Health and Nutrition Evaluation Survey (NHANES IV), 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.