March 31, 1987

820K87109

XYLENES

Health Advisory
Office of Drinking Water
U.S. Environmental Protection Agency

I. INTRODUCTION

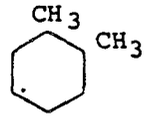
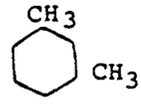
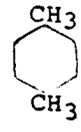
The Health Advisory (HA) Program, sponsored by the Office of Drinking Water (ODW), provides information on the health effects, analytical methodology and treatment technology that would be useful in dealing with the contamination of drinking water. Health Advisories describe nonregulatory concentrations of drinking water contaminants at which adverse health effects would not be anticipated to occur over specific exposure durations. Health Advisories contain a margin of safety to protect sensitive members of the population.

Health Advisories serve as informal technical guidance to assist Federal, State and local officials responsible for protecting public health when emergency spills or contamination situations occur. They are not to be construed as legally enforceable Federal standards. The HAs are subject to change as new information becomes available.

Health Advisories are developed for One-day, Ten-day, Longer-term (approximately 7 years, or 10% of an individual's lifetime) and Lifetime exposures based on data describing noncarcinogenic end points of toxicity. Health Advisories do not quantitatively incorporate any potential carcinogenic risk from such exposure. For those substances that are known or probable human carcinogens, according to the Agency classification scheme (Group A or B), Lifetime HAs are not recommended. The chemical concentration values for Group A or B carcinogens are correlated with carcinogenic risk estimates by employing a cancer potency (unit risk) value together with assumptions for lifetime exposure and the consumption of drinking water. The cancer unit risk is usually derived from the linear multistage model with 95% upper confidence limits. This provides a low-dose estimate of cancer risk to humans that is considered unlikely to pose a carcinogenic risk in excess of the stated values. Excess cancer risk estimates may also be calculated using the One-hit, Weibull, Logit or Probit models. There is no current understanding of the biological mechanisms involved in cancer to suggest that any one of these models is able to predict risk more accurately than another. Because each model is based on differing assumptions, the estimates that are derived can differ by several orders of magnitude.

This Health Advisory is based on information presented in the Office of Drinking Water's Health Effects Criteria Document (CD) for Xylenes (U.S. EPA, 1985a). The HA and CD formats are similar for easy reference. Individuals desiring further information on the toxicological data base or rationale for risk characterization should consult the CD. The CD is available for review at each EPA Regional Office of Drinking Water counterpart (e.g., Water Supply Branch or Drinking Water Branch), or for a fee from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161, PB # 86-117942/AS. The toll-free number is (800) 336-4700; in the Washington, D.C. area: (703) 487-4650.

II. GENERAL INFORMATION AND PROPERTIES

	Xylene	Ortho-	Meta-	Para-
CAS No.	1330-20-7	95-47-6	108-38-3	106-42-3
Structural Formula				

Synonyms

- Xylols; dimethylbenzene

Uses

- As solvents for paints, inks and adhesives, and as components of detergents and other industrial and household products.

Properties (Verschueren, 1983)

	Xylene	Ortho-	Meta-	Para-
Chemical Formula		C_8H_{10}	C_8H_{10}	C_8H_{10}
Molecular Weight		106.16	106.16	106.16
Boiling Point		144.4°C	139.0°C	138.4°C
Melting Point		-25°C	-48°C	-13°C
Density		--	--	--
Vapor Pressure, mm Hg, 20° C		5	6	6.5
Water Solubility, mg/l, 20° C		175	160	--
25° C		--	--	198
Log Octanol/Water Partition Coefficient[a]		3.12	3.20	3.15
Taste Threshold[b]	0.3-1.0 mg/L	--	--	--
Odor Threshold		--	--	--
Conversion Factor	1 ppm = 4.3 mg/m^3			

[a] Leo et al. (1971)
[b] National Inst. for Water Supply (1977)

Occurrence

° Xylene occurs naturally as a component of petroleum oil.

° Xylenes are produced in large amounts, 5 billion lbs in 1982 (U.S. ITC, 1984). Xylenes are also produced indirectly in large volumes during gasoline refining and other operations. Xylene content of gasoline can be as high as several percent.

° Releases of xylenes to the environment are largely to air due to their volatile nature, with smaller amounts to water and soil. Releases of xylenes to water are due to spills and leaks of gasoline and other petroleum products and, to a lesser extent, from the disposal of waste from paints, inks and other industrial products. Because of the widespread use of petroleum products, releases of xylene occur nationwide.

° Xylenes degrade rapidly in air with a half life of a few days. Xylenes released to surface water rapidly volatilize to the air. Xylenes released to the ground bind somewhat to soil and slowly migrate with ground water. Xylenes are biodegraded readily in soils and surface waters. In the absence of biodegradation, xylenes are expected to be stable in ground water.

° Xylenes occur at low levels in drinking water, food, and air. Xylene occurs in both ground and surface public water supplies, with higher levels occurring in surface water supplies. The EPA's Community Water Supply Survey, found 3% of all ground water derived public drinking water systems sampled had levels greater than 0.5 ug/L. The highest level reported in ground water was 2.5 ug/L. The survey reported that 6% of all surface water derived drinking water system are contaminated at levels higher than 0.5 ug/L. None of the systems were reported to contain levels higher than 5.2 ug/L. No information on the occurrence of xylene in foods has been identified. Xylenes are found in the air of urban and suburban areas at levels of approximately 2 ug/L. Because of the widely dispersed low levels of xylenes reported in water, air is likely to be the major source of exposure.

III. PHARMACOKINETICS

Absorption

° Xylenes are absorbed readily after inhalation. Data on absorption after ingestion are not available. Sedivec and Flek (1976) exposed human volunteers to 0.2 mg/L (200 mg/m^3) o-, m- and p-xylene vapors and also to their mixture at a ratio of 1:1:1 for an 8-hour period. The amount absorbed or retained was 63.6% $\pm$ 4.2% for all isomers.

Distribution

° Using whole-body autoradiography to detect radiolabeled xylene and metabolites, Bergman (1978) reported distribution of the compound in many tissues and organs of exposed mice. ^{14}C-m-Xylene was administered

to mice by inhalation for 10 minutes. Whole mice were frozen and sectioned before exposure to X-ray film. In mice sacrificed immediately after xylene exposure, radiolabel was detected in the lungs, liver and kidneys. Rapid distribution to the brain and adipose tissue also was evident. Two hours after exposure, radiolabel in the lungs was restricted to the bronchi. In addition to the previously noted organs, radiolabel was detected in the intestine after two hours. The last traces of xylene were detected in the adipose tissue of mice sacrificed four hours after exposure.

- In rats exposed to ^{14}C-p-xylene for 1-8 hours by inhalation at 208 mg/m^3 (48 ppm), radiolabel was detected (in decreasing concentration) in the kidneys, subcutaneous fat, sciatic nerve, blood, liver, lungs, spleen, muscles, cerebrum and cerebellum (Carlson, 1981). Distribution to all tissues was rapid, allowing near maximal levels in tissues (except in kidneys and subcutaneous fat) within one hour.

Metabolism

- Metabolism of xylenes varies somewhat according to the isomer but, in general, proceeds by oxidation of methyl groups and ring hydroxylation. The resulting metabolites include methyl hippuric acid (95%) and xylenols (1-2%) (Harper et al. 1975).

Excretion

- Elimination of xylenes is primarily through urinary excretion of metabolites, representing nearly 95% of the absorbed dose, and the remaining 5% by pulmonary exhalation of unchanged solvent (Sedivec and Flek, 1976; Astrand et al., 1978).

IV. HEALTH EFFECTS

Humans

- The lowest oral lethal dose (LDLo) for humans has been reported as 50 mg/kg (NIOSH, 1978).

- Xylenes produce central nervous system disturbances as reflected in changes in numerative ability, short-term memory and electroencephalographic patterns.

- Gamberale et al. (1978) observed no adverse health effects in fifteen male subjects at rest following 70 minutes of inhalational exposure to xylene at 435 and 1300 mg/m^3. However, in another experiment, eight male subjects were exposed to xylene at 1300 mg/m^3 with 30 minutes of exercise on a bicycle ergometer which was continued during behavior tests. The authors concluded that there was evidence of reduction in the performance level on three of the four tests. The tests conducted were: simple addition and choice reaction time, short-term memory and critical Hicker fusion frequency.

- Savolainen et al. (1980) observed adverse effects on the psychophysiological functions in eight male students following inhalational exposure to m-xylene at 391 mg/m^3 for five consecutive days and one day after the weekend. Body balance, reach on time and manual coordination were impaired. However, tolerance against the observed effects developed during one working week.

Animals

Short-term exposure

- In rats, oral LD_{50} values range from 4,300 to 5,000 mg/kg(NIOSH, 1978), whereas inhalation LC_{50}s (four hours) are 20,600 to 29,000 mg/m^3 (Carpenter et al., 1975; Harper et al., 1975).

Long-term Exposure

- Carpenter et al. (1975) exposed rats to mixed xylenes at 770, 2000 or 3500 mg/m^3 for six hours/day, five days/week for 13 weeks duration. No effects on body weight gain, hematology, blood chemistry, kidney, or liver weights or tissue histology were reported at two lower dose levels. At the highest dose level, one rat treated at 3500 mg/m^3 for seven weeks showed slight renal tubular regeneration and, at 13 weeks, the response was noted in rats in a non-dose-related manner.

- Jenkins et al. (1970) reported the results of repeated (30 exposures) or continuous inhalation exposure (90 days) to o-xylene by rats, guinea pigs, monkeys and dogs. The exposure levels were 337 or 3,358 mg/m^3 in rats and monkeys. One of the dogs exhibited tremors of varying severity throughout exposure. No significant effects were observed with respect to body weight, hematology, and histopathological examination at the lower dose of 337 mg/m^3 xylene.

- Ultrastructural hepatic effects have been reported in rats following subchronic oral exposure (200 mg/kg diet for up to 6 months) (Bowers et al., 1982). Two types of intracellular vesicles in rats treated with o-xylene were observed. One type appeared to be an extension of the endoplasmic reticulum and the second vesicle type was associated with the hepatocyte plasmalemma.

- Tatrai et al. (1981) reported hepatomegally and ultrastructurally evident proliferation of the smooth endoplasmic reticulum following chronic inhalation exposure of 4750 mg/m^3, eight hours/day, seven days/week for one year in rats.

Reproductive Effects

- No information was found in the available literature on the reproductive effects of xylene.

Developmental Effects

- Twenty CFY rats, 240 to 280 g, were exposed to 1,000 mg/m^3 of mixed xylenes 24 hours/day during days 9 to 14 of pregnancy, and although

there were increased incidences of fused sternebrae and extra ribs in the offspring, the authors interpreted these as signs of embryotoxicity rather than teratogenicity (Hudak and Ungvary, 1978). No signs of maternal toxicity were noted. In another study, Charles River rats aged 12 weeks were exposed to 0, 100 or 400 ppm of xylenes (0, 434 or 1,730 mg/m^3) during days 6 to 15 of pregnancy (25 rats per group); the authors reported no signs of teratogenicity whether on the per-fetus or the per-litter basis (Litton Bionetics, 1978).

Mutagenicity

- Xylene was not mutagenic in the Ames test with or without activation or in other short-term *in vitro* assays (Litton Bionetics, 1978).

Carcinogenicity

- A long-term carcinogenicity bioassay in rats and mice has been conducted by the NTP; however, the final report is not yet released by the NTP (1986).

V. QUANTIFICATION OF TOXICOLOGICAL EFFECTS

Health Advisories (HAs) are generally determined for One-day, Ten-day, Longer-term (approximately 7 years) and Lifetime exposures if adequate data are available that identify a sensitive noncarcinogenic end point of toxicity. The HAs for noncarcinogenic toxicants are derived using the following formula:

$$HA = \frac{(NOAEL \text{ or } LOAEL) \times (BW)}{(UF) \times (\_\_\_ \text{ L/day})} = \_\_\_ \text{ mg/L } (\_\_\_ \text{ ug/L})$$

where:

NOAEL or LOAEL = No- or Lowest-Observed-Adverse-Effect-Level in mg/kg bw/day.

BW = assumed body weight of a child (10 kg) or an adult (70 kg).

UF = uncertainty factor (10, 100 or 1,000), in accordance with NAS/ODW guidelines.

___ L/day = assumed daily water consumption of a child (1 L/day) or an adult (2 L/day).

One-day Health Advisory

A One-day HA for xylenes may be developed from the experiment conducted in human subjects by Gamberale et al. (1978). In this study, a NOAEL was identified at an inhalation concentration of 1300 mg/m^3 for approximately one hour. Other researchers also have observed CNS effects at or near similar concentrations following exercise in terms of performance tests. The calculations for a One-day HA for a 10 kg child are as follows:

Step 1: Determination of the Total Absorbed Dose (TAD)

$$\text{Total absorbed dose} = \frac{(1300 \text{ mg/m}^3)\ (1 \text{ m}^3)\ (0.64)}{(70 \text{ kg})} = 11.9 \text{ mg/kg/day}$$

where:

1,300 mg/m^3 = NOAEL based on absence of reduction in the performance level on tests in humans.

1 m^3 = assumed amount of air inhaled during one hour by a human.

0.64 = 64% absorption factor in humans (Sedivek and Flek, 1976).

70 kg = assumed body weight of an adult.

Step 2: Determination of a One-day HA

$$\text{One-day HA} = \frac{(11.9 \text{ mg/kg/day})\ (10 \text{ kg})}{(10)\ (1 \text{ L/day})} = 11.9 \text{ mg/L} = 12 \text{ mg/L (12,000 ug/L)}$$

where:

11.9 mg/kg/day = TAD.

10 = uncertainty factor, chosen in accordance with NAS/ODW guidelines for use with a NOAEL from a human study.

10 kg = assumed body weight of a child.

1 L/day = assumed daily water consumption of a child.

Ten-day Health Advisory

Insufficient data using oral exposure to calculate a Ten-day Health Advisory are available currently. The Longer-term HA for the 10 kg child (7800 ug/L) is recommended for a ten-day exposure.

Longer-term Health Advisory

The study by Carpenter et al. (1975) is the most appropriate basis for calculating a Longer-term HA. A group of male rats were exposed by inhalation to mixed xylenes at 770, 2000, or 3500 mg/m^3 for six hours/day on five days/week for up to thirteen weeks. No effects on body weight, hematology, blood chemistry, kidney or liver weight, or tissue histology were observed at 770 or 2000 mg/m^3 exposure levels of xylene. Based on the 2000 mg/m^3 exposure level as a NOAEL, a Longer-term HA may be derived for a 10 kg child as follows:

Step 1: Determination of the Total Absorbed Dose (TAD)

$$\text{TAD} = \frac{(2{,}000 \text{ mg/m}^3)\ (6 \text{ hours/day})\ (1 \text{ m}^3\text{/hour})\ (5/7)\ (0.64)}{(70 \text{ kg})} = 78 \text{ mg/kg/day}$$

where:

2,000 mg/m^3 = NOAEL based on the absence of various toxicological parameters in rats.

6 hr/day = duration of exposure.

1 m^3/hr = assumed respiratory volume for a rat.

5/7 = Conversion of 5 day/week dosing regimen to daily dosing regimen.

0.64 = absorption efficiency in humans.

70 kg = assumed body weight of an adult.

Step 2: Determination of the Longer-term HAs

For a 10 kg child:

$$\text{Longer-term HA} = \frac{(78 \text{ mg/kg/day})\ (10 \text{ kg})}{(100)\ (1 \text{ L/day})} = 7.8 \text{ mg/L } (7{,}800 \text{ ug/L})$$

where:

78 mg/kg/day = TAD.

10 kg = assumed body weight of a child.

100 = uncertainty factor, chosen in accordance with NAS/ODW guidelines for use with a NOAEL from an animal study.

1 L/day = assumed daily water consumption of a child.

For a 70 kg adult:

$$\text{Longer-term HA} = \frac{(78 \text{ mg/kg/day})\ (70 \text{ kg})}{(100)\ (2 \text{ L/day})} = 27.3 \text{ mg/L } (27{,}300 \text{ ug/L})$$

where:

78 mg/kg/day = TAD.

70 kg = assumed body weight of an adult.

100 = uncertainty factor, chosen in accordance with NAS/ODW guidelines for use with a NOAEL from an animal study.

2 L/day = assumed daily water consumption of an adult.

Lifetime Health Advisory

The Lifetime HA represents that portion of an individual's total exposure that is attributed to drinking water and is considered protective of noncarcinogenic adverse health effects over a lifetime exposure. The Lifetime HA is derived in a three step process. Step 1 determines the Reference Dose (RfD), formerly called the Acceptable Daily Intake (ADI). The RfD is an estimate of a daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime, and is derived from the NOAEL (or LOAEL), identified from a chronic (or subchronic) study, divided by an uncertainty factor(s). From the RfD, a Drinking Water Equivalent Level (DWEL) can be determined (Step 2). A DWEL is a medium-specific (i.e., drinking water) lifetime exposure level, assuming 100% exposure from that medium, at which adverse, noncarcinogenic health effects would not be expected to occur. The DWEL is derived from the multiplication of the RfD by the assumed body weight of an adult and divided by the assumed daily water consumption of an adult. The Lifetime HA is determined in Step 3 by factoring in other sources of exposure, the relative source contribution (RSC). The RSC from drinking water is based on actual exposure data or, if data are not available, a value of 20% is assumed for synthetic organic chemicals and a value of 10% is assumed for inorganic chemicals. If the contaminant is classifed as a Group A or B carcinogen, according to the Agency's classification scheme of carcinogenic potential (U.S. EPA, 1986), then caution should be exercised in assessing the risks associated with lifetime exposure to this chemical.

Compound-specific, chronic ingestion data for xylenes do not exist at this time. In the absence of appropriate ingestion studies, the Lifetime Health Advisory for xylenes will be derived from the inhalation studies of Jenkins et al. (1970) instead of the Bowers et al. (1982) study, even though the route and duration of exposure used in the Jenkins study are not ideal for development of a Lifetime HA.

The study by Bowers et al. (1982) was designed primarily to investigate the first hepatocyte changes following long-term exposure to low levels of o-xylene or other methylbenzenes administered to aged male rats, weighing 800 to 900 g, in the diet at 200 mg/kg food for up to six months prior to electron microscopic examination of their livers, but not other tissues. Certain major weaknesses of this study rule out its consideration in the development of a Lifetime HA. These weaknesses are: (1) the use of aged animals weighing 800 to 900 g in the experiment; (2) the stability of o-xylene was not monitored (i.e., any loss due to evaporation not mentioned); (3) the use of a single exposure level; (4) the lack of histological examination of tissues other than liver of animals on test diet; and (5) ultrastructural changes in the hepatocytes of rats ingesting o-xylene was not stated specifically for o-xylene.

The inhalation study by Jenkins et al. (1970) was selected as the basis for the Lifetime HA. In sthis study, o-xylene was administered by inhalation to rats, guinea pigs, monkeys and dogs for 30 repeated exposures at 3,358 mg/m^3, eight hours/day, five days/week or 90 days continuous exposure at 337 mg/m^3. At 3,358 mg/m^3, two rats died on the third day of exposure and another rat and one monkey died on day seven; one of the dogs exhibited tremors of varying severity throughout the exposure. Besides the above mentioned observations, no significant effects were observed with respect to body weight, hematology, and histopathological examination at either dose.

Using 337 mg/m^3 as a NOAEL, the Lifetime HA for a 70 kg adult is calculated as follows:

Step 1: Determination of the Total Absorbed Dose (TAD):

$$TAD = \frac{(337\ mg/m^3)\ (20\ m^3/day)\ (0.64)}{70\ kg} = 61.62\ mg/kg/day$$

where:

337 mg/m^3 = NOAEL based on the absence of toxicological effects in rats.

20 m^3/day = assumed respiratory volume per day of a rat.

0.64 = assumed absorption factor for xylenes (64%).

70 kg = assumed body weight of an adult.

Step 2: Determination of the Reference Dose (RfD)

$$RfD = \frac{61.62\ mg/kg/day}{(1,000)} = 0.06162\ mg/kg/day$$

where:

61.62 mg/kg/day = TAD.

1,000 - uncertainty factor, chosen in accordance with NAS/ODW guidelines for use with a NOAEL from an animal study of less-than-lifetime duration.

Step 3: Determination of the Drinking Water Equivalent Level (DWEL)

$$DWEL = \frac{(0.06162\ mg/kg/day)\ (70\ kg)}{(2\ L/day)} = 2.16\ mg/L\ (2,200\ ug/L)$$

where:

0.06162 mg/kg/day = RfD.

70 kg = assumed body weight of an adult.

2 L/day = assumed daily water consumption of an adult.

Step 4: Determination of Lifetime HA:

Lifetime HA = 2 mg/L x 0.20 = 0.4 mg/L (400 ug/L)

where:

2 mg/L = DWEL.

0.20 = assumed relative source contribution of water.

It should be noted that an estimated concentration for detection by taste and odor in surface water was 0.3 to 1.0 mg/L (National Inst. for Water Supply, 1977) and that the HA may exceed these thresholds for some individuals.

Evaluation of Carcinogenic Potential

- The carcinogenic potential of xylene will be assessed when the report of the NTP animal bioassay for carcinogenicity (1986) is available for review.
- IARC has not evaluated the xylenes for their carcinogenic potential.
- Applying the criteria proposed in EPA's guidelines for assessment of carcinogenic risk (U.S. EPA, 1986), the xylenes may be classified in Group D: Not classified. This category is for agents with inadequate animal evidence of carcinogenicity.

VI. OTHER CRITERIA, GUIDANCE AND STANDARDS

- NAS (1980) calculated SNARLs (Suggested-no-adverse-response-levels) for xylenes in drinking water. The NAS-SNARL value was 21 mg/L xylene for a 1-day exposure and 11.2 mg/L for a 7-day exposure (for a 70 kg adult).
- U.S. EPA (1981) also provided draft HAs for a 1-day, 10-day, and longer-term exposure to xylenes in drinking water. These HAs for a 10 kg child were 12.0 mg/L, 1.2 mg/L, and 0.62 mg/L of xylene, respectively.
- ACGIH (1981) has recommended a TWA of 100 ppm.

VII. ANALYTICAL METHODS

- Analysis of xylene(s) is by a purge-and-trap gas chromatographic procedure used for the determination of volatile aromatic and unsaturated organic compounds in water (U.S. EPA, 1985b). This method calls for the bubbling of an inert gas through the sample and trapping benzene on an adsorbent material. The adsorbant material is heated to drive off xylene(s) onto a gas chromatographic column. The gas chromatograph is temperature programmed to separate the method analytes which are then detected by the photoionization detector. This method is applicable to the measurement of xylene(s) over a concentration range of 0.02 to 1500 ug/L. Confirmatory analysis for xylene(s) is by mass spectrometry (U.S. EPA, 1985c). The detection limit for confirmation by mass spectrometry is 0.2 ug/L.

VIII. TREATMENT TECHNOLOGIES

- Treatment technologies which will remove xylene from water include granulated activated carbon (GAC) and aeration. Limited data suggest that conventional treatment may be partially effective in xylene removal.

- Dobbs and Cohen (1980) developed adsorption isotherms for several organic compounds including p-xylene. It was reported that Filtrasorb® 300 carbon exhibited adsorptive capacities of 130 mg, 85 mg, 54 mg and 35 mg p-xylene/g carbon when the initial xylene concentrations were 10, 1.0, 0.1 and 0.01 mg/L, respectively. These values along with Freundlich constants of K = 85 and 1/n = 0.19 indicate that p-xylene and its closely related isomers, o-xylene and m-xylene, should be amenable to carbon adsorption. Powdered activated carbon (PAC) added at the well field to xylene-contaminated water containing 0.03 to 0.5 ug/L removed 60 to >99% of the xylene (U.S. EPA, 1985d). The higher the xylene load the less efficient the adsorption. GAC was slightly less effective when used on water containing 0.05 ug/L in xylene. In 16 samples tested the average removal efficiency was 50% (McCarty et al., 1979a). When the m-xylene (0.046 ug/L) and p-xylene (0.012 ug/L) were measured separately only 20% and 17% removals were experienced using adsorption on GAC. Each of these studies, however, were conducted on wastewater containing a number of organic contaminants and therefore are not completely representative of what might be expected with potable water treatment.

- Xylene is amenable to aeration on the basis of its Henry's Law Constant of 255 atoms at 20°C (U.S. EPA, 1985d). Although only 19% of the xylene in wastewater could be removed by aeration, the process was much more successful in the treatment of potable well water contaminated by a gasoline spill (McCarty et al., 1979b). At air-to-water ratios of 17 to 1 or greater, 80 to 100% removal of all three xylene isomers was accomplished. At low air to water ratios (8:1), poor removal performance was experienced. Average influent concentrations for the o, m and p isomers were 10, 2.9 and 6.9 ug/L, respectively.

- Air stripping is an effective, simple and relatively inexpensive process for removing xylene and other organics from water. However, use of this process then transfers the contaminant directly to the air stream. When considering use of air stripping as a treatment process, it is suggested that careful consideration be given to the overall environmental occurrence, fate, route of exposure, and various hazards associated with the chemical.

IX. REFERENCES

ACGIH. 1981. American Conference of Governmental Industrial Hygienists. TLVs - Threshold limit values for chemical substances in workroom air adopted by ACGIH for 1981. Cincinnati, OH.

Astrand, I., J. Engstrom and P. Ovrum. 1978. Exposure to xylene and ethylbenzene. I. Uptake, distribution and elimination in man. Scand. J. Work Environ. Health. 4(3):185-194.

Bergman, K. 1978. Application of whole-body autoradiography to distribution studies of organic solvents. Int. Symp. Control Air Pollut. Work Environ. (Part 2):128-139.

Bowers, D.E., Jr., M.S. Cannon and D.H. Jones. 1982. Ultrastructural changes in livers of young and aging rats exposed to methylated benzenes. Am. J. Vet. Res. 43(4):679-683.

Carlson, A. 1981. Distribution and elimination of carbon C^{14}-labeled xylene in rats. Scand. J. Work Environ. Health. 7:51-55.

Carpenter, C.P., E.R. Kinkead, D.L. Geary, Jr., L.J. Sullivan and J.M. King. 1975. Petroleum hydrocarbon toxicity studies: V. Animal and human response to vapors of mixed xylenes. Toxicol. Appl. Pharmacol. 33:543-558.

Dobbs, R.A., and J.M. Cohen. 1980. Carbon adsorption isotherms for toxic organics. EPA 600/8-80-023. MERL, EPA. Cincinnati, Ohio.

Gamberale, F., G. Annwall and M. Hultegren. 1978. Exposure to xylene and ethylbenzene. III. Effects on central nervous functions. Scand. J. Work Environ. Health. 4:204-211.

Harper, C., R.T. Drew and J.R. Fouts. 1975. Benzene and p-xylene: A comparison of inhalation toxicities and in vitro hydroxylations. In: D.J. Jollow, J.J. Kocsis, R. Snyder and H. Vainio, eds. Biologically reactive intermediates. London, England: Plenum Press. pp. 302-311.

Hudak, A., and G. Ungvary. 1978. Embryotoxic effects of benzene and its methyl derivatives: toluene, xylene. Toxicology. 11:55-63.

Jenkins, L.J., R.A. Jones and J. Siegel. 1970. Long-term inhalation screening studies of benzene, toluene, o-xylene and cumene on experimental animals. Toxicol. Appl. Pharmacol. 16:818-823.

Leo, A., C. Hansch and D. Elkins. 1971. Partition coefficients and their uses. Chem. Rev. 71:583.

Litton Bionetics, Inc. 1978. Mutagenicity evaluation of xylene: Final report. LBI Project No. 20847. Submitted to American Petroleum Institute, Washington, D.C. 150 pp.

McCarty, P.L., D. Argo and M. Reinhard. 1979a. Operational experiences with activated carbon adsorbers at Water Factory 21. J. AWWA. 11:683-689.

McCarty, P.L., K.H. Sutherland, J. Graydon and M. Reinhard. 1979b. Volatile organic contaminants removal by air stripping. Presented at the Seminar on Controlling Organics in Drinking Water, American Water Works Annual Conference, San Francisco, CA.

Middleton, F.M., A.A. Rosen and R.H. Burttschell. 1958. Taste and odor research tools for water utilities. J. Am. Water Works Assoc. 50:21-28.

NAS. 1980. National Academy of Sciences. Drinking Water and Health, Volume 3. National Academy Press. Washington, D.C. p. 181.

National Institute for Water Supply. 1977. Compilation of odor threshold values in air and water.

NIOSH. 1978. Registry of toxic effects of chemical substances. U.S. Department of Health, Education and Welfare. Publication No. 79-100, p. 1303.

NTP. 1986. National Toxicology Program. National Toxicology Program/Toxicology Testing Program. Chemicals on Standard Protocol. Management Status Report. Nov. 1986.

Savolainen, K., V. Riihimaki, A.M. Seppalainen and M. Linnoila. 1980. Effects of short-term m-xylene exposure and physical exercise on the central nervous system. Int. Arch. Occup. Environ. Hlth. 45:105-121.

Sedivec, V., and J. Flek. 1976. The adsorption, metabolism and excretion of xylenes in man. Int. Arch. Occup. Environ. Hlth. 37:205-217.

Tatrai, E., G. Ungvary and I.R. Cseh. 1981. The effect of long-term inhalation of o-xylene on the liver. Ind. Environ. Xenobiotics. Proc. Int. Conf.. pp. 293-300.

U.S. EPA. 1979. U.S. Environmental Protection Agency. Water Related Environmental Fate of 129 Priority Pollutants, Office of Water Planning and Standards, EPA-440/4-79-029, December, Washington, D.C.

U.S. EPA. 1980a. U.S. Environmental Protection Agency. Ambient water quality criterion for xylenes. Office of Water Planning and Standards, Washington, D.C.

U.S. EPA. 1980b. U.S. Environmental Protection Agency. The analysis of aromatic chemical indicators of industrial contamination in water by purge and trap method. Cincinnati, Ohio: U.S. EPA Organic Analyses Section, Environmental Monitoring and Support Laboratory.

U.S. EPA. 1981. U.S. Environmental Protection Agency. Advisory opinion for xylenes (dimethylbenzenes). Office of Drinking Water.

U.S. EPA. 1983. U.S. Environmental Protection Agency. Xylene occurrence in drinking water, food, and air. Office of Drinking Water.

U.S. EPA. 1984a. U.S. Environmental Protection Agency. Intermedia priority pollutants guidance documents. Office of Toxic Substances.

U.S. EPA. 1985a. U.S. Environmental Protection Agency. Draft health effects criteria document. Office of Drinking Water.

U.S. EPA. 1985b. U.S. Environmental Protection Agency. *Method* 503.1. Volatile Aromatic and Unsaturated Organic Compounds in Water by Purge and Trap Gas Chromatography. Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, June 1985.

U.S. EPA. 1985c. U.S. Environmental Protection Agency. Method 524.1. Volatile Organic Compounds in Water by Purge and Trap Gas Chromatography/ Mass Spectrometry. Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268, June 1985.

U.S. EPA. 1985d. U.S. Environmental Protection Agency. Technologies and costs for the removal of synthetic organic chemicals from potable water supplies. Science and Technology Branch, CSD, ODW, Washington, D.C.

U.S. EPA. 1986. U.S. Environmental Protection Agency. Final guidelines for carcinogenic risk assessment. Federal Register. 51(185):33992-34003. September 24.

U.S. ITC. 1984. U.S. International Trade Commission. Synthetic organic chemicals United States production, 1983. USITC Publication 1422. Washington, D.C. 20436.

Verschueren, K. 1983. Handbook of environmental data on organic chemicals. New York: Van Nostrand Reinhold Company. pp. 638-642.