

5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Phenol has been identified in at least 481 of the 1,467 current or former EPA National Priorities List (NPL) hazardous wastes sites (HazDat 1998). However, the number of sites evaluated for phenol is not known. The frequency of these sites within the United States can be seen in Figure 5-1. Of these sites, 477 are located in the United States and 4 are located in the Commonwealth of Puerto Rico.

Phenol is released primarily to the air and water as a result of its manufacture and use and as a result of wood burning and auto exhaust. Phenol mainly enters the water from industrial effluent discharges. Phenol disappears rapidly in air by gas-phase hydroxyl radical reaction (estimated half-life 14.6 hours), but may persist in water for a somewhat longer period. Half-lives for biodegradation range from less than 1 day in samples of lake water to 9 days in estuarine water; a typical half-life for photooxidation by photochemically produced peroxy radicals is approximately 19 hours. In soil, phenol will generally biodegrade rapidly; however, biodegradation of phenol in water or soil may be hindered or precluded by the presence of high, toxic concentrations of phenol or other chemicals, or by other factors such as a lack of nutrients or microorganisms capable of degrading phenol. If biodegradation is sufficiently slow, phenol in sunlit water will undergo photooxidation with photochemically produced peroxy radicals, and phenol in soil will leach to groundwater. Since plants can metabolize phenol readily, exposure through eating food derived from plants grown in phenol-containing soil is probably minimal. Phenol may remain in air, water, and soil for much longer periods if it is continually or consistently released to these media from point sources.

Phenol has been measured in effluents (up to 53 ppm), ambient water (from 1.5 to >100 ppb), drinking water (not quantified), groundwater (from 1.9 to >10 ppb), rain (0.075–1.2 ppb), sediment (>10 ppb), and ambient air (0.03–44 ppb). Occupational exposures occur through inhalation and dermal exposure; air concentrations monitored in various workplaces range from 0.1 to 12.5 mg/m³ (0.03–32 ppm). Occupational as well as consumer exposure may also occur through dermal contact with phenol or phenol-containing products.

5. POTENTIAL FOR HUMAN EXPOSURE

5.2 RELEASES TO THE ENVIRONMENT

According to the TRI, in 1996, a total of about 23.5 million pounds (10.6 million kg) of phenol was released to the environment from 689 large processing facilities (TRI96 1998). Table 5-1 lists amounts released from these facilities. In addition, an estimated 3.3 million pounds (1.5 million kg) were released by manufacturing and processing facilities to publicly owned treatment works (POTWs) and an estimated 8.5 million pounds (3.8 million kg) were transferred offsite (TRI96 1998). The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

Phenol has been identified in a variety of environmental media (air surface water, groundwater, soil, and sediment) collected at 481 of the 1,467 NPL hazardous waste sites (HazDat 1998).

5.2.1 Air

According to the TRI, in 1996, the estimated releases of phenol of 9.5 million pounds (4.3 million kg) to air from 635 large processing facilities accounted for about 5% of total environmental releases (TRI96 1998). Table 5-1 lists amounts released from these facilities. The TRI data should be used with caution, however, since only certain types of facilities are required to report. This is not an exhaustive list.

During manufacturing, phenol is released primarily to the atmosphere from storage tank vents and during transport loading (Delaney and Hughes 1979). Other major sources of release to the atmosphere are residential wood burning and automobile exhaust (Scow et al. 1981). Volatilization from environmental waters and soils has been shown to be a slow process (see Section 5.3.1) and is not expected to be a significant source of atmospheric phenol. Phenol has been detected at a concentration of 0.36 ppb in the emissions of a waste incinerator plant in Germany (Jay and Stieglitz 1995). Phenol is also found in cigarette smoke and in plastics (Graedel 1978), but no data are available to determine the extent of exposure to phenol from these sources.

5.2.2 Water

According to the TRI, in 1996, the estimated releases of phenol of 72,55 pounds (32,650 kg) to water from 220 large processing facilities accounted for about 0.3% of total environmental releases (TR196 1998).

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

State ^b	Number of Facilities	Total of reported amounts released in pounds per year ^a							Total Environment ^e
		Air ^c	Water	Land	Underground Injection	POTW ^d Transfer	Off-site Waste Transfer		
AL	30	396,256	5,344	13,899	0	4,055	39,513	459,067	
AR	14	59,333	1,071	327	1,392	0	6,133	68,256	
AZ	4	3,668	0	0	0	0	13,756	17,424	
CA	25	100,792	2,714	0	0	426,725	144,299	674,530	
CO	1	0	0	0	0	0	3,345	3,345	
CT	8	16,581	0	0	0	5,987	47,591	70,159	
DE	1	63	0	0	0	5	0	68	
FL	9	130,619	404	10	0	3,900	136,647	271,580	
GA	26	283,854	1,166	3,325	0	6,799	110,232	405,376	
IA	8	59,447	552	2,262	0	0	748,476	810,737	
ID	1	755	5	5	0	0	0	765	
IL	36	672,577	1,878	3,215	0	1,430,152	602,140	2,709,962	
IN	33	1,194,276	9,329	3,372	110,000	1,579	380,631	1,699,187	
KS	8	194,981	1,720	232	548	4,114	24,601	226,196	
KY	11	235,558	855	7,502	0	152,690	629,679	1,026,284	
LA	28	263,918	3,431	850	130,311	0	466,678	865,188	
MA	7	59,264	0	0	0	338	14,141	73,743	
MD	2	45,805	0	0	0	4,400	16,300	66,505	
ME	7	37,555	302	118	0	2	737	38,714	
MI	33	193,425	7,652	9,642	0	65,089	211,701	487,509	
MN	10	135,671	1,293	3	0	250	12,319	149,536	
MO	10	84,683	1	0	0	605	95,795	181,084	
MS	18	144,137	2,738	543	0	224	818	148,460	
MT	2	1,380	250	0	0	0	5	1,635	
NC	26	335,372	1,095	765	0	737	114,352	452,321	
NE	3	56,207	0	0	0	0	2,044	58,251	
NH	3	2,114	0	1	0	0	16,573	18,688	
NJ	9	51,810	6,287	230	0	317,750	81,035	457,112	
NY	21	151,883	555	0	0	37,294	1,030,762	1,220,494	

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

State ^b	Number of Facilities	Total of reported amounts released in pounds per year ^a						
		Air ^c	Water	Land	Underground Injection	POTW ^d Transfer	Off-site Waste Transfer	Total Environment ^e
OH	55	1,237,909	2,288	18,125	460,000	43,438	1,681,659	3,443,419
OK	7	37,511	471	19	0	0	12,455	50,456
OR	18	73,458	625	1	0	2,984	21,868	98,936
PA	32	364,657	2,625	1,021	0	213,875	192,753	774,931
PR	1	640	0	0	0	0	255	895
RI	1	197	0	0	0	2,316	1,642	4,155
SC	24	1,415,260	6,381	8,622	0	807	119,508	1,550,578
TN	17	326,085	345	1,028	0	60,316	57,481	445,255
TX	66	532,158	5,889	2,940	1,343,119	436,982	718,088	3,039,176
UT	3	6,407	32	12,000	0	0	198	18,637
VA	18	250,313	295	68,894	0	26,471	11,531	357,504
VI	1	54,876	1,504	44	0	0	0	56,424
VT	1	9,722	0	0	0	0	0	9,722
WA	12	172,668	1,833	29	0	750	5,454	180,734
WI	30	65,344	990	0	0	29,655	423,747	519,736
WV	7	87,398	635	25	0	0	283,914	371,972
WY	2	5,915	0	10	0	0	0	5,925

Source: TRI96 1998

^aData in TRI are maximum amounts released by each facility

^bPost office state abbreviations used

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

^dPOTW= publicly owned treatment works

^eThe sum of all releases of the chemical to air, land, and water, and underground injection wells; and transfers off-site by a given facility

5. POTENTIAL FOR HUMAN EXPOSURE

Table 5-1 lists amounts released from these facilities. The TRI data should be used with caution, however, since only certain types of facilities are required to report. This is not an exhaustive list.

The most common anthropogenic sources of phenol in natural water include coal tar (Thurman 1982) and waste water from manufacturing industries such as resins, plastics, fibers, adhesives, iron, steel, aluminum, leather, rubber (EPA 1981), and effluents from synthetic fuel manufacturing (Parkhurst et al. 1979). Phenol is also released from paper pulp mills (Keith 1976) and wood treatment facilities (Goerlitz et al. 1985). Other releases of phenol result from commercial use of phenol and phenol-containing products, including slimicides, general disinfectants (Hawley 1981; Budavari et al. 1989), and medicinal preparations such as ointments, ear and nose drops, cold sore lotions, mouthwashes, gargles, toothache drops, analgesic rubs (Douglas 1972), throat lozenges (EPA 1980), and antiseptic lotions (Musto et al. 1977). It has been estimated that 3.8 kg/day of phenol are released to Newark Bay, in New Jersey, from municipal treatment facilities (Crawford et al. 1995). Two natural sources of phenol in aquatic media are animal wastes and decomposition of organic wastes (EPA 1980). No data are available to determine the extent of exposure from these sources.

5.2.3 Soil

According to the TRI, in 1996, the estimated releases of phenol of 159,059 pounds (71,577 kg) to soil from 102 large processing facilities accounted for about 0.7% of total environmental releases (TR196 1998). Table 5-1 lists amounts released from these facilities. The TRI data should be used with caution, however, since only certain types of facilities are required to report. This is not an exhaustive list.

Phenol may be released to the soil during its manufacturing process, loading and transport when spills occur, and when it leaches from hazardous waste sites and landfills (Xing et al. 1994). Generally, data on concentrations of phenol found in soil at sites other than hazardous waste sites are lacking. This may be due in part to a rapid rate of biodegradation and leaching (see Sections 5.3.1 and 5.3.2.3). Phenol can be expected to be found in soils that receive continuous or consistent releases from a point source. Phenol that leaches through soil to groundwater spends at least some time in that soil as it travels to the groundwater. Phenol has been found in groundwater, mainly at or near hazardous waste sites.

5. POTENTIAL FOR HUMAN EXPOSURE

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

Phenol is released into the air and discharged into water from both manufacturing and use. Based on its high water solubility (see Table 3-2) and the fact that it has been detected in rainwater, some phenol may wash out of the atmosphere; however, it is probable that only limited amounts wash out because of the short atmospheric half-life of phenol. During the day, when photochemically produced hydroxyl radical concentrations are highest in the atmosphere, very little atmospheric transport of phenol is likely to occur.

In water, neither volatilization nor sorption to sediments and suspended particulates is expected to be an important transport mechanism. Using the Henry's Law constant, a half-life of 88 days was calculated for evaporation from a model river 1 m deep with a current of 1 m/second, and with a wind velocity of 3 m/second (Lyman et al. 1982). The biological treatment of waste water containing phenol has shown that less than 1% of phenol is removed by stripping (Kincannon et al. 1983; Petrasek et al. 1983).

Phenol has been reported in sediments at up to 608 ppm dry weight; however, it is not known whether the location of the site where this concentration was reported is at or near a point source of release, such as a hazardous waste dump. The average concentration (6.1 ppb dry weight) of the sediment concentration contained in the STORET database (EPA 1988b) and the concentration found in the Pacific Ocean near Los Angeles (10 ppb dry weight) is probably more representative of ambient sediment phenol concentrations. The concentrations of the overlying waters were not reported. The moderately low soil sorption partition coefficient (1.21-1.96) suggests that sorption to sediment is not an important transport process. There is very little sorption of phenol onto aquifer materials (Ehrlich et al. 1982), suggesting that phenol sorption to sediments may also be minimal. Based on the soil adsorption coefficient, phenol released to soil is expected to leach to groundwater; however, the rate of phenol biodegradation in the soil may be so rapid, except in cases of large releases such as spills or continuous releases such as leaching from landfill sites, that the probability of groundwater contamination may be low (Ehrlich et al. 1982). Phenol has been detected in groundwater as a result of leaching through soil from a spill of phenol (Delfino and Dube 1976), from landfill sites (Clark and Piskin 1977), and from hazardous waste sites (Plumb 1987). The sorption coefficient for phenol by soils increases with increasing soil organic matter which may indicate that soil organic matter may be the primary phenol sorbent in soil (Xing et al. 1994).

5. POTENTIAL FOR HUMAN EXPOSURE

Phenol is not expected to bioconcentrate significantly in aquatic organisms. Reported log bioconcentration factors (BCF) in fish for phenol include 0.28 for goldfish, (Kobayashi et al. 1979) and 1.3 for golden orfe (Freitag et al. 1984). The highest mean level of phenol detected in bottom fish from Commencement Bay in Tacoma, WA, was 0.14 ppm (Nicola et al. 1987). The levels of phenol in the water or sediments were not stated.

Since the pK_a of phenol is 9.686 at 20°C it will exist in a partially dissociated state in water and moist soil. Therefore, its transport in these media in the environment would be affected by the pH of the medium.

Although it has been shown that plants readily uptake phenol (Cataldo et al. 1987), bioaccumulation does not take place due to a high rate of respiratory decomposition of phenol to CO_2 .

5.3.2 Transformation and Degradation

5.3.2.1 Air

Because phenol absorbs light in the region of 290-330 nm (Sadtler 1960), it might photodegrade directly in the atmosphere. The gas-phase reaction of phenol with photochemically produced hydroxyl radicals is probably a major removal mechanism in the atmosphere. An estimated half-life for phenol for this reaction is 0.61 days (Hendry and Kenley 1979). The reaction of phenol with nitrate radicals during the night may constitute a significant removal process. This is based on a rate constant of 3.8×10^{12} cm^3 /molecule second for this reaction, corresponding to a half-life of 15 minutes at an atmospheric concentration of 2×10^8 nitrate radicals per cm^3 (Atkinson et al. 1987). The reaction of phenol with nitrate radicals present in the atmosphere during smog episodes may decrease the half-life of phenol in polluted atmospheres. The above data indicate that phenol has a short half-life in the atmosphere, probably less than 1 day.

5.3.2.2 Water

Because phenol absorbs light in the region of 290-330 nm (Sadtler 1960), it might photodegrade directly in surface waters. As a class, phenols react relatively rapidly in sunlit natural water via reaction with photochemically produced hydroxyl radicals and peroxy radicals; typical half-lives for hydroxyl and peroxy radical reactions are on the order of 100 and 19.2 hours of sunlight, respectively (Mill and Mabey 1985). The estimated half-life for the reaction of phenol with photochemically produced singlet oxygen in sunlit

5. POTENTIAL FOR HUMAN EXPOSURE

surface waters contaminated by humic substances is 83 days (assuming Switzerland summer sunlight and a singlet oxygen concentration of 4×10^{-14} molar [M]) (Scully and Hoigne 1987). The rate constant for the reaction of phenol with ozone in water has been reported to range from 1.5×10^{-5} to 6×10^{-5} milliseconds⁻¹ (Beltran and Alvarez 1996).

Phenol is readily biodegradable in natural water, provided the concentration is not high enough to cause significant inhibition. Complete degradation in less than 1 day has been reported in water from three lakes; the rates of degradation increase with increasing concentration of phenol and increasing trophic levels of water, and are affected by the concentration of organic and inorganic nutrients in the water (Rubin and Alexander 1983). Complete removal of phenol in river water has been reported after 2 days at 20 °C and after 4 days at 4 °C (Ludzack and Ettinger 1960). The degradation of phenol is somewhat slower in salt water, and a half-life of 9 days has been reported in an estuarine river (Lee and Ryan 1979). Rapid degradation of phenol also has been reported in various sewage and water treatment processes. Removal in aerobic activated sludge reactors is frequently >90% with a retention time of 8 hours (Stover and Kincannon 1983). In aerobic reactors using municipal seed (conventional activated sludge organisms) and in reactors using an industrial seed (mixture of organisms), it was noted that concentrations as low as 50 mg/L inhibited organism respiration rates, but complete inhibition was not observed at concentrations as high as 200 mg/L (Davis et al. 1981). Utilization is also very high in anaerobic reactors, although acclimation periods are longer and degradation usually takes about 2 weeks (Boyd et al. 1983; Healy and Young 1978). One method of phenol breakdown is accomplished by the bacterium *Pseudomonas* sp. CF600, which uses a set of enzymes encoded by the plasmid *dmp* operon (Powlowski and Shingler 1994). The use of sequence batch reactors (SBR) in treating sludge contaminated with phenolic compounds has proven effective in breaking down the compounds biologically with no evidence of phenol volatility (Al-Harazin et al. 1991). Levels as high as a 1-time treatment of 1,600 mg/L can be broken down by 75% with a 1-day retention time. Lower concentrations as high as 800 mg/L can be broken down to less than 0.5 mg/L with a 1-day retention time. The alga *Ochromonas dunica* has also been shown to degrade phenol (Semple and Cain 1996). When grown in the dark with 0.1-1 mM phenol as the sole carbon source, phenol was removed within 3 days. Because of biodegradation, groundwater is generally free of phenol even though it is highly mobile in soil (HSDB 1997). However, monitoring data in Section 5.4.2 contain groundwater concentrations in areas of large phenol releases.

While the evidence presented in the literature cited above suggests that phenol can be rapidly and virtually completely degraded under both natural water and sewage treatment plant conditions, monitoring data

5. POTENTIAL FOR HUMAN EXPOSURE

presented in Section 5.4 below indicate that phenol, despite this apparent biodegradability, is still present in the environment. This suggests that the exact conditions under which phenol is rapidly degraded are not present in all instances. In some situations, the concentration of phenol may be too high or the populations of microorganisms may not be present in sufficient concentration for significant biodegradation to occur.

5.3.2.3 Sediment and Soil

Available data indicate that phenol biodegrades in soil under both aerobic and anaerobic soil conditions. The half-life of phenol in soil is generally less than 5 days (Baker and Mayfield 1980; HSDB 1998), but acidic soils and some surface soils may have half-lives of between 20 and 25 days (HSDB 1998). Mineralization in an alkaline, para-brown soil under aerobic conditions was 45.5, 48, and 65% after 3, 7, and 70 days, respectively (Haider et al. 1974). Half-lives for degradation of low concentrations of phenol in two silt loam soils were 2.70 and 3.51 hours (Scott et al. 1983). Plants have been shown to be capable of metabolizing phenol readily (Cataldo et al. 1987).

While degradation is slower under anaerobic conditions, evidence presented in the literature suggests that phenol can be rapidly and virtually completely degraded in soil under both aerobic and anaerobic conditions (HSDB 1998).

Phenol is not expected to adsorb to sediment in the water column (HSDB 1998).

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to phenol depends in part on the reliability of supporting analytical data from environmental samples and biological specimens. In reviewing data on phenol levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable.

5.4.1 Air

There are very few monitoring data concerning the presence of phenol in ambient air. Phenol was found at a median concentration of 30 parts per trillion (ppt) in seven samples from 1 U.S. urban/suburban site in 1974 and at an overall median concentration of 5,000 ppt in 83 samples from 7 source-dominated sites between

5. POTENTIAL FOR HUMAN EXPOSURE

1974 and 1978 (Brodzinsky and Singh 1982). The individual medians of the 7 source sites ranged from 520 to 44,000 ppt (Brodzinsky and Singh 1982). During a smog episode in West Covina, CA, in July of 1973, phenol concentrations ranged from 16 to 91 ppt, with a mean concentration of 60 ppt (Cronn et al. 1977). Phenol was detected, but not quantified, in air above the Niagara River in September of 1982 (Hoff and Chan 1987). Phenol concentrations in 2 urban areas ranged from 13 to 91 ppt and from <5 to 75 ppb with 50% of all measurements less than 8 ppb (Scow et al. 1981). Phenol was found at approximately 1 ppb in the ambient air near a fishmeal factory in Japan (Hoshika et al. 1981).

Phenol and other volatile organic compounds were measured in the air of 50 homes or apartments in Finland (Kostiainen 1995). The average concentration was 0.23 ppb, with a range of 0-0.77 ppb. Phenol levels were not significantly higher in houses in which people complained of symptoms that resembled those of a sick building syndrome.

5.4.2 Water

Phenol has been detected in surface waters, rainwater, sediments, drinking water, groundwater, industrial effluents, urban runoff, and at hazardous waste sites. Background levels of phenol from relatively pristine sites can be as high as 1 ppb for unpolluted groundwater and have been reported to range from 0.01 to 1 ppb in unpolluted rivers (Thurman 1985). Phenol has been detected in Lake Huron water at 3-24 ppb (Konasewich et al. 1978) and industrial rivers in the United States at 0-5 ppb (Sheldon and Hites 1978, 1979). The annual mean concentration of phenol in water from the lower Mississippi River was 1.5 ppb (EPA 1980). River water in an unspecified location in the United States was reported to contain 10-100 ppb of phenol (Jungclaus et al. 1978). Phenol was detected, but not quantified, in a Niagara River watershed (Elder et al. 1981) and in 2 of 110 raw water samples analyzed during the National Organic Monitoring Survey (EPA 1980). In the STORET database, 7% of 2,181 data points for U.S. surface waters were positive for the presence of phenol; the mean and range of the reported concentrations were 533 ppb and 0.002-46,700 ppb, respectively (EPA 1988c).

In general, higher levels of phenol appear to be found in lakes and rivers that serve as water sources and discharge receivers for industrial and population centers, probably as a result of industrial activity and commercial use of phenol-containing products. For example, the presence of higher levels of phenol in the Delaware River near Philadelphia is the result of industrial effluents discharged into the sewer system (Sheldon and Hites 1979).

5. POTENTIAL FOR HUMAN EXPOSURE

The presence of phenol in drinking water probably results from using contaminated surface water or groundwater as a source. Its presence in groundwater is probably the result of release to soil, often industrial releases or leachate from waste dumps, and the subsequent leaching of phenol through the soil to the groundwater. Phenol has been detected, but not quantified, in drinking water in the United States from 5 of 14 drinking water treatment plants (Fielding et al. 1981). It was detected in drinking water in Great Britain between March and December of 1976 in 2 of 4 sites (groundwater source) and in 30% of an unspecified number of sites (surface water source) (Fielding et al. 1981). Phenol levels in tap water, spring water, and mineral water in Italy were 0.58, 0.051, and 0.161 $\mu\text{g/L}$, respectively (Achilli et al. 1995). Phenol was detected at a maximum concentration of 1,130 ppm in 9 wells in Wisconsin after a spill, and was detected for at least 1.5 years after the spill (Delfino and Dube 1976). It was found at concentrations up to 10.4 ppm in groundwater from a sand aquifer adjacent to waste ponds at a wood-preserving facility in Florida (Goerlitz et al. 1985), and was detected at 6.5-10,000 ppb in 2 aquifers 15 months after the completion of a coal gasification project (Stuermer et al. 1982). Phenol was detected at a maximum concentration of 1.9 ppm in leachates from landfill sites in Illinois (Clark and Piskin 1977). Near a landfill in central Florida, phenol was found in groundwater and surface water at about 17 and 15 ppb, respectively (Chen and Zoltek 1995). In the STORET database, 18.3% of 3,443 data points for U.S. groundwaters are positive for the presence of phenol; the mean and range of the reported concentrations are 1.499 ppm (mean) and from not detected to 420 ppm (range) (EPA 1988c). Phenol was detected, but not quantified, in the groundwater at 13.6% of 178 CERCLA hazardous waste sites (Plumb 1987).

Phenol was detected during seven rain events in Portland, OR between February and April of 1984. Concentrations in rain ranged from more than 75 to 1,200 ppt, and averaged above 280 ppt. Gas-phase concentrations ranged from 220 (56.1 ppt) to 410 ng/m^3 (105 ppt) and averaged 320 ng/m^3 (82 ppt) (Leuenberger et al. 1985).

Phenol has been detected in the effluent discharges of a variety of industries. It was found in petroleum refinery waste water at concentrations of 33.5 ppm (Pfeffer 1979) and 100 ppb (Paterson et al. 1996), in the treated and untreated effluent from a coal conversion plant at 4 and 4,780 ppm, respectively (Parkhurst et al. 1979), and in shale oil waste water at a maximum of 4.5 ppm (Hawthorne and Sievers 1984). It has also been detected in the effluent from a chemical specialties manufacturing plant at 0.01-0.30 ppm (Junglaus et al. 1978), in effluent from paper mills at 5-8 ppb (Keith 1976; Paterson et al. 1996), and at 0.3 ppm in a 24-hour composite sample from a plant on the Delaware River, 2 and 4 miles downriver from a sewage treatment plant (Sheldon and Hites 1979).

5. POTENTIAL FOR HUMAN EXPOSURE

Phenol has also been found in the primary and secondary effluent from the Los Angeles City Treatment Plant at concentrations of 32 and <10 ppb, respectively (Young et al. 1983). It was found in 3 of 86 samples of runoff from 2 of 15 cities at 3-10 ppb by the U.S. Nationwide Urban Runoff Program as of July of 1982 (Cole et al. 1984). In the STORET database, 50% of 525 data points for U.S. industrial effluents were positive for the presence of phenol. The mean and range of the reported concentrations were 215 and 1.0-29,000 ppb, respectively (EPA 1988c).

5.4.3 Sediment and Soil

Very few data concerning the presence of phenol in soils were found. Phenol generally does not adsorb very strongly to soils and tends to leach rapidly through soil, which may account for the lack of monitoring data, since any phenol released to soils is likely to leach to groundwater.

Sediment collected 6 km northwest of the Los Angeles County waste-water treatment plant discharge zone at Palos Verdes, CA, contained 10 ppb (dry weight) phenol (Gossett et al. 1983). In the STORET database, 9.7% of 1,158 data points for U.S. sediment were positive for the presence of phenol. The mean and range of the reported concentrations (dry weight) were 6.1 ppm (mean) and from not detected to 608 ppm (range) (EPA 1988c).

5.4.4 Other Environmental Media

Phenol has been reported at concentrations of 7 and 28.6 ppm in smoked summer sausage and smoked pork belly, respectively (EPA 1980), and was identified but not quantified in mountain cheese (Dumont and Adda 1978), fried bacon (Ho et al. 1983), fried chicken (Tang et al. 1983), and black fermented tea (Kaiser 1967). Phenol has also been found in honey at concentrations ranging from 0 (detection limit 0.1 ppm) to 19 ppm (Spoms 1981). It was present each time the honey was collected with phenol-treated boards.

Phenol has been found in bottomfish from 5 sites in Commencement Bay in Tacoma, WA, at a highest maximum average and overall maximum concentration of 0.14 and 0.22 ppm, respectively (Nicola et al. 1987). Phenol has been reported to be a natural component of animal matter; it has been found at 0-1.6 ppm in rabbit muscle tissue (EPA 1980).

5. POTENTIAL FOR HUMAN EXPOSURE

Phenol is also found in medicinal preparations including ointments, ear and nose drops, cold sore lotions, mouthwashes, gargles, toothache drops, and analgesic rubs (Douglas 1972). A commercial antiseptic lotion was reported to contain 1.4% phenol (Musto et al. 1977). Package labeling information indicates that commercial throat lozenges contain up to 29 mg of phenol per lozenge (PDR 1998). Other consumer products such as disinfectants and cleaners may contain concentrations of phenol ranging from 0.45-26% (CA EPA 1998; Forum for Scientific Excellence, Inc. 1990). It has been found that the smoke of 1 nonfilter cigarette contains 60-140 µg of phenol, 19-35 µg for a filter-tipped cigarette, and 24-107 µg in cigars (IARC 1986; NCI 1998).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Data concerning concentrations of phenol in ambient air are insufficient to estimate the potential for exposure by inhalation. However, it is known that the smoke of 1 nonfilter cigarette contains 60-140 µg phenol, while levels of phenol range from 19-35 µg in the smoke of filter-tipped cigarettes, and from 24-107 µg in the smoke of cigars (IARC 1986; NCI 1998). Indoor environments polluted with tobacco smoke contain measurable amounts of phenol (Guerin et al. 1982).

Phenol concentrations in surface and drinking waters are expected to vary with location and proximity to varying industrial and municipal discharges. Considering the lack of quantitative, current monitoring data and the probable seasonal, spatial, and temporal variations in the concentrations of phenol at these sources, it is not possible to estimate accurately a potential daily dose of phenol from drinking contaminated water or from dermal exposure to contaminated water. Nonetheless, it is probable that only those systems that receive their water from contaminated surface water and groundwater contain phenol. Ingestion of phenol via consumption of food cannot be estimated from the available data.

Few data concerning occupational exposures to phenol were located. The average airborne concentrations of phenol to which workers were exposed at three locations within two wood creosote impregnation plants ranged from 0.03 to 0.5 ppm (Heikkila et al. 1987). A phenol concentration of approximately 0.5 ppm was measured in the workroom air at a casting factory in Osaka City, Japan (Kuwata et al. 1980), and concentrations as high as 3.2 ppm were measured in Japanese Bakelite factories (Ohtsuji and Ikeda 1972). Considering the lack of quantitative monitoring data for phenol in occupational atmospheres, it is not possible to estimate the potential for occupational exposure to phenol. The data, however, do show that exposure to phenol through breathing and dermal contact with contaminated workroom atmospheres is

5. POTENTIAL FOR HUMAN EXPOSURE

possible. The National Occupational Exposure Survey (NOES) conducted by NIOSH estimated that 584,385 workers were exposed to phenol in the United States (NOES 1990). The NOES database does not contain information on the frequency, concentration, or duration of exposures. The survey provides only estimates of workers potentially exposed to chemicals in the workplace.

Exposure to phenol also occurs through the use and subsequent ingestion of phenol-containing products, including mouthwashes, gargles, toothache drops, (Douglas 1972), and throat lozenges (EPA 1980). Cepastat[®] lozenges, an over-the-counter remedy for sore throats, contain up to 29 mg phenol/lozenge (PDR 1998). If a patient (adults and children over 6) takes the maximum recommended dose of 300 mg phenol/day, this would result in an approximate dose of 4-8 mg/kg/day.

Dermal exposure also occurs through the use of phenol-containing ointments, ear and nose drops, analgesic rubs (Douglas 1972), and antiseptic lotions (Musto et al. 1977). It is not possible to estimate dose levels for these sources given the available data.

The estimated relative contributions of the various exposure routes and sources of total phenol exposure cannot be estimated using the available data. Nonetheless, for persons not exposed to phenol in the workplace, exposure will most likely result from: inhalation of contaminated ambient air, primarily in the vicinity of industries and municipalities that release significant amounts of phenol into the atmosphere; ingestion of drinking water from contaminated surface waters or groundwaters; ingestion of phenol-containing products; and dermal exposure to contaminated water and to phenol-containing products. Dermal contact with phenol or ingestion of phenol-containing products probably constitutes the largest consumer exposure, although this exposure may occur on an acute basis. Inhalation and dermal exposures appear to be most significant in occupational settings. Total phenol exposure for workers exposed to phenol in the workplace is probably substantially higher than for those not exposed in the workplace.

5.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans and briefly considers potential pre-conception exposure to germ cells. Differences from adults in susceptibility to hazardous substances are discussed in 2.6 Children's Susceptibility.

5. POTENTIAL FOR HUMAN EXPOSURE

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

Oral, dermal, and combined oral-dermal exposures are the most likely routes by which children will be exposed to phenol. Oral exposure to low levels of phenol among children is likely because many consumer products contain phenol, particularly in medicines such as gargles, tooth drops, throat lozenges, ointments, and others (Douglas 1972; EPA 1980). Products other than medicines that contain phenols include general disinfectants, cleaners, and epoxies.

Accidental phenol poisoning from the ingestion of these products and these mentioned previously could result, depending on the product ingested, since the range of concentrations in consumer products range from 0.45-26% (CA EPA 1998; Douglas 1972; EPA 1980; Forum for Scientific Excellence, Inc. 1990; Musto 1977; Spiller et al. 1993). In the case of accidental ingestion, health effects may be the result of phenol and/or other chemical constituents depending on their concentrations in the product. In a study by Spiller et al. (1993), the mean age of accidental acute exposure cases to a disinfectant containing 26% phenol reported to regional poison control centers was 10 years, and 75% of the cases involved children less than 5 years old.

Some foods containing phenol have been identified (see Section 5.4.4) and could result in low levels of phenol exposure in children. In addition, phenol is produced endogenously as a breakdown product of protein metabolism; normal concentrations in urine generally do not exceed 20 mg/L (ACGIH 1991).

Since phenol can be readily absorbed through the skin (ACGIH 1991), children may be more susceptible to low levels of phenol exposure since they have a higher skin-surface-area to weight ratio. Since young children are more likely to come in contact with the floor and other low-lying areas, they may be exposed to phenol found in consumer products such as general disinfectants used to clean toilets, floors, drains, and other areas (Budavari 1989; CA EPA 1998; Hawley 1981).

5. POTENTIAL FOR HUMAN EXPOSURE

Exposure to phenol through inhalation is a less probable route than oral and dermal. It is known that both cigarettes and cigars contain small amounts (19-140 µg) of phenol (IARC 1986; NCI 1998), and smoking these products indoors produces a measurable amount of phenol (Guerin et al. 1982). If children are present in indoor environments polluted with tobacco smoke, they may be exposed to low levels of phenol.

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Populations with potentially high exposure to phenol generally include those who are exposed to relatively highly contaminated environments over long periods of time. These include populations exposed to both identified and unidentified phenol-containing waste disposal sites and landfills. Populations residing in the vicinity of industries that manufacture or use phenol and large population centers may be exposed to potentially high levels of phenol. Persons who work at establishments that manufacture or use phenol have a risk for high exposure to phenol. Populations that regularly ingest food contaminated with phenol or that regularly ingest or come in contact with phenol-containing products are at risk for high exposure to phenol. Populations that live near a phenol spill site, especially those whose water supply sources are near the spill sites, have a risk for high exposure to phenol. Relatively high exposure may also result from exposure to emissions from municipal waste incinerators and cigarette smoke, although no quantitative data concerning phenol emission from these sources were located.

5.8 ADEQUACY OF THE DATABASE

Section 104(I)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of phenol 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 phenol.

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

5. POTENTIAL FOR HUMAN EXPOSURE

5.8.1 Identification of Data Needs

Physical and Chemical Properties. Knowledge of physical and chemical properties is essential for estimating the partitioning of a chemical in the environment. Information about the physical and chemical properties of phenol is available (Hawley 1981; HSDB 1998; IARC 1989), and the database is adequate for the input requirements of environmental models that predict the behavior of a chemical under specific conditions.

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 chemical release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1996, became available in May of 1998. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Additional production data are available from the Chemical Marketing Reporter (CMR 1996), and import/export data for phenol are available on the National Trade Data Bank (NTDB 1996). Additional data are not needed at this time.

Environmental Fate. Based on the physical properties of phenol, volatilization and sorption of phenol to sediments are not expected to be important transport mechanisms (Lyman et al. 1982). The adsorption of phenol to soils has been shown to increase with increasing organic matter (Xing et al. 1994). Photochemical degradation of phenol is thought to be an important process both in air (Hendry and Kenley 1979) and water (Scully and Hoigne 1987). Phenol is also readily biodegradable (Ludzack and Ettinger 1960; Rubin and Alexander 1983; Scott et al. 1983; Stover and Kincannon 1983). Additional studies that examine the volatilization and sorption of phenol to soil and sediments are needed to help predict the environmental fate of phenol.

Bioavailability from Environmental Media. Data from monitoring studies indicate that phenol is present in the environment (Brodzinsky and Singh 1982; Gossett et al. 1983; Hoff and Ghan 1987; Konasewich et al. 1978; Scow et al. 1981; Sheldon and Hites 1978,1979; Thurman 1985) as well as in environmental organisms (Nicola et al. 1987). Exposure to phenol is most likely to be highest in areas at or near industrial centers and population centers where drinking and bathing water, ambient air, and certain foods, such as fish, are obtained from sources contaminated with phenol. Reliable data on the bioavailability

5. POTENTIAL FOR HUMAN EXPOSURE

of phenol from inhaled air and from skin exposed to phenol vapor have been reported for humans (Piotrowski 1971). Studies of bioavailability of phenol from ingested soil and foods and dermal contact with contaminated water are needed for evaluating the hazards posed by ingesting materials that have been contaminated with phenol.

Food Chain Bioaccumulation. No studies were located regarding the food chain bioaccumulation of phenol from environmental media. Data from monitoring studies indicate that phenol is present in the environment as well as in environmental organisms (Nicola et al. 1987). The available bioaccumulation studies are concerned only with exposure of fish to aqueous concentrations of phenol. Although the results of these studies indicate a low potential for bioaccumulation (see Section 5.3.1), the detection of phenol in fish (see Section 5.4.4) indicates that phenol can be found in aquatic organisms; it is possible that food chain bioaccumulation may occur. A clearer understanding of the potential for bioaccumulation would aid in determining how levels in the environment affect the food chain and potentially impact human exposure levels. A study examining phenol levels in organisms from several trophic levels is needed.

Exposure Levels in Environmental Media. Phenol has been measured in air (Brodzinsky and Singh 1982; Cronn et al. 1977; Scow et al. 1981), water (EPA 1980; Sheldon and Hites 1978, 1979; Thurman 1985), and sediments (Gosset et al. 1983). Additional more recent monitoring data are needed to help estimate human exposure to phenol.

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

Exposure Levels in Humans. Data concerning exposure levels in humans are incomplete and not current (Heikkila et al. 1987; Kuwata et al. 1980; Qhtsuji and Ikeda 1972). A detailed recent database of exposure would be helpful in determining the current exposure levels, thereby allowing the estimation of the average daily dose associated with various scenarios such as living near a hazardous waste site or landfill, or with drinking water containing phenol. An environmental media monitoring program would provide the necessary information for estimating environmental exposures, while a detailed examination of the uses of phenol and the kinds of potential exposure in addition to workplace monitoring would probably provide adequate workplace information. The environmental media that would provide the most useful information

5. POTENTIAL FOR HUMAN EXPOSURE

are air, groundwater, and surface and drinking water in urban and industrial locations, and air, groundwater, and surface water at hazardous waste sites. Performing the monitoring over a 1-year period would allow estimation of seasonal variations.

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

Exposures of Children. Children are likely to be exposed to low levels of phenol from the use of many consumer products including medicines and cleaning agents (Budavari et al. 1989; Douglas 1972; EPA 1980; Hawley 1981). There are no known data that quantify the level of exposure to phenol in children. It is likely that young children may be exposed to low levels of phenol because they come into contact with the floor and other areas where disinfectants containing phenol might be used. More studies are needed to assess whether children differ in their weight-adjusted intake of phenol, as little or no information is known. Studies are needed to measure the baseline phenol level in children's urine in order to use phenol levels in urine as a biomarker of exposure.

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

5.8.2 Ongoing Studies

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

No additional on-going studies regarding environmental fate or exposure data for phenol were located.