

5. POTENTIAL FOR HUMAN EXPOSURE

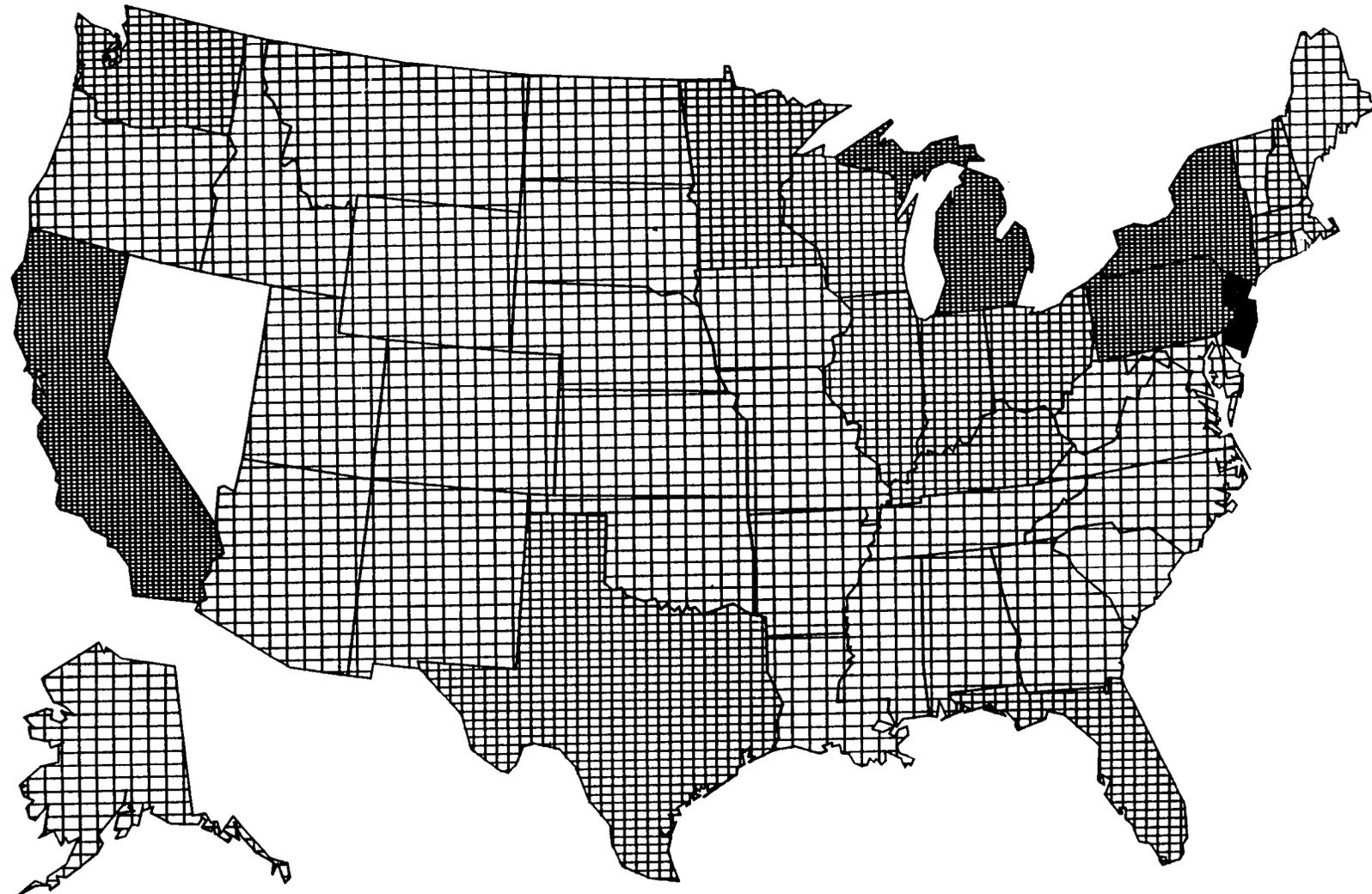
5.1 OVERVIEW

Xylenes are ubiquitously distributed in the environment. They have been detected in the atmosphere, rainwater, soils, surface waters, sediments, drinking water, aquatic organisms, and human blood, urine, and expired breath. Xylenes do not occur in the environment naturally except in smoke from forest fires or as constituents of petroleum which may seep into the oceans from underground deposits. Xylenes are released to the atmosphere primarily as fugitive emissions from industrial sources (e.g., petroleum refineries, chemical plants), in automobile exhaust, and through volatilization from their use as solvents. Discharges into waterways and spills on land result primarily from use, storage, and transport of petroleum products and waste disposal. Most of the xylene released to the environment partitions to the atmosphere. The small amount of xylene that may be released to soil is moderately mobile and can leach into the groundwater where it may persist for several years.

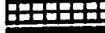
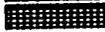
Xylenes are rapidly transformed in the troposphere where photooxidation by hydroxyl radicals is the dominant process. Xylenes are stable to hydrolysis and oxidation in the aquatic environment, but some evidence indicates that they may be biotransformed by microorganisms in groundwater. Biotransformation of xylene in surface waters is probably not significant because of the volatility of the compound. Biodegradation is an important process mainly in subsurface soils since xylenes in surface soils undergo photooxidation or volatilize to the atmosphere. Sorption of xylene to soils is more important in dry soils and increases in soils and sediments as organic matter content increases. Xylene has been found to bioaccumulate to very modest levels (e.g., bioconcentration factors of less than 100), although food-chain biomagnification has not been observed. Xylene or its metabolites have been detected in human urine, blood, and expired air samples among members of the general population. Human exposure to xylene is believed to occur via inhalation of indoor and workplace air, inhalation of automobile exhaust, ingestion of contaminated drinking water, smoking, and inhalation and dermal absorption of solvents containing xylene.

To date, total xylenes have been identified at 658 of the total 1,408 NPL sites (HAZDAT 1993). However, the total number of sites evaluated for xylenes is not known. The frequency of these sites within the United States can be seen in Figure 5-1; of these sites, 656 are located in the United States, and 2 are located in the Commonwealth of Puerto Rico (not shown).

FIGURE 5-1. FREQUENCY OF NPL SITES WITH XYLENE CONTAMINATION *



FREQUENCY

	1 TO 10 SITES		11 TO 29 SITES
	48 TO 52 SITES		65 SITES

*Derived from HazDat 1994

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5.2 RELEASES TO THE ENVIRONMENT**5.2.1 Air**

Based on the low vapor pressures of the xylenes (6-16 torr), volatilization is the dominant process governing the environmental behavior of these chemicals. This means that most of the xylene released to the environment ultimately partitions into the atmosphere. Most annual releases of xylenes are refinery losses into the atmosphere during the production, transportation, and processing of petroleum. Other significant sources of xylene emissions are from the use of solvents, as a component of automobile exhaust gases, evaporation of gasoline into the air during its transportation and distribution, and releases from the chemical industry (Merian and Zander 1982).

Releases of xylene are also associated with outgassing from landfills where disposal of industrial, hazardous, and mixed municipal wastes occur. In Finland during 1989-1990, all three xylene isomers were detected in gases released from closed municipal landfills at average concentrations of 0.86, 3.6, and 1.2 mg/m³ (0.20, 0.83, and 0.28 ppm) for the *o*-, *m*-, and *p*-isomers, respectively. Concentrations of all of the xylene isomers in off-gases from an active landfill were 30-35 times higher (Assmuth and Kalevi 1992). In 1987-1988, air emissions of mixed xylene, for facilities in the Houston, Texas, ship channel industrial area were 551 tons per year. The emissions resulted in an ambient concentration in this area of 1.6 parts per billion volume (ppbv) (LaGrone 1991).

According to TRI (TRI90 1992), an estimated total of 135 million pounds of mixed xylene, amounting to 99.5% of total environmental releases, was discharged to air from manufacturing and processing facilities in the United States in 1990. Data from 1992 (Table 5-1) suggests that the amount of mixed xylenes released to the air was reduced to about 2 million pounds and accounted for about 99.9% of the total xylenes released into the environment (TRI92 1994). Releases to the air of specific isomers in 1990 were: 1.2 million pounds for *m*-xylene, 2.0 million pounds for *o*-xylene, and 4.7 million pounds for *p*-xylene; the remainder of the releases were identified as mixed xylene (TRI90 1992). The estimates for 1992 are 1.2 million pounds for *m*-xylene (Table 5-2), 2 million pounds for *o*-xylene (Table 5-3), and 4 million pounds for *p*-xylene (Table 5-4) (TRI92 1994). The data listed in the TRI should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list.

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Mixed Xylene

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
AK	2	3594-23543	0-5	5-10	0	3604-23553	0-5	10-237
AL	93	0-775004	0-250	0	0-15	0-775004	0-49468	0-464559
AR	69	3-130750	0-250	0-250	0	3-130750	0-5	0-130005
AZ	11	26-58800	0	0-44	0	26-58800	0-2100	0-171001
CA	163	0-171600	0-289	0-2000	0-232	0-171600	0-40000	0-740000
CO	14	0-22925	0-250	0	0	0-22925	0-250	0-14289
CT	29	103-38400	0-270	0	0	103-38400	0-62400	0-147295
DE	5	684-348038	0-530	0-156	0	684-348038	0-3	210-468818
FL	50	0-112000	0	0	0-120	0-112000	0-1940	0-1122372
GA	95	0-491000	0-150	0-5	0	0-491000	0-9261	0-480000
IA	88	0-303661	0-250	0-1203	0	0-303661	0-5	0-305261
ID	1	0	0	0	0	0	0	1446
IL	213	0-772300	0-82	0-250	0	0-772300	0-150000	0-937960
IN	215	0-478000	0-1400	0-25932	0-5	0-478000	0-1350	0-888142
KS	53	0-419300	0-260	0	0	0-419300	0-3360	0-148854
KY	69	10-1610000	0-250	0-250	0	10-1610000	0-12277	0-1968302
LA	65	0-614300	0-1062	0-750	0-4500	0-614300	0-30	0-258279
MA	50	10-29000	0-5	0	0	10-29000	0-19022	0-93938
MD	23	269-252900	0-1	0	0	269-252900	0-310	0-170000
ME	14	1390-98000	0	0	0	1390-98000	0	0-19193
MI	160	2-657399	0-30	0-32603	0-1200	2-657399	0-4678	0-2932550
MN	76	7-423700	0-190	0	0	7-423700	0-750	0-569000
MO	109	0-841000	0-14	0-1290	0	0-841000	0-2700	0-1235002

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Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Mixed Xylene (continued)

State ^b	Number of facilities	Range of reported amounts released in pounds per year ^a						
		Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
MS	67	1-675352	0-250	0-5500	0	1-675352	0-250	0-67300
MT	6	255-99000	0-5	0-20	0	260-99022	0-5	0-4696
NC	109	0-190905	0-45	0	0	0-190905	0-26655	0-231792
ND	8	3009-70000	0	0-3	0	3009-70003	0	0-2459
NE	31	35-189000	0-5	0	0	35-189000	0-5	0-40200
NH	9	250-133500	0	0	0	250-133500	0	250-8931
NJ	109	0-204500	0-481	0-95859	0	0-204500	0-18719	0-799619
NM	7	500-46000	0	0-700	0	500-46700	0-5	0-10050
NV	5	539-34150	0	0	0	539-34150	0	0-50
NY	110	0-339000	0-830	0-250	0	0-339005	0-4150	0-715220
OH	234	0-1155447	0-40	0-250	0	0-1155447	0-6500	0-2567400
OK	40	250-365593	0-44	0-890	0	250-365593	0-90	0-531182
OR	26	255-78800	0	0	0	255-78800	0-109	0-18000
PA	194	0-200000	0-250	0-4100	0	0-200000	0-29000	0-765855
PR	15	0-41346	0	0	0	0-41346	0-9900	0-6514459
RI	9	555-114683	0	0	0	555-114683	0-5	0-13929
SC	63	0-199400	0-2100	0-250	0	0-199400	0-48000	0-124098
SD	17	116-427689	0	0	0	116-427689	0	0-64933
TN	111	0-1153683	0-761	0-9100	0-6574	0-1153683	0-9100	0-940579
TX	225	0-511800	0-3100	0-1100000	0-150000	0-1222420	0-75636	0-522793
UT	21	0-46000	0	0-750	0	0-46000	0-22000	0-36422
VA	94	3-350770	0-15150	0-1	0	3-365920	0-499	0-1178094
VI	1	232382	1079	0	0	233461	0	0

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Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Mixed Xylene (continued)

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
VT	2	3602-33293	0	0	0	3602-33293	0-250	250-1293
WA	38	500-178574	0-250	0-250	0	500-178574	0-5	0-30005
WI	120	0-355227	0-87	0-632	0	0-355227	0-420	0-458177
WV	30	0-93000	0-250	0-250	0	0-93011	0-250	0-306321
WY	6	296-193265	0-5	0-28	0	296-193275	0-250	0-407

Source: TRI92 1994

^a Data in TRI are maximum amounts released by each facility.^b Post office state abbreviations used^c The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility

POTW = Publicly owned treatment works

Table 5-2. Releases to the Environment from Facilities That Manufacture or Process m-Xylene

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
AL	1	69000	0	5	0	69005	0	490
AR	3	99-6300	0	0	0	99-6300	0	25-32262
CA	9	0-12000	0-310	0-860	0	0-12860	0-5	0-9132
GA	1	4	0	0	0	4	0	0
HI	2	8500-19100	0-250	0-250	0-5	8505-19600	0	0
IA	1	289	0	0	0	289	0	10475
IL	3	524-24500	0	0	0	524-24500	0	0-8120
IN	1	12064	0	0	0	12064	0	7459
KS	1	560	5	0	0	565	0	5182
KY	2	1078-98854	0	0	0	1078-98854	0	12864-32327
LA	2	640-33800	0	0	0	640-33800	0	0
MN	1	5	0	0	0	5	0	0
MO	3	8-5898	0-17	0	0	13-5898	0	0-21643
MS	4	52-198000	0-68	0-88	0	52-198156	0	0-3960
NC	1	12	0	0	0	12	0	0
NJ	1	6	0	0	0	0	0	9506
NY	1	22100	480	0	0	22580	0	0
OH	1	500	0	0	0	500	250	0
OR	1	14000	0	0	0	14000	0	4735
PA	2	3600-4920	0	0	0	3600-4920	0	8-17075
PR	7	1-176003	0	0	0	1-176003	0	0-62
TN	3	1895-24000	0	0-1800	0	1895-25800	0-85235	0-85234
TX	15	0-217390	0-244	0-3100	0	0-220490	0-68900	0-37482

Table 5-2. Releases to the Environment from Facilities That Manufacture or Process m-Xylene (continued)

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
UT	2	9437-16000	0	0	0	9437-16000	0-1301	0-12
WI	1	250	0	0	0	250	0	2835
WV	1	11420	0	0	0	11420	0	0

Source: TRI92 1994

^a Data in TRI are maximum amounts released by each facility.

^b Post office state abbreviations used

^c The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility

POTW = Publicly owned treatment works

Table 5-3. Releases to the Environment from Facilities That Manufacture or Process o-Xylene

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
AL	3	100-38000	0-5	0-5	0	105-38005	0	0-609775
AR	2	48-250	0	0	0	48-250	0	12-250
CA	11	0-8993	0-170	0-1200	0	0-8993	0-634	0-5419
CT	1	30846	0	0	0	30846	22700	116825
GA	2	2202-18400	0	0	0	2202-18400	0-120	0-414000
HI	2	5490-11400	0-250	0-250	0-5	5495-11900	0	0
IL	3	11701-40200	0	0	0	11701-40200	0	0-4060
IN	1	110000	0	0	0	110000	0	49700
KS	2	6550-6910	0-5	0	0	6550-6915	0	250-7909
KY	1	367	0	0	0	367	1	4597
LA	4	29-90752	0-339	0	0	29-91091	0	0-63421
MI	1	2750	5	0	0	2755	0	87010
MO	4	10-30100	0-250	0-5	0	15-30355	0	0-1800
MS	2	10-104300	0-68	0-88	0	10-104456	0	0-1
NC	3	0-495000	0	0	0	0-495000	0	0-13927
NJ	2	293-1500	0	0	0	293-1500	0-1353	89984-106791
NY	2	17620-72361	0-250	0	0	17870-72361	0-31	0-180222
OH	3	0-14600	0	0	0	0-14600	0	0-21465
PA	3	96-22256	0	0	0	96-22256	0-572	8-14548
PR	4	5-158218	0	0-4	0	5-158222	0-5	0-53
RI	1	378	0	0	0	378	2	14042
SC	2	560-74000	0-3	0	0	560-74003	0	0
TN	4	5179-93000	0-470	0	0	5179-93000	0-636	0-292312

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Table 5-3. Releases to the Environment from Facilities That Manufacture or Process o-Xylene (continued)

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
TX	18	0-167440	0-31	0-4400	0	0-171840	0-26500	0-10472
UT	1	5431	0	0	0	5431	650	12
WI	1	10200	0	0	0	10200	4	390000
WV	1	5160	0	0	0	5160	0	0

Source: TR192 1994

^a Data in TRI are maximum amounts released by each facility.

^b Post office state abbreviations used

^c The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility

POTW = Publicly owned treatment works

Table 5-4. Releases to the Environment from Facilities That Manufacture or Process p-Xylene

Range of reported amounts released in pounds per year ^a								
State ^b	Number of facilities	Air	Water	Land	Underground injection	Total environment ^c	POTW transfer	Off-site waste transfer
AL	1	1139000	0	15	0	1139015	0	200
CA	9	0-5820	0-150	0-550	0	0-5820	0-634	0-4306
HI	2	4800-7500	0-250	0-250	0-5	4805-8000	0	0
LA	1	69000	0	0	0	69000	0	0
MA	3	180-1500	0	0	0	180-1500	0-5	340-43126
MO	1	5	5	0	0	10	0	0
MS	1	171000	68	88	0	171156	0	1
NC	2	262000-800000	0-1	1	0	262001-800002	0	0-7190
NJ	1	1500	0	0	0	1500	250	0
NY	1	4090	250	0	0	4340	0	0
PA	2	1384-3300	0	0	0	1384-3300	0	8-72
PR	1	240970	0	0	0	240970	0	62
SC	2	123000-493900	0	0-90	0	123090-493900	0	0
TN	3	3848-94800	0	0	0	3848-94800	0-486	0
TX	12	0-154240	0-95	0-3100	0	0-157340	0-68900	0-5188
UT	1	3295	0	0	0	3295	650	12
VI	1	203312	1043	0	0	204355	0	0
WV	1	3640	0	0	0	3640	0	0

Source: TRI92 1994

^a Data in TRI are maximum amounts released by each facility.^b Post office state abbreviations used^c The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility

POTW = Publicly owned treatment works

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5.2.2 Water

Xylenes may be introduced into groundwater by fuel oil, gasoline, or solvent spills, infiltration of polluted surface waters, leaking underground petroleum storage tanks, or leaching from disposed wastes (Giger and Schaffner 1981). It was estimated that over 10,000 water-polluting spills of oil and hazardous substances occur annually in the United States (Faust 1977).

A total xylene concentration (concentration includes ethylbenzene) of 1.2 ppb was detected in effluent from containment ponds in the containment area of an oil spill that accumulated along the banks of the Atigun River, Alaska (Lysyj et al. 1980). Treated effluents from offshore oil drilling platforms in the Gulf of Mexico contained an average concentration of 0.3 mg/L (ppm) (concentration includes ethylbenzene) (Lysyj et al. 1980). Final effluent from a Los Angeles County waste-water treatment plant, sampled between November 1980 and August 1981, contained *o*-xylene and *p*-xylene at concentrations of 40 and 30 µg/L (ppb), respectively (Gossett et al. 1983). All three xylenes have been detected in the leachate from landfills at concentrations ranging from 10 to 4,400 µg/L (ppb) for hazardous waste landfills and from 3.7 to 38 µg/L (ppb) for domestic landfills (Forst et al. 1989a,b).

According to TRI (TRI90 1992), an estimated total of 42,362 pounds of mixed xylene, amounting to less than 0.03% of total environmental releases, was discharged to water from manufacturing and processing facilities in the United States in 1990. In 1992 about 304 pounds of xylene (<0.02% of the total) were released to water (TRI92 1994). Releases to water of the specific isomers were: 1,086 and 1,387 pounds for *m*-xylene in 1990 and 1992 (Table 5-2), 2,541 and 1,868 pounds for *o*-xylene in 1990 and 1992 (Table 5-3), and 676 and 1,868 pounds for *p*-xylene in 1990 and 1992 (Table 5-4); the remainder of the releases were identified as mixed xylene. In 1990, an estimated total of 1.9 million pounds of mixed xylene, amounting to 1.3% of the total environmental releases, was discharged to publicly owned treatment works (TRI90 1992). In 1992, about 535 pounds of xylene (0.03% of the total) was released to publicly owned treatment works (TRI92 1994). Of the releases to publicly owned treatment works in 1990, 1,013 pounds were identified as *m*-xylene, 55,154 pounds were *o*-xylene, and 256 pounds were *p*-xylene (TRI90 1992). The individual isomers released in 1992 were 156,993 pounds *m*-xylene (Table 5-2), 53,212 pounds *o*-xylene (Table 5-3), and 70,927 pounds *p*-xylene (Table 5-4) (TRI92 1994). The data listed in the TRI should be used with caution since only certain types of facilities are required to report. This is not a complete list.

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5.2.3 Soil

No quantitative information was available in the literature regarding total releases of xylene to soil. Atmospheric xylene may reach soils either by wet deposition by precipitation or through dry deposition of material adsorbed to particulate matter in air. Xylene may also reach soils from the introduction of man-made wastes (e.g., landfills) or as a result of accidental releases (e.g., spills).

According to TRI (TRI90 1992), an estimated total of 408,592 pounds of mixed xylene, amounting to less than 0.3% of the total environmental releases, was discharged to land from manufacturing and processing facilities in the United States in 1990. Releases to land of the specific isomers were: 1,130 pounds for *m*-xylene, 1,842 pounds for *o*-xylene, and 1,376 pounds for *p*-xylene; the remainder of the releases were identified as mixed xylene. Relative to 1990, the amount of mixed xylenes released to land decreased to about 535 pounds in 1992 (TRI92 1994). In contrast, releases to land of the specific isomers increased and in 1992 were 6,189 pounds for *m*-xylene (Table 5-2), 5,967 pounds for *o*-xylene (Table 5-3), and 4,101 pounds for *p*-xylene (TRI92 1994). The data listed in the TRI should be used with caution since only certain types of facilities are required to report. This is not a complete list.

5.3 ENVIRONMENTAL FATE**5.3.1 Transport and Partitioning**

Volatilization is the dominant transport mechanism for xylenes. In a global sense, most (99.68%) of the xylenes released into the environment ultimately partitions into the atmosphere as shown by the fugacity model (Jori et al. 1986). Table 5-5 shows the calculated equilibrium distribution for releases of xylene to the environment. The diffusion coefficient for *o*-xylene is 0.092 cm²/sec (Cobb and Braman 1991). As the magnitude of the Henry's law constant for xylene presented in Chapter 3 indicates, xylene is highly volatile and is likely to partition readily into the atmosphere from water. Because of its volatility, xylene are generally not persistent in surface water in high concentrations. The half-life associated with volatilization from surface waters for *o*-xylene at a depth of 1 meter is reported to be 5.6 hours but will vary in accordance with turbulence and water depth (Mackay and Leinonen 1975).

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TABLE 5-5. Characteristics of Different Environmental Compartments and Xylene Concentrations on Emission of 100 mol^a

Compartment	Volume (m ³)	Amount (%)	Concentration	
			(mol/m ³)	(ppm)
Air	10 ¹⁰	99.6837	0.99×10 ⁻⁸	880×10 ⁻⁶
Soil	9×10 ³	0.0089	98.88×10 ⁻⁸	70×10 ⁻⁶
Water	7×10 ⁶	0.2656	3.79×10 ⁻⁸	4×10 ⁻⁶
Biomass	3.5	0.1261×10 ⁻⁴	360.28×10 ⁻⁸	382×10 ⁻⁶
Suspended solids	35	0.6942×10 ⁻⁴	198.34×10 ⁻⁸	140×10 ⁻⁶
Sediments	2.1×10 ⁴	0.0416	198.09×10 ⁻⁸	140×10 ⁻⁶
Total amount	NA	99.9999	NA	NA

^aDerived from theoretical calculations based on a simple closed air/water/soil chamber model (Jori et al. 1986).

NA = Not applicable

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When spilled on land, xylenes volatilize or leach into the ground. Volatilization half-lives for the three xylene isomers in soil are not available in the literature. Using an estimated soil organic carbon partition coefficient (K_{oc}) of 2.40×10^2 and a dimensionless Henry's law constant (H) of 2.12×10^{-1} , the calculated air-soil partition coefficient (K_{as}) for total xylenes is 1,100, where $K_{as} = K_{oc}/H$. In general, calculated K_{as} values of 10,000 or less correlate well with chemicals that volatilize completely from soil in 1 year or less as determined by iterative modeling using a time-dependent soil volatilization model with reservoir depletion (Hwang et al. 1986). However, calculated K_{as} values for individual soils suggest that as soil organic content increases beyond 1%, the residence time of xylene in soil increases correspondingly. Studies in soils and sediments based on log octanol:water partition coefficients (K_{ow}) indicate that xylenes tend to adsorb to organic matter (log K_{ow} of 3.20 for *m*-xylene, 2.77 for *o*-xylene, and 3.15 for *p*-xylene) (Chiou et al. 1982; Gherini et al. 1989). A general increasing trend for the relative retention of xylene in soil with increasing soil organic matter has been observed by a number of investigators (Green et al. 1981; Kango and Quinn 1989; Nathwani and Phillips 1977; Seip et al. 1986); however, the presence of other organic pollutants that compete for sorption sites on the soil may increase the transport of the xylene through the soil to the underlying groundwater (Stuart et al. 1991). In subsurface soils with low organic carbon content, xylene is more likely to infiltrate into groundwater from soil (EPA 1985a). According to the Exposure Analysis Modeling System (EXAMS) model of EPA (1981), total steady-state xylene accumulation in bottom sediments from surface waters ranged from 4.5% to 70% of the total xylene load from the model, depending upon the percent organic matter present.

When xylene was spilled at an application depth of 7.2 cm (2.9 inches) or less on loam-textured soil at moisture contents ranging from 0.15 to 0.26 kg/kg, 1-4% volatilized, 0.5-35% leached, 50-85% degraded, and 6-12% remained after about 80 days in the soil (Aurelius and Brown 1987). Most of the observed volatilization occurred immediately after application. The fractions of applied xylene that were retained, volatilized, or degraded were greatest in the driest soil. This is because, while the dryness allows for greater initial retention, there is less moisture to entrap the subsurface soil and prevent it from later volatilizing or degrading (Aurelius and Brown 1987). Thus, following a spill on wet soil, a greater percentage of xylene will initially evaporate. That which remains, however, will then be blocked by the moisture and less able to volatilize or degrade.

Xylene moves through unsaturated (drier) soil faster than water and other polar solvents (Amoozegar et al. 1986; Barbee and Brown 1986). For example, diffusion coefficients of approximately 0.02 and

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0.005 cm²/sec were measured in dry and wet (12-15%) cores taken from the first natural barriers at the Los Alamos National Laboratory chemical waste site (Fuentes et al. 1991). Additional field data suggesting that concentrated organics may leach 10-1,000 times faster than water in unsaturated soil were provided by Griffin et al. (1984). This increased conductivity is probably due to cracks in the soil through which the organics move rapidly (Aurelius and Brown 1987). At high water contents, water displaces a number of organics from mineral surfaces (Rhue et al. 1988). Because xylene is hydrophobic, it does not easily diffuse through water films into the soil matrix (Barbee and Brown 1986); consequently, the presence of water vapor on the surface of soil particles reduces xylene sorption from the vapor phase of the soil onto the soil particles (Pennell et al. 1992). Thus, in the presence of a hydraulic gradient, xylene probably moves as a separate immiscible organic phase floating on the water films in the soil pores (Aurelius and Brown 1987). Xylene moved as a relatively uniform front through loamy sand; however, in silt loam and clay, xylene moved preferentially through large pores in the soil structure (Barbee and Brown 1986). Because of its ability to desiccate clays, xylene may have further opened these natural macropores, thereby facilitating rapid movement. Even though xylene may move slowly through a wet clay by diffusion and convection, there is, in principle, a danger that it will eventually cause shrinking and cracking and thereby allow fluid transmission in bulk (Green et al. 1981). The behavior of underground xylene at a particular spill/waste site will be highly dependent on that site's specific hydrogeologic characteristics.

Measured log K_{ow} values are 2.77, 3.15, and 3.20 for *o*-, *p*-, and *m*-xylenes, respectively (Chiou et al. 1982; Gherini et al. 1989). The rapid oxidation of xylene isomers to their corresponding polar metabolites seems to preclude bioconcentration in higher animal systems and, therefore, bioaccumulation up the food chain is unlikely (NRC 1980). Bioconcentration factors (BCFs) for *o*-, *m*-, and *p*-xylenes have been estimated to be 45, 105, and 95, respectively (EPA 1985a). Bioconcentration of xylene has been observed in shrimp (*Pandalus platyceros*) (Sanborn and Malins 1980), manila clams (*Tapes semidecussate*) (Nunes and Benville 1979), and eels (*Anguilla japonica*) (Ogata and Miyake 1978). A bioconcentration factor of 6 has been reported for tissue uptake in clams throughout an 8-day exposure to *o*-, *m*-, and *p*-xylenes (Nunes and Benville 1979), and bioconcentration factors of 21.4, 23.6, and 23.6 have been reported for eels exposed to 50 ppm of *o*-, *m*-, and *p*-xylenes, respectively (Ogata and Miyake 1978). Tissue levels reached a steady state after 10 days. The green alga *Selenastrum capricornutum* has bioconcentration factors of 257, 251, and 218 for *p*-, *m*-, and *o*-xylenes, respectively (Herman et al. 1991). Bioconcentration has been predicted for all isomers of xylene because of their tendency to partition into the octanol phase of the octanol-water system (EPA

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1978). Scientists generally regard BCFs below 20 as indicative of little or no bioconcentration, 20-100 as equivocal, and less than 1,000 as indicative of modest bioconcentration.

5.3.2 Transformation and Degradation

5.3.2.1 Air

Xylene is transformed in the atmosphere by photooxidation. Phototransformation in the atmosphere is believed to be the most quantitatively important transformation process for xylene in terms of the percentage of substance transformed (an estimated 99.96%) (Jori et al. 1986). Direct photolysis is not expected because xylene does not significantly absorb light at wavelengths greater than 290 nm (Jori et al. 1986), and therefore, direct reactions of the xylene with the hydroxyl radicals and the removal of a hydrogen atom may account for only 10% of the degradation reactions (Tuazon et al. 1986). Based on an estimated rate constant of 0.0287 hour^{-1} (Jori et al. 1986), the half-life for the photooxidation of xylenes in the atmosphere is estimated to be 0.5-1.0 days (Grosjean 1991). The transformation of xylene by reaction with hydroxyl radicals prevails over that of reaction with ozone or peroxy radical and is likely to be the only significant atmospheric removal process for xylene (Atkinson et al. 1982; Fox et al. 1984; Mill 1980; Roberts et al. 1984). Major photodegradation products formed by the cleavage of the aromatic ring in the presence of nitric oxide are: *o*-tolualdehyde, methylglyoxal, 4-nitro-*o*-xylene, and 2,3-dimethylphenol for *o*-xylene; 2,6-dimethylphenol, 2,4-dimethylphenol, methylglyoxal, and *m*-tolualdehyde for *m*-xylene; and *p*-tolualdehyde and 2,5-dimethylphenol for *p*-xylene (Atkinson et al. 1991; Gery et al. 1987). Xylene also participates in ancillary photooxidation reactions including the conversion of nitric oxide to nitrogen dioxide; *m*-xylene is more than twice as reactive as *o*-xylene and *p*-xylene (14% reacted in 1st hour of irradiation compared with 7%) (Altshuller et al. 1962; Kopczynski 1964). Other photooxidation products resulting from ring-cleavage of the xylene isomers include glyoxal and methylglyoxal which may form approximately 30-50% of the photooxidation products (Tuazon et al. 1986); *o*-xylene also forms formaldehyde, acetaldehyde, biacetyl nitrate, and peroxyacetylnitrate (Bandow and Washida 1985; Darnall et al. 1979; Shepson et al. 1984; Tagaki et al. 1980). Reported half-lives for the oxidation of *o*-, *m*-, and *p*-xylene by hydroxyl radicals range from 0.4 to 1.0 day (ECETOC 1986; Mill 1980). The reported half lives for the reaction with ozone are much greater, ranging from 5,000 to 6,200 days (ECETOC 1986). The products of photoreaction with hydroxyl radicals are ultimately degraded to carbon dioxide and water after absorption in the hydrosphere (Guisti et al. 1974).

5.3.2.2 Water

In surface waters, volatilization is the dominant removal process. Therefore, biotransformation of xylene in surface waters is probably not significant. The estimated half-life for biodegradation of xylene in water (247.5 hours/10.3 days) (Jori et al. 1986) is considerably greater than the half-life predicted for volatilization of xylene from water (5.6 hours) (Mackay and Leinonen 1975). The applicability of these values to *in situ* situations is very limited.

Oxidation reactions are not expected to be significant transformation processes for xylene in aquatic systems (Mill 1980). However, aqueous solutions of xylene have undergone photooxidation in the presence of hydroxyl radical donors such as hydrogen peroxide (commonly found in water), titanium dioxide (found in soils), and humic substances. *m*-Xylene degrades more rapidly than the two other isomers under these particular conditions (half-lives of 0.2-3.0 hours compared with 0.5-9.1 hours, respectively). Whether or not these conditions will apply to a given xylene-release site depends on the situation at that site. Degradation products include tolualdehyde and methyl benzyl alcohols (Beyerle-Pfnur et al. 1989). In addition, xylene is reported to be resistant to hydrolysis (HSDB 1988).

Xylene concentrations detected in tap water (treated water) of several monitoring studies were not significantly different from those at the source (raw water) (Keith et al. 1976; Otson et al. 1982a; Saunders et al. 1975; Williams et al. 1982), which may support the idea that biodegradation of xylene in water is limited and that little or no oxidation or hydrolysis occurs.

Although xylene was observed to completely degrade in groundwater in one continuous percolation experiment using the resident microflora as the inoculum (Kappeler and Wuhrmann 1978a), xylene generally appears to be poorly to moderately biodegraded in groundwater. Xylene has also been observed to persist in groundwater particularly at sites where concentrations are high. For example, in a field study following an oil spill from the Trans-Alaskan Pipeline in the Atigun Pass, Alaska, on June 10, 1979, xylene was not detected in the 40-km-long watershed of the containment area 18 days after the spill. This suggested xylene persistence in the groundwater of the containment area as opposed to movement in the groundwater to the watershed area (Lysyj et al. 1980). One explanation for the lack of biodegradation of xylene in groundwater is that degradation is primarily a function of co-metabolism and that some other degradable hydrocarbons such as naphthalene must also be present as a substrate (Jorgensen and Aamand 1991).

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However, under denitrifying conditions (i.e., nitrate was present in the substrate), biodegradation of *m*- and *p*-xylene occurred within 40 days. Although *o*-xylene was resistant to degradation when it was the sole carbon source, it was slowly removed in the presence of other hydrocarbons (Hutchins 1991). Similar results have been seen in other studies of the anaerobic biodegradation of all three xylene isomers under denitrifying conditions (Gersberg et al. 1991; Hutchins et al. 1991, 1992). Use of nitrate injection for aquifers contaminated with a mixture of benzene, toluene, and xylene (common fuel hydrocarbons) has been recommended as a possible remediation process to enhance biodegradation. Under anaerobic sulfate-reducing conditions, biodegradation of the xylene isomers is also facilitated (Edwards et al. 1992). *m*-Xylene is more susceptible than *o*-xylene to anaerobic biodegradation under sulfate-reducing conditions and has a shorter acclimation period before degradation commences; however, in aquifers contaminated with landfill leachate, both xylene isomers are significantly biodegraded in less than 100 days under experimental conditions involving forced introduction of microbe nutrients (Acton and Barker 1992).

Field evidence of xylene transformation during transport in anoxic groundwater at a landfill in North Bay, Ontario, suggests that anaerobic transformation of xylene probably occurs in landfills and their leachate plumes. The extent of this transformation is difficult to determine, and it is clearly neither rapid nor complete (Barker 1987). The treatment of groundwater contaminated with xylene using biological reactors such as an upflow aerated column and a rotating disc biological contractor is an effective removal mechanism. The xylenes are removed principally by biodegradation rather than volatilization from water or adsorption to the sludge (Van der Hoek et al. 1989).

Xylene is degraded in standard biodegradability tests using various inoculum including sewage and activated sludge, but the rate can vary according to the source of the microbial population and whether or not the microbial population was acclimated to utilize xylene by pre-exposure to the chemical (Bridie et al. 1979). Acclimation increased degradation in a filtered sewage seed from 52% to 57% (*o*-xylene) and from 44% to 74% (*p*-xylene) of the theoretical 5-day Biological Oxygen Demand (BOD) values (Bridie et al. 1979). A concentration of 500 mg/L of *o*-, *m*-, or *p*-xylene was toxic to unacclimatized activated sludge microorganisms during the first 24 hours of aeration (Marion and Malaney 1964). In other studies, *m*-xylene was found to be toxic to microorganisms, yielding only about 10% of the theoretical BOD after 8 days, while *o*-xylene and *p*-xylene were more degradable, varying between 63% and 26% of the theoretical BOD (Malaney 1960; Malaney and McKinney 1966; Marion and Malaney 1964). The relatively high concentrations of xylene used in some of these

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studies may result in toxicity to test microorganisms and could account for the low degradation rates (EPA 1985a). The limiting factor in xylene biodegradation appears to be oxygen (Jenkins et al. 1993; Morgan et al. 1993). Jenkins et al. (1993) have shown that the addition of oxygen microbubbles to water in a soil column enhanced the degradation of xylenes. In contrast, addition of hydrogen peroxide as an oxygen source at a concentration of 200 mg/L completely inhibited degradation as a result of toxicity (Morgan et al. 1993).

5.3.2.3 Sediment and Soil

On surface soils the major fate process for xylene will be volatilization, but of the little that does not volatilize or leach into the soil, photo-induced oxidation is likely to be a significant transformation process for xylene. Based on theoretical calculations, using a simple closed environmental simulation with an estimated rate constant of 0.0287 hour^{-1} , the half-life for the photooxidation of xylene in soils is estimated to be 24.1 hours (Jori et al. 1986). The applicability of these calculations to *in situ* situations is very limited. *p*-Xylene was found to disappear from the surface of soils (sterile and nonsterile) with a half-life of approximately 2.2 days; the abiotic mechanism of loss was not determined (Anderson et al. 1991). No other quantitative information was found in the available literature regarding photooxidation of xylene in surface soils. This mechanism is not expected to degrade a substantial fraction of a xylene spill because most of the xylene will evaporate or leach into subsurface soil.

Biodegradation is considered to be the only significant transformation mechanism for xylene in subsurface soil, but is likely to be a slow process based on xylene's rate of degradation in other media (EPA 1984a, 1985a). Biodegradation half-lives for xylene in soil were not found in the available literature; however, numerous bacteria (including several strains of *Pseudomonas*, *Flavobacterium*, and *Nocardiu*) capable of utilizing *p*- and *m*-xylene as carbon sources in the growth medium have been isolated from soils (Davis et al. 1968; Gibson et al. 1974; Haigler et al. 1992). According to several degradative pathways that have been proposed, both the *m*- and *p*-isomers are oxidized to their respective intermediate products, which in turn undergo aromatic ring cleavage (Davis et al. 1968; Davey and Gibson 1974; Gibson et al. 1974; Omori and Yamada 1970). Since many of the decomposition products of xylene biodegradation are hydrophilic (e.g., xylenols, benzoic acids, etc.), they are easily subject to further microbial biodegradation (Merian and Zander 1982). The importance of the methyl group position to breakdown of xylene isomers is indicated by the fact that cultures of

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Pseudomonas grown on *p*-xylene were capable of oxidizing both *m*-xylene and toluene, but neither *p*-xylene-grown cultures nor *m*-xylene-grown cultures were capable of oxidizing *o*-xylene (Davis et al. 1968). Mixed aquifer cultures are able to aerobically degrade *p*-xylene after an acclimation period of 10 days. The zero-order biodegradation rate was 2 mg/L/day; however, the presence of other hydrocarbons may have an inhibitory effect on the degradation rate and acclimation period (Alvarez and Vogel 1991). The relevance of these observations to xylene in subsurface conditions is unknown because there are little data concerning the availability of subsurface microbes or oxygen for most waste sites.

Based on theoretical calculations using a simple closed environmental simulation with an estimated rate constant of 0.0028 hour^{-1} (Jori et al. 1986), the half-life for the biodegradation of xylene in sediments is estimated to be 247.5 hours. These calculations did not consider the effects of complex sedimentary stratification and other conditions that might exist in the field. Anaerobic fermentative/methanogenic bacteria capable of degrading *o*-xylene were isolated from creosote-contaminated aquifer sediments in Pensacola, Florida. Although an acclimation period of 2-3 months was required, complete mineralization of 50 $\mu\text{mol/L}$ (μM) *o*-xylene was rapid (1-2 weeks) after degradation was initiated. *p*-Xylene or *m*-xylene were not degraded by these cultures (Beller et al. 1991; Edwards and Grbic-Galic 1994). Natural organic substances, for example, acetate, H_2 , propionate, and glucose, inhibited the degradation of *o*-xylene (Edwards and Grbic-Galic 1994), so the relevance of these observations to contaminated sites is unknown. Anaerobic cultures of denitrifying bacteria that were capable of degrading 100 μM *o*-xylene by more than 20% after 100 hours in the presence of toluene were isolated from soils and sludges. The bacteria did not initially utilize either *m*- or *p*-xylene, although after 2 weeks in the presence of xylenes, a subculture was isolated that specifically degraded *m*-xylene (Evans et al. 1991).

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

Xylene has been detected in areas where anthropogenic sources are not evident indicating that very low concentrations may be ubiquitous in the atmosphere. Average background levels of *o*-, *m*-, and *p*-xylene, measured over the North Atlantic in 1977, were 13, 21, and 9.2 ng/m^3 (0.003, 0.0048, and 0.002 ppb), respectively (Eichmann et al. 1979). Similar measurements over the Indian Ocean gave

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average concentrations of 0.9, 1.1, and 0.15 ng/m³ (0.21, 0.25, and 0.03 ppt), respectively (Eichmann et al. 1980), while over the Pacific Ocean concentrations ranged from below the detection limit (0.05 ppbv) to 0.31 ppbv for *m*- and *p*-xylene and from 0.01 to 0.77 ppbv for *o*-xylene (Greenberg and Zimmerman 1984). All three xylene isomers were detected in the air of the Brazilian rainforest in 1979-1980, at concentrations ranging from below the detection limit (0.05 ppbv) to 0.12 ppbv (Greenberg and Zimmerman 1984).

Since one of the largest sources of xylene release into the atmosphere is auto emissions, atmospheric concentrations are related to urbanization. Ambient air concentrations of xylene in industrial and urban areas of the United States have been reported to range from 0.003 to 0.38 mg/m³ (0.001-0.088 ppm) (Merian and Zander 1982). Median *o*-xylene concentrations calculated from a compilation of atmospheric data on organic chemicals were 0.41 µg/m³ (0.094 ppb) in rural/remote areas (114 observations), 5.2 µg/m³ (1.2 ppb) in urban/suburban areas (1,885 observations), and 3.5 µg/m³ (0.81 ppb) in source-dominated areas (183 observations) (EPA 1983). The median concentrations for the combined *m*- and *p*-isomers were 0.38 µg/m³ (0.088 ppb) in rural/remote areas (115 observations), 12 µg/m³ (2.8 ppb) in urban/suburban areas (1,911 observations), and 7.4 µg/m³ (1.7 ppb) in source-dominated areas (186 observations) (EPA 1983). Air samples in highly industrialized areas of Illinois (Chicago and East St. Louis) between 1986 and 1990 had mean concentrations of 3.9-16 µg/m³ (0.90-3.7 ppb) (for *m*- and *p*-xylene combined) and 2.9-3.3 µg/m³ (for *o*-xylene and styrene combined). Levels in rural areas of Illinois were 1.2 µg/m³ (0.28 ppb) (for *m*- and *p*-xylene combined) and 1.1 µg/m³ (for *o*-xylene and styrene combined). Automotive and other types of paints, chemical plants, and vehicle exhaust were the major sources of these chemicals (Sweet and Vermette 1992).

Air samples collected at 12 cities around the United States between 1979 and 1984 contained average concentrations of 1.0-10.2 ppb for *m*- and *p*-xylene combined and 0.3-4.2 ppb for *o*-xylene (Singh et al. 1985). In 1981, atmospheric concentrations of *m*- and *p*-xylene combined and *o*-xylene, measured at a downtown Los Angeles location, were 11-45 ppbv and 4-13 ppbv, respectively (Grosjean and Fung 1984). Between 1984 and 1986, ambient air monitoring was conducted in 39 cities nationwide. All three isomers of xylene were detected in all cities at a median concentration of 7.2 ppb (range, 1.3-338 ppb for *m*- and *p*-xylenes combined and 0.9-79 ppb for *o*-xylene) (Seila et al. 1989). In 1990, *o*-xylene was measured at 4.2-6.9 µg/m³ (0.97-1.6 ppb) in ambient outdoor air in Atlanta, Georgia (Stevens and Vossler 1991).

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Recent studies have indicated that xylene is also a common but low contaminant of indoor air both at home and in the workplace. Concentrations of *m*- and *p*-xylene measured in homes at 15 locations in the United States ranged from 10 to 47 $\mu\text{g}/\text{m}^3$ (2.3-10.8 ppb) (Seifert and Abraham 1982). Similar results were reported during a 1981 study of the correlation between breath concentration and personal and outdoor air concentrations of 350 New Jersey residents (Wallace et al. 1986). The weighted median indoor air concentrations of *o*-xylene and the combined *m*- and *p*-xylene isomers were 4.9 and 14 $\mu\text{g}/\text{m}^3$ (1.1 and 3.2 ppb), respectively. Breath concentrations showed significant correlation with personal air concentrations but only weak correlation with outdoor air concentrations. Concentrations in indoor air were usually higher than in outdoor air, indicating that the source of the xylene was building materials or household products (e.g., cleaning agents) (Wallace et al. 1986, 1987c).

However, in areas where heavy automotive traffic has increased outdoor xylene concentrations, ventilating homes by leaving windows open may actually result in additional increases in indoor xylene levels (Hung and Liao 1991). That indoor sources of xylene contribute significantly to the levels of these chemicals in interior spaces was also demonstrated in an indoor air monitoring study conducted in February and March 1989 on the premises of the Library of Congress in Washington, DC. *p*-Xylene and *o*-xylene were present at mean levels of 7.2 $\mu\text{g}/\text{m}^3$ (1.7 ppb) and 3.2 $\mu\text{g}/\text{m}^3$ (0.7 ppb) in indoor air and 3.2 $\mu\text{g}/\text{m}^3$ (0.7 ppb) and 1.2 $\mu\text{g}/\text{m}^3$ (0.3 ppb) in outdoor air, respectively (NIOSH 1990a). Analysis of a building with "sick building syndrome" in the summer of 1987 showed significant differences in the concentrations of xylenes in indoor and outdoor air. Combined *m*- and *p*-xylene concentrations were 12-22 $\mu\text{g}/\text{m}^3$ (2.8-5.1 ppb) and 3.9 $\mu\text{g}/\text{m}^3$ (0.9 ppb) for indoor and outdoor air, respectively, while *o*-xylene concentrations were 4.3-6.8 $\mu\text{g}/\text{m}^3$ (0.99-1.6 ppb) for indoor air and 2.8 $\mu\text{g}/\text{m}^3$ (0.64 ppb) for outdoor air. Higher levels of the xylenes were detected during autumn for indoor but not outdoor samples. Potential sources were tobacco smoke and other consumer products including carpet adhesive (Weschler et al. 1990).

5.4.2 Water

Limited monitoring data are available on ambient concentrations of xylenes in surface waters. In view of the rapid volatilization of xylenes, their presence in surface waters is unlikely to be significant. Surface waters generally contain average xylene concentrations of <1 ppb total xylenes except in areas where there are fuel processing activities, such as petroleum refining (ECETOC 1986; Otson et al. 1982b; Sauer et al. 1978). Typical surface water concentrations range from not detected to 2 $\mu\text{g}/\text{L}$ (ppb) (Otson et al. 1982b; Sauer et al. 1978).

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Data on the occurrence of xylene in public drinking water supplies are available from several federal, regional, and state surveys (EPA 1985a). In most cases, less than 6% of the groundwater and surface water systems sampled contained detectable levels of xylenes (EPA 1985a; NJDEP 1984). Typical xylene concentrations (all isomers) ranged from 0.2 to 9.9 µg/L (ppb) with mean concentrations of less than 2 µg/L (ppb) (EPA 1985a; Keith et al. 1976; NJDEP 1984; Williams et al. 1982).

The migration of petroleum products from leaking underground storage tanks and pipelines poses a groundwater contamination problem. Gasoline-contaminated groundwater in Los Angeles contained levels of xylenes as high as 153 µg/L (ppb) (Karlson and Frankenberger 1989).

5.4.3 Sediment and Soil

Although several investigators (Aurelius and Brown 1987; Barbee and Brown 1986; Griffin et al. 1984) refer to leaching of xylene from waste disposal sites as a source of xylene levels in groundwater samples, virtually no data are available on actual measurements of xylene in soil. While no quantitative data on the presence of xylene in soil were found in the available literature, the rapid volatilization of this chemical makes its presence in surface soils unlikely.

5.4.4 Other Environmental Media

Xylene has been detected in cigarette smoke, consumer products, and some foods. The gas phase delivery of *p*-xylene in ultra-low tar delivery cigarette smoke ranges from <0.01 to 8 µg/cigarette, while the ranges for *m*- and *o*-xylene are <0.01-20 µg/cigarette and <0.005-10 µg/cigarette, respectively (Higgins et al. 1983). Data were not located for regular strength or unfiltered cigarettes. The 1,095 household products (aerosols, paints, varnishes, shellac and rust preventives) surveyed by the Consumer Product Safety Commission (Fishbein 1985) contained an average of 9.5% mixed xylene. The largest number of products containing mixed xylene were household aerosols and paints, varnishes, shellac, and rust preventatives.

Xylene has also been detected in distillates of rainbow trout and in carp tissue samples from three rivers not known to be contaminated (Hiatt 1983). The estimated tissue concentrations of *m*- and *p*-xylene in rainbow trout and carp were 0.05 and 0.12 mg/kg (ppm), respectively (Hiatt 1983).

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Eggs, whether stored or used fresh, contained detectable levels of all three xylene isomers when scrambled. The polystyrene packing case in which some of the eggs had been stored also contained detectable levels of the xylene. Actual concentrations of the xylene isomers were not measured in any of the egg or packaging samples (Matiella and Hsieh 1991).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The principal population at risk of significant xylene exposure is workers; however, members of the general population are exposed to low levels of xylene primarily by breathing ambient air, particularly in areas with heavy traffic, near gasoline filling stations, near industrial sources such as refineries, or areas where xylenes are used as solvents. The California Total Exposure Assessment Methodology (TEAM) Study conducted in 1984 in Los Angeles County (an urban area) and Contra Costa County (a rural area) monitored volatile organic compounds in ambient (outdoor) air, personal air, and breath samples for 188 people. (Personal air is defined as air samples which were collected using a sampling vest worn by the participant with the pump and collection cartridge placed close to the breathing level.) In Los Angeles, all three xylene isomers were detected in each air type; higher levels were measured during the winter for all air types and all xylene isomers compared with summer levels. Average concentrations (in $\mu\text{g}/\text{m}^3$ [ppb]) were (Wallace et al. 1988):

<u>Location</u>	<u>Sample type</u>	<u><i>m-, p-Xylene</i> (ppb)</u>	<u><i>o-Xylene</i> (ppb)</u>
Los Angeles (February)	Personal air	28 (6.5)	13 (3.0)
	Outdoor air	24 (5.5)	11 (2.5)
	Breath	3.5 (0.8)	1.0 (0.2)
Los Angeles (June)	Personal air	24 (5.5)	7.2 (1.7)
	Outdoor air	9.4 (2.2)	2.7 (0.6)
	Breath	2.8 (0.6)	0.7 (0.2)
Contra Costa (June)	Personal air	11 (2.5)	4.4 (1.0)
	Outdoor air	2.2 (0.5)	0.7 (0.2)
	Breath	2.5 (0.6)	0.6 (0.1)

Smoking was determined to be the major determinant for the presence of xylene in breath and personal air, with concentrations in the breath of smokers more than double those of nonsmokers. Auto-related situations, such as pumping gasoline and exposure to exhaust, as well as type of employment also contributed significantly to increased concentrations of xylene in breath and personal air (Wallace et al. 1988). A second TEAM study in 1987, of the same Los Angeles families, showed similar trends in

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relative concentrations of xylene in personal, indoor, and outdoor air. Again, outdoor concentrations were lower than indoor concentrations which, in turn, were lower than personal air samples. Mean xylene concentrations (in $\mu\text{g}/\text{m}^3$ [ppb]) were (Wallace et al. 1991):

<u>Date</u>	<u>Sample type</u>	<u><i>m-, p-Xylene</i> (ppb)</u>	<u><i>o-Xylene</i> (ppb)</u>
February	Personal	43 (9.9)	16 (3.7)
	Indoor	30 (6.9)	12 (2.8)
	Outdoor	18 (4.2)	6.5 (1.5)
	Breath (median value)	2.5 (0.6)	0.8 (0.2)
July	Personal	27 (6.2)	9.2 (2.1)
	Indoor	12 (2.8)	4.3 (1.0)
	Outdoor	7.4 (1.7)	2.8 (0.6)
	Breath (median value)	0.7 (0.2)	0.25 (0.1)

Xylene has been detected in indoor air, mainly in residences, at mean concentrations of 0.2–26 $\mu\text{g}/\text{m}^3$ (0.05–5.6 ppb) for *o*-xylene, 2.95–41.53 $\mu\text{g}/\text{m}^3$ (0.68–9.56) for *m*-xylene, and 17–44 $\mu\text{g}/\text{m}^3$ (3.9–10.1 ppb) for *m*- and *p*-xylene combined (Samfield 1992). Exposure may also arise from ingestion of contaminated drinking water. Common activities identified with increased potential exposure include pumping gasoline, visiting service stations, traveling in a car, painting, scale model building, pesticide use, and smoking (Wallace et al. 1986; 1987c). Of 237 consumer products tested for *m*-xylene and 221 tested for *o*- and *p*-xylene, 101 products contained *m*-xylene and 93 products contained *o*- and *p*-xylene at concentrations greater than 0.1% weight (Sack and Steel 1991). The concentrations and percentage of positive samples were as follows (Sack et al. 1992):

<u>Product</u>	<u><i>m-Xylene</i></u>		<u><i>o-, p-Xylene</i></u>	
	<u>% Xylene</u>	<u>Concentration of Xylene</u>	<u>% Xylene</u>	<u>Concentration of</u>
<u>Xylene</u>				
Automotive products	26.7	10.6	10.0	31.0
Household cleaners, polishers	33.3	1.4	0.0	0.0
Paint-related products	60.3	4.2	58.2	2.8
Fabric and leather treatments	0.0	0.0	33.3	0.1
Oils, greases, and lubricants	9.3	0.2	11.9	0.2
Adhesive-related products	9.1	0.2	9.1	0.2

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Based on the estimates of EPA (1983) of median atmospheric concentrations of xylene in rural, urban, and source-dominated areas (see Section 5.4.1) and assuming inhalation of 23 m³/day by a 70-kg adult, the daily *o*-xylene intake from air for adults exposed to the median levels in rural, urban, and source-dominated areas would be 0.1, 1.7, and 1.2 µg/kg/day, respectively. The median *m*- and *p*-xylene intake would be 0.1, 3.9, and 2.4 µg/kg/day, respectively (EPA 1985a). Assuming a typical ambient air xylene concentration of 4.0 ppb, the average daily intake of xylene from air is estimated to be 353 µg (HSDB 1988).

General population exposure to xylene can also occur through dermal contact with the many consumer products containing xylene, including cleaning solvents, insecticides, lacquers, paint thinners and removers, and pesticides (EPA 1985a; Fishbein 1985; Gleason et al. 1969). Dermal absorption is reported to be minor following exposure to xylene vapor but may be significant following contact with the liquid (EPA 1985a). The percutaneous absorption rate of *m*-xylene in humans was approximately 2 µg/cm²/minute through the skin of the hands (Engstrom et al. 1977).

Assuming the highest reported concentration of total xylenes (*m*-, *o*-, and *p*-xylene) (750 µg/L) and a daily intake of 2 liters of drinking water, the adult maximum daily intake for total xylenes through consumption of drinking water is estimated to be 2,760 µg/day or 39.4 µg/kg/day (EPA 1985a).

Occupational exposure to mixed xylene may occur during their production as well as their end use as industrial solvents. Occupational exposures result from inhalation or dermal exposure and are usually associated with process, storage, or fugitive emissions at petroleum chemical, paint, and plastics plants (Fishbein 1985, 1988). Average daily intake from individual occupational exposure sources has not been estimated. Results of a study of solvent exposures in 1981 involving eighty-nine workers in seven plants of three companies applying paints and glues, primarily by spraying, showed that most solvent spraying activities surveyed showed only low-to-moderate exposures to xylene relative to the Threshold Limit Value (TLV) in the presence of ordinary general room ventilation (Whitehead et al. 1984). The average time-weighted average (TWA) concentrations of xylene for high-aromatic spraying in booths (3.5 ppm), solvent wiping (0.7 ppm), and paint mixing (3.7 ppm) were well below the TLV for xylene (100 ppm) (Whitehead et al. 1984).

The National Occupational Hazard Survey (NOHS) conducted by the National Institute for Occupational Safety and Health (NIOSH) ranked xylene 13th based on average concentrations in

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workplace air out of approximately 7,000 chemicals (NIOSH 1976). The NOHS estimated that 1,016,020 workers in 99,920 U.S. plant sites were potentially exposed to total xylenes in the workplace in 1970 (NIOSH 1976). An estimated 5,778 workers in 179 plants, 4,621 workers in 96 plants, and 1,912 workers in 62 plants were potentially exposed to *o*-xylene, *m*-xylene, and *p*-xylene, respectively. These estimates were derived from observations of the actual use of total xylenes and individual isomers and the use of trade name products known to contain xylene (see Table 5-6 for composition breakdown of the estimates). The largest numbers of workers exposed to total xylenes were employed by automotive dealers, service stations, or special trade contractors and in the chemical and allied products, transportation equipment, machinery (except electrical), fabricated metal products, and electrical equipment and supplies industries. In addition, the largest numbers of workers exposed to single xylene isomers were employed in the rubber and plastics products, printing and publishing, petroleum and coal products, chemicals and allied products, and fabricated metal products industries.

Preliminary data from a second workplace survey, the National Occupational Exposure Survey (NOES), conducted by NIOSH from 1980 to 1983, indicated that 1,106,789 workers, including 211,806 women, in 74,063 plants were potentially exposed to mixed xylene in the workplace in 1980 (NIOSH 1984). An estimated 5,596 workers (including 1,314 women) in 331 plants, 16,863 workers (including 1,194 women) in 1,610 plants, and 1,160 workers (including 545 women) in 178 plants were potentially exposed to *o*-, *m*-, and *p*-xylene, respectively. The largest numbers of workers exposed to mixed xylene were employed in the machinery (except electrical), special trade contractors, fabricated metal products, and health services industries (as assemblers, janitors, cleaners, painting and paint-spraying machine operators, and automobile mechanics). The largest numbers of workers exposed to *o*-xylene were employed in the chemical and allied products industry (as machine operators [not specified], chemical technicians, production inspectors, checkers, and examiners). The largest numbers of workers exposed to *m*-xylene were employed in the electric, gas, and sanitary services and business services industries (as electrical power installers and repairers, supervisors, plumbers, pipe fitters, steam fitters, order clerks, and chemists [except biochemists]). The largest numbers of exposed workers exposed to *p*-xylene were employed in the health services industries (as clinical laboratory technologists and technicians). These estimates were derived from observations of the actual use of mixed xylene and the individual xylene isomers and the use of trade name products known to contain xylene (see Table 5-6 for percentage breakdown).

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TABLE 5-6. Percentage Breakdown of NIOSH Occupational Exposure Estimates from the NOHS and NOES Databases^a

Chemical	NOHS		NOES	
	Actual ^b	Trade name ^c	Actual	Trade name
<i>o</i> -Xylene	14%	86%	96%	4%
<i>m</i> -Xylene	No data	100%	23%	77%
<i>p</i> -Xylene	41%	59%	75%	25%
Total xylenes	9% ^d	35% ^d	19%	81%

^aDerived from NIOSH 1976, 1984

^bActual observations are surveyor observations in which the surveyor observed the use of the specific agent.

^cTrade name observations in NOHS database are surveyor observations in which the surveyor observed the use of a trade name product known to contain the specific agent.

^dRemainder is composed of generic observations (i.e., observations of the use of generic products suspected of containing xylene), which are not included in the total exposure estimates provided.

NIOSH = National Institute for Occupational Safety and Health; NOES = National Occupational Hazard Survey;
NOHS = National Occupational Exposure Survey

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Neither the NOHS nor the NOES databases contain information on the frequency, level, or duration of exposure of workers to any of the chemicals listed therein. The surveys only provide estimates of workers potentially exposed to the chemicals.

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Among persons not occupationally exposed to xylenes, the highest exposure levels result from smoking and from contact with consumer products containing xylene (Wallace et al. 1988, 1991). Populations living near chemical waste sites where xylene is improperly stored are also likely to be at risk of increased exposure to xylene vapors via inhalation or dermal contact.

Workers in certain occupational groups appear to have the greatest potential for exposure to high concentrations of xylenes. Based on the available case reports of xylene toxicity in humans, painters (or paint industry workers) and laboratory workers appear to be most frequently affected (EPA 1985a). In general, workers involved in the distillation and purification of xylene or employed in industries using xylene as a raw material (e.g., gasoline component) may be at higher risk of exposure (EPA 1985a). The use of xylene in improperly ventilated areas is often the cause for toxic levels of exposure, and increased exposures or breath concentrations have been observed for wood processing plant workers, gas station employees, metal workers, and furniture refinishers.

5.7 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 xylene is available. Where adequate information is not available, ATSDR, in conjunction with the 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 xylene.

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

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that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of xylene have been well studied, and reliable values for key parameters are available for use in environmental fate and transport models (CHEMFATE 1988; HSDB 1992). On this basis, further studies of the physical-chemical properties of xylene are not essential at the present time.

Production, Import/Export, Use, Release, and Disposal. Potential for human exposure to xylene is expected to be quite high based on the high volume of production and the widespread domestic and industrial uses of xylene.

Recent estimates of xylene production capacity indicate that over 14 billion pounds of mixed xylene and over 8.2 billion pounds of xylene isomers may be produced in the United States each year (SRI 1992). Further information on the amounts of xylenes used in various products would be helpful in estimating human exposure to xylenes from consumer products.

Xylenes are widely used in industry as solvents and as precursors of other products (i.e., polyester). Exposure of individuals may occur as a result of releases to the environment (approximately 135 million pounds per year) (TRI90 1992) and as a result of the presence of xylenes in gasoline, paint products, insecticides, and cigarette smoke (Wallace et al. 1991). Limited information was obtained on the occurrence of xylenes in food. Consequently, dietary intake and its contribution to total exposure could not be evaluated. This information would be helpful in estimating potential human exposure.

Because of its widespread use and release into the environment, xylene has been distributed to most environmental media. It has been detected in air (Wallace et al. 1991), surface water, sediments (Otson et al. 1982b), drinking water (EPA 1985a), and aquatic organisms (Hiatt 1983). There are virtually no data on the actual levels of xylenes in soil. Reports of levels in the various environmental media are dated within the last 10 years, with some as current as 1990. Information on the most recent distribution of xylene would be helpful in estimating exposure.

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Incineration is the primary method for disposal of xylene, although information on the disposal methods is not detailed (HSDB 1992). Information on the amount of xylene disposed of by incineration as well as the amount of xylene disposed of or abandoned at hazardous waste sites is important for estimating the potential human exposure. Criteria for the disposal of xylenes are currently subject to frequent revision.

According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1990, became available in May of 1992. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Environmental Fate. Volatilization of xylene is the dominant fate. Xylene released to surface water primarily volatilizes (Mackay and Leinonen 1975). Xylene also sorbs to soils and sediments and leaches into groundwater (Gherini et al. 1989); however, there is considerable variation and uncertainty in estimates of persistence in these media. Photooxidation appears to be the most important transformation process in the atmosphere and in surface soils (Anderson et al. 1991; Jori et al. 1986). Biodegradation is likely to be the only significant degradation process for xylene in subsurface soils and aquatic systems (EPA 1984a, 1985a; Haigler et al. 1992). Additional data on the partitioning of xylene released to soil and groundwater and on longevity and the rates of biotransformation in soils, sediments, and in particular, groundwater is important to further define potential pathways of human exposure and to estimate ambient concentrations in environmental media.

Bioavailability from Environmental Media. Xylene is absorbed during inhalation (Morley et al. 1970), oral (Abu Al Ragheb et al. 1986; Ogata et al. 1979), and dermal contact (Riihimaki and Pfaffli 1978; Skowronski et al. 1990). Approximately 50% of the xylene that is inhaled is absorbed into the body (Riihimaki and Sevolainen 1980; Wallen et al. 1985), while 90% of ingested xylene is absorbed (Bray et al. 1949). However, limited information was found in the available literature regarding the uptake of xylene components by living organisms from contaminated media such as soil (Turkall et al. 1992) and sediments to which the xylene is sorbed or from contaminated surface waters. Information on uptake would be helpful in estimating human exposure from contaminated environmental media.

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Food Chain Bioaccumulation. Xylenes are bioconcentrated in aquatic organisms to a limited extent (Nunes and Benville 1979; Ogata and Miyake 1978). The degree of concentration is believed to be limited by the rapid metabolism and excretion of xylene from some aquatic species. However, additional data on the bioconcentration of xylene by aquatic organisms from contaminated surface waters and sediments would be useful. No information was found in the literature regarding the bioconcentration of xylene in plants or biomagnification of xylene among food chain trophic levels. Although bioconcentration has been predicted for all isomers of xylene because of their tendency to partition into the octanol phase of the octanol-water system, the rapid oxidation of xylene during metabolism seems to preclude bioconcentration in higher animal systems. Thus, biomagnification is not expected to be important for xylene. However, data on the bioaccumulation of xylene in commercially important fish and shellfish would be useful since consumption of contaminated fish and shellfish may be a potential source of human exposure.

Exposure Levels in Environmental Media. Relatively recent levels of xylene in ambient air and in polluted atmospheres have been determined (Stevens and Vossler 1991; Wallace et al. 1991). There are limited monitoring data on xylene levels in surface waters, and few of the data that are available are considered to be current (EPA 1985a). In addition, very few estimates of the levels of xylene in soils and surface waters in the vicinity of industrial sites (such as fuel processing plants) were found in the available literature. More monitoring data are needed to better characterize ambient concentrations of xylene in soils, surface water, and groundwater, particularly in the vicinity of hazardous waste sites and petroleum refineries. These data would be useful to estimate the exposure of populations coming into contact with xylene through inhalation of contaminated air or consumption of contaminated surface or groundwater.

The available data allow characterization of human exposure to xylene from most exposure pathways, particularly air (Wallace et al. 1988, 1991). Estimates of human intake of xylene from contaminated air and drinking water have been made based on background levels that have been recorded (EPA 1985a). In addition, estimates exist for absorption following dermal contact that results from immersion in xylene (EPA 1985a). More information on the levels of xylene in contaminated media in the vicinity of hazardous waste sites is necessary before estimates of human intake from these sites can be calculated.

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

Exposure Levels in Humans. Xylene has been detected in human blood, urine, and exhaled breath. However, exposure associated with living or working near hazardous waste sites and refineries has not been assessed. The most important human exposure sources, workplace and ambient air, are well understood (Fishbein 1985, 1988; Wallace et al. 1988, 1991). Additional monitoring programs involving analysis of human breath or urine would be useful in assessing the magnitude of exposures and in estimating the average daily dose associated with various sources, particularly for populations in the vicinity of hazardous waste sites.

Several sectors of the work force have the greatest levels of exposure to xylene. Total xylene exposure has been found to be greatest among those employed in the machinery (except electrical), special trade contracting, fabricated metal products, and health services industries (as assemblers, janitors and cleaners, painting and paint-spraying machine operators, and automobile mechanics) (EPA 1985a). More current information on occupational exposure would be useful.

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

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

5.7.2 On-going Studies

David Hendricks (Colorado State University) is studying the sorption of toluene and xylene by chromatography-grade silica and alumina (FEDRIP 1994). This research, sponsored by the National

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Institute of Environmental Health Sciences, should provide insight into how competition between xylene and toluene affects transport through soils.

Dr. M.L. Brusseau (sponsored by the U.S. Department of Agriculture) at the University of Arizona is studying mechanisms involved in nonequilibrium sorption of organic chemicals including *p*-xylene (FEDRIP 1994). Studies are being completed in aquifer systems under natural and induced gradients.

Mark Tumeo at the University of Alaska is studying the environmental transport of xylenes and other hydrocarbons under freezing conditions (FEDRIP 1994). The research, sponsored by the National Science Foundation, will include the development of a computer model to predict the fate of hydrocarbons in ice and ice/soil systems.

As part of the Third National Health and Nutrition Evaluation Survey, the Environmental Health Laboratory Sciences Division of the National Center for Environmental Health, Centers for Disease Control, will be analyzing human blood samples for xylene 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.

