Canadian Environmental Protection Act

Priority Substances List
Assessment Report No.4

Toluene

Government of Canada / Gouvernement du Canada
Environment Canada / Environnement Canada
Health Canada / Santé Canada

Canada

CANADA'S GREEN PLAN

Canadian Environmental Protection Act

PRIORITY SUBSTANCES LIST ASSESSMENT REPORT NO. 4

TOLUENE

Government of Canada
Health and Welfare Canada
Environment Canada

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Overview of Findings

Toluene is used in Canada in a variety of applications that lead to its entry into the Canadian environment. This entry results in measurable concentrations of toluene in the various media to which humans and other organisms may be exposed.

Except in cases of spills or occasional discharge of contaminated effluent, concentrations of toluene in ambient surface water have been at least 40 times less than those which induce adverse effects in rainbow trout, the most sensitive aquatic species in long-term studies. The highest reported levels in undiluted effluent discharge were about 170 times less than concentrations which induce adverse effects in coho salmon, the most sensitive species in short-term studies. Concentrations of toluene in a river following a chemical spill were about 250 times less than those which induce adverse effects in short-term studies in coho salmon.

The effect levels reported in inhalation studies conducted in laboratory animals are considered relevant to wild mammals. The highest mean concentration in air measured in cities is almost 10 000 times less than the lowest reported effect level for mammals in long-term inhalation studies.

Because of its short persistence in the atmosphere and low absorption of ultraviolet radiation, toluene is not associated with depletion of stratospheric ozone or with global warming.

Based on data on concentrations of toluene in ambient air, at self-serve gasoline stations, in consumer products, drinking water and food (fish only), the total average daily intakes of toluene for various age groups in the general population have been estimated. These average daily intakes of toluene are considerably less (by approximately 50 to 670 times) than the tolerable daily intake derived on the basis of data from clinical studies in human volunteers and that calculated from bioassays in animal species (by approximately 60 to 780 times). This tolerable daily intake is the intake to which it is believed that a person can be exposed over a lifetime without deleterious effect.

Based on these considerations, the Ministers of Environment Canada and of Health and Welfare Canada have concluded that the current concentrations of toluene present in the environment do not constitute a danger in Canada to the environment or to the environment on which human life depends or to human life or health. Therefore, toluene is not considered to be "toxic" as interpreted under section 11 of the *Canadian Environmental Protection Act.*

1.0 Introduction

The *Canadian Environmental Protection Act* (CEPA) requires the federal Ministers of Environment Canada and of Health and Welfare Canada to prepare and publish a Priority Substances List that identifies substances, including chemicals, groups of chemicals, effluents and wastes which 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 interpreted 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 which are assessed to be "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 ultimate disposal.

The assessment of whether toluene is "toxic", as interpreted in CEPA, was based on the determination of whether it **enters** or may enter the Canadian environment in a concentration or quantities or under conditions that could lead to **exposure** of humans or other biota to the extent that adverse **effects** could result.

For assessment of data other than those considered to be critical for determination of whether or not toluene is "toxic" under the Act, evaluations of agencies such as the International Programme on Chemical Safety and the United States Agency for Toxic Substances and Disease Registry have been consulted where available and considered to be appropriate. A background report was prepared under contract between February and July 1989, by the Midwest Research Institute to identify relevant sources of data. The Canadian Petroleum Products Institute (CPPI) was consulted concerning relevant data for consideration in preparation of the Supporting Document and Assessment Report (PACE, 1987; 1989). To identify literature not included in previous reviews, on-line commercial and government databases including HSDB, ENVIROLINE, EMBASE, MEDLINE, TOXLINE, TOXLIT, RTECS, the STN CA HLE, CURRENT CONTENTS, and NTIS (1980 to 1989) were searched. More recently, a search of CHEMID, RTECS, TOXLINE and TOXLIT (1989 to 1991) was conducted to identify data relevant to the human health assessment, while BIOSIS and Chemical Abstracts (January 1986 to September 1991) were searched for data relevant to the environmental assessment. Although much of the research on toluene has been conducted outside of Canada, data on sources, use patterns, fate, and effects of toluene on the Canadian environment were emphasized where available.

Data relevant to the assessment of whether toluene is "toxic" to human health obtained after the completion of these sections of this report (i.e., June 1991) were not considered for

inclusion. Similarly, data relevant to assessment of whether toluene is "toxic" to the environment, obtained after February 1992, have not been incorporated.

Although review articles were consulted where considered appropriate, all original studies which form the basis for the determination of "toxic" under CEPA have been critically evaluated by the following staff of National Health and Welfare Canada (effects on human health) and of Environment Canada (effects on the environment):

D.S. Caldbick (Environment Canada)
P.K.L. Chan (Health and Welfare Canada)
R. Chénier (Environment Canada)
T. Dann (Environment Canada)
G. Fox (Environment Canada)
M.E. Meek (Health and Welfare Canada)
W.M.J. Strachan (Environment Canada)

In this report, an overview of the findings which will appear in the *Canada Gazette* is presented. In addition, an extended summary of the technical information which is critical to the assessment and which is included in greater detail in a supporting document is presented in section 2. The assessment of whether toluene is "toxic" under CEPA is presented in section 3. The effects of photochemical reaction products of toluene are not addressed in this assessment but are considered in the Federal/Provincial Management Plan for nitrogen oxides (NO_x) and volatile organic compounds (VOCs) [CCME, 1990].

Following circulation and external peer review of the draft health-related sections of the Supporting Document by staff of the United States Agency for Toxic Substances and Disease Control, and the British Industrial Biological Research Association Toxicology International in Great Britain, they were approved by the Standards and Guidelines Rulings Committee of the Bureau of Chemical Hazards of Health and Welfare Canada. Sections on environmental effects were reviewed externally by the Canadian Petroleum Products Institute and approved by the Priority Substances List Program Manager of Environment Canada. The final Assessment Report was reviewed and approved by Environment Canada/Health and Welfare Canada CEPA Management Committee.

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

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2.0 Summary of Critical Supporting Data

2.1 Identity and Physical/Chemical Properties

Toluene (CAS Registry No. 108-88-3) is a clear, colourless liquid with a sweet, pungent odour. It is a monocyclic aromatic compound with one hydrogen on the benzene ring substituted by one methyl group (molecular formula $C_6H_5CH_3$). Toluene is a volatile liquid that is flammable and explosive and has a relatively high vapour pressure (3.7 kPa at 25^0C). Toluene is moderately soluble in water (535 mg/L at 25^0C) and is miscible with most organic solvents. The log octanol/water partition coefficient of toluene is moderately low (2.69).

Toluene is formed from petroleum by catalytic dehydrogenation of fractions containing methylcyclohexane. Industrial grade toluene is 98% pure and may contain up to 2% xylenes and benzene (DOE, 1984).

2.2 Production and Uses

A commercial use pattern survey has been completed for toluene (Corpus Information Services, 1989). Based on data collected in this survey, 438 kton of isolated (purified) toluene were produced in Canada, in 1989, and 45 kton were imported, for a total Canadian supply of 483 kton. Of these, 220 kton were exported, resulting in total domestic consumption of 263 kton of isolated toluene. Toluene is produced at four plants in the Sarnia/Corunna area in Ontario and at two plants in Montréal, Quebec.

The dominant end-use for isolated toluene in Canada is the production of benzene by the hydrodealkylation process. In 1989, approximately 180 kton of toluene were reported to be consumed for this purpose and about 58 kton were used as a solvent (Corpus Information Services, 1989). Toluene is used as a solvent in paints and varnishes, pesticide formulations, printing inks, adhesives and sealants, cleaning agents, and for chemical extractions (Levelton and Associates Ltd., 1990). About 25 kton of isolated toluene were used for other purposes in 1989, including synthesis of chemical products other than benzene.

In addition to the above uses for isolated toluene, toluene is a natural component of petroleum (Kirk *et al.*, 1983). All toluene present in gasoline in Canada occurs as a result of the normal petroleum refining process; no isolated toluene is added during blending. An estimated 34 000 ML of gasoline are sold annually in Canada (Oilweek, 1988). Based on an average toluene content in gasolines of 8.3% by weight (Madé, 1991), about 2 000 kton of toluene are present in the gasoline sold annually in Canada; most of this toluene is burned during normal engine operation. The total yearly consumption of toluene in Canada, including both isolated toluene and toluene as a component of gasoline, is estimated to be 2 263 kton.

2.3 Sources and Releases

Toluene is a natural component of coal and petroleum (Kirk *et al.*, 1983). It may therefore be introduced into the environment through petroleum seepage and weathering of exposed coal-containing strata and into ground water from petroliferous rocks. The magnitude of such releases to the environment is unknown (U.S. EPA, 1987). Toluene is also produced by incomplete combustion of natural fuel materials, and as such is released during forest fires (MRI, 1989).

Estimated atmospheric releases of toluene in Canada are summarized in Table 1. The principal source of airborne releases of toluene is solvent uses, accounting for an estimated 51% of total releases. Light duty automobiles emit an estimated 32% of total releases, with all vehicle sources accounting for about 38% of the total.

Table 1 - Estimated Atmospheric Releases of Toluene in Canada

Sources	Estimated Atmospheric Releases (kilotonnes/year)	% of Total Estimated Atmospheric Releases	References
Industrial Processes			
Toluene and Other Chemical Production	0.2	0.2	MRI, 1989
Coke Oven Emissions	1.1	1.0	MRI, 1989
Solvents	54.0	51.0	Levelton and Associates Ltd., 1990
[Subtotal]	*[53.3]*	*[52.2]*	
Transportation Sources			
Light Duty Vehicles	34.0	32.1	Madé, 1991; CCM, 1990; Zafonte and Lyons, 1989; Sigsby *et al*., 1987; Black *et al*., 1980
Heavy Duty Vehicles	1.0	1.0	Madé, 1991; CCME, 1990; Hampton *et al*., 1983
Marine/Air/Rail	0.5	0.5	CCME, 1990; U.S. EPA, 1990
Off-road	4.3	4.0	Madé, 1991; CCME, 1990
Gasoline Marketing	3.3	3.1	Madé, 1991; CCME, 1990; U.S. EPA, 1990; Scheff *et al*., 1989
[Subtotal]	*[43.1]*	*[40.7]*	
Other Sources			
Landfills	0.4	0.3	Wood and Porter, 1986; Wineman *et al*., 1985
Forest Fires	4.4	4.2	MRI, 1989
Other Inadvertent Releases	2.7	2.6	MRI, 1989
[Subtotal]	*[7.5]*	*[7.1]*	
TOTAL	**105.9**	**100.0**	

Total emissions of toluene to the atmosphere are expected to decline in the future, primarily due to the reduction of 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). For example, by 2005, total VOC emissions from light duty vehicles and solvents are expected to decrease by 53% and 14%, respectively, from their 1985 levels if all control measures identified in Phase I of the NOx-VOC Management Plan are implemented (CCME, 1990). Equivalent reductions for toluene emissions from these two sources can be expected.

Toluene can be released to soil through petroleum spills and from leaking underground storage tanks, but the magnitude of such entry is not known (Bobra, 1991). Toluene is also released into the soil at waste disposal sites (Barker, 1987; Johnson *et al.*, 1989; Lesage *et al.*, 1990).

Toluene can be released into water through chemical spills and spills of petroleum products (Gilbert *et al.* 1983; Upper Great Lakes Connecting Channels Management Committee, 1988) and from discharges of industrial and municipal effluents (OME, 1989; NAQUADAT, 1991). Information on total amounts released from such sources in Canada are not available. However, estimates for the United States indicate that gasoline and oil spills account for about 90% of all toluene releases into water (Gilbert *et al.* 1983).

It has been estimated that in the United States in 1978, 99.8% of all toluene releases were directly to the atmosphere, 0.1% to water, and 0.1% to land (Gilbert *et al.* 1983). Assuming similar proportions for Canada, estimates for releases would be 0.1 kton to soil and 0.1 kton to water, based on Canadian atmospheric releases of about 100 kton per year (Table 1).

2.4 Environmental Fate and Concentrations

2.4.1 *Fate*

Because of its relatively high vapour pressure and moderate solubility in water, the atmosphere plays an important role in the distribution and ultimate fate of toluene (SRI, 1980; Mackay *et al.*, 1992). Based on various modelling simulations, it has been predicted that about 99% of toluene released into the environment should be present in the atmosphere (Slooff and Blokzijl, 1988; Nielsen and Howe, 1991; Mackay *et al.*, 1992). Once released to the atmosphere, either directly or by volatilization from other media, toluene photooxidizes relatively quickly in a reaction with hydroxyl radicals to yield cresols, benzaldehyde, and a number of other products that are themselves degraded further (NRC, 1980; Finlayson-Pitts and Pitts, 1986; Atkinson, 1990). The minimum tropospheric lifetime for toluene has been calculated to be 4.5 hours (Finlayson-Pitts and Pitts, 1986), but half-lives as long as 10 days have been calculated for northern latitudes in winter [Syracuse Research Corporation, 1983]. Toluene is not associated with depletion of stratospheric ozone or with global warming because of its relatively short atmospheric lifetime and because it does not absorb ultraviolet radiation (NRC, 1980).

Gilbert *et al.* (1983) calculated a half-life of 9 seconds for volatilization of toluene from the soil surface. For the top centimetres of soil, the half-lives were calculated to be less than 1 hour for volatilization from dry soil and less than 1 day from wet soil; for the top 10 cm of soil, half-lives were less than 3 days for dry soil and less than 1 month for wet soil (SRI, 1980).

At depths greater than 10 cm, biodegradation replaced volatilization as the major cause of toluene removal (SRI, 1980). Toluene biodegrades fairly rapidly in most soils. Half-lives ranging from under 2 days to 92 days were reported for the biodegradation of toluene in various soil systems under different experimental conditions (Slooff and Blokzijl, 1988; Mackay *et al.*, 1992).

Because of its solubility in water, toluene may leach to ground water. From 2 to 13% of the toluene applied on a sandy soil eluted through a column 140 cm high (Wilson *et al.*, 1981). Movement through the soil may be impeded by the presence of organic matter (Seip *et al.*, 1986) and clay (Johnson *et al.*, 1989).

Toluene is rapidly lost from the water column by volatilization. The half-life in still water 1 m deep has been estimated to be *5.2* hours; it would be shorter for turbulent water (Mackay and Leinonen, 1975). Volatilization rates were calculated for lakes (8 days) and rivers (1 to 2 days) [SRI, 1980] and for streams and rivers (36 minutes to 47 days) [U.S. EPA, 1987].

In lakes and ponds, it has been estimated that biodegradation of toluene takes place with half-lives ranging from less than one week to several weeks, depending on the extent of acclimatization of organisms (SRI, 1980). Biodegradation may predominate over volatilization in the removal of toluene from surface waters in warm weather (Wakeham *et al.*, 1985). In marine ecosystems, the estimated half-life of toluene at temperatures of 2 to 10^0C was 6 days, with the loss due mainly to volatilization; at temperatures of 18 to 19^0C, the half-life was only 1 day, due to rapid biodegradation (Wakeham *et al.*, 1985). No data are available regarding the fate of toluene under ice in winter.

Toluene in water can be biodegraded anaerobically as well as aerobically. In the United States, toluene in ground water was degraded by only a few percent per week (Wilson *et al.*, 1983). Adaptation of microfauna to toluene exposure leads to considerably faster biodegradation of toluene (Armstrong *et al.*, 1991).

Based on its octanol/water partition coefficient and aqueous solubility, bioconcentration factors for toluene in biota have been predicted to be between 15 and 70 (SRI, 1980; Veith *et al.*, 1980; U.S. EPA, 1987). Values less than 100 generally indicate that a compound is unlikely to undergo significant bioconcentration in organisms or biomagnification along food chains (U.S. EPA, 1987).

Experimental studies confirm that toluene is not bioconcentrated to a significant extent in a variety of aquatic animals. Bioconcentration factors in selected tissues of several aquatic animals range from less than 1 to about 140 (Syracuse Research Corporation, 1983; Freitag *et al.*, 1985). The highest value (140) was recorded in the hepatopancreas of the crayfish *(Orconectes rusticus)* [Syracuse Research Corporation, 1983]. In contrast, algae have been reported to accumulate toluene to a greater degree. Bioconcentration factors of 380 (dry weight) were recorded in *Chtoretla fusca* after exposure to toluene at 0.05 mg/L for 24 hours (Geyer *et al.*, 1984). Miller *et al.* (1976) found no evidence that toluene bioaccumulates in higher plants.

2.4.2 *Concentrations*

Concentrations of toluene in ambient air in six urban areas and at two rural sites in Canada were measured between 1983 and 1989 (Dann *et al.*, 1989). The mean airborne concentrations of toluene at the urban locations ranged from 5.2 to 44.2 µg/m^3 with 24-hour maxima for individual samples in the range of 9.0 to 145.0 µg/m^3; mean toluene concentrations

at the rural Walpole Island, Ontario, site were 3.5 and 5.0 μg/m^3. These concentrations are similar to those reported in ambient air in the United States (Shah and Singh, 1988) and Europe (Nielsen and Howe, 1991).

In studies in the United States, there has been a reduction in concentrations of toluene in urban ambient air since the 1960s, largely as a result of decreases in emissions of volatile organic compounds (including toluene) from light duty vehicles (Syracuse Research Corporation, 1983; Lonneman *et al.*, 1986). In Canada, the mean concentration of toluene in air in downtown Toronto in August 1971 was 113 μg/m^3 (Pilar and Graydon, 1973), whereas the mean concentration of toluene at two Toronto sites between November 1988 and February 1989 was 15.6 μg/m^3 (Dann *et al.*, 1989), based on determination by comparable methods of analysis.

Because toluene volatilizes from gasoline, the highest ambient concentrations have been recorded in the immediate vicinity of gasoline marketing stations. The overall average concentrations of toluene at self-serve stations were 535 pg/rn^3 in the winter (0 to 6 450 μg/m^3) and 202 μg/m^3 in the summer (0 to 14 500 μg/m^3). Mean concentrations of toluene in samples of air taken close to the marketing pumps were 1 880 μg/m^3 in the winter (70 to 10 000 μg/m^3) and 2 550 μg/m^3 in the summer (20 to 20 200 μg/m^3) [PACE, 1987; 1989].

Samples of the indoor air of 18 homes near an abandoned waste disposal site in Montréal were collected and analyzed by gas chromatography (Dann and Gonthier, 1986; Gonthier, 1986). The mean concentration of toluene in air was 37 μg/m^3 (detection limit of 0.1 μg/m^3), which was not statistically significantly different than that in control homes, located elsewhere. The mean airborne concentration of toluene in 10 Canadian homes was 52 μg/m^3 when determined using passive sampling suitable for collection of volatile organics (Otson and Benoit, 1985). In a recent study (Chan *et al.*, 1990), samples of indoor air were collected in 12 homes in the metro-Toronto area in November or December 1986, and again in six of these homes in February or March 1987. The mean concentrations of toluene were 53.6 μg/m^3 and 39.9 μg/m^3 in samples collected in November or December, and February or March, respectively. There was no indication in this study of possible sources of toluene in the homes. These concentrations are comparable to levels determined in indoor air in larger studies in the United States with mean values falling within the range of 8 to 82 μg/m^3 (Montgomery and Kalman, 1989; Shah and Heyerdahl, 1988).

In a total of more than 800 water samples taken across Canada from 1985 to 1988, concentrations of toluene in only six samples were greater than 0.5 μg/L. These included one surface water sample (0.9 μg/L), one drinking water sample (0.6 μg/L), two ground water samples (0.6 and 3.9 μg/L), and two samples of undiluted sewage treatment plant effluent (31 and 32 μg/L) [NAQUADAT, 1991].

Concentrations of toluene in Canadian drinking water supplies averaged 2.0 μg/L and ranged up to 27 μg/L at 30 water treatment plants across Canada in a survey conducted in 1979 (Otson *et al.*, 1982). Toluene concentrations in treated supplies in this survey were often greater than those in the raw water sources. It was concluded that the levels of toluene increased upon water treatment, although the total organic carbon levels decreased or remained the same. The mechanism of the toluene formation is unknown. In another survey of water supplies at nine municipalities along the Great Lakes between 1982 and 1983 (Otson, 1987), the mean concentrations of toluene (detection limit of 0.1 μg/L) in raw water were 0.3 μg/L in the summer, 0.1 μg/L in the winter and 0.5 μg/L in the spring. Mean concentrations in treated water were < 0.1, 0.3 and 0.7 μg/L, in the summer, winter and spring, respectively. In other

surveys of drinking water supplies in Ontario and the Atlantic Provinces, concentrations have been lower, ranging up to only a few µg/L (OME, 1987; DOE, 1989a-d).

Toluene has been reported in industrial effluents. Raw process effluent from petroleum refineries in Ontario contained an average concentration of toluene of 0.6 µg/L (OME, 1989). The average daily concentration for the refinery with the greatest discharge of toluene was 2.1 µg/L (maximum of 17.1 µg/L); the average daily loading was 0.05 kg/d in the process effluent.

Concentrations of toluene along a 6 km industrialized section of the St. Clair River near Sarnia, Ontario, where several petrochemical industries were located, ranged from below the detection limit (0.1 µg/L) to 2.2 µg/L (Comba and Kaiser, 1987). Toluene levels were below the detection limit upstream from the industrialized section and returned to near or below detection levels about 1 kin downstream of the industrialized section. A mean toluene concentration of 0.4 µg/L was calculated for the sampling stations along the industrialized section of the river. Following a spill of toluene, benzene, and xylenes in the St. Clair River, concentrations of toluene of 22 µg/L were recorded in the river (OME, 1992).

The highest concentrations of toluene in water in Canada have been recorded in ground water near waste disposal sites. Levels observed directly beneath six landfill sites in Ontario ranged from less than 0.2 µg/L to 730 µg/L (Barker, 1987). In samples taken in a contaminated shallow aquifer at a depth of 6 m beside an existing industrial chemical waste disposal lagoon, concentrations of toluene above 3 900 µg/L were reported (Lesage *et al.*, 1990).

Data also indicate that concentrations in ground water can be high in the vicinity of natural sources. In a study using eight test wells near Belleville, Ontario, Slaine and Barker (1990) reported concentrations of toluene up to 295 µg/L. Evidence indicated that the toluene originated from bituminous deposits.

Data on concentrations of toluene in soils and sediments in Canada have not been identified. Given the fate of toluene in the environment, measurable concentrations of toluene in soil would be expected to occur only in the case of spills (DOE, 1984) or around waste disposal sites (Johnson *et al.*, 1989).

Few data on concentrations of toluene in food are available. Toluene has been detected but not quantified in roasted filberts, peanuts, and macadamia nuts (Gilbert *et al.*, 1983), in cheese (Meinhart and Schreier, 1986), in tomatoes and its products (Chung *et al.*, 1983), in baked potatoes (Coleman *et al.*, 1981), in dry red beans (Buttery *et al.*, 1975), in winged beans and soybeans (del Rosario *et al.*, 1984), and in eggs (MacLeod and Cave, 1976). Available quantitative data on concentrations of toluene in foodstuffs are limited to fish from contaminated areas in the United States for which the maximum concentration detected in one sample was 35 µg/g (Gilbert *et al.*, 1983).

In a United States national survey of toluene in human adipose tissue, the concentrations ranged from not detected (detection limit of 0.0002 µg/g) to 0.250 µg/g and there was a slight trend toward higher concentration with age. There was about a fivefold variation in concentration by geographic region (Stanley, 1986). Detectable levels of toluene in mothers' milk for populations in the vicinity of chemical manufacturing plants and/or industrial user facilities in the United States were reported, though not quantified, by Pellizzari *et al.* (1982).

2.5 Toxicokinetics and Metabolism

Toluene is rapidly and efficiently absorbed through the lungs (about 50 to 80%) [Low *et al.*, 1988], and much of the inhaled toluene can reach the brain before it is detoxified in the liver, the major site of toluene metabolism (Sato, 1988). Absorption from the gastrointestinal tract is slower and less efficient (Pyykko *et al.*, 1977). Initially, toluene is distributed to the highly vascularized, lipid-rich tissues, such as the brain, kidney, and liver but accumulates principally in adipose tissue (Sato, 1988). About 20% of the absorbed dose is expired unchanged from the lungs. The remainder is metabolized principally by oxidation to benzyl alcohol, which is subsequently oxidized to form benzaldehyde and benzoic acid. Most benzoic acid is conjugated with glycine to form hippuric acid and excreted in the urine (Ogata *et a!.*, 1970).

2.6 Mammalian Toxicology

The acute toxicity of inhaled or ingested toluene is relatively low. The oral LD_{50} for toluene in the rat is between 2.6 and 7.5 g/kg body weight, depending on the strain, age, and sex. Repeated short-term exposure of animal species to moderate to high concentrations of toluene causes central nervous system depression and adverse effects on the liver, kidney and lungs. The lowest concentration at which effects have been reported in well-documented and adequate subchronic bioassays following inhalation is 100 ppm (375 mg/m^3) which induced a decrease in body weight (7.5 and 12% reduction in final weight relative to controls in males and females, respectively) in a 14-week study in mice conducted by the National Toxicology Program (Huff, 1990).

Effects following ingestion of toluene in subchronic studies have also been reported. In the best documented and most complete study conducted to date (a recently reported NTP bioassay in rats and mice), the lowest no-observed-effect-level (NOEL) was that in rats - 312 mg/kg bw/d based on an increase in relative liver and kidney weights of males observed at doses of 625 mg/kg/d and greater (Huff, 1990).

The most extensive available studies of the chronic toxicity and/or carcinogenicity of toluene include inhalation bioassays in rats and mice conducted by the NTP (Huff, 1990) and in rats by the Chemical Industry Institute of Toxicology (CIIT, 1980). Adverse effects were not observed in the latter study; failure to test the maximum tolerated dose may have reduced the sensitivity of this bioassay. In the former well-documented and extensive study, the lowest-observed-effect-level (LOEL) was 600 ppm (2 250 mg/m^3) based on the observation of increased histopathological effects on the olfactory epithelium in the female rats. There were no compound-related neoplasms in either of these studies and NTP concluded that under the conditions of their 2-year inhalation bioassays, there was no evidence of carcinogenic activity for male or female F344/N rats and no evidence of carcinogenic activity for male or female B6C3F$_1$ mice.

In the only identified carcinogenesis bioassay by the oral route (Maltoni *et al.*, 1983; 1985), the authors concluded that toluene caused an increase in total malignant tumours in rats, some of which are relatively rare. Owing to limitations of the study, however, these results are considered to be equivocal.

The weight of evidence indicates that toluene is not mutagenic in mammalian or microbial systems and results concerning its potential to act as a promoter are inconclusive.

Toluene does not appear to be teratogenic in mice, rats, or rabbits, on the basis of limited data. It is fetotoxic at high concentrations (1 000 mg/m^3) which are not toxic to the dam, causing a reduction in fetal weight in mice and rats, and retarded ossification with some increase in minor skeletal anomalies (Ungvary and Tatrai, 1985).

There has been no evidence of carcinogenicity, mutagenicity or ocular toxicity of several of the metabolites of toluene, such as benzyl alcohol, benzaldehyde, benzoic acid and hippuric acid, in studies conducted to date (Huff, 1990; Ikeda, 1987).

With the exception of some unconfirmed behavioural effects reported at very low concentrations (Geller *et al.*, 1979; Horiguchi and Inoue, 1977) and biochemical effects in the brain, the significance of which is unclear, neurotoxic effects have resulted only following exposure to levels greater than those reported to induce other effects in subchronic studies. Data on immunotoxic effects of toluene in animals are limited and inconclusive (e.g., Aranyi *et al.*, 1985; Hsieh *et al.*, 1989).

2.7 Effects on Humans

Available data on the effects of exposure to toluene in humans are derived from studies in volunteers, effects of its use as a solvent of abuse and epidemiological studies of exposed workers. In cases of intentional abuse, exposures have been extremely high (up to 112 500 mg/m^3). Moreover, reported cases of intentional abuse and epidemiological studies of occupationally-exposed populations have generally involved exposures to complex mixtures with toluene as the principal constituent, and the power of most of the epidemiological studies has been limited. These investigations are, therefore, of less value than clinical studies in human volunteers in assessing exposure-response relationships for toluene.

In general, most clinical studies have involved fairly short-term single (20 minutes to 8 hours) or repeated exposures (6 to 7 hours per day for periods of 3 to 4 days or 8 hours biweekly for a period of 8 weeks) of a limited number of subjects (n = 3 to 43) to concentrations ranging from 37.5 to 3 000 mg/m^3. In most of these studies, adverse effects have not been observed following exposure to 375 mg/m^3 or less for single periods of from 20 minutes to 3.5 hours (Gamberale and Hultengren, 1972 in IPCS, 1985; Winneke, 1982 in IPCS, 1985) or repeated exposures for 3 to 7 hours for periods up to 3 days based on a variety of tests of neurological function (Echeverria *et al.*, 1989; Ogata *et al.*, 1970). However, decrease in neurological function as measured by a variety of tests, an increase in neurological symptoms and irritation of the respiratory tract following exposure of 16 volunteers to 375 mg/m^3 6 hours/day for 4 days have been reported (Andersen *et al.*, 1983). These effects are reversible on cessation of exposure, but become increasingly severe and persistent with increasing concentration and/or duration of exposure. No adverse effects were seen at 150 mg/m^3 in this study. Adverse effects on visual vigilance following exposure of 18 to 30 volunteers to 375 mg/m^3 for 4 hours (Dick *et al.*, 1984) and on neurological function following single or repeated exposure to 375 mg/m^3 or less of toluene have also been reported in several other studies, which are less reliable owing to limitations of design (Baelum *et al.*, 1985; von Oettingen *et al.*, 1942 in IPCS, 1985).

2.8 Effects on the Environment

The information available on the acute and chronic toxicity of toluene includes data for species from a number of trophic levels from algae through to fish and amphibians in the

aquatic environment. Information on toxicity to terrestrial species is limited to bacteria, invertebrates, and plants. Although no data were found for wild mammals, the toxicity of toluene to these organisms can be assessed by extrapolation from the results of toxicity studies conducted with laboratory mammals (reported in section 2.6, Mammalian Toxicology, above). No data were available on the effects on birds.

Since toluene is a volatile substance that disappears rapidly from solution, it is difficult to maintain test concentrations for sufficient time to establish concentration-effects profiles for aquatic organisms. Aquatic toxicity data considered in this report are primarily derived from studies where measured toluene concentrations were used to calculate toxicity thresholds, and where tests were conducted under flow-through conditions, static renewal conditions, or using closed vessels with minimal headspace, thereby allowing better maintenance of toluene concentrations. Data from such studies are more meaningful than those from open static tests and from those where thresholds were based on nominal concentrations.

Acute toxicity studies are available for several species at various trophic levels. The 72-hour EC_{50} for the freshwater alga *Selenastrurn capricornutum* was reported to be 12.5 mg/L (Galassi *et al.*, 1988). Growth of the marine diatoms *Skeletonema costatum, Amphidinium carterae, Cricosphaera carterae,* and *Dunaliella tertiolecta* decreased at concentrations of toluene greater than 10 mg/L; growth rates for the latter two species were actually stimulated by 10 to 40% at concentrations of toluene less than 1 mg/L (Dunstan *et al., 1975).*

Among the most sensitive freshwater invertebrates, the 48-hour LC_{50} for the water flea, *Daphnia magna,* was 11.5 mg/L (Bobra *et al.*, 1983). Among marine invertebrates, the 96-hour LC_{50} for larvae of the crab *Cancer magister* was 28 mg/L (Caldwell *et al.*, 1976), and for the grass shrimp, *Palaemonetes pugio,* the 24-hour LC_{50} were 25.8 mg/L for larvae and 17.2 mg/L for adults (Potera, 1975).

The most sensitive fish species were salmonids, including adult rainbow trout, *Oncorhynchus mykiss,* with a 96-hour LC_{50} of 5.8 mg/L (Galassi *et al.*, 1988) and fry of coho salmon, *Oncorhynchus kisutch,* with a 96-hour LC_{50} of 5.5 mg/L (Moles *et al.*, 1981).

The no-observed-effect-concentration (NOEC) for toluene in relation to soil microbial respiration and ammonification ranged from 100 to 1 300 mg/kg and was less than 26 mg/kg (dry weight) for nitrification (Sloof and Blokzijl, 1988). Chlorosis and growth inhibition of terrestrial plants may be induced at levels of more than 6 000 mg/m^3 air, 500 mg/L water, and 1 000 mg/kg soil; growth stimulation may occur at 5 to 50 µg/L (Miller *et al.*, 1976; Syracuse Research Corporation, 1983; Sloof and Blokzijl, 1988).

In long-term studies, the 8-day EC_{50} for growth of *Selenastrum capricornutum* was 9.4 mg/L (Herman *et al.*, 1990). Black *et al.* (1982) determined the toxicity of toluene to the early life stages of rainbow trout, leopard frog *(Rana pipiens)* and northeastern salamander *(Ambystoma gracile).* Eggs of each species were exposed continuously to toluene from within 30 minutes of fertilization (embryos) on through to 4 days post-hatch (larvae), resulting in continuous exposures of 27 days for trout, 9 days for frog, and 9.5 days for salamander. The LC_{50}s for continuous exposure were 0.02 mg/L for trout, 0.39 mg/L for frog, and 0.85 mg/L for salamander. In a 32-day exposure test with embryo-larvae of fathead minnows, the lowest-observable-effect-concentration (LOEC) for weight gain was 6 mg/L (Devlin *et al.*, 1982). Moles *et al.* (1981) studied the growth of coho salmon fry exposed for 40 days to toluene in fresh water. Growth per day, determined from weights and lengths, decreased linearly with increasing concentrations of toluene; the LOEC was 2.8 mg/L and the NOEC was 1.4 mg/L.

Ward *et al*. (1981) exposed embryos and larvae of the marine sheepshead minnow *(Cyprinodon variegatus)* from fertilization to 28 days post-hatch. The LOEC for hatching success and survival was 7.7 mg/L and the NOEC was 3.2 mg/L.

In a 28-day test with earthworms *(Eisenia foetida),* toluene affected mortality, cocoon production, and appearance; appearance was the most sensitive parameter, with a NOEC of between 15 and 50 mg/kg Soil (dry weight) [Sloof and Blokzijl, 1988]. The LC_{50} was between 150 and 280 mg/kg.

3.0 Assessment of "Toxic" under CEPA

As described in the Introduction of this report, the following assessment is organized to address sources of toluene in the environment (i.e., entry), the exposure of humans and other biota, and potential resulting harmful effects.

3.1 Entry

Toluene enters the Canadian environment primarily through atmospheric releases; about 106 kton are released yearly to the atmosphere. Major sources are solvents (54 kton emitted per year) and light duty vehicles (34 kton/year), together accounting for more than 80% of atmospheric releases. Toluene is released to the soil in spills and in leachate from contaminated landfill sites, and to water through spills and discharge of contaminated effluents. Toluene has been measured in Canada in the atmosphere and in certain samples of drinking water, surface water, ground water, industrial effluents, and leachate from waste disposal sites.

3.2 Exposure

Toluene does not persist in water or soil because it biodegrades and volatilizes rapidly to the atmosphere. It does not persist in the atmosphere because it undergoes rapid photooxidation.

Mean airborne toluene concentrations in cities ranged from 5.2 to 44.2 $\mu g/rn^3$, with 24-hour maxima for individual samples ranging from 9.0 to 145.0 $\mu g/m^3$. Mean concentrations of toluene close to self-serve gasoline pumps ranged from 20 to 20 200 $\mu g/m^3$; the average concentrations at the pumps were 1 880 pg/rn^3 in the winter and 2 550 pg/rn^3 in the summer.

From a total of more than 800 water samples taken across Canada, concentrations of toluene above 0.5 µg/IL were only recorded in six samples, including only one surface water sample (0.9 µg/L). The highest concentration of toluene measured in other studies of ambient surface water was 0.5 µg/L. Ambient concentrations of toluene in surface water can therefore be considered to be less than 0.5 µg/L. Concentrations of 22 µg/L were recorded following a spill, while the highest concentration in an effluent was 32 µg/L.

Accumulation of toluene is not expected to be important in any terrestrial or aquatic organism and there are no reports indicating any significant organism bioconcentration or food chain biomagnification.

Since humans are exposed to toluene in all media, total intake has been assessed on a multimedia basis. Estimates of the average daily intake (on a body weight basis) of toluene from various sources for different age groups in the Canadian population, and the assumptions on which they are based, are presented in Table 2. For the general population, the most significant route of exposure is inhalation from air, with estimated intakes ranging from 1.0 to 20.4 µg/kg bw/d. Estimated intake from fish and drinking water is considerably less, ranging from 0.04 to 0.2 µg/kg bw/d and 0.03 to 0.1 µg/kg bw/d, respectively. It should be noted, however that, particularly for food, available data are extremely limited. Estimated intake of toluene at self-serve gasoline stations is less than that from ambient air, ranging from 0.4 to 0.9 µg/kg bw/d. Estimated intake of toluene in consumer products is similar to that from self-serve gasoline stations, ranging from 0 to 1.2 µg/kg bw/d. Cigarette smoke is by far the greatest source of exposure to toluene for smokers. Estimated intakes from mainstream smoke range from 45.2 to 57.1 µg/kg bw/d for individuals 12 years or older. Based on available data,

and as indicated in Table 2, it has been estimated that the total daily intake of toluene for the different age groups ranges from 1.8 to 21.6 µg/kg bw/d. For smokers, the total daily intake will be much higher, up to 71.3 µg/kg bw/d for adults. These estimated intakes which are expected to be typical for the majority of the general population are based on mean values measured in the general environment. Elevated concentrations present, for example, in ground water below waste disposal sites and following gasoline and oil spills, were not considered relevant to estimation of exposure for the general population.

Table 2 - Estimated Daily Intake of Toluene by Canadians from Various Sources

Substrate/Medium	Estimated Intake Micrograms per Kilogram of Body Weight per Day				
	0 – 0.5 yr[b]	0.5 – 4 yr[c]	5 –11 yr[d]	12 – 19 yr[e]	20 – 70 yr[f]
Air (Urban)	1.7 - 14.7	2.0 - 17.0	2.4 - 20.4	2.1 – 17.5	1.5 – 12.6
(Rural)	1.2 - 1.7	1.3 - 1.9	1.6 - 2.3	1.4 - 2.0	1.0 – 1.4
Water	0.03	0.1	0.08	0.04	0.04
Food (Fish)	0.04	0.1	0.2	0.1	0.1
Consumer Products	0	0	0	0.2 – 1.2	0.1 – 0.9
Self-serve Gasoline Station					
(Summer)	0.7	0.8	0.9	0.8	0.6
(Winter)	0.5	0.6	0.7	0.6	0.4
Total Estimated Intake	1.8 - 15.5	2.1 - 18.0	2.6 - 21.6	2.3 – 19.6	1.6 – 14.2
Cigarette Smoking					
(Main-stream)	0	0	0	45.2	57.1
(Side-stream)[8]	0.04	0.05	0.06	0.05	0.04

a Mean concentrations in air are 5.2 - 44.2 µg/m^3 and 3.5 - 5.0 µg/m^3 for urban and rural locations, respectively (Dann *et al*, 1989); mean concentration in drinking water is 2.0 µg/L (Otson *et al*, 1982) and in fish is 1 µg/g (Gilbert *et al*, 1983). It is assumed that consumer products contain 5% toluene, exposure lasts 5 - 30 mm, once per week, and that toluene is absorbed through one hand at a rate of 20 mg/h (Gilbert *et al*,1983). For self-serve gasoline stations, the mean airborne concentrations are 2.55 mg/m^3 **(**PACE, 1987) and 1.88 mg/m^3 (PACE, 1989) in summer and winter, respectively. It is also assumed that the average driver spends 10 minutes per week at the gas station. Cigarettes are estimated to contain 160 µg toluene/cigarette, and side-stream smoke contains 960 µg/cigarette (USDHHS, 1986); it is assumed that adults aged 20 - 70 years smoke 25 cigarettes per day and those 12 - 19 years smoke 15 cigarettes per day.

b Weighs 6 kg, breathes 2 m^3 air, drinks 0.1 L water, (modified from EHD, 1988), and consumes 0.25 g fish daily (HWC, 1977).

c Weighs 13 kg, breathes 5 m^3 air, drinks 0.8 L water, (modified from EHD, 1988), and consumes 1.52 g fish daily (HWC, 1977).

d Weighs 26 kg, breathes 12 m^3 air, drinks 1.1 L water, (modified from EHD, 1988), and consumes 4.81 g fish daily (HWC, 1977).

e Weighs 53 kg, breathes 21 m^3 air, drinks 1.1 L water, (modified from EHD, 1988), and consumes 5.06 g fish daily (HWC, 1977).

f Weighs 70 kg, breathes 20 m^3 air, drinks 1.5 L water, (from ERD, 1988), and consumes 6.59 g fish daily (HWC, 1977).

g It is assumed that the average home volume is 340 m^3 with one individual smoking 2 cigarettes per hour over a 5-hour period and a collection efficiency (CE) of 0.11 for tobacco smoke and based on a formula where dose = respiration rate/hour x duration x concentration x collection efficiency (Rickert and LABSTAT INC., 1988).

3.3 Effects

3.3.1 Human Health

Available epidemiological data are inadequate to assess the carcinogenicity and clastogenicity of toluene in humans. Toluene has not been found to be carcinogenic following inhalation in rats and mice in a well-conducted bioassay (Huff, 1990) and in rats in a less sensitive bioassay (CIIT, 1980). In the only carcinogenesis study by the oral route, the authors concluded that toluene caused an increase in the total malignant tumours in rats (Maltoni *et al.*, 1983; 1985). Owing to limitations of this study, however, these results are considered equivocal. The weight of evidence indicates that toluene is not genotoxic in mammalian or microbial systems. It has been classified, therefore, in Group IV-C (probably not carcinogenic to man) of the classification scheme developed for use in the derivation of the "Guidelines for Canadian Drinking Water Quality" (EHD, 1989).

For compounds classified in Group IV-C, a tolerable daily intake (TDI) is derived on the basis of a no- or lowest-observed-(adverse)-effect-level (NO[A]EL or LO[A]EL) in humans or animal species divided by an uncertainty factor. For toluene, a tolerable daily intake or concentration for the most important route of exposure (i.e., inhalation) can be derived on the basis of results in both humans and animals. (Although data on concentrations of toluene in food are limited, on the basis of available information on levels in fish and drinking water and physical/chemical properties, it is estimated that intake in food and drinking water is negligible compared to that inhaled.) Therefore, a TDI based on the results of inhalation studies in animal species was derived as follows:

$$\text{TDI} = \frac{(375\ \text{mg/m}^3) \times (6.5/24) \times (5/7) \times 0.043\ \text{m}^3/\text{d}}{100 \times 0.025\ \text{kg}}$$

$$= 1.25\ \text{mg/kg/d}\ (1\ 250\ \mu\text{g/kg/d})$$

where:

- .375 mg/m^3 is the lowest NO(A)EL or LO(A)FL in inhalation bioassays of adequate quality in animal species conducted to date (LOEL for a decrease in body weight in mice; Huff, 1990);
- 6.5/24 and 5/7 is the conversion of dosing for 6.5 hours/day, 5 days/week to continuous exposure;
- 0.043 m^3/d is the assumed inhaled air volume of mice (Altmar and Dittmer, 1972);
- 0.025 kg is the assumed body weight of mice (NIOSH, 1985); and
- 100 is the uncertainty factor (x 10 for intraspecies variation; x 10 for interspecies variation; no factor introduced for a LOEL rather than a NOEL since observed effect was a decrease in body weight gain without other evidence of toxicity; additional factor of 10 usually introduced for less than chronic study-however, NOEL in chronic studies more than the LOEL used here).

On the basis of results of the clinical study by Andersen *et al.* (1983), a tolerable daily concentration (TDC) is derived as follows:

$$\text{TDC} = \frac{(150\ \text{mg/m}^3) \times (6/24)}{10}$$

$$= 3.75\ \text{mg/m}^3\ (3\ 750\ \mu\text{g/m}^3)$$

where:

- 150 mg/m^3 is the lowest NOEL based on decrease in neurological function as measured by a variety of tests, an increase in neurological symptoms and irritation of the respiratory tract in an adequate clinical study in human volunteers;
- 6/24 is the conversion of 6-hour daily dosing to continuous exposure;
- 10 is the uncertainty factor (x 10 for intraspecies variation).

A TDI calculated from the TDC by incorporation of the mean inhalation volume and body weight of man (i.e., 20 m^3 and 70 kg; [EHD, 1988]) is 1.07 mg/kg bw/d (1 070 µg/kg bw/d).

3.3.2 *Environment*

For aquatic biota, the most sensitive organism identified in long-term tests was the early life stages of rainbow trout. The reported LC_{50} was 0.02 mg/IL for continuous 27-day exposure of the embryo-larval stages. Coho salmon fry was the most sensitive aquatic organism in acute tests, with a 96-hour LC_{50} of 5.5 mg/L. The 40-day NOEC for growth of coho salmon fry was 1.4 mg/L and the LOEC was 2.8 mg/L.

The effect levels reported in inhalation studies conducted in laboratory animals are considered relevant to wild mammals. The lowest reported effect level was 375 mg/m^3 for mice under conditions of subchronic or chronic exposure to toluene by inhalation.

3.4 Conclusions

Toluene is used in Canada in a variety of applications that lead to its entry into the Canadian environment. These releases result in measurable or predictable concentrations of toluene in the various media to which humans and other organisms may be exposed.

3.4.1 *Paragraph 11(a) - Effects on the Environment*

Except in cases of spills or occasional discharge of contaminated effluent, concentrations of toluene in ambient surface water in Canada are 0.5 µg/L or less. This is at least 40 times lower than the 27-day LC_{50} (0.02 mg/L) for early life stages of rainbow trout, the most sensitive aquatic species in long-term studies. The highest reported level for undiluted effluent discharge was 32 µg/L. This is about 170 times less than the 96-hour LC_{50} (5.5 mg/L) for fry of the coho salmon, the most sensitive aquatic species in acute studies. Concentrations of toluene in a river following a chemical spill were 22 µg/L. This is about 250 times lower than the 96-hour LC_{50} for coho salmon.

The highest mean atmospheric concentration measured in cities (44 µg/m^3) is almost 10 000 times less than the lowest reported effect level for mammals in long-term inhalation studies (375 mg/m^3).

Therefore, on the basis of available data, toluene is not considered to be "toxic" as interpreted under paragraph 11(a) of CEPA.

3.4.2 *Paragraph 11(b) - Effects on the Environment on which Human Life Depends*

Because of its short persistence in the atmosphere and failure to absorb ultraviolet radiation, toluene is not associated with depletion of stratospheric ozone or with global warming.

Therefore, on the basis of available data, toluene is not considered to be "toxic" as interpreted under paragraph 11(*b*) of CEPA.

3.4.3 *Paragraph 11(c) - Effects on the Human Life or Health*

The estimated total average daily intakes of toluene for various age groups in the Canadian population range from 1.6 to 21.6 µg/kg bw/d, though it should be noted that the available data on toluene concentrations in foodstuffs are extremely limited. These average daily intakes of toluene are considerably less (by approximately 50 to 670 times) than the tolerable daily intake derived on the basis of bioassays in animal species (by approximately 60 to 780 times) and that calculated from data from clinical studies in human volunteers.

Therefore, on the basis of available data, toluene is not considered to be "toxic" as interpreted under paragraph 11*(c)* of CEPA.

3.4.4 *General Conclusions*

Therefore, on the basis of available data, toluene is not considered to be "toxic" as interpreted under paragraphs 11(a), *(b)* and *(c)* of CEPA.

4.0 Recommendations for Research

1. To permit a more complete assessment of exposure of the Canadian population to toluene, additional data on concentrations of toluene in the vicinity of Canadian point sources such as coke producers and automobile manufacturing plants and in foodstuffs are desirable, though the priority for this research is considered to be low.

2. Additional data on the interactions of toluene with other substances, and on the mechanisms and the significance of neurotoxicity induced by toluene, are desirable. The priority for this research is considered to be low.

3. Few data are available on the occurrence of toluene as a natural contaminant of ground waters. Additional information on the frequency and magnitude of such natural contamination is desirable. The priority for this research is considered to be low.

4. It is possible that toluene concentrations under ice during the winter may reach levels sufficiently high to affect biota in the winter and spring, though relevant data are lacking. Information on the concentrations and fate of toluene under ice and the potential effects on aquatic biota is, therefore, desirable. The priority for this research is considered to be low.

5. Additional data on the effects of chronic exposure to toluene on growth, survival and reproduction of sensitive freshwater fish are desirable to better estimate the potential harm that could result from continuous exposure to low concentrations of toluene. The priority for this research is considered to be low.

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