Canadian Environmental Protection Act

Priority Substances List
Assessment Report

Xylenes

Government of Canada
Environment Canada
Health Canada

Aussi disponible en français sous le titre de :
Loi canadienne sur la protection de l'environnement
Liste des substances d'intérêt prioritaire
Rapport d'évaluation : Xylènes

CANADIAN CATALOGUING IN PUBLICATION DATA

Main entry under title:

Xylenes
(Priority substances list assessment report)
Issued also in French under title: Xylènes.
At head of title: *Canadian Environmental Protection Act.*
Includes bibliographical references.
ISBN 0-662-21040-9
Cat. No. En40-215/22E

1. Xylenes — Environmental aspects.
2. Environmental monitoring — Canada.
I. Canada. Environment Canada.
II. Canada. Health Canada.
III. Series

TD887.X94 1993 363.73‘84 C93-099689-5

Canada Communication Group — Publishing
Ottawa, Canada K1A 0S9
Cat. No. En40-215/22E
ISBN 0-662-21040-9

Printed on recycled paper

Table of Contents

List of Tables

Synopsis

In Canada, xylenes are produced from the catalytic reforming of petroleum and as by-products of the cracking of crude and heavy oil. Each year, an estimated 2 600 kilotonnes is consumed in Canada as a component of gasoline and 145 kilotonnes of purified xylenes for other uses, including as solvents and as chemical feedstock. Xylenes are released into the air principally from their use as solvents and from transportation sources, and into soil and water through spills and leakage of petroleum and other chemical products. These releases have resulted in the presence of measurable concentrations of xylenes in air, water, and soil in Canada although xylenes do not persist in any of these media.

Although most xylenes are released into the air, concentrations to which wildlife are exposed are at least 1 000 times less than the effects threshold estimated for inhalation of xylenes by mammals. Concentrations in ambient air are at least 1 million times less than the effects threshold recorded for plants. Concentrations of xylenes in surface water are at least 100 times less than the effects threshold estimated for the most sensitive aquatic species.

Xylenes are not expected to be associated with global warming or with the depletion of stratospheric ozone because they do not persist in the atmosphere, and because of their limited absorption of infrared radiation and their non-halogenated nature.

Based on data on concentrations of xylenes in ambient air, indoor air, drinking water, and at self-serve gasoline stations, the total average daily intake of xylenes has been estimated for various age groups in the general population. Although data on concentrations of xylenes in foodstuffs were inadequate, it is likely that intake from this source is negligible compared to that which is inhaled. The estimated total average daily intake of xylenes is less (by 15 to 45 times) than the tolerable daily intake derived on the basis of studies in laboratory species. The tolerable daily intake is the intake which it is believed that a person can be exposed to daily, over a lifetime, without harmful effect.

Based on these considerations, it has been concluded that xylenes are not entering the environment in quantities or under conditions that may be harmful to the environment, or that may constitute a danger to the environment on which human life depends, or to human life or health.

1.0 Introduction

The *Canadian Environmental Protection Act* (CEPA) requires the Minister of the Environment and the Minister of Health to prepare and publish a Priority Substances List that identifies substances, including chemicals, groups of chemicals, effluents, and wastes, that may be harmful to the environment or constitute a danger to human health. The Act also requires both Ministers to assess these substances and determine whether they are "toxic" as defined in section 11 of the Act which states:

> ". . .a substance is toxic if it is entering or may enter the environment in a quantity or concentration or under conditions
>
> > (*a*) having or that may have an immediate or long-term harmful effect on the environment;
> >
> > (*b*) constituting or that may constitute a danger to the environment on which human life depends; or
> >
> > (*c*) constituting or that may constitute a danger in Canada to human life or health."

Substances that are assessed as "toxic" according to section 11 may be placed on Schedule I of the Act, and considered for possible development of regulations, guidelines, or codes of practice to control any aspect of their life-cycle, from the research and development stage through manufacture, use, storage, transport, and disposal.

The assessment of whether xylenes are "toxic", as defined in CEPA, was based on the determination of whether they **enter** or are likely to enter the Canadian environment in a concentration or quantities or under conditions that could lead to **exposure** of humans or other biota at levels that could cause adverse **effects**.

For the assessment of data other than those considered to be critical for the determination of whether xylenes are "toxic" under the Act, evaluations such as those of the U.S. Environmental Protection Agency (U.S. EPA, 1985), the U.S. Agency for Toxic Substances and Disease Registry (ATSDR, 1990), and a background report prepared by M.A. Moss of Dalhousie University (1990) were consulted. The Canadian Petroleum Products Institute provided two reports on exposure to motor gasoline hydrocarbon vapours at service stations (PACE, 1987, 1989). To identify literature not included in previous reviews, the following on-line commercial and government databases were searched: HSDB, ENVIROLINE, EMBASE, MEDLINE,

TOXLINE, TOXLIT, RTECS, Chemical Abstracts, Current Contents, and NTIS (1980 to 1989). Then, a search of CHEMID, RTECS, TOXLINE, and TOXLIT (1989 to June 1991) was conducted to identify data relevant to assessment of effects on human health. BIOSIS and Chemical Abstracts (January 1986 to December 1992) were searched for further data relevant to the environmental assessment. Although much of the research on xylenes has been conducted outside of Canada, where possible, Canadian data on sources, use patterns, fate, and effects of xylenes on the environment were emphasized.

Data relevant to the assessment of whether xylenes are “toxic” to human health, obtained after the completion of the health-related sections of this report (June 1991), were not considered for inclusion. Similarly, data relevant to the assessment of whether xylenes are “toxic” to the environment, obtained after the completion of these sections of the report (December 1992), have not been incorporated.

Although review articles were consulted where considered appropriate, all original studies that form the basis for determining whether xylenes are “toxic” under CEPA have been critically evaluated by the following staff of Health Canada (human exposure and effects on human health) and Environment Canada (entry, environmental exposure, and effects on the environment):

L. Brownlee (Environment Canada)
D. Caldbick (Environment Canada)
P. Chan (Health Canada)
R. Chénier (Environment Canada)
T. Dann (Environment Canada)
G.A. Fox (Environment Canada)
M.E. Meek (Health Canada)
W.M.J. Strachan (Environment Canada)

This report presents a synopsis that will appear in the *Canada Gazette*. Section 2.0 presents an extended summary of the technical information that is critical to the assessment. Section 3.0 presents the assessment of whether xylenes are “toxic”, as defined under CEPA. Supporting Documentation, in which the technical information is presented in greater detail, has also been prepared and is available upon request. The effects of photochemical reaction products of xylenes are not addressed here but are considered in the Federal/Provincial Management Plan for nitrogen oxides (NO_X) and volatile organic compounds (VOCs) [CCME, 1990].

The health-related sections of this report were circulated and underwent external peer review by CanTox Inc. Canada (Supporting Documentation only), and the British Industrial Biological Research Association Toxicology International, Great Britain. The sections were then approved by the Standards and Guidelines Rulings Committee

of the Bureau of Chemical Hazards of Health Canada. As part of the review and approvals process established by Environment Canada for its contribution to these reports, the environmental sections of the Assessment Report and Supporting Documentation were reviewed externally by the following: D.A. Birkholz (Enviro-Test Laboratories, Edmonton), A. Bollo Kamara (Alberta Environment, Edmonton), I. Guay (Ministère de l'Environnement du Québec, Sainte-Foy), R. Lafleur (Canadian Petroleum Products Institute, Ottawa), J.F. Payne (Department of Fisheries and Oceans, St. John's), D. Singleton (National Research Council, Ottawa), and E.J. Williams (Shell Canada Ltd., Calgary). The final Assessment Report was reviewed and approved by the Environment Canada/Health Canada CEPA Management Committee.

Copies of this Assessment Report and the unpublished Supporting Documentation are available upon request from:

Environmental Health Centre
Health Canada
Room 104
Tunney's Pasture
Ottawa, Ontario, Canada
K1A 0L2

Commercial Chemicals
Branch
Environment Canada
14th Floor
Place Vincent Massey
351 Saint-Joseph Boulevard
Hull, Quebec, Canada
K1A 0H3

2.0 Summary of Information Critical to Assessment of "Toxic"

2.1 Identity, Properties, Production and Uses

Xylenes are monocyclic aromatic compounds with two methyl groups attached to the benzene ring [molecular formula $C_6H_4(CH_3)_2$]. There are three isomers of xylenes: *ortho*- or *o*-xylene (1,2-dimethylbenzene), *meta*- or *m*-xylene (1,3-dimethylbenzene), and *para*- or *p*-xylene (1,4-dimethylbenzene). Xylenes are clear, colourless, volatile liquids with a strong, aromatic odour. They have relatively high vapour pressures (1 100 to 1 170 Pa at 25°C), moderate solubilities in water (160 to 220 mg/L at 25°C), and moderately low octanol/water partition coefficients (log K_{ow} of 3.15 to 3.20) [Mackay *et al.*, 1992]. Xylenes do not absorb ultraviolet light of wavelengths greater than 260 nm (NRC, 1980), and only weakly absorb infrared radiation at wavelengths of 7 to 13 μm (Sadtler Research Laboratories, 1982). Gases involved in enhanced global warming strongly absorb radiation of wavelengths of 7 to 13 μm, enabling them to trap and re-radiate a portion of the earth's thermal radiation (Wang *et al.*, 1976; Ramanathan *et al.*, 1985).

Xylenes can be identified and quantified using routine chromatographic techniques. While *o*-xylene is recognized as a distinct product in chemical analyses, the *m*- and *p*- isomers are generally not separated during most routine analyses. Therefore, results of analyses of xylenes in environmental samples are usually presented as the concentration of the *o*- isomer and the total concentration of the combined *m*- and *p*-isomers. In this report, the term xylenes refers to the mixture of all three isomers.

Most xylenes are produced by the catalytic reforming of petroleum and as by-products of the cracking of crude and heavy oil. Minor amounts are produced from coal-derived coke oven light oil (Fishbein, 1985). Commercial xylenes from petroleum sources contain approximately 20% o-xylene, 44% *m*-xylene, 20% *p*-xylene, and 15% ethylbenzene. Xylenes derived from coal-tar contain approximately 10 to 15% *o*-xylene, 45 to 70% *m*-xylene, 28% *p*-xylene, and 6 to 10% ethylbenzene (Low *et al.*, 1989).

In 1990, 514 kilotonnes (kt) of isolated (purified) xylenes were produced in Canada and 5 kt were imported, for a total Canadian supply of 519 kt (Corpus Information Services, 1991). Of these, 186 kt were exported, resulting in a total domestic consumption of 333 kt of isolated xylenes. Xylenes are currently produced at the following locations: four plants in the Sarnia/Corunna area, in Ontario; one plant in Hamilton, Ontario; and one plant in Montréal, Quebec. Canada's production capacity for isolated xylenes is under 790 kt/year. In Canada, the major end-use for isolated xylenes is as an octane enhancer in gasoline; 188 kt were consumed for this use in

1990. A further 58 kt were used as solvents (Corpus Information Services, 1991) in such products as paints, varnishes and other coatings, pesticide formulations, printing inks, dyes, adhesives and sealants, cleaning agents, degreasing agents, paint removers, and for chemical extractions (Levelton and Associates Ltd., 1990). About 87 kt of isolated xylenes were used for other purposes in 1990, predominantly as feedstock for the plastics industry.

In addition, xylenes are a natural minor component of petroleum (Kirk *et al*., 1983). Over 90% of xylenes present in gasoline in Canada occur as a result of cracking and reforming during the normal petroleum refining process. Additional isolated xylenes may be added to gasoline during blending to increase the octane rating. An estimated 34 000 megalitres of gasoline are sold annually in Canada (Oilweek, 1988). Based on an average content of xylenes in gasolines of about 10.5% by weight (Alberta Research Council, 1992), 2 600 kt of xylenes are estimated to be in the gasoline sold annually in Canada, including the approximately 188 kt added during blending. Most of the xylenes in gasoline are burned during normal engine operation.

Therefore, the total consumption of xylenes in Canada in 1990 is estimated to be 2 745 kt. This number is based on an estimated 2 600 kt of xylenes in gasoline and 145 kt of isolated xylenes used for purposes other than gasoline blending.

2.2 Entry into the Environment

Since xylenes are a natural minor component of crude oil and coal distillates (Kirk *et al*., 1983), they may be introduced into the ground through petroleum seepage and weathering of exposed coal-containing strata, and into groundwater from petroliferous rocks (Hunt, 1979). The magnitude of such releases to the environment is unknown (U.S. EPA, 1987). Concentrations of xylenes of 21 μg/L *o*-xylene and 50 μg/L *m*- and *p*-xylenes were measured in eight test wells near Belleville, Ontario. Xylenes were present most likely as a result of natural contamination from bituminous deposits (Slaine and Barker, 1990).

Estimated atmospheric releases of xylenes in Canada are summarized in Table 2.1. Total yearly releases are estimated to be 96 kt: solvents account for an estimated 58% of the total releases, and transportation sources account for an estimated 39% of total releases of which an estimated 32% is released from light-duty automobiles.

Total emissions of xylenes into the atmosphere are expected to decline in the future, mainly because of the planned reduction of emissions of volatile organic compounds (VOCs) from light-duty vehicles, and the efforts to reduce VOC emissions from a variety of other sources for purposes of ground-level ozone control (CCME, 1990). Emissions of xylenes from light-duty vehicles have been reduced since the early 1970s (Lonneman *et al*., 1986; Sigsby *et al*., 1987).

Table 2.1
Estimated Major Atmospheric Releases of Xylenes in Canada

Sources	Estimated Atmospheric Releases (kilotonnes/year)	% of Total Estimated Atmospheric Releases	References
Industrial Processes			
Petroleum Production	1.6	1.7	CCME, 1990; Jaques, 1990; Scheff *et al*., 1989
Xylenes and Other Chemical Production	0.5	0.5	CCME, 1990; Jaques, 1990
(Subtotal)	**(2.1)**	**(2.2)**	
Solvent Sources			
Paints and Coatings	42.0	43.8	Levelton and Associates Ltd., 1990
Inks	1.0	1.0	Levelton and Associates Ltd., 1990
Adhesives	2.0	2.1	Levelton and Associates Ltd., 1990
Pesticides	3.0	3.1	Levelton and Associates Ltd., 1990
Other	8.0	8.3	Levelton and Associates Ltd., 1990
(Subtotal)	(56.0)	(58.3)	
Transportation Sources			
Light-duty Vehicles	30.6	31.8	Sigsby *et al*., 1987; Jaques, 1990
Heavy-duty Vehicles	2.4	2.5	Sigsby *et al*., 1987; Jaques, 1990
Marine/Air/Rail	1.8	1.9	Sigsby *et al*., 1987; Jaques, 1990
Off-road	2.2	2.3	Sigsby *et al*., 1987; Jaques, 1990
Gasoline Marketing and Storage	0.7	0.7	Sigsby *et al*., 1987; Jaques, 1990
(Subtotal)	(37.7)	(39.2)	
Total	95.8	100	

Xylenes enter water from the discharge of industrial and municipal effluents. Data on total environmental loadings from such sources are not available. In Ontario, xylenes were detected in effluents from a variety of industrial and municipal sources. The highest mean concentrations of xylenes in effluents released into surface water were 2.2 μg/L *o*-xylene in storm-water effluent from petroleum refineries (OME, 1990), and 3.3 μg/L *m*- and *p*-xylenes combined in effluents from a coke plant (OME, 1991).

The highest maximum concentrations of xylenes were in raw sewage, with concentrations of 570 μg/L *o*-xylene and 1 700 μg/L *m*- and *p*-xylenes combined at one site (OME, 1988).

Xylenes can enter soil and water through spills of petroleum and other chemical products. Based on the reported number, volume, and recovery rates for spills of xylenes (1980 to 1990), and petroleum products (1988) [NATES, 1992], and the assumption that the mean concentration of xylenes in spilled petroleum products is 10%, approximately 600 tonnes per year could have remained in the environment. Also, xylenes can be released to soil from leaking underground storage tanks that contain gasoline, diesel fuel, or heating oil. About 3% to 20% of the estimated 200 000 storage tanks in Canada have the potential to leak (Barker *et al*., 1989; DOE, 1989). Reliable estimates of the total amounts of xylenes released from storage tanks are not available. Also, xylenes are released into the soil and groundwater at waste disposal sites (Barker, 1987; Lesage *et al*., 1990, 1991; Pakdel *et al*., 1992).

The highest concentrations of xylenes in groundwater in Canada have been recorded near waste disposal sites, including beneath landfill sites (from less than 0.2 μg/L to 123 μg/L of *o*-xylene and 0.2 to 191 μg/L *m*- and *p*-xylenes combined; Barker, 1987), near deep injection wells formerly used for the disposal of liquid industrial waste (from 325 to 374 μg/L xylenes at depths of 61 to 192 metres [Lesage *et al*., 1991]), and near an active industrial chemical waste disposal lagoon (up to 1 700 μg/L *o*-xylene and 3 100 μg/L *m*- and *p*-xylenes combined [Lesage *et al*., 1990]). Such levels vary considerably, and Pakdel *et al*. (1992) reported similar or considerably lower concentrations at other disposal sites.

About 300 registered pest-control products in Canada contain xylenes (Davis, 1991). Since many of these products are applied to crop foliage or directly to the soil, much of the xylenes in these formulations can be expected to reach the soil surface.

2.3 Exposure-related Information

2.3.1 Fate

Because of the relatively high vapour pressures and moderate water solubilities of xylenes, the atmosphere plays an important role in their distribution and fate (Mackay *et al*., 1992). Modelling simulations predict that most xylenes released into the environment should be present in the atmosphere (Mackay *et al*., 1992). Once released into the atmosphere, either directly or by volatilization from other media, xylenes photo-oxidize relatively quickly in a reaction with OH radicals in the presence of nitrogen dioxide to yield tolualdehydes, methyl glyoxal, methylbenzylnitrates, dimethylphenols, and nitroxylenes, which are themselves degraded further (Finlayson-Pitts and Pitts, 1986; Atkinson, 1990). Though there are other reaction

products, they have not been identified individually (Atkinson *et al*., 1991). Various tropospheric lifetimes for xylenes have been calculated to range from 0.5 to 1.5 days (Finlayson-Pitts and Pitts, 1986; Güsten *et al*., 1984; Jori *et al*., 1986).

Xylenes are rapidly lost from surface water by volatilization. The half-life in still water 1 metre deep has been estimated to be 5.6 hours; it would be shorter in turbulent water (Mackay and Leinonen, 1975). Volatilization rates were calculated for lakes (8 days) and rivers (1 to 2 days) [SRI, 1979] and for streams and rivers (36 minutes to 47 days) [U.S. EPA, 1987], with reported variations due to differences in conditions such as depth and flow rates of streams and rivers. No data are available regarding the fate of xylenes under ice in winter.

Volatilization half-lives, ranging from less than 1 minute to 2.2 days, have been estimated for all three xylene isomers on the soil surface (U.S. EPA, 1987; Anderson *et al*., 1991). Volatilization should be much slower for xylenes incorporated into soil, with rates decreasing rapidly with soil depth.

Although xylenes are only moderately soluble in water, they may leach through soils to groundwater. Movement through soils is expected to be slowed by the presence of organic matter (Seip *et al*., 1986), clay (Johnson *et al*., 1989), and high moisture content (Aurelius and Brown, 1987). However, xylenes have been reported to move through clay soils (Green *et al*., 1983; Anderson *et al*., 1985). Based on theoretical considerations and limited data, the xylene isomers are not expected to be hydrolysed, photolyzed or oxidized significantly in soil (U.S. EPA, 1987).

Xylenes are degraded by micro-organisms in soil, groundwater, surface water, and sediments, under both aerobic and anaerobic conditions (Holm *et al*., 1991; Edwards *et al*., 1991; Reinhard *et al*., 1991; Hutchins and Wilson, 1991). Half-lives for biodegradation by unacclimated organisms in water have been estimated to be between 7 and 28 days for each of the three isomers in aerobic systems, and between 180 and 360 days for *o*-xylene and 28 and 112 days for *m*- and *p*-isomers in anaerobic systems (Howard *et al*., 1991). Micro-organisms can degrade xylenes by oxidation of both the aromatic ring and the methyl substituents, yielding products such as dimethylphenols, methylsalicylic acid, toluic acids, and ring fission products of methylcatechols (Gibson and Subramanian, 1984).

Based on their octanol/water partition coefficients, Jori *et al*. (1986) calculated a bioconcentration factor (BCF) of 80 for xylenes in fathead minnows, using the equation of Veith *et al*. (1979). Values less than 100 generally indicate that a compound is unlikely to bioconcentrate significantly in organisms or biomagnify along food chains (U.S. EPA, 1987). Experimental studies indicate that xylenes are absorbed very rapidly by molluscs and fish but are not bioconcentrated to a significant extent. BCFs of 6 to 177 have been observed in molluscs, eels, and trout (Nunes and Benville,

1979; Ferrario *et al*., 1985; Ogata and Miyake, 1978; Walsh *et al*., 1977). In rainbow trout exposed to 0.36 to 1.3 mg/L emulsified xylenes under flow-through conditions for 56 days, the maximum BCFs ranged from 14.0 to 14.7, and there was no increase in the concentrations in the fillets from day 2 to day 56 (Walsh *et al*., 1977).

2.3.2 Concentrations

Mean concentrations of *o*-xylene in ambient air at 17 Canadian urban or suburban sites in nine cities during 1988 and 1989 ranged from 0.7 to 7.6 μg/m^3, with 24-hour maxima of 3.8 to 23.4 μg/m^3. Mean concentrations of *m*- and *p*-xylenes (combined) ranged from 1.8 to 18.3 μg/m^3, with 24-hour maxima of 10.7 to 47.8 μg/m^3. At a rural site at Walpole Island, Ontario, mean concentrations of *o*-xylene and *m*- and *p*-xylenes (combined) were 0.5 and 1.7 μg/m^3, respectively (Dann and Wang, 1990). The highest combined mean concentration for the 3 isomers at any one urban site in 1989 was 25.9 μg/m^3, while the combined mean concentration for the 3 isomers at the rural site was 2.2 μg/m^3.

The highest concentrations in ambient air have been recorded in the immediate vicinity of gasoline stations in five Canadian cities. The overall average concentrations of xylenes at self-serve stations were 221 μg/m^3 in the winter and 85 μg/m^3 in the summer. Mean concentrations of xylenes in samples at the marketing pumps were 716 μg/m^3 in the winter and 970 μg/m^3 in the summer (PACE, 1987, 1989).

The concentrations of xylenes can be higher in indoor air than in ambient air because of the following: the presence of household products, including solvents for cleaning and paint stripping; building materials; and personal activities, such as smoking. In surveys of approximately 400 homes in New Jersey, North Carolina, and North Dakota (Wallace *et al*., 1987a), the population-weighted median concentrations in indoor air ranged from 2.3 to 8.0 μg/m^3 *o*-xylene and 6.2 to 22 μg/m^3 *m*- and *p*-xylenes combined. These values were approximately 2 to 10 times higher than the concentrations in outdoor air. Identified data on concentrations of xylenes in indoor air in Canada are restricted to a limited and possibly unrepresentative number of homes in Toronto, with mean levels ranging from 8.5 to 18.2 μg/m^3 *o*-xylene and 25.1 to 31.1 μg/m^3 *m*- and *p*-xylenes combined (Chan *et al*., 1990), and in Montréal, with maximum concentrations of 34.0 μg/m^3 *o*-xylene and 74.6 μg/m^3 *m*- and *p*-xylenes combined (Otson and Benoit, 1985).

Concentrations of xylenes were not quantifiable in 824 water samples taken from surface water, groundwater wells, and treated drinking water in six Canadian provinces from 1985 to 1988 (detection limit of 0.5 μg/L for *o*-xylene and for *m*- and *p*-xylenes combined) [NAQUADAT, 1991]. In a survey of samples of raw water for drinking water supplies in the Great Lakes taken between 1982 and 1983, Otson (1987) reported that the concentration of each xylene isomer was generally below the

detection limit of 0.1 μg/L. The mean concentrations of xylenes in Canadian drinking water supplies, at 30 water treatment plants sampled across Canada in 1979, were less than 1 μg/L (the detection limit of the analytical method) [Otson *et al*., 1982]. In more recent surveys of water supply systems conducted in Ontario in 1987 and in the Atlantic provinces between 1985 and 1987, concentrations of xylenes were generally less than the detection limit of 0.5 μg/L (OME, 1987; DOE, 1989a, 1989b, 1989c, 1989d).

Data on concentrations of xylenes in soils and sediments in Canada have not been identified. In view of the sources and fate of xylenes in the environment, measurable concentrations of xylenes in soil would be expected to occur only near point sources such as spills, leaks, and waste disposal sites, or in areas with natural contamination from bituminous deposits (Section 2.2).

There are few identified quantitative data on concentrations of xylenes in food. Trace concentrations of *o*-xylene have been reported in split peas (0.008 μg/g), lentils (0.003 μg/g), and beans (average concentration: 0.009 μg/g; maximum concentration: 0.025 μg/g) in the United States by Lovegren *et al*. (1979).

Available data on levels of xylenes in human tissues or fluids are limited. Pellizzari *et al.* (1982) reported concentrations of xylenes in mothers' milk, in populations living near chemical manufacturing plants and/or industrial facilities that use xylenes in the United States. Xylenes were detected but not quantified in 8 of a total of 12 samples collected. The detection limit for these analyses was not specified by the authors.

2.4 Effects-related Information

2.4.1 Experimental Animals and In Vitro

The acute toxicity of xylenes is relatively low. For inhalation, reported 4-hour LC_{50}s in rats ranged from 6 350 ppm (27 622 mg/m^3) to 6 700 ppm (29 145 mg/m^3). In mice, the 6-hour LC_{50} values for the individual isomers ranged from 3 907 to 5 267 ppm (16 995 to 22 911 mg/m^3). The oral LD_{50}s for xylenes (60% *m*-, 14% *p*-, 9% *o*-xylene, and 17% ethylbenzene), administered by gavage in corn oil, were 3.5 g/kg bw in rats and 5.6 and 5.3 g/kg bw, respectively, in male and female mice (NTP, 1986). The organs most notably affected following acute exposure are the lungs, liver, and nervous system.

Repeated short-term exposure to moderate to high concentrations of xylenes causes cardiovascular, hepatic, and neurological effects. The reported lowest-observed-adverse-effect-level (LOAEL) of xylenes (composition unspecified), for effects other than neurological in short-term inhalation studies, was 230 ppm (1 000 mg/m^3), which resulted in coronary changes in rats (Morvai *et al*., 1987). The lowest

no-observed-adverse-effect-level (NOAEL) in short-term studies, in which the individual xylene isomers was administered orally to rats, was 250 mg/kg bw/day (for each of the three individual isomers). This level is based predominantly on decreases in body weight and increases in liver weight observed at higher doses (Condie *et al*., 1988).

In the limited number of sub-chronic inhalation studies available, the lowest concentration at which effects were observed was 320 ppm (1 400 mg/m^3). This was in small groups (n = 6 to 8) of rats continuously exposed to xylenes (composition unspecified) for 90 days. At this concentration, an increase in the liver to body weight ratio was observed following 30 days exposure, but not after inhalation for 90 days (Kyrklund *et al*., 1987). In another study, there were no effects on body weight increase, and liver and kidney weight (examined in dogs only), haematological parameters, blood chemistry, or upon histopathological examination in rats or beagle dogs exposed to 770, 2 000 or 3 500 mg/m^3 xylenes (7.84% *p*-, 65.01% *m*- and 7.63% *o*-xylenes, 19.7% ethylbenzene and 0.14% toluene), 6 hours/day, 5 days/week for 13 weeks (Carpenter *et al*., 1975). The lowest reported no-observed-effect-level (NOEL) in sub-chronic studies in which xylenes (17.6% *o*-, 62.3% *m*- and *p*-xylenes, and 20% ethylbenzene) were administered orally was 150 mg/kg bw/day, based predominantly on effects on the liver and kidney of rats observed at the next highest dose (750 mg/kg bw/day) [Condie *et al*., 1988]. The lowest NOEL in a sub-chronic study in two species (gavage in corn oil) conducted by the National Toxicology Program was 500 mg/kg bw/day xylenes (60% *m*-, 14% *p*-, 9% *o*-xylene, and 17% ethylbenzene), based on decreases in growth in rats observed at the next highest dose (1 000 mg/kg bw/day) [NTP, 1986]. The NOAEL in a sub-chronic study in which *m*-xylene was administered orally to rats was 200 mg/kg bw/day; this was the NOEL in a similar study for *p*-xylene (Hazleton Labs, 1988a, 1988b).

The most extensive bioassay of the chronic toxicity and carcinogenicity of xylenes (60% *m*-, 14% *p*-, 9% *o*-xylene, and 17% ethylbenzene) is a study conducted on rats and mice (gavage in corn oil) by the National Toxicology Program (NTP, 1986). In this study, decreased survival (though some deaths were gavage-related) and lower body weights (5 to 8%, considered to be indicative of slight toxicity) were observed in male rats at the highest dose (LOEL = 500 mg/kg bw/day; NOEL = 250 mg/kg bw/day). Male and female mice in the high dose group (1 000 mg/kg bw/day) were hyperactive for 5 to 30 minutes after dosing; there were no other compound-related non-neoplastic effects (NOAEL in mice = 1 000 mg/kg/day). Based on the lack of compound-related neoplastic lesions observed in these 2-year bioassays, it was concluded that there was no evidence of carcinogenicity of xylenes for male or female F344/N rats or B6C3F$_1$ mice.

Maltoni *et al*. (1985) reported an increase in the total number of Sprague-Dawley rats with malignant tumours at 141 weeks following administration of xylenes (composition unspecified) by gavage in olive oil for 104 weeks. However, because of limitations of the design and documentation of this study, these results are considered suspect.

Xylenes have not induced mutations or increased the frequency of sister chromatid exchange in various short-term *in vitro* bioassays, nor caused chromosomal aberrations *in vivo* or *in vitro* in mammalian or human cell cultures, with the exception of two limited studies as summarized in ATSDR (1990). In one study (Donner *et al*., 1980), weak mutagenic activity was observed in *Drosophila* exposed to technical grade xylenes containing 18.3% ethylbenzene. In the other study, Myhr *et al*. (1990) reported positive results in a mouse lymphoma L5178Y cell mutation assay in which cells were exposed to xylenes (composition unspecified). These positive results contrast the negative results obtained in a similar investigation conducted by Lebowitz *et al*. (1979).

In inhalation studies conducted to date, xylenes have not been teratogenic, but they have induced feto-toxic effects, sometimes at doses below those which were toxic to the mothers. With the exception of unconfirmed results reported by Mirkova *et al*. (1983), the lowest concentration of xylenes reported to induce feto-toxic effects in the absence of maternal toxicity in available investigations was 500 mg/m^3. At this concentration, in a study that was documented incompletely, moderate embryotoxic effects were observed. Researchers noted retardation of skeletal development and of body weight increase in the offspring of rabbits exposed on days 7 to 20 of gestation to xylenes, the composition of which was unspecified (Ungvary and Tatrai, 1985). In rats, maternal toxicity and feto-toxicity were observed following exposure to 250 mg/m^3 on days 7 to 15 of pregnancy (Ungvary and Tatrai, 1985). In the study by Mirkova *et al*. (1983), decreased fetal weight, abnormal ossification of the sternum, and impaired formation of the skull were reported when rats were exposed to 50 and 500 mg/m^3 on days 1 to 21 of gestation. However, the composition of the mixture administered was not specified, the health of the test animals may have been compromised, and the presence or absence of maternal toxicity was not addressed. In a single identified study in which xylenes (9.1%, 60.2% and 13.6% *o*-, *m*- and *p*-xylenes, respectively, and 17% ethylbenzene) were administered orally by gavage in cottonseed oil to CD-1 mice, feto-toxic effects and malformations were observed, but only at high doses (2 060 mg/kg bw per day) which were toxic to the mothers (Marks *et al*., 1982).

The lowest concentration of the individual xylene isomers reported to induce embryo- and feto-toxic effects in the absence of maternal toxicity following inhalation in a limited number of available studies is 150 mg/m^3. At this concentration, increased

implantational loss and decreased placental weight and retardation in skeletal development of offspring were observed, following continuous exposure of pregnant rats to *p*-xylene on days 7 to 14 of gestation (Ungvary *et al*., 1980).

In the only identified study of reproductive toxicity (Bio/Dynamics, 1983), there were no treatment-related effects on the following: mating, fertility or pregnancy indices; gestation length; parturition data; litter size; or pup survival. This was a one-generation study in rats exposed to concentrations of up to 2 100 mg/m^3 xylenes (20.42% *o*-, 44.2% *m*-, 20.3 % *p*-xylenes, 12.8% ethylbenzene and 2.4% toluene), 6 hours/day for 131 days before mating, and during a 20-day mating period (both sexes), and on days 1 to 20 of gestation and days 5 to 20 of lactation (females). There were some feto-toxic effects at the highest concentration in this study (LOAEL = 2 100 mg/m^3, NOAEL = 1 050 mg/m^3).

Identified investigations of the neurotoxicity of xylenes in laboratory animals are principally restricted to those in which only biochemical effects in the brain, clinical signs, or behavioural effects were examined. These results often followed exposure to one concentration of xylenes only, the composition of which was often unspecified, or, in a few cases, to the individual isomers. The lowest concentration at which neurobehavioural effects of xylenes were reported, following inhalation, was 113 ppm (492 mg/m^3, composition unspecified) for 2 hours, for which Ghosh *et al*. (1987) observed decreases in the reinforcement rate to which tolerance developed in rats. Biochemical effects on the brain, the significance of which is unclear, have been observed at concentrations as low as 50 ppm (218 mg/m^3) *m*-xylene, administered for 2 weeks to rats (Savolainen and Pfaffli, 1980).

2.4.2 Humans

The effects of xylenes on humans have been examined in laboratory studies with volunteers and in epidemiological studies of occupationally-exposed populations. There have also been several case reports of neurological effects following exposure to xylenes. In many of the reported epidemiological studies (Angerer and Wulf, 1985; Askergren, 1982; Franchini *et al*., 1983; Haglund *et al*., 1980; Kilburn *et al*., 1985; Mikulski *et al*., 1972; Seppalainen *et al*., 1978), workers were exposed to thinners and solvents that also contained high percentages of benzene or toluene and other aromatic or non-aromatic compounds. Therefore, it is not possible in most cases to attribute the observed effects to xylenes alone.

Transient, mildly adverse effects, such as impairment of body balance, reaction-time performance and equilibrium, have been observed in human volunteers by one group of investigators, following volunteer exposure to xylene concentrations of 100 ppm (435 mg/m^3) or greater (Riihimaki and Savolainen, 1980; Savolainen *et al*., 1980,

1982, 1984, 1985). However, in other studies by the same and different investigators, such effects were not observed at higher concentrations (Savolainen, 1980; Seppalainen *et al*., 1989).

2.4.3 Ecotoxicology

Information on the acute and chronic toxicity of xylenes was identified for aquatic species from a number of trophic levels and taxa, including algae to fish and amphibians. Data on toxicity to terrestrial and avian species are limited to bacteria and plants. Only the more sensitive responses are noted in this report.

Growth of the alga *Selenastrum capricornutum* was reduced by 50% after 72 hours of exposure to 3.2 to 4.9 mg/L of each of the three xylene isomers (Galassi *et al*., 1988). Exposure for 30 minutes to 300 mg/L resulted in a 65 to 100% kill of the freshwater macrophytes *Elodea* and *Potamogeton* (Frank *et al*., 1961).

The most sensitive freshwater organism was the water flea (*Daphnia magna)* with 24-hour LC_{50}s of 1.0 mg/L for *o*-xylene, 3.6 mg/L for *p*-xylene, and 4.7 mg/L for *m*-xylene (Galassi *et al*., 1988). Among marine organisms, the most sensitive species was the bay shrimp (*Crago franciscorum)* with 96-hour LC_{50}s of 1.1 mg/L for *o*-xylene, 1.7 mg/L for *p*-xylene, and 3.2 mg/L for *m*-xylene (Benville and Korn, 1977).

The most sensitive freshwater fish was the rainbow trout (*Oncorhynchus mykiss*), with 96-hour LC_{50}s of 2.6, 7.6, and 8.4 mg/L for the *p*-, *o*-, and *m*- isomers, respectively (Galassi *et al*., 1988). The most sensitive marine species tested was the young of the striped bass (*Morone saxatilis)*, with 96-hour LC_{50}s of 1.7, 8.0, and 9.7 mg/L for the *p*-, *m*-, and *o*- isomers, respectively (Benville and Korn, 1977).

Among terrestrial plants, exposure of barley to 20 g/m^3 of xylenes vapour for 4 hours resulted in 80% injury of leaves within 24 hours, with leaves recovering to 10% injury 4 weeks after exposure (Currier, 1951; Currier and Peoples, 1954).

The 8-day EC_{50} for growth of *Selenastrum capricornutum* ranged from 3.9 to 4.4 mg/L for each of the three xylene isomers (Herman *et al*., 1990). Black *et al*. (1982) determined the toxicity of *m*-xylene to the early life stages of the leopard frog (*Rana pipiens*) and rainbow trout. Eggs of each species were exposed continuously to *m*-xylene from within 30 minutes of fertilization (embryos) to 4 days post-hatch (larvae), resulting in total continuous exposures of 9 days for the frog, and 27 days for the trout. The LC_{50}s for continuous exposure were 3.53 mg/L for the frog and 3.77 mg/L for the trout.

3.0 Assessment of "Toxic" under CEPA

3.1 CEPA 11(*a*): Environment

Xylenes enter the Canadian environment primarily through atmospheric releases, as a result of their use as solvents and their release from transportation sources. Xylenes are released into the soil and groundwater in spills and in leachate from contaminated waste disposal sites, and to surface water through spills and discharge of contaminated effluents. Xylenes do not persist in water or soil because of their high volatility and their biodegradation, nor do they persist in the atmosphere because of their rapid photo-oxidation. Accumulation of xylenes is not expected to be significant in terrestrial or aquatic organisms, and there are no reports indicating significant bioconcentration in organisms or biomagnification in the food chain.

Since xylenes are found primarily in the air, terrestrial wildlife, particularly herbivores that eat plants exposed to atmospheric xylenes, may be among the organisms with the highest overall exposure. Only direct exposure of wildlife to air can be evaluated, since no data are available to estimate concentrations of xylenes in terrestrial plants resulting from atmospheric deposition and plant uptake. Walpole Island is a rural site on the St. Clair River, located in an industrialized region of southern Ontario. Therefore, the site could potentially represent the highest concentration of xylenes in a rural setting. The mean concentration for *o*-, *m*-, and *p*-xylenes combined was 2.2 $\mu g/m^3$ at Walpole Island in 1989. The highest combined mean concentration for the three isomers at any one urban site in 1989 was 25.9 $\mu g/m^3$. Dose-dependent maternal toxicity and fetal-skeletal retardation were recorded in rats exposed by inhalation to xylenes (LOEL = 250 mg/m^3) [Ungvary and Tatrai, 1985]. Using a factor of 100 to account for differences between species, and to convert a LOAEL to a NOAEL, yields an estimated effects threshold of 2.5 mg/m^3. The mean concentration at Walpole Island was at least 1 000 times less than this estimated effects threshold. Therefore, terrestrial mammalian wildlife should not be at risk from direct exposure to xylenes in rural air.

There are insufficient data available to assess wildlife exposure in the aquatic environment or potential effects of xylenes on birds in terrestrial or aquatic environments. However, in view of the environmental fate and concentrations of xylenes, and the considerations outlined above for mammalian wildlife, xylenes are unlikely to affect birds or aquatic mammals.

Concentrations in ambient air are at least 1 million times less than the lowest effect threshold recorded for terrestrial plants (20 g/m^3 for barley).

Based on available data, the aquatic organism most sensitive to the effects of xylenes is the water flea (*Daphnia magna*), with 24-hour LC_{50}s of 1.0 mg/L for *o*-xylene, 3.6 mg/L for *p*-xylene, and 4.7 mg/L for *m*-xylene. Dividing these values by 20 to convert the acute thresholds to chronic NOECs for non-persistent, non-bioaccumulative substances, and to account for differences in species sensitivity and extrapolation from laboratory to field effects, yields estimated effects thresholds for long-term exposure of 50 μg/L for *o*-xylene, 180 μg/L for *p*-xylene, and 235 μg/L for *m*-xylene. Concentrations of xylenes in ambient surface water have been reported to be below the detection limits (as high as 0.5 μg/L for *o*-xylene and for *m*- and *p*-xylenes combined). Therefore ambient concentrations are at least 100 times less than the estimated effects threshold for *o*-xylene, and at least 360 to 470 times less than the estimated effects thresholds for *m*- and *p*-xylenes.

Therefore, on the basis of available data, it has been concluded that xylenes are not entering the environment in quantities or under conditions that may be harmful to the environment.

3.2 CEPA 11(*b*): Environment on which Human Life Depends

Xylenes will not contribute directly to global warming because of the following: their short residence time in the troposphere, their low atmospheric concentrations relative to known greenhouse gases (Jaques, 1992), and their low absorption of radiation within the critical wavelengths between 7 and 13 μm. Unlike substances associated with depletion of stratospheric ozone (Firor, 1990), xylenes do not persist in the atmosphere and are not halogenated. Therefore, they are not expected to contribute to stratospheric ozone depletion.

Therefore, on the basis of available data, it has been concluded that xylenes are not entering the environment in quantities or under conditions that may constitute a danger to the environment on which human life depends.

3.3 CEPA 11(*c*): Human Life or Health

Population Exposure

The general population's estimated daily intake of xylenes is presented in Table 3.1. In the table, the sources of exposure are, in order of their relative contribution: indoor air, ambient air, air at self-serve gasoline stations, and water. Available data on concentrations of xylenes in foodstuffs were insufficient to estimate intake. However, based on consideration of physical-chemical properties, it is likely that dietary intake is minimal, compared to the sources considered here.

Table 3.1
Estimates of the Intake of Xylenes for Canadians

Substrate/Medium[a]	Estimated Intake (Micrograms per Kilogram of Body Weight per Day) 0 to 0.5 yr[b]	0.5 to 4 yr[c]	5 to 11 yr[d]	12 to 19 yr[e]	20 to 70 yr[f]
Ambient Air	0.2 to	0.3 to	0.3 to	0.2 to	0.2 to
(Urban)	2.2	2.9	3.4	2.5	2.5
(Rural)	0.2	0.2	0.3	0.2	0.2
Indoor Air	2.8 to	3.8 to	4.4 to	3.3 to	3.3 to
	3.7	5.0	5.7	4.3	4.3
Drinking Water	0	< 0.03	< 0.02	< 0.01	< 0.01
Self-serve Gasoline Station (Summer and Winter)	0.2 to 0.3	0.2 to 0.3	0.3 to 0.4	0.2 to 0.3	0.2 to 0.3
Total Estimated Intake	3.2 to 6.2	4.3 to 8.2	5.0 to 9.5	3.7 to 7.1	3.7 to 7.1
Cigarette Smoking				< 0.01 to	< 0.01 to
(Mainstream)	–	–	–	10.0	13.8
(Sidestream)	1.8	2.4	2.8	2.1	2.1

a. Mean concentrations of xylenes in ambient air are 2.5 to 25.9 and 2.2 μg/m^3 for urban and rural locations, respectively (Dann and Wang, 1990); mean concentrations in indoor air in the homes of non-smokers in various seasons are 14 to 18.2 μg/m^3 (Wallace and Pellizzari, 1986; Wallace *et al*., 1987b). It is assumed that people generally spend 7 hours outdoors and 17 hours indoors (NHW, 1989). Mean concentrations in drinking water are generally < 0.5 μg/L (Otson *et al*., 1982; OME, 1987; DOE, 1989a, 1989b, 1989c, 1989d). For self-serve gasoline stations, the mean airborne concentrations are 716 μg/m^3 in winter and 973 μg/m^3 in summer, respectively (PACE, 1987, 1989). It is also assumed that the average person spends 10 minutes (0.02 hour) per week at the gas station. Cigarettes are estimated to contain < 0.01 to 38 μg xylenes/cigarette for ultra-low tar and high tar cigarettes, respectively, in the mainstream smoke (Higgins *et al*., 1983); it is assumed that adults aged 20 to 70 years smoke 25 cigarettes per day and those aged 12 to 19 years smoke 15 cigarettes per day. The intake from sidestream smoke is estimated based on the difference in concentrations of xylenes between homes with smokers and those with non-smokers in the winter (i.e., 8.9 μg/m^3) [Wallace and Pellizzari, 1986; Wallace *et al*., 1987b] and the assumption that people spend 17 hours indoors (NHW, 1989); data were insufficient to estimate intake from food or from soil.
b. Weighs 7 kg, breathes 2 m^3 air, and drinks 0 L water daily (EHD, 1991).
c. Weighs 13 kg, breathes 5 m^3 air, and drinks 0.8 L water daily (EHD, 1991).
d. Weighs 27 kg, breathes 12 m^3 air, and drinks 0.9 L water daily (EHD, 1991).
e. Weighs 57 kg, breathes 19 m^3 air, and drinks 1.3 L water daily (EHD, 1991).
f. Weighs 69 kg, breathes 23 m^3 air, and drinks 1.5 L water daily (EHD, 1991).

The estimated total average daily intake of xylenes for the various age groups in the general population ranges from 3.2 to 9.5 μg/kg bw/day. Smokers who smoke 20 cigarettes per day may increase their total intake of xylenes by < 0.01 to 13.8 μg/kg bw/day.

Effects

Technical grade xylenes, which are used commercially, contain ethylbenzene and all three isomers of xylene. In the majority of toxicological studies conducted to date, experimental animals have been exposed to this mixture rather than to the individual isomers. Also, in epidemiological studies, workers have been exposed to technical grade xylenes and other solvents. Therefore, available data are insufficient to assess the health risks associated with exposure to the individual xylene isomers. Moreover, in the general environment, the population is more likely to be exposed to xylenes than to the individual isomers. For the above reasons, the following discussion addresses principally the ternary mixture of xylenes.

Epidemiological studies are limited to a few investigations of small populations of workers exposed to thinners and solvents that contain xylenes, high percentages of benzene or toluene, and other aromatic and non-aromatic compounds. Because of the limited power of these studies and possible confounding by accompanying exposure to other substances, which may have contributed to observed effects, available epidemiological data are inadequate to assess the health risks (including carcinogenicity) of xylenes in humans.

Xylenes have not been carcinogenic following oral administration to rats and mice in a well-conducted bioassay (NTP, 1986). However, results of another carcinogenesis bioassay by the oral route (Maltoni *et al*., 1985) are not considered to contribute meaningfully to the weight of evidence for carcinogenicity because of the study's limitations. The weight of available evidence also indicates that xylenes are not genotoxic. Xylenes have been classified, therefore, in Group IV (probably not carcinogenic to humans) of the classification scheme, developed by the Bureau of Chemical Hazards for use in the derivation of the *Guidelines for Canadian Drinking Water Quality* (EHD, 1989).

For compounds classified in Group IV, a tolerable daily intake (TDI) is derived on the basis of a NO(A)EL or LO(A)EL in humans or animal species, in studies conducted by the most relevant route of exposure, divided by an uncertainty factor. For xylenes, studies in which volunteers have been exposed are limited principally to those involving short-term repeated exposure of a limited number of subjects to 100 ppm (435 mg/m^3) *m*-xylene or greater (Riihimaki and Savolainen, 1980; Savolainen, 1980; Savolainen *et al*., 1980, 1982, 1984, 1985; Seppalainen *et al*., 1989). Due to these limitations of the available studies in volunteers and the epidemiological studies

mentioned (i.e., the limited power to detect effects and confounding by concomitant exposure to other substances), available data are considered insufficient for development of a TDI on the basis of studies in humans.

Inhalation is considered to be the most important route of exposure to xylenes for the general public (see "Population Exposure"). Therefore, a TDI for humans has been derived on the basis of the results of studies in animal species exposed to xylenes by inhalation. The lowest concentration at which meaningful effects (feto-toxic effects in the absence of maternal toxicity) have been observed, following exposure by inhalation to xylenes, is 500 mg/m^3 in a limited study[1] (Ungvary and Tatrai, 1985). At this concentration, moderate embryotoxic effects, such as a retardation of body weight increase, were observed in the offspring of rabbits exposed to xylenes of unspecified composition continuously on days 7 to 20 of gestation. However, it should be noted that in the same study, maternal (unspecified) and fetal (skeletal retardation) toxicity were observed in rats exposed during gestation to 250 mg/m^3 (the lowest concentration administered), indicating that the rats may be a more sensitive species. The available data do not preclude the possibility that a similar pattern to that observed in rabbits might be observed in rats exposed to lower concentrations.

At similar concentrations (492 mg/m^3 for 2 hours), transient neurobehavioural effects in rats have been observed (Ghosh *et al*., 1987). At slightly lower concentrations (50 ppm, 218 mg/m^3 for 2 weeks), biochemical effects on the brain, the significance of which is unclear, have been reported in rats (Savolainen and Pfaffli, 1980). In the longest-term studies of the effects of xylenes following inhalation (i.e., sub-chronic studies), the lowest concentration at which effects (a transient increase in the liver to body weight ratio) were observed, in the limited number of available studies, is 320 ppm (1 400 mg/m^3), in small groups of rats continuously exposed to xylenes (composition unspecified; single exposed group) for 90 days (Kyrklund *et al*., 1987). In another adequate study of a range of end-points, there were no effects in rats or beagle dogs exposed to up to 3 500 mg/m^3 xylenes, 6 hours/day, 5 days/week for 13 weeks (Carpenter *et al*., 1975).

On the basis of these data, the TDI is derived as follows:

$$\textbf{TDI} = \frac{(250\ \text{mg/m}^3) \times (0.144\ \text{m}^3\text{/day})}{(0.25\ \text{kg}) \times 1\,000}$$

$$= 0.144\ \text{mg/kg bw/day (144 μg/kg bw/day);}$$

where:

250 mg/m^3 = the lowest LOEL for meaningful effects reported in a bioassay of adequate quality (though documentation was incomplete) in the most sensitive species (Ungvary and Tatrai, 1985);

1. Documentation of the protocol and results in the published account was incomplete.

0.144 m^3/day	=	assumed inhaled air volume of an adult rat (Altman and Dittmer, 1972);
0.25 kg	=	assumed body weight of an adult rat (NIOSH, 1985); and
1 000	=	uncertainty factor (× 10 for intra-species variation; × 10 for inter-species variation; × 10 for LOEL rather than NOEL [although observed effects at the LOEL were only moderately feto-toxic; documentation was also limited]. No additional factor was incorporated for the limited period of exposure, since feto-toxic effects occur at doses below those which induce adverse effects in sub-chronic and chronic studies).

The lowest concentration of the individual xylene isomers, reported to induce adverse effects in animal species following inhalation, is 150 mg/m^3. At this concentration, there were implantational loss and decreased placental weight, and retardation in skeletal development of offspring in the absence of maternal toxicity. The observations followed continuous exposure of pregnant rats to *p*-xylene on days 7 to 14 of gestation (Ungvary *et al*., 1980). This is only slightly less than the LOEL used above in the derivation of a TDI for xylenes.

The database on effects of long-term exposure to xylenes following ingestion is more complete than for that of inhalation. The lowest reported NOEL in the longest-term study conducted to date in which xylenes have been administered orally (gavage in corn oil) is 250 mg/kg bw/day, based on a 5 to 8% decrease in body weight in male rats observed at the next highest dose (500 mg/kg bw/day) in a 2-year bioassay conducted by the National Toxicology Program (NTP, 1986). The decrease in body weight was considered to be indicative of slight toxicity. Survival was also reduced at 500 mg/kg bw/day in this study, however, some of these deaths were gavage-related. The NOAEL in the only available study of developmental toxicity, in which xylenes were administered orally, was considerably greater than the NOAEL in the NTP bioassay – i.e., 1 030 mg/kg bw/day (Marks *et al*., 1982). NO(A)ELs for the individual isomers in sub-chronic studies, in which *m*- or *p*-xylene was administered, are slightly less than the NOAEL in the 2-year NTP bioassay – i.e., 200 mg/kg bw/day (Hazleton Labs, 1988a, 1988b). A TDI derived from the studies in which xylenes have been administered orally would be considerably greater than a TDI derived on the basis of inhalation bioassays. For example, a TDI of 1 800 μg/kg bw/day can be calculated by division of the NOEL in male rats in the NTP bioassay (250 mg/kg bw/day), by an uncertainty factor of 100, for intra- and inter-species variation, and converting 5 days per week of dosing to 7 days per week. The more conservative TDI derived above, on the basis of results of studies in which xylenes have been administered by inhalation is, therefore, considered to be protective, based on consideration of results of studies in which the compound was administered orally.

The estimated total average daily intake of xylenes from various sources for different age groups in the Canadian population ranges from 3.2 to 9.5 μg/kg bw/day. These estimated total average daily intakes of xylenes are 15 to 45 times less than the tolerable daily intake derived above on the basis of bioassays in animal species.

Therefore, on the basis of available data, it has been concluded that xylenes are not entering the environment in quantities or under conditions that may constitute a danger in Canada to human life or health.

3.4 Conclusion

On the basis of available data, it has been concluded that xylenes are not entering the environment in quantities or under conditions that may be harmful to the environment, or that may constitute a danger to the environment on which human life depends, or to human life or health.

4.0 Recommendations for Research and Evaluation

Acquisition of additional data in the following areas would permit a more complete evaluation of the effects of xylenes on human health and environmental organisms in Canada. The priority for this work is low.

1. Additional monitoring data, particularly for indoor air, since this appears to be the principal source of exposure for the general population.

2. Quantitative information on the concentrations of xylenes in foodstuffs.

3. The prevalence and extent of natural contamination of groundwater by xylenes.

4. Additional studies of the developmental effects of xylenes and the individual isomers.

5. Better characterization of the delivered dose to the fetus, using physiologically-based pharmacokinetic methods.

6. The effects of chronic exposure to low concentrations of xylenes on growth, survival, and reproduction of sensitive freshwater fish and invertebrates.

7. The concentrations and persistence of xylenes under ice and the potential effects on aquatic biota under such conditions.

5.0 References

Alberta Research Council. 1992. Composition of Canadian summer and winter gasolines (1991–1992). Report for the Canadian Petroleum Products Institute and Energy, Mines and Resources Canada, Ottawa. November 1992.

Altman, P.D., and D.S. Dittmer, eds. 1972. Biology Data Book, 2nd edition, Vol. 1–3. Federation of American Societies for Experimental Biology. Bethesda, Maryland.

Anderson, T.A., J.J. Beauchamp, and B.T. Walton. 1991. Fate of volatile and semi-volatile organic chemicals in soil: Abiotic versus biotic losses. J. Environ. Qual. 20: 420–424.

Anderson, D.C., K.W. Brown, and J.C. Thomas. 1985. Conductivity of compacted clay soils to water and organic liquids. Waste Manage. Res. 3: 339–349.

Angerer, J., and H. Wulf. 1985. Occupational chronic exposure to organic solvents: XI. Alkylbenzene exposure of varnish workers: effects on haematopoietic system. Int. Arch. Occup. Environ. Health 56: 307–321.

Askergren, A. 1982. Organic solvents and kidney function. Adv. Mod. Environ. Toxicol. 2: 157–172.

Atkinson, R. 1990. Gas-phase tropospheric chemistry of organic compounds: A review. Atmos. Environ. 24A: 1–41.

Atkinson, R., S.M. Aschmann, and J. Arey. 1991. Formation of ring-retaining products from the OH radical-initiated reactions of *o*-, *m*- and *p*-xylene. Int. J. Chem. Kinet. 23: 77–97.

ATSDR (Agency for Toxic Substances and Disease Registry). 1990. Total Xylenes. Draft document. U.S. Public Health Service. 185 pp.

Aurelius, M.W., and K.W. Brown. 1987. Fate of spilled xylene as influenced by soil moisture content. Water Air Soil Pollut. 36: 23–31.

Barker, J.F. 1987. Volatile aromatic and chlorinated organic contaminants in groundwater at six Ontario landfills. Water Pollut. Res. J. Can. 22: 33–48.

Barker, J.F., E.A. Sudicky, C.I. Mayfield, and R.W. Gilham. 1989. Petroleum hydrocarbon contamination of groundwater: natural fate and *in situ* remediation. A summary report. Petroleum Association for Conservation of the Canadian Environment, Ottawa. PACE Report No. 89–5. 28 pp.

Benville, P.E., and S. Korn. 1977. The acute toxicity of six monocyclic aromatic crude oil components to striped bass (*Morone saxatilis*) and bay shrimp (*Crago franciscorum*). Calif. Fish Game 63(4): 204–209.

Bio/Dynamics Inc. 1983. Parental and fetal reproduction inhalation toxicity study in rats with mixed xylenes. Vol. I and II. Contract prepared for the American Petroleum Institute, Washington, D.C.

Black, J.A., W.J. Birge, W.E. McDonnell, A.G. Westerman, B.A. Ramey, and D.J. Bruser. 1982. The aquatic toxicity of organic compounds to embryo-larval stages of fish and amphibians. Research Report No. 133. Project No. B-071-KY. United States Dept. of the Interior. Agreement No. 14-34-0001-0223(FY1980).

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.

CCME (Canadian Council of Ministers of the Environment). 1990. Management Plan for Nitrogen Oxides (NO_X) and Volatile Organic Compounds (VOCs). Phase I. Canadian Council of Ministers of the Environment. CCME-EPC/TRE-31E.

Chan, C.C., L. Valner, J.W. Martin, and D.T. Williams. 1990. Determination of organic contaminants in residential indoor air using an absorption-thermal desorption technique. J. Air Waste Manage. Assoc. 40: 62–67.

Condie, L.W., J.R. Hill, and J.F. Borzelleca. 1988. Oral toxicology with xylene isomers and mixed xylenes. Drug Chem. Toxicol. 11: 329–354.

Corpus Information Services. 1991. Xylene. CPI Product Profiles. Don Mills, Ontario.

Currier, H.B. 1951. Herbicidal properties of benzene and certain methyl derivatives. Hilgardia 20: 383–406.

Currier, H.B., and S.A. Peoples. 1954. Phytotoxicity of hydrocarbons. Hilgardia 23: 155–173.

Dann, T., and D. Wang. 1990. Unpublished data. Environment Canada, River Road Environmental Technology Centre, Gloucester, Ontario.

Davis, T. 1991. Pesticides Directorate Pesticide Information Data Base. Unpublished data. Agriculture Canada, Pesticides Directorate, Ottawa.

DOE (Environment Canada). 1989. Detection, prevention and remediation of leaks from underground storage tanks. Report EPS 2/PN/1. Environment Canada, Ottawa.

DOE (Environment Canada). 1989a. Atlantic Region Federal-Provincial Toxic Chemical Survey of Municipal Drinking Water Sources, Data Summary Report, Province of Nova Scotia, 1985–1988. Environmental Protection Service, Environment Canada, Water Quality Branch, Atlantic Region. IWD-AR-WQB-89-154.

DOE (Environment Canada). 1989b. Atlantic Region Federal-Provincial Toxic Chemical Survey of Municipal Drinking Water Sources, Data Summary Report, Province of New Brunswick, 1985–1988. Environmental Protection Service, Environment Canada, Water Quality Branch, Atlantic Region. IWD-AR-WQB-89-155.

DOE (Environment Canada). 1989c. Atlantic Region Federal-Provincial Toxic Chemical Survey of Municipal Drinking Water Sources, Data Summary Report, Province of Prince Edward Island, 1985–1988. Environmental Protection Service, Environment Canada, Water Quality Branch, Atlantic Region. IWD-AR-WQB-89-156.

DOE (Environment Canada). 1989d. Atlantic Region Federal-Provincial Toxic Chemical Survey of Municipal Drinking Water Sources, Data Summary Report, Province of Newfoundland, 1985–1988. Environmental Protection Service, Environment Canada, Water Quality Branch, Atlantic Region. IWD-AR-WQB-89-157.

Donner, M., J. Maki-Paakkanen, H. Norppa, M. Sorsa, and H. Vainio. 1980. Genetic toxicology of xylenes. Mutation Res. 74: 171–172.

Edwards, E.A., L.E. Wills, D. Grbic-Galic, and M. Reinhard. 1991. Anaerobic degradation of toluene and xylene – evidence for sulphate as the terminal electron acceptor. In: R.E. Hinchee, and R.F. Olfenbuttel, eds. *In Situ* Bioreclamation. Butterworth-Heinemann, Boston. 463–471.

EHD (Environmental Health Directorate). 1989. Guidelines for Canadian Drinking Water Quality – Supporting Documentation. Bureau of Chemical Hazards, Department of National Health and Welfare.

EHD (Environmental Health Directorate). 1991. Draft internal report on recommended approach and reference values for exposure assessments for CEPA Priority Substances. Bureau of Chemical Hazards. Unpublished. September 1991.

Ferrario, J.B., G.C. Lawler, I.R. Deleon, and J.L. Laseter. 1985. Volatile organic pollutants in biota and sediments of Lake Pontchartain. Bull. Environ. Contam. Toxicol. 34: 246–255.

Finlayson-Pitts, B.J.F., and J.N. Pitts Jr. 1986. Atmospheric Chemistry: Fundamentals and Experimental Techniques. John Wiley, New York. 1098 pp.

Firor, J. 1990. The Changing Atmosphere – A Global Challenge. Yale University Press, New Haven & London.

Fishbein, L. 1985. An overview of environmental and toxicological aspects of aromatic hydrocarbons. III. Xylene. Sci. Tot. Environ. 43: 165–183.

Franchini, I., A. Cavatorta, M. Falzoi, S. Lucertini, and A. Mutti. 1983. Early indicators of renal damage in workers exposed to organic solvents. Int. Arch. Occup. Environ. Health 52: 1–9.

Frank, P.A., N.E. Otto, and T.R. Bartley. 1961. Techniques for evaluating aquatic weed herbicides. Weeds 9(4): 515–521.

Galassi, S., M. Mingazzini, L. Vigano, D. Cesareo, and M.L. Tosato. 1988. Approaches to modelling toxic responses of aquatic organisms to aromatic hydrocarbons. Ecotoxicol. Environ. Saf. 16: 158–169.

Ghosh, T.K., R.J. Copeland, R.N. Parui, S. Mookherjee, and N. Pradhan. 1987. Effects of xylene inhalation on fixed-ratio responding in rats. Pharmacol. Biochem. Behav. 27: 653–657.

Gibson, D.T., and V. Subramanian. 1984. Microbial degradation of aromatic hydrocarbons. In: D.T. Gibson, ed., Microbial Degradation of Organic Compounds. Marcel Dekker, New York. 181 pp.

Green, W.J., G.F. Lee, R.A. Jones, and T. Palit. 1983. Interaction of clay soils with water and organic solvents: Implications for the disposal of hazardous wastes. Environ. Sci. Technol. 17: 278–292.

Güsten, H., L. Klasinc, and D. Maric. 1984. Prediction of the abiotic degradability of organic compounds in the troposphere. J. Atmosph. Chem. 2: 83–93.

Haglund, U., I. Lundberg, and L. Zech. 1980. Chromosome aberrations and sister chromatid exchanges in Swedish paint industry workers. Scand. J. Work Environ. Health 6: 291–298.

Hazleton Labs (Hazleton Laboratories America Inc.). 1988a. Sub-chronic toxicity in rats with *m*-xylene. Final Report for Dynamic Corporation, Rockville, Maryland.

Hazleton Labs (Hazleton Laboratories America Inc.). 1988b. Sub-chronic toxicity in rats with *p*-xylene. Final Report for Dynamic Corporation, Rockville, Maryland.

Herman, D.C., W.E. Inniss, and C.I. Mayfield. 1990. Impact of volatile aromatic hydrocarbons, alone and in combination, on growth of the freshwater alga (*Selenastrum capricornutum*). Aquat. Toxicol. 18(2): 87–100.

Higgins, C.E., W.H. Griest, and G. Olerich. 1983. Application of tenax trapping to analysis of gas phase organic compounds in ultra-low tar cigarette smoke. J. Assoc. Off. Anal. Chem. 66: 1074–1083.

Holm, P.E., P.H. Nielsen, and T.H. Christensen. 1991. Aerobic groundwater and groundwater sediment degradation potential for xenobiotic compounds measured *in situ*. In: R.E. Hinchee, and R.F. Olfenbuttel, eds. *In Situ* Bioreclamation. Butterworth-Heinemann, Boston. 413–419.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko. 1991. Handbook of Environmental Degradation Rates. Lewis Publishers, Chelsea, Michigan.

Hunt, T.M. 1979. Petroleum Chemistry and Geology. W.H. Freeman and Co., San Francisco, California.

Hutchins, S.R., G.W. Sewell, D.A. Kovacs, and G.A. Smith. 1991. Biodegradation of aromatic hydrocarbons by aquifer micro-organisms under denitrifying conditions. Environ. Sci. Technol. 25: 68–76.

Hutchins, S.R., and J.T. Wilson. 1991. Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions. In: R.E. Hinchee, and R.F. Olfenbuttel, eds. *In Situ* Bioreclamation. Butterworth-Heinemann, Boston. 157–172.

Jaques, A. 1992. Canada's greenhouse gas emissions: Estimates for 1990. Report EPS 5/AP/4, Environment Canada, Hull.

Jaques, A.P. 1990. National Inventory of Sources and Emissions of Benzene (1985). Report EPS 5/AP/1, Environment Canada, Hull.

Johnson, R.L., J.A. Cherry, and J.F. Pankow. 1989. Diffusive contaminant transport in natural clay: a field example and implications for clay-lined waste disposal sites. Environ. Sci. Technol. 23: 340–349.

Jori, A., D. Calamari, A. DiDomenico, C.L. Galli, E. Galli, M. Marinovich, and V. Silano. 1986. Ecotoxicological profile of xylenes. Ecotoxicol. Environ. Safety 11: 44–80.

Kilburn, K.H., B.C. Seidman, and R. Warshaw. 1985. Neurobehavioral and respiratory symptoms of formaldehyde and xylene exposure in histology technicians. Arch. Environ. Health 40: 229–233.

Kirk, R.E., D.F. Othmer, M. Grayson, and D. Eckroth. 1983. Kirk-Othmer Encyclopedia of Chemical Technology. John Wiley, New York.

Kyrklund, T., P. Kjellstrand, and K. Haglid. 1987. Brain lipid changes in rats exposed to xylene and toluene. Toxicology 45: 123–133.

Lebowitz, H., D. Brusick, D. Matheson, D.R. Jagannath, M. Reed, S. Goode, and G. Roy. 1979. Commonly used fuels and solvents evaluated in a battery of short-term bioassays. Environ. Mutagen 1: 172–173.

Lesage, S., J.K. Ritch, and E.J. Treciokas. 1990. Characterization of groundwater contaminants at Elmira, Ontario, by thermal desorption, solvent extraction GC-MS and HPLC. Water Pollut. Res. J. Can. 25: 275–292.

Lesage, S., R.E. Jackson, M. Priddle, P. Beck, and K.G. Raven. 1991. Investigation of possible contamination of shallow groundwater by deeply injected liquid industrial wastes. Ground Water Monitoring Review. Winter 1991: 151–159.

Levelton, B.H. and Associates Ltd. 1990. Reduction of VOC emissions from solvents by product substitution, process changes or add-on controls. Contract report prepared for Environment Canada, Industrial Programs Branch.

Lonneman, W.A., R.L. Seila, and S.A. Meeks. 1986. Non-methane organic composition in the Lincoln Tunnel. Environ. Sci. Technol. 20: 790–796.

Lovegren, N.V., G.S. Fisher, M.G. Legendre, and W.H. Schuller. 1979. Volatile constituents of dried legumes. J. Agric. Food Chem. 27: 851–853.

Low, L.K., J.R. Meeks, and C.R. Mackerer. 1989. Health effects of the alkylbenzenes. II. Xylenes. Toxicol. Ind. Health 5: 85–105.

Mackay, D., and P.J. Leinonen. 1975. Rate of evaporation of low-solubility contaminants from water bodies to atmosphere. Environ. Sci. Technol. 9: 1178–1180.

Mackay, D., W.Y. Shiu, and K.C. Ma. 1992. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Volume 1. Lewis Publishers, Boca Raton. 697 pp.

Maltoni, C., B. Conti, G. Cotti, and F. Belpoggi. 1985. Experimental studies on benzene carcinogenicity at the Bologna Institute of Oncology: current results and ongoing research. Am. J. Ind. Med. 7: 415–446.

Marks, T.A., T.A. LeDoux, and J.A. Moore. 1982. Teratogenicity of a commercial xylene mixture in the mouse. J. Toxicol. Environ. Health 9: 97–105.

Mikulski, P.I., R. Wiglusz, A. Bublewska, and J. Uselis. 1972. Investigation of exposure of ship’s painters to organic solvents. Br. J. Ind. Med. 29: 450–453.

Mirkova, E., C. Zaikov, G. Antov, A. Mikhailova, L. Khinkova, and I. Benchev. 1983. Prenatal toxicity of xylene. J. Hygiene Epidem. Microb. Immun. 27: 337–343.

Morvai, V., G. Ungvary, H.J. Herrmann, and C. Kuhne. 1987. Effects of quantitative undernourishment, ethanol and xylene on coronary microvessels of rats. Acta Morphologica Hungarica 35: 199–206.

Myhr, B., D. McGregor, L. Bowers, C. Riach, A.G. Brown, I. Edwards, D. McBride, R. Martin, and W.J. Caspary. 1990. L5178Y mouse lymphoma cell mutation assay results with 41 compounds. Environ. Mol. Mutagen 16: 138–167.

NAQUADAT (National Water Quality Data Bank). 1991. Water Quality Branch, Inland Waters Directorate. Environment Canada, Ottawa.

NATES (National Analysis of Trends in Emergencies System). 1992. Xylenes. Environment Canada, Environmental Emergencies Branch, Hull.

NHW (National Health and Welfare Canada). 1989. Exposure Guidelines for Residential Indoor Air Quality. A report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health. Environmental Health Directorate. EHD-TR-156.

NIOSH (National Institute for Occupational Safety and Health). 1985. Registry of Toxic Effects of Chemical Substances. 1983–84 Cumulative supplement to the 1981–82 edition. U.S. Department of Health and Human Services.

NRC (National Research Council). 1980. The Alkyl Benzenes. Committee on Alkyl Benzene Derivatives, Board of Toxicology and Environmental Health Hazards, Assembly of Life Sciences, National Academy Press, Washington, D.C.

NTP (National Toxicology Program). 1986. Toxicology and carcinogenesis studies of xylenes (mixed). National Toxicology Program, Research Triangle Park, North Carolina. Technical report series No. 327. NIH Publication No. 87–2583.

Nunes, P., and P. Benville. 1979. Uptake and depuration of petroleum hydrocarbons in the Manila clam (*Tapes semidecussata*). Reeve. Bull. Environ. Contam. Toxicol. 21: 719–726.

Ogata, M., and Y. Miyake. 1978. Disappearance of aromatic hydrocarbons and organic sulfur compounds from fish flesh reared in crude oil suspension. Water Res. 12: 1041–1044.

Oilweek. 1988. Canadian motor gasoline sale (Table). Oilweek February 22, 1988. 16.

OME (Ontario Ministry of the Environment). 1987. Drinking Water Surveillance Program. Overview Annual Report 1987. ISSN: 0840–5093. 180 pp.

OME (Ontario Ministry of the Environment, Water Resources Branch). 1988. Thirty-seven Municipal Water Pollution Control Plants. Pilot Monitoring Study. Volume 1, Interim Report. ISBN 0-7729-4900-X.

OME (Ontario Ministry of the Environment, Water Resources Branch). 1990. Second Report on the Monitoring Data for the Petroleum Refining Sector. ISBN 0- 7729-7331-8.

OME (Ontario Ministry of the Environment, Water Resources Branch). 1991. Status Report on the Effluent Monitoring Data for the Iron and Steel Sector for the Period from November 1, 1989 to October 31, 1990. PIBS 1675. Log 91-2310-034. ISBN 0-7729-8819-6.

Otson, R. 1987. Purgeable organics in Great Lakes raw and treated water. Int. J. Environ. Anal. Chem. 31: 41–53.

Otson, R., and F.M. Benoit. 1985. Surveys of selected organics in residential air. In: D.S. Walkinshaw, ed. Indoor Air Quality in Cold Climates. An Air Pollution Control Association Speciality Conference. 224–236.

Otson, R., D.T. Williams, and P.D. Bothwell. 1982. Volatile organic compounds in water at thirty Canadian potable water treatment facilities. J. Assoc. Off. Anal. Chem. 65: 1370–1374.

PACE (Petroleum Association for Conservation of the Canadian Environment). 1987. A Study of Exposure to Motor Gasoline Hydrocarbon Vapours at Service Stations (Phase II – Summer Study). PACE Report No. 87–5. Ottawa, Ontario.

PACE (Petroleum Association for Conservation of the Canadian Environment). 1989. A Study of Exposure to Motor Gasoline Hydrocarbon Vapours at Service Stations (Phase III – Winter Study). PACE Report No. 89–3. Ottawa, Ontario.

Pakdel, H., G. Couture, C. Roy, A. Masson, J. Locat, P. Gélinas, and S. Lesage. 1992. Developing methods for the analysis of toxic chemicals in soil and groundwater: The case of Ville Mercier, Quebec, Canada. In: S. Lesage, and R.E. Jackson, eds. Groundwater Contamination and Analysis at Hazardous Waste Sites. Marcel Dekker, New York. 38l–421.

Pellizzari, E.D., T.D. Hartwell, B.S.H. Harris III, R.D. Waddell, D.A. Whitaker, and M.D. Erickson. 1982. Purgeable organic compounds in mother’s milk. Bull. Environ. Contam. Toxicol. 28: 322–328.

Ramanathan, V., R.J. Cicerone, H.B. Singh, and J.T. Kiehl. 1985. Trace gases and their potential role in climate change. J. Geophys. Res. 90(D3): 5547–5566.

Reinhard, M., L.E. Wills, H.A. Ball, T. Harmon, D.W. Phipps, H.F. Ridgway, and M.P. Eisman. 1991. A field experiment for the anaerobic biotransformation of aromatic hydrocarbon compounds at Seal Beach, California. In: R.E. Hinchee, and R.F. Olfenbuttel, eds. *In Situ* Bioreclamation. Butterworth-Heinemann, Boston. 487–496.

Riihimaki, V., and K. Savolainen. 1980. Human exposure to *m*-xylene. Kinetics and acute effects on the central nervous system. Ann. Occup. Hyg. 23: 411–422.

Sadtler Research Laboratories. 1982. Infrared Spectra of Priority Pollutants and Toxic Chemicals. Sadtler Research Laboratories, Philadelphia, Pennsylvania.

Savolainen, K. 1980. Combined effects of xylene and alcohol on the central nervous system. Acta Pharmacol. Toxicol. 46: 366–372.

Savolainen, K., and P. Pfaffli. Dose-dependent neurochemical changes during short-term inhalation exposure to *m*-xylene. Arch. Toxicol. 45: 117–122.

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. Health 45: 105–121.

Savolainen, K., V. Riihimaki, and A. Laine, 1982. Biphasic effects of inhaled solvents on human equilibrium. Acta Pharmacol. Toxicol. 51: 237–242.

Savolainen, K., J. Kekoni, V. Riihimaki, and A. Laine. 1984. Immediate effects of *m*-xylene on the human central nervous system. Arch. Toxicol. 7: 412–417.

Savolainen, K., V. Riihimaki, O. Muona, J. Kekoni, R. Luukkonen, and A. Laine. 1985. Conversely exposure-related effects between atmospheric *m*-xylene concentrations and human body sense of balance. Acta Pharmacol. Toxicol. 57: 67–71.

Scheff, P.A., R.A. Wadden, B.A. Bates, and P.F. Aronian. 1989. Source fingerprints for receptor modeling of volatile organics. J. Air Pollut. Control Assoc. 39: 469–478.

Seip, H.M., J. Alstad, G.E. Carlberg, K. Martinsen, and R. Skaane. 1986. Measurement of mobility of organic compounds in soils. Sci. Tot. Environ. 50: 87–101.

Seppalainen, A.M., K. Husman, and C. Martenson. 1978. Neurophysiological effects of long-term exposure to a mixture of organic solvents. Scand. J. Work Environ. Health 4: 304–314.

Seppalainen, A.M., A. Laine, T. Salmi, V. Riihimaki, and E. Verkkala. 1989. Changes induced by short-term xylene exposure in human evoked potentials. Int. Arch. Occup. Environ. Health 61: 443–449.

Sigsby, J.E., Jr., S. Tejada, W. Ray, J.M. Lang, and J.W. Duncan. 1987. Volatile organic compound emissions from 46 in-use passenger cars. Environ. Sci. Technol. 21: 466–475.

Slaine, D.D., and J.F. Barker. 1990. The detection of naturally occurring BTX during a hydrogeologic investigation. Ground Water Monit. Rev. Spring 1990: 89–94.

SRI International. 1979. Human exposure to atmospheric concentrations of selected chemicals. Vol. I. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. A-29-4-A29-72.

Stanley, J.S. 1986. Broad Scan Analysis of Human Adipose Tissue: Volume II: Volatile Organic Compounds. Final Report. Prepared by Midwest Research Institute for Office of Pesticide and Toxic Substances, U.S. Environmental Protection Agency, Washington, D.C.

Ungvary, G., and E. Tatrai. 1985. On the embryotoxic effects of benzene and its alkyl derivatives in mice, rats, and rabbits. Arch. Toxicol. Suppl. 8. 425–430.

Ungvary, G., E. Tatrai, A. Hudak, G. Barcza, and M. Lorincz. 1980. Studies on the embryotoxicity of *ortho*-, *meta*-, and *para*-xylene. Toxicology 18: 61–74.

U.S. EPA (U.S. Environmental Protection Agency). 1987. Occurrence of Synthetic Organic Chemicals in Drinking Water, Food, and Air. PB89-192520. Office of Drinking Water. Washington, D.C. 175 pp.

Veith, G.D., D.L. DeFoe, and B.V. Bergstedt. 1979. Measuring and estimating the bioconcentration factor of chemicals in fish. J. Fish. Res. Board Can. 36: 1040–1048.

Wallace, L.A., and E.D. Pellizzari. 1986. Personal air exposures and breath concentrations of benzene and other volatile hydrocarbons for smokers and non-smokers. Toxicol. Lett. 35: 113–116.

Wallace, L.A., E.D. Pellizzari, T.D. Hartwell, C. Sparacino, R.W. Whitmore, L. Sheldon, H. Zelon, and R. Perritt. 1987a. The TEAM study: Personal exposures to toxic substances in air, drinking water, and breath of 400 residents of New Jersey, North Carolina, and North Dakota. Environ. Res. 43: 290–307.

Wallace, L.A., E.D. Pellizzari, T.D. Hartwell, R. Perritt, and R. Ziegenfus. 1987b. Exposures to benzene and other volatile compounds from active and passive smoking. Arch. Environ. Health 42: 272–279.

Walsh, D.F., J.G. Armstrong, T.R. Bartley, H.A. Salmon, and P.A. Frank. 1977. Residues of emulsified xylene in aquatic weed control and their impact on rainbow trout (*Salmo gairdneri*). Bureau of Reclamation, U.S. Department of Interior, Denver, Colorado. REC-ERC-76-11 (NTIS PB 267 270). 15 pp.

Wang, W.C., Y.L. Yung, A.A. Lacis, T. Mo, and J.E. Hansen. 1976. Greenhouse effects due to man-made perturbations of trace gases. Science 194(4266): 685–690.