

5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Styrene is a widely used industrial chemical with reported atmospheric emissions of more than 30 million pounds annually in the United States. Styrene photodegrades in the atmosphere, usually with a half-life of less than 12 hours, depending on the levels of hydroxyl radical and ozone. Styrene is moderately mobile in soil and volatilizes from water to the atmosphere. Styrene may also undergo biodegradation in soil and water. Bioconcentration does not appear to be significant.

The principal route of styrene exposure for the general population is probably by inhalation of contaminated indoor air. Mean indoor air levels of styrene have been reported in the range of 1-9 $\mu\text{g}/\text{m}^3$, attributable to emissions from building materials, consumer products, and tobacco smoke. Occupational exposure to styrene by inhalation is the most likely means of significant exposure. The highest potential exposure is probably in the reinforced plastics industry and polystyrene factories. Exposure may also be high in areas near major spills. Exposure to styrene from hazardous waste sites is potentially important but the magnitude of the problem is unknown.

Styrene has been identified in 52 of the 1,177 NPL hazardous waste sites in the United States (View 1989). The frequency of these sites within the United States can be seen in Figure 5-1.

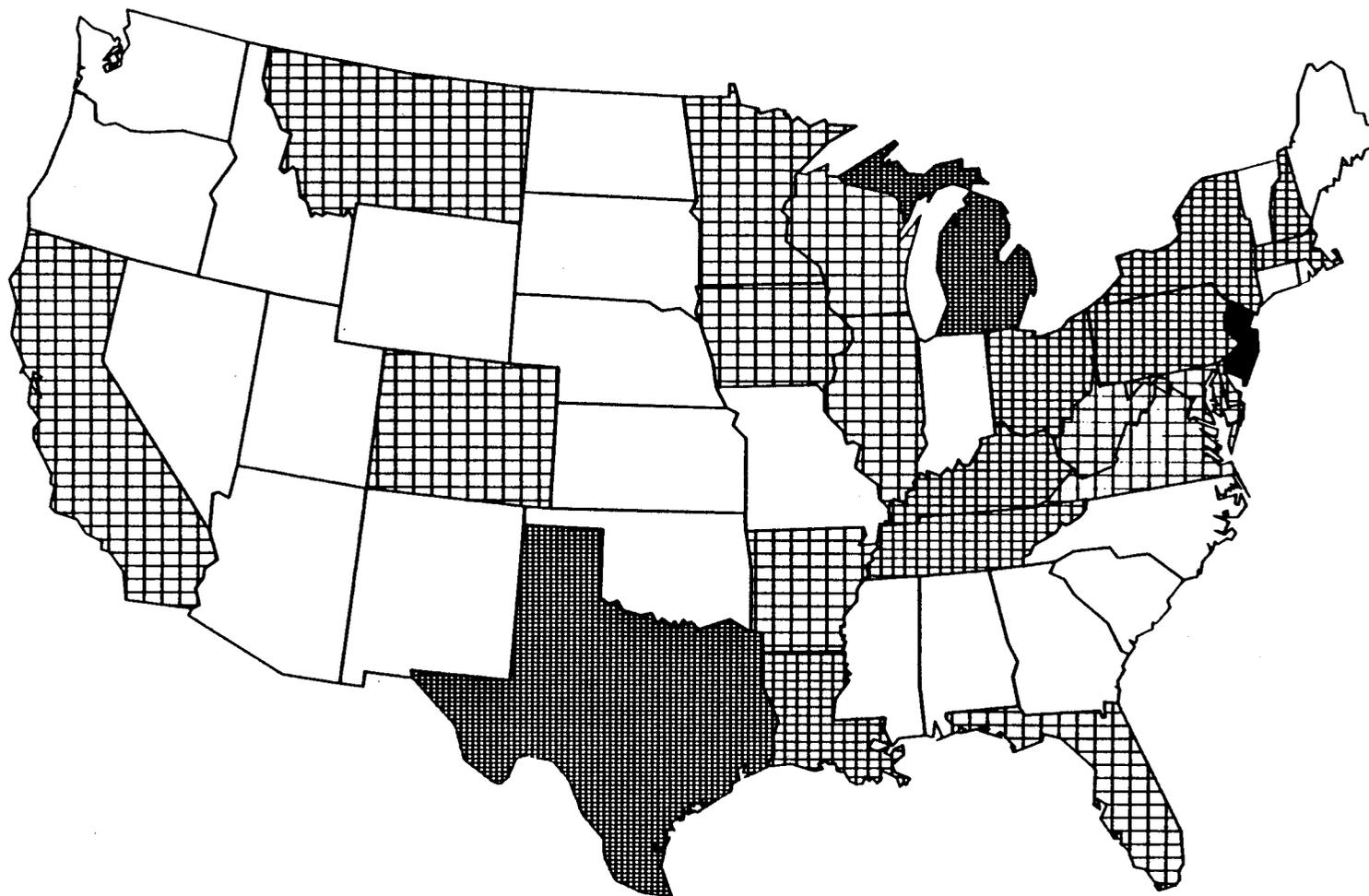
5.2 RELEASES TO THE ENVIRONMENT

Manufacturers, processors, and users of styrene are required to report the quantities of styrene released to environmental media annually (EPA 1988a). The data currently available, compiled in the Toxic Chemical Release Inventory (TRI 1989), are for releases in 1987 and are summarized in Table 5-1. Data relevant to specific media are discussed below.

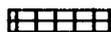
5.2.1 Air

Styrene may be emitted to the atmosphere from industrial production and usage processes, motor vehicle operation, combustion processes, building materials, and consumer products. Estimated industrial styrene emissions reported to EPA for the 1987 Toxics Release Inventory (TRI) totaled over 30 million pounds, 18 million pounds from point sources and more than 12 million pounds as fugitive emissions (EPA 1989c). Styrene ranked 20th among air emissions chemicals in the United States in 1987. Since EPA regulations which require reporting of toxic chemical emissions apply only to selected facilities producing and/or using substantial quantities of the chemical (EPA 1988a), the total air emissions of styrene are probably greater than those reported. Typical sources of industrial styrene emissions are those facilities producing styrene, polystyrene, other plastics, synthetic rubber, and resins (Abrams et al. 1975; EPA 1987d; Graedel 1978; IARC 1979; NIOSH 1983). Facilities reporting styrene emissions for the TRI are listed in Table 5-1.

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



FREQUENCY

 1 SITE
 2 TO 3 SITES
 6 SITES

 9 SITES

* Derived from View 1989

TABLE 5-1. Releases to the Environment from Facilities That Manufacture or Process Styrene^a

State ^d	No. of facilities	Range of reported amounts released in thousands of pounds ^b						
		Air	Underground injection	Water	Land	Total Environment ^e	POTW ^c transfer	Off-site waste transfer
AL	10	0.1-77	0-0	0-0.3	0-0	0.1-77	0-0	0-4.6
AR	14	0-641.2	0-0	0-0.8	0-0.3	0-641.2	0-2	0-25.3
AZ	8	3.8-273	0-0	0-0	0-0	3.8-273	0-0	0-0.8
CA	81	0-240	0-0	0-0.1	0-0.8	0-240	0-28.2	0-86.1
CO	5	0-4.3	0-0	0-0.5	0-7.8	0-12.1	0-0	0-7.8
CT	5	0-11.8	0-0	0-0.3	0-0	0-11.8	0-0.3	0-291.4
DE	3	8-51.3	0-0	0-0	0-0	8-51.3	0-0.1	0-22.6
FL	44	0-1,000	0-0	0-0	0-20	0-1,000	0-0.1	0-107.3
GA	24	0-248	0-0	0-0.1	0-45	0-248	0-0.3	0-526
IA	16	0-643	0-0	0-0.1	0-0.3	0-643	0-16	0-8.4
ID	2	20-26	0-0	0-0	0-0	20-26	0-0	0-0.8
IL	49	0-856	0-0	0-0.3	0-6.6	0-856	0-0.3	0-899.6
IN	50	0-525	0-0	0-0	0-3.9	0-525	0-0	0-216.7
KS	13	0-39.9	0-0	0-0	0-0.8	0.3-39.9	0-0.1	0-6.6
KY	21	0.1-184.7	0-0	0-0.1	0-18	0.1-184.7	0-15.9	0-70.2
LA	16	0.1-199	0-0	0-1.1	0-0	0-199	0-0	0-26.5
MA	13	0-120	0-0	0-0.3	0-0	0-120	0-0.3	0-404.9
MD	14	0-57.6	0-0	0-0.3	0-0.3	0-57.6	0-0.3	0-0.8
ME	5	0.5-41	0-0	0-0	0-0	0.5-41	0-0.3	0-0
MI	32	0-337	0-0	0-0.3	0-0.3	0-337	0-3.8	0-257
MN	10	0.2-355.2	0-0	0-0.1	0-0	0.2-355.2	0-0	0-7.2
MO	17	0-40	0-0	0-0	0-0.3	0-40	0-0	0-1,258
MS	10	0.3-121.9	0-0	0-0.3	0-0	0.3-121.9	0-0	0-13.7
MT	2	2.4-2.6	0-0	0-0.3	0-0	2.4-2.8	0-0	0-0.3
NC	39	0-222.8	0-0	0-0	0-0	0-222.8	0-1.2	0-22
ND	1	8.2-8.2	0-0	0-0	0-0	8.2-8.2	0-0	0-0
NE	5	0-36	0-0	0-0	0-11.7	0-36	0-0	0-11.7
NH	5	0.5-22.5	0-0	0-0	0-0	0.5-22.5	0-0.3	0-3.2
NJ	32	0.1-85	0-0	0-0.2	0-0	0-85	0-0.3	0-87
NM	1	5.2-5.2	No Data	0-0	0-0	5.2-5.2	0-0	0-0
NV	3	1.4-24.6	0-0	0-0	0-0	1.4-24.6	0-0	0-0.8
NY	13	0-46.3	0-0	0-0.7	0-27.8	0-46.3	0-0.3	0-73.6
OH	70	0-299	0-0	0-9.6	0-25	0-299.3	0-42.7	0-680
OK	6	4.8-164.1	0-0	0-0.3	0-0.3	5.3-164.1	0-0.3	0-20
OR	11	0.5-188	0-0	0-0	0-0	0.5-188	0-0	0-9.6
PA	47	0-230	0-0	0-2	0-5	0-230	0-39.2	0-117.5
PR	3	0.1-0.3	0-0	0-0	0-0	0.1-0.3	0-0.1	0-0.1
RI	5	9.1-87.5	0-0	0-0	0-0	9.1-87.5	0-0	0-6.8
SC	25	0-258.6	0-0	0-1.5	0-0.3	0-258.8	0-3.1	0-176.4
SD	2	14.4-37.1	0-0	0-0	0-0	14.4-37.1	0-0	0-0

5. POTENTIAL FOR HUMAN EXPOSURE

TABLE 5-1 (Continued)

State ^d	No. of facilities	Range of reported amounts released in thousands of pounds ^b						Off-site waste transfer
		Air	Underground injection	Water	Land	Total Environment ^c	POTW ^e transfer	
TN	36	0.5-222.4	0-0	0-0.1	0-0.1	0.5-222.4	0-68.5	0-39.5
TX	78	0-1,188	0-0.3	0-18	0-18.8	0-1,188	0-5.9	0-18,099
UT	2	0.3-0.9	0-0	0-0	0-0	0.3-0.9	0-0	0-0
VA	17	0.1-305.8	0-0	0-0.3	0-0.8	0.1-305.8	0-0.3	0-5.2
WA	26	0.7-213.6	0-0	0-0	0-0	0.7-213.6	0-0	0-13.1
WI	23	0-200.8	0-0	0-0.3	0-0.3	0-200.8	0-0.3	0-44.7
WV	9	0.1-760	0-0	0-1.1	0-100	1.2-760	0-190	0-158.8
WY	1	0.5-0.5	No Data	0-0	0-0	0.5-0.5	0-0	0-0

^aTRI 1989

^bData in TRI are maximum amounts released by each facility. Quantities reported here have been rounded to the nearest hundred pounds, except those quantities > 1 million pounds which have been rounded to the nearest thousand pounds.

^cPublicly owned treatment works

^dPost office state abbreviation

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

5. POTENTIAL FOR HUMAN EXPOSURE

Styrene has been identified as a component of motor vehicle emissions from both gasoline- and diesel-powered engines (Hampton et al. 1982, 1983). Styrene emission rates ranging from 6.2 to 7.0 mg/km distance for gasoline powered vehicles and 1.4-2.1 mg/km for diesel trucks have been reported (Hampton et al. 1983).

Styrene may also be emitted into the air by various combustion processes. Styrene has been identified in the stack emissions from waste incineration (Junk and Ford 1980) and Kleindienst et al. (1986) reported the presence of styrene in wood smoke emissions, but no quantitative data were reported.

Emissions of styrene from various building materials and consumer products may contribute significantly to indoor air pollution. A styrene emission rate from glued carpet of 98 ng/min/m² was calculated by Wallace et al. (1987b) and Girman et al. (1986) identified styrene as a major emittant from adhesives used in the constructing and finishing of buildings. Polystyrene products such as packaging materials, toys, housewares, and appliances that may contain small amounts of the monomer also contribute to air levels. Styrene was also detected in sidestream smoke emitted from cigarettes but concentrations were not reported (IARC 1979).

5.2.2 Water

The principal sources of styrene releases to water are industrial effluents. Styrene has been detected in effluents from chemical, textile, latex, and coal gasification plants (Pellizzari et al. 1979; Shackelford and Keith 1976). Styrene was also identified in one of 63 industrial effluents at a concentration of <10 µg/L (Perry et al. 1979). Styrene occurred at concentrations up to 83 µg /L in coal gasification effluents (Pellizzari et al. 1979) and King and Sherbin (1986) reported styrene concentrations up to 970 µg /L in chemical plant effluents. The daily styrene loading from a single chemical plant into the St. Clair River (just south of Lake Huron on the Michigan/Ontario border) was estimated at 133 kg (King and Sherbin 1986). Styrene was detected (but not quantified) in the leachate from an industrial landfill in a study of 58 municipal and industrial landfill leachates (Brown and Donnelly 1988).

Styrene has been detected in both surface and groundwater at hazardous waste sites. Data from the Contract Laboratory Program (CLP) Statistical Database indicate styrene occurred at about 2% of the sites sampled at geometric mean concentrations in positive samples of 9.3 µg/L and 5.3 µg/L in surface water and groundwater, respectively (CLPSD 1986). Note that the CLPSD includes data from both NPL and non-NPL sites.

5.2.3 Soil

Soil and sediments may become contaminated with styrene by chemical spills, landfill disposal of styrene-containing wastes or discharge of styrene-contaminated water. Styrene was detected in soil samples at 3.5% of

5. POTENTIAL FOR HUMAN EXPOSURE

455 hazardous waste sites at a geometric mean concentration in positive samples of 0.530 mg/kg (CLPSD 1986).

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

In the atmosphere, styrene exists as a vapor. Styrene is an oily liquid that is slightly volatile; its vapor pressure has been determined to be approximately 5 mmHg at 20°C (Verschueren 1983). A small fraction of the styrene released to the atmosphere may dissolve into condensed water vapor such as clouds and raindrops. A Henry's law constant (H) is a measure of the tendency of a chemical to partition between its gas phase and water. A value for H has not been experimentally measured for styrene, but it may be estimated by dividing the vapor pressure of styrene by its solubility in water at the same temperature (Mabey et al. 1982). In this case, the value of H is approximately 2.61×10^{-3} atm-m³/mole at 25°C. Analogous air-water partition coefficients were measured for styrene at 37°C, yielding a value of approximately 5.4×10^{-1} atm-m³/mole (Sato and Nakajima 1979). The magnitude of the values suggest that only a small fraction of vapor-phase styrene would dissolve into water. Physical processes such as precipitation and dry deposition would not be significant mechanisms for removing styrene from the atmosphere because of its high photochemical reactivity (EPA 1984b).

The magnitude of the estimated Henry's law constant (2.61×10^{-3} atm-m³/mole, assuming a water solubility of 300 mg/L at 25°C) suggests that a large fraction of the chemical dissolved in water will volatilize into the atmosphere, depending on temperature gradients, relative humidity, air currents, and the extent of mixing of the solution. The rate of styrene volatilization from water has not been experimentally measured, but its half-life in moving water that is 1 meter in depth may be on the order of 6 hours, based on the empirical relationship reported by Dilling (1977) for the volatilization of chlorinated hydrocarbons from water. The half-life of styrene in the Rhine River was estimated from field measurements at about 14 hours, but it was not certain whether styrene volatilized, biodegraded, and/or photodegraded (Zoeteman et al. 1980). Volatilization from ponds and lakes would be slower; half-life estimates range from 3 to 13 days (EPA 1984b).

Styrene is only sparingly soluble in water, but its exact solubility is uncertain. Values reported for the solubility of styrene range from 160 mg/L at 23°C to 310 mg/L at 20°C (Banerjee et al. 1980; Valvani et al. 1981; Verschueren 1983).

Styrene in water may also partition to soils and sediments. The extent of adsorption of sparingly water-soluble compounds is often correlated with the organic carbon content of the adsorbent (Hassett et al. 1983). When adsorption is expressed as a function of organic-carbon content, an organic carbon/water partition coefficient (K_{oc}) is generated, and may be used to rank the relative mobility of the chemical in soil. A K_{oc} value for styrene has

5. POTENTIAL FOR HUMAN EXPOSURE

not been experimentally measured, but may be estimated from its solubility in water, using the empirical regression of Hassett et al. (1983). Assuming that the solubility of styrene is 300 mg/L, a calculated K_{oc} value for styrene is 260. The magnitude of this estimated K_{oc} suggests that styrene is "moderately mobile" in soil (Roy and Griffin 1985). In surface soils, where the amount of organic carbon will be highest, the movement of styrene will be retarded by adsorption. In deeper subsurface environments where the amount of organic carbon may be low, adsorption may not be as significant. Based on field measurements, the rate of movement of styrene in an aquifer was about 80 times slower than that of the groundwater, (Roberts et al. 1980) which is attributed to adsorption. No information was located to corroborate the estimated K_{oc} value, and apparently there are no studies in which the adsorption-desorption characteristics of styrene by soils and sediments have been measured.

The octanol/water partition coefficient (K_{ow}), which reflects the partitioning of a chemical between octanol and water, is believed to be a good indication of the tendency for a chemical to accumulate in the fatty structures in plants and animal tissues (Kenaga and Goring 1980). The K_{ow} of styrene has been measured to be 1,445 (Banerjee et al. 1980) and 891 (Valvani et al. 1981), suggesting that styrene will partition to fat tissues. This is shown to be the case by the work of Engstrom et al. (1978a) and by Stanley (1986).

Even though styrene does tend to partition into fat, it does not tend to bioaccumulate to high levels, mainly because of its metabolism and excretion. A bioconcentration factor (BCF) relates the concentration of a chemical in an organism to the concentration of the chemical in the medium in which it is exposed. Based on the empirical regression of Kenaga (1980), the BCF for styrene is about 25. An experimentally-measured BCF for goldfish was 13.5 (Ogata et al. 1984). These low BCFs suggest that bioconcentration is not a significant fate of styrene released into the environment (EPA 1984b). No other measured BCFs were located to corroborate these reported values.

5.3.2 Transformation and Degradation

5.3.2.1 Air

The major fate of atmospheric styrene is determined by the rate of photooxidation. Styrene may be transformed by direct photolysis, but the half-life of this process may be on the order of 50 years (EPA 1984b). Kopczyński et al. (1972) found that styrene was not degraded by photolysis after 6 hours of exposure.

Styrene is more quickly photooxidized by ozone and hydroxyl radicals. The rate constant for the reaction of styrene with ozone at ambient temperatures (about 25°C) has been measured and is approximately 0.17 to 2.16×10^{-19} cm³/molecule-sec (Atkinson et al. 1982; Hendry and Kenley 1979). Assuming that the mean concentration of ozone in the troposphere is 1012 molecules/cm³ (Cupitt 1980), then the half-life of styrene would be approximately 13 hours. The rate constant for the reaction of styrene with

5. POTENTIAL FOR HUMAN EXPOSURE

hydroxyl radicals has been measured as 5.3×10^{-11} cm³/molecule-sec (Bignozzi et al. 1981). Assuming that the concentration of tropospheric hydroxyl radicals varies from 3×10^5 to 1×10^7 molecules/cm³ (MacLeod et al. 1984), it follows that the atmospheric half-life of styrene would be between 0.5 and 17 hours. Consequently, because of the combined effect of ozone- and hydroxyl radical-initiated decay, it appears likely that styrene is labile in the troposphere. Transformation products include various oxygen-containing and saturated hydrocarbons (Sloane and Brudzynski 1979).

5.3.2.2 Water

Little is known about abiotic transformations of styrene in water. The reaction of styrene with peroxy radicals appears to be too slow to be significant (EPA 1984b), and no relevant information regarding photochemical reactions in water was located. There is no information that styrene will hydrolyze in water, nor would its chemical structure suggest such potential.

Styrene biodegrades in various aquatic systems. Styrene was only slightly biodegraded in the presence of one type of sewage (Pahren and Bloodgood 1961), but Bridie et al. (1979) found that 42% of the styrene initially present degraded in 5 days when unadapted sewage was used as the source of microorganisms. Very low concentrations of styrene (less than 10 µg/L) were almost completely degraded in 20 minutes in an aerobic biofilm reactor after acclimation, but the chemical was persistent in a methanogenic biofilm column (Bouwer and McCarty 1984). It was found that the rate of styrene biodegradation in groundwater was slow (Wilson et al. 1983). The half-life of styrene in groundwater was estimated to be between 6 weeks and 7.5 months. Although these studies have demonstrated the potential for styrene to biodegrade in water, no information was located about styrene degradation in ambient surface waters.

5.3.2.3 Soil

Styrene may also biodegrade in soils. Microorganisms were isolated from soil that were capable of using styrene as a sole-carbon source (Sielicki et al. 1978). Biodegradation products included phenylethanol and phenylacetic acid. Cultures of propane-utilizing bacteria isolated from soil and lake samples were able to degrade styrene (Hou et al. 1983). No information was located on the biodegradation of styrene in field soils.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

Styrene is a common contaminant of ambient urban air. Concentrations of styrene greater than rural air concentrations have been identified in urban and industrial source areas, near hazardous waste sites, in motor vehicle tunnels, in indoor air, and in workplace environments. A summary of monitoring data for these locations is presented in Table 5-2. The data suggest that indoor air concentrations of styrene may be considerably higher

5. POTENTIAL FOR HUMAN EXPOSURE

than outdoor concentrations. Cigarette smoke has been implicated as a significant source of styrene in indoor air (Wallace 1987; Wallace et al. 1986a).

5.4.2 Water

Styrene is not frequently found in United States water supplies. Styrene was not detected in any of the more than 1,000 samples of drinking water analyzed during three federal surveys (EPA 1988b), but has been reported occasionally in drinking water supplies in several states (Abrams et al. 1975; Coleman et al. 1984; Kleopfer and Fairless 1972; Kool et al. 1982; Sanjivamurthy 1978; Shackelford and Keith 1976) well water (Kelley 1985; Krill and Sonzogni 1986), river water (Shackelford and Keith 1976; Sheldon and Hites 1978) and Lake Erie (Konasewich et al. 1978). Quantitative data were not available in these reports. Styrene concentrations in raw and treated waters ranged from 0.1 to ≥ 1.0 $\mu\text{g/L}$ in an evaluation of organic compounds in Canadian water supplies at nine municipalities along the Great Lakes (Otson 1987).

5.4.3 Soil

Limited data were located regarding estimation of styrene in soils or sediments (see Section 5.2.3).

5.4.4 Other Environmental Media

Styrene has been detected among the natural volatile components of roasted filberts, dried legumes, fried chicken, nectarines, and Beaufort cheese (Dumont and Adda 1978; Kinlin et al. 1972; Lovegren et al. 1979; Takeoko et al. 1988; Tang et al. 1983). Styrene may also enter foods by migration from polystyrene food containers and packaging materials (EPA 1988b). Concentrations of styrene measured in yogurt packaged in polystyrene containers ranged from 5.5 to 150 $\mu\text{g/L}$ (Withey 1976). Mean levels of styrene in foods packaged in plastic in the United Kingdom ranged from <1 to 180 $\mu\text{g/kg}$ (Gilbert and Startin 1983). Similar concentrations of styrene were detected in other dairy products packaged in polystyrene containers (IARC 1979). The rate of styrene migration into food is mainly a function of the diffusion coefficient of the monomer in the polymer and of the lipophilicity of the food (Till et al. 1987). For example, 4%-6% of the free monomer in polystyrene packaging migrated into corn oil or sunflower oil within 10 days, while only 0.3%-0.6% migrated into milk, beef or water. Similarly, migration of styrene from foam cups into liquids such as water, tea or coffee was about 8 ng/cm^2 , while migration into 8% ethanol (as might be encountered in wine or other alcoholic drinks) was 36 ng/cm^2 (Varner and Breder 1981). However, Withey and Collins (1978) found no clear relationship between the styrene monomer content of packaging material (which varied widely) and the amount leached into food after comparable residence times. Styrene was detected, but not quantified, in samples of mother's milk from four urban areas (Pellizzari et al. 1982).

5. POTENTIAL FOR HUMAN EXPOSURE

TABLE 5-2. Styrene Concentrations in Representative Air Samples in the United States

Location	Concentration ($\mu\text{g}/\text{m}^3$)		Reference
	Maximum	Mean	
Rural/ suburban	No data	0.28-0.34 ^a	Shah and Heyerdahl 1988; Graedel 1978
Urban	0.63-21	0.29-3.8	Grosjean and Fung 1984; Harkov et al. 1985; Hunt et al. 1986; Shah and Heyerdahl 1988; Wallace et al. 1986b; Wallace 1987
Industrial source areas	25	1.3 ^a -2.1	Brodinzky and Singh 1983; Pellizzari et al. 1978; Shah and Heyerdahl 1988
Hazardous waste sites	65	1.1-6.4	Harkov et al. 1985; La Regina and Bozzelli 1986
Tunnel	6.6	1.1-6.6 ^b	Hampton et al. 1983
Indoors	6,500	0.8-8.9	Shah and Heyerdahl 1988; Wallace et al. 1986a; Wallace 1987
Workplace	4.5x10 ⁶	<1-1.5x10 ⁶	Bartolucci et al. 1986; Cocheo et al. 1983; NIOSH 1983

^aMedian value^bRange of values, no mean given

5. POTENTIAL FOR HUMAN EXPOSURE

Styrene has been identified as a component of cigarette smoke (EPA 1984b) and has been detected in concentrations of 18 μg /cigarette in the smoke of cigarettes made in the United States (IARC 1979). Indoor air concentrations of styrene may be significantly higher in homes of smokers than nonsmokers (Wallace 1987).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Exposure to styrene may occur by inhalation, ingestion, or dermal absorption. The most likely mode of exposure of the general population to styrene is by inhalation of indoor air (EPA 1988b). Based on the EPA (1989e) estimate that the average person spends 20.4 hours/day indoors (inhaling about 17 m^3 of air during that time based on an air inhalation rate of 20 m^3/day) and the range of mean indoor air concentrations presented in Table 5-2, typical indoor exposure levels to styrene may range from 14 to 151 μg /day. Additional exposures may occur from inhalation of outdoor air and ingestion of food which was stored in polystyrene containers. Outdoor air concentrations are likely to be lower in rural than urban areas and are likely to be small compared to indoor air concentrations. Exposure from municipal drinking water is probably insignificant. However, groundwater at hazardous waste sites where styrene has been detected may provide significant exposure to styrene if used as local water supply.

Worst-case exposure estimates for styrene of 0-0.5 μg /day from drinking water, 30 μg day from food, and 65,000 μg /day from air were calculated by EPA (1988b). These estimates are based on the highest levels estimated or monitored and, therefore, reflect the highest potential exposure rather than typical exposure for the general population.

Exposure of the general population to styrene is confirmed by human monitoring data. Styrene has been identified in adipose tissue at concentrations of 8-350 ng/g (Stanley 1986), in blood at a mean concentration of 0.4 μg /L (Antoine et al. 1986) and in exhaled breath at mean concentrations of 0.7-1.6 μg / m^3 (Wallace 1987).

A large number of workers are potentially exposed to styrene. NIOSH estimates that approximately 300,000 workers at 22,000 facilities may be exposed to styrene (NOES 1989), about 30,000 of these on a full-time basis (NIOSH 1983). The highest potential exposure occurs in the reinforced plastics industry, where workers may be exposed to high air concentrations and also have dermal exposure to liquid styrene or resins (Lemasters et al. 1985; NIOSH 1983). Hemminki and Vainio (1984) estimated that heavily exposed workers in this industry in Finland might be exposed to up to 3 g of styrene per day. Significant occupational exposures may also occur in other industrial settings, including styrene polymerization, rubber manufacturing, and styrene-polyester resin facilities (Engstrom et al. 1978b; NIOSH 1983; Rappaport and Fraser 1977).

5. POTENTIAL FOR HUMAN EXPOSURE

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

People working in various styrene industries are likely to have the highest exposures to styrene. Lower levels may be encountered near industrial facilities or hazardous waste sites emitting styrene to outdoor air. High indoor styrene concentrations in the home may be due to emissions from building materials, consumer products, and tobacco smoke. Smokers and those eating a high proportion of foods packaged in polystyrene may also have above average exposure to styrene.

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 styrene 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 styrene.

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 or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Data Needs

Physical and Chemical Properties. The solubility of an organic compound in water is indicative of how that chemical will partition between water, soil, and organisms (Banerjee et al. 1980; Hassett et al. 1983; Valvani et al. 1981). Clarification of the exact solubility of styrene in water would be helpful because currently a range of values is reported. The Henry's law constant and K_{oc} value for styrene need to be verified experimentally to provide more accurate predictions of air-water and soil-water partitioning.

Production, Import/Export, Use, and Disposal. Substantial quantities of styrene are currently produced and used in the United States (Heylin 1989; HSDB 1989; SRI 1989; USITC 1988). Production and import quantities, producers, and uses are well documented. There has been an increase in production volume over the past decade and further increases are projected. However, data on current styrene imports were not available. Quantities of styrene disposed of by various disposal methods are not known. Styrene releases into water are regulated by EPA, but styrene is not listed as a hazardous waste constituent and, therefore, land disposal restrictions do not apply to this compound. Additional information on disposal methods used for styrene and styrene-containing products and the quantities disposed of by each

5. POTENTIAL FOR HUMAN EXPOSURE

method would help to better characterize the potential for human exposure to this compound from disposal at waste sites or other locations.

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 Toxic Release Inventory (TRI), which contains this information for 1987, became available in May of 1989. This database will be updated yearly and should provide a list of industrial production facilities and emissions. It is likely that styrene will continue to be a high volume production chemical.

Environmental Fate. Styrene will partition among the environmental media, with a tendency to volatilize from water to air and to adsorb to soils (EPA 1984b; Roberts et al. 1980; Sato and Nakajima 1978). However, data on styrene volatilization from water and confirmation of the estimated K_{oc} value by adsorption/desorption data would be useful to estimate more accurately the tendency of styrene to partition to air and soil. Confirmation of the K_{oc} would also provide a more reliable basis for estimating the mobility of styrene in the various types of soil.

Although the reaction mechanisms of styrene transformations in the atmosphere are fairly well understood (Atkinson et al. 1982; Bignozzi et al. 1981; Hendry and Kenley 1979; Sloane and Brudzynski 1979), more information regarding the environmental fates of the transformation products would allow a more accurate prediction of the atmospheric fate of this compound. Data on biodegradation of styrene would be useful in predicting the fate and persistence of the compound in water and soil.

Bioavailability from Environmental Media. Styrene is known to be absorbed following inhalation, oral and dermal contact (Dutkiewicz and Tyras 1968; Engstrom et al. 1978a, 1978b; Ramsey and Anderson 1984; Ramsey and Young 1978; Withey 1976; Withey and Collins 1979). Absorption rates via inhalation are known (Withey and Collins 1978). Additional data are needed to evaluate absorption rates following oral and dermal exposure. It is believed that absorption of styrene from the gut is generally rapid and therefore contact with styrene contaminated food, soil, or water will probably also result in significant absorption. However, this may depend on the medium in which it is contained. However, actual absorption rates associated with ingestion are unknown and should be investigated.

Food Chain Bioaccumulation. Bioconcentration of styrene in aquatic organisms is not likely to be significant, based on both a measured BCF for a single species and an estimated BCF (EPA 1984b; Kenaga 1980; Ogata et al. 1984). No data on biomagnification of styrene in the food chain were located. Since significant bioaccumulation is unlikely, this lack of data may not be a major limitation. However, additional information on bioconcentration in several species would confirm this prediction.

5. POTENTIAL FOR HUMAN EXPOSURE

Exposure Levels in Environmental Media. Monitoring data for styrene in air are extensive and recent data are available (Shah and Heyerdahl 1988; Wallace 1987). However, monitoring data in other environmental media using current, sensitive analytical methods are sparse. Additional data on styrene levels in water and soil, especially in the vicinity of hazardous waste sites would be useful in assessing the potential for human exposure. Quantification of styrene in cigarette smoke would also help in assessing exposure from smoking and passive smoke inhalation. Estimates of human intake from air, water, and soil have been made (EPA 1988b) and will undoubtedly be revised as additional data become available.

Exposure Levels in Humans. Styrene has been detected in human blood, breath, milk, and adipose tissue of the general population (Antoine et al. 1986; Pellizzari et al. 1982; Stanley 1986; Wallace.1987) and metabolites of styrene have been detected in urine of workers exposed to styrene (Elia et al. 1980; Sollenberg et al. 1988). Additional data on blood levels of styrene will be generated by the on-going study described in Section 5.7.2. However, data generated by biological monitoring of populations in the vicinity of waste sites with the most sensitive methods (Section 6.1) would be useful in assessing the magnitude of human exposures from this source.

Exposure Registries. No exposure registries for styrene were located. This compound is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The compound 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 the exposure to this compound.

5.7.2 On-going Studies

As part of the Third National Health and Nutrition Evaluation Survey (NHANES III), the Environmental Health Laboratory Sciences Division of the Center for Environmental Health and Injury Control, Centers for Disease Control, will be analyzing human blood samples for styrene and other volatile organic compounds (NCHS 1988; Needham 1989). These data will give an indication of the frequency of occurrence and background levels of these compounds in the general population.

No other on-going studies on the fate, transport, or exposure potential of styrene were located.