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HEALTH AND OTHER EFFECTS OF SHORT-TERM EXPOSURE TO CHEMICALS AFFECTING TASTE AND ODOUR OF DRINKING WATER

Final Report to the Department of the Environment

DWI 4049
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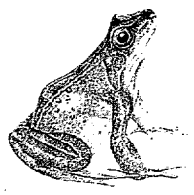

HEALTH AND OTHER EFFECTS OF SHORT-TERM EXPOSURE TO CHEMICALS AFFECTING TASTE AND ODOUR OF DRINKING WATER

Final Report to the Department of Environment

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EXECUTIVE SUMMARY

Chemical incidents affecting drinking water are often detected by their effect on taste and odour. Such incidents vary from contamination by man-made substances such as fuels and industrial chemicals to contamination by naturally occurring compounds such as those produced by various algae and micro-organisms. In addition, chemical treatment including disinfection of water, may transform raw water contaminants into ones which have undesirable taste and/or odour properties. For example, chlorophenols are formed when raw water containing trace amounts of phenols from natural or industrial sources, is chlorinated.

Although it may be natural for consumers to assume that drinking water with an unpleasant taste or smell is not safe to drink, there does not appear to be a direct relationship between taste and odour and effects on health. Some compounds are toxic at concentrations in water which do not produce any taste or odour, whereas chemicals such as chlorophenols are typically detected by taste and odour at concentrations well below those likely to result in any health effects. The toxicity of a compound depends on the duration of exposure and higher concentrations may be tolerated if exposure is only for a short period. Although for many chemicals the taste and odour thresholds are lower than the health-based guidance value, such organoleptic effects cannot be ignored because populations exposed to unpalatable water frequently report a higher incidence of symptoms such as headache, nausea and gastrointestinal upset when compared to unexposed populations.

This reference guide is intended for use in assessing the possible health effects of chemical incidents which affect the taste and odour of drinking water. It contains data summaries on 20 priority chemicals or groups of chemicals which are considered most likely to give rise to a taste and odour incident. The data summaries provide information on taste and odour thresholds and health effects associated with short-term exposure of up to 1 week. The priority chemicals were chosen on the basis of a review of incidents which have occurred in Europe and North America over the last 20 years and which have resulted in taste and odour effects. The introduction to the data summaries gives information about the background to the project and an explanation of the terms used in the data summaries.

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APPENDICES

1. INTRODUCTION

Chemical incidents affecting drinking water are often detected by their effect on taste and odour. Such incidents vary from contamination by man-made substances such as fuels and industrial chemicals to contamination by naturally occurring compounds such as those produced by various algae and micro-organisms. Another common source can be by-products formed during drinking water disinfection. For example, chlorophenols are formed when raw water containing trace amount of phenols, from natural or industrial sources, is chlorinated.

Although it may be natural for consumers to assume that drinking water with an unpleasant taste or smell is not safe to drink, there does not appear to be a direct relationship between taste and odour and effects on health. Some compounds are toxic at concentrations in water which do not produce characteristic taste or odour, whereas chemicals such as chlorophenols are typically detected by taste and odour at concentrations well below those likely to result in any health effects. It should be emphasised that the toxicity of a compound depends on the duration of exposure and that higher concentrations may be tolerated if exposure is only for a short period.

The Department of the Environment awarded a programme of research relating to the health and other effects of short-term exposure to chemicals affecting taste and odour of drinking water, which is managed by the Drinking Water Inspectorate (DWI).

The objective of the project is to provide a simple reference guide to water suppliers and local authorities in assessing possible short-term health effects of chemical incidents affecting taste and odour of drinking water.

2. REVIEW OF TASTE AND ODOUR INCIDENTS

The first phase of the project was to determine a list of chemicals believed to be important in affecting the taste and odour quality of drinking water. This involved a review of incidents which have occurred in Europe and North America over the last 20 years. A comprehensive literature search utilising WRc in-house sources and external databases (including Chemical Abstracts on STN and a number of databases hosted by DIALOG) was undertaken which generated an initial list of chemicals which is given in Appendix A.

In general, the cause of consumer complaints about taste and odour can be divided up into a number of broad categories. These include those associated with disinfection, pollution (e.g. industrial, permeation of plastic pipes), with the distribution system itself and those of biological origin.

a) For the complaints linked with disinfection, these tend to be associated with large (or variable) chlorine residuals or with the production of disinfection by-products. For example, chlorine may chlorinate organic substances, e.g. phenols to produce chlorophenols, or may oxidise organic substances. For waters which contain bromide or iodide, these species can be oxidised by chlorine to form bromine and iodine which can halogenate organic substances more readily than chlorine. In some instances, the resulting by-products such as bromophenols can cause taste and odour at extremely low concentrations. Also, there have been a number of instances where aldehydes have been formed during ozonation causing 'fruity, sweet' tastes.

b) Many complaints may be traced back to substances of biological origin, in particular the production of odorous compounds by algae and micro-organisms in surface waters, finished water storage facilities or the distribution system.

c) Although there have been numerous instances of raw water pollution by industrial chemicals, a much smaller number has caused taste and odour complaints in drinking water. However, there have been many occasions where contamination has occurred through permeation of plastic pipes by compounds such as diesel fuel, petrol and other fuel-like substances. Also, backflow incidents have on occasion resulted in taste and odour complaints.

d) A number of taste and odour complaints can be traced to corrosion products (e.g. copper) or may be a result of components that leach from linings of water pipes or storage facilities (e.g. plasticisers, solvents).

e) The origin of many complaints can also be traced back to problems with internal plumbing. These often arise from the use of unapproved materials in consumers' systems, for example resulting in washers that decay.

A point that should be emphasised is that in many cases of consumer complaints the exact cause of the taste and odour problem cannot be readily established.

3. COMPILATION OF DATA SUMMARIES ON PRIORITY CHEMICALS

The chemicals which were identified in the initial review of taste and odour incidents were prioritised in order to establish the 'top 20' priority chemicals/groups of chemicals considered as most likely to give rise to an incident. Data summaries were then prepared to give information on the range of taste and odour thresholds reported in the literature and to assess any potential health effects following short-term exposure of up to 1 week.

The top twenty list of priority chemicals are listed in Appendix B and the individual data summaries are given and ordered alphabetically in Appendix C.

The individual data summaries follow the same general format as follows:

- Indication of the source of chemical
- Summary of Health Effects
- Short-term Health Guideline Values
- Taste and Odour Effects
- Overall evaluation

A more detailed explanation of how to interpret the data given in the sections 'Short-term Health Guideline Values' and 'Taste and Odour Effects' is given in sections 3.1 and 3.2.

3.1 Short-term Health Guideline Values

In the first instance, this section details any short-term health advisory values which have been established by the United States Environmental Protection Agency (USEPA). These short-term health advisories are based on a 1- or 10-day exposure period and a brief description of how the health advisories have been derived by the USEPA has been included. It should be noted that the derivation of these health advisories is intended to provide a wide margin of safety and therefore it does not necessarily mean that the presence of the chemical at a concentration exceeding the health advisory renders the drinking water unsafe to drink. Where a concentration of chemical exceeds a health advisory or is present for longer periods than those specified for the health advisories, further toxicological advice should be sought (see section 3.3).

In the absence of short-term health advisories derived by the USEPA, where appropriate, WRc has proposed 'Suggested-No-Adverse-Response-Levels" otherwise known as SNARLs. A SNARL represents an estimate of a concentration of a chemical(s) in drinking water which is considered safe for human consumption over specific durations of exposure, namely 24 hours or 7 days. They are derived by WRc toxicologists and do not constitute standards. Like the USEPA health advisories, they are intended to provide a wide margin of safety and the basis of their derivation has been included. However, they should be used with care and therefore should the concentration of a pollutant approach

the SNARL, or be present for longer periods than those for which SNARLs are given, further toxicological advice should be sought (see section 3.3).

3.2 Taste and Odour Effects

This section provides information on the range of threshold concentrations which have been reported to cause taste and odour effects in drinking water. In the majority of cases the concentrations are calculated as those most likely to be detectable by 50% of the population. For most compounds, a wide range of thresholds has been reported, indicating that there can be considerable variation in the taste and odour thresholds reported by different individuals. For some substances the distribution of sensitivity across a population can be bimodal. In these cases, which include styrene and butyric acid, part of the population will be insensitive or virtually insensitive to any concentration. It is also recognised that the sensitivity of a particular individual can vary from day to day. Consequently, the level and quality of taste and odour that is regarded as acceptable can vary enormously. However, as part of the overall evaluation for a particular chemical, advice has been given on the concentrations most likely to cause taste and odour effects.

3.3 Further advice

For an incident which may result in a potential health hazard or cause alarm to consumers owing to changes in taste, odour or appearance of their water, then expert toxicological advice should be immediately obtained and the relevant local and health authorities must be notified. Where an incident could involve significant health risk or concern to consumers, the Drinking Water Inspectorate must also be notified as soon as possible. For incidents involving private supplies, the local authority must be notified.

Further advice on the technical aspects of this report can be obtained from the National Centre for Environmental Toxicology which is managed by WRc (Telephone No. 01491 571531). The National Centre also provides a subscription based enquiry and advisory service for chemical incidents affecting the quality of drinking water. This provides advice on health risks and other aspects such as taste and odour and is available for emergency advice 24 hours a day. All UK water suppliers subscribe to this independent service through their joint research programmes.

The National Poisons Information Service (NPIS) is available to public health physicians and to other clinicians. Toxicological information can be obtained through the Poisons Centres which are located in London, Belfast, Cardiff, Edinburgh, Birmingham, Leeds and Newcastle (see Appendix F). The 1993 World Health Organization (WHO) 'Guidelines for Drinking-Water Quality' is also a useful document for guidance especially when the duration of exposure becomes longer-term.

4. GLOSSARY OF TERMS

Acute toxicity: Toxicity manifested within a relatively short time period (e.g. as short as a few minutes to as long as several days). Such toxicity is frequently caused by a relatively high single dose of the toxicant.

Carcinogenicity (carcinogen(ic)): The potential for a chemical to induce cancer. It is usually identified from toxicity data generated in laboratory animals. It may, however, also be apparent in human studies (epidemiology) which compare the incidence of cancer in exposed populations (often occupational groups) with those who have not been exposed to the chemical. The great majority of studies are based on very long exposure periods.

CNS: Central nervous system.

Chronic toxicity: Toxicity manifested after a long time period of uptake of small quantities of a toxicant.

Embryotoxic: The potential for a chemical to cause toxic effects on an embryo.

Fetotoxic: The potential for a chemical to cause toxic effects on a foetus.

Health Advisory: The concentration of a chemical in drinking water which is not expected to cause any adverse non-carcinogenic effects for the period stated, with a margin of safety. They are derived by the United States Environmental Protection Agency and are not legal standards but serve as a technical guideline.

LD_{50}: The dose of a chemical which is lethal to 50% of the test population (usually rodents) and which is used as an indication of a chemical's short-term toxicity.

LD_{Lo}: The lowest dose of a chemical which has caused death in the test population.

International Agency for Research on Cancer (IARC): An international body which specifically evaluates the carcinogenic risk of chemicals.

Intraperitoneal: administration of a chemical via injection in the peritoneal cavity.

In vitro: Isolated from the living organism and artificially maintained e.g. in a test tube.

In vivo: Within a living organism.

Mutagenicity (mutagen(ic)): the ability of a chemical to cause changes in the genetic material (DNA) within a cell which can be passed on to daughter cells following cell division.

NOAEL (No-observable-adverse-effect-level): the dose of a chemical at which no statistically significant increase in frequency or severity of adverse effects is observed between the exposed and non-exposed control population.

Organoleptic: The taste and odour aspects of water quality.

Reference Dose (RfD): an estimate of the daily dose of a chemical which a person can be exposed to over a lifetime which appears to be without appreciable risk to health.

SNARL (Suggested No Adverse Response Level): A rough guide to the concentration of a chemical(s) in drinking water which is considered safe for human consumption over a specified time period, usually 24 hours or 7 days. They are derived by WRc toxicologists and do not constitute standards.

TD_{Lo}: the lowest dose of a chemical shown to cause toxic effects in a test population.

Teratogenicity (teratogen(ic)): the ability of a chemical to cause birth defects in offspring.

Tolerable daily intake (TDI): an estimate of the daily dose of a chemical which a person can be exposed to over a lifetime which appears to be tolerated without appreciable risk to health based on the facts known at the time.

USEPA: United States Environmental Protection Agency.

WHO: World Health Organization.

APPENDIX A INITIAL LIST OF COMPOUNDS ASSOCIATED WITH TASTE AND ODOUR COMPLAINTS

1. Problems associated with disinfection

Aldehydes

- Acetaldehyde
- Methional
- Butyraldehyde
- 2-Methylbutanal (2-methylbutyraldehyde)
- 2-Methylpropanal (*iso*butyraldehyde)
- 3-Methylbutanal (*iso*valeraldehyde)
- Phenylacetaldehye
- Vanillin
- Heptanal
- Octanal
- Nonanal
- Decanal
- Benzaldehyde

Bromophenols

- 2-Bromophenol
- 4-Bromophenol
- 2,4-Dibromophenol
- 2,6-Dibromophenol
- 2,4,6-Tribromophenol

Bromochlorophenols

- 4-Bromo-2-chlorophenol
- 4-Bromo-2,6-dichlorophenol

Chlorine

Chlorine dioxide

Chlorophenols

- 2-Chlorophenol
- 4-Chlorophenol
- 2,4-Dichlorophenol
- 2,6-Dichlorophenol
- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol

Decane nitrile

Dichloramine

Haloforms (THMs)

- Iodoform
- Bromoform

- Chloroform
- Bromochloroiodomethane
- Bromodiiodomethane
- Chlorodiiodomethane
- Dibromoiodomethane
- Dichloroiodomethane

Iodophenols
Monochloramine
Nonane nitrile
Trichloramine (nitrogen trichloride)

2. Biological origin

Aldehydes (e.g. hexanal, *n*-heptanal, octanal, nonanal, decanal)
Cadin-4-ene-1-ol
Chloroanisoles

- 2-Chloroanisole
- 4-Chloroanisole
- 2,4-Dichloroanisole
- 2,6-Dichloroanisole
- 2,3,6-Trichloroanisole
- 2,4,6-Trichloroanisole
- 2,3,4,6-Tetrachloroanisole
- 2,3,4,5,6-Pentachloroanisole

Geosmin
Guaiacol
Indole
2-*iso*Butyl-3-methoxypyrazine
2-*iso*Propyl-3-methoxypyrazine
Mercaptans

- Allyl mercaptans
- Benzyl mercaptan
- Crotyl mercarptan
- Ethyl mercaptan
- Methyl mercaptan

2-Methylisoborneol
Skatole
Sulphides

- Alkyl sulphides (e.g. diphenyl sulphide, ethyl sulphide, methyl sulphide)
- Dimethyltrisulphide
- Hydrogen sulphide
- Dimethyldisulphide

Thymol
Trans-2-cis-6-nonadienal

3. Pollution (Industrial/permeation of pipes)

C2 and C3 alkylbenzenes

- *n*-Propylbenzene
- Ethylbenzene
- *iso*Propylbenzene
- Trimethylbenzenes (1,2,3-; 1,2,4-; 1,3,5-trimethylbenzene)
- Xylenes (*m*-xylene, *o*-xylene, *p*-xylene)

Aluminium
Aniline
Benzaldehyde
Benzene
Benzeneacetonitrile
Benzothiazole
Bis(2-chloro*iso*propyl)ether
Chlordane
Creosote
Cresols and chlorinated cresols

- *o*-Cresol
- *m*-Cresol
- *p*-Cresol
- 4-Chloro-*o*-cresol
- 6-Chloro-*o*-cresol
- 4-Chloro-*m*-cresol
- 6-Chloro-*m*-cresol
- 2-Chloro-*m*-cresol
- 2-Chloro-*p*-cresol

Dichlorobenzenes

- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene

Diesel fuel
Diisopropylether
2-Ethyl-5,5-dimethyl-1,3-dioxane (EDD)
Ethylxylene
Fuel oil
Galaxolide
Hydraulic fluid
2-Hydroxy-4-(methylthio)butanoic acid
(breakdown product methyl(methylmethio)methyl disulphide)
Indane
Indene
*p-iso*Propyltoluene
Kerosene
2-Mercaptobenzothiazole
2-Methylbenzothiazole

Methylnaphthalenes (i.e. 1-methylnaphthalene, 2-methylnaphthalene)
2-Methylthiobenzothiazole
Methylstyrene
Monochlorobenzene
MTBE
Naphthalene
Nitrotoluene
N-phenylformamide
Petrol
Styrene
Tetrachloroethane
Tetrachloroethylene
TNT
Toluene
Trichlorobenzenes

- 1,2,3-Trichlorobenzene
- 1,2,4-Trichlorobenzene
- 1,3,5-Trichlorobenzene

1,1,1-Trichloroethane
Trichloroethylene
White spirit

4. Distribution system (pipes, reservoirs)

Copper
Iron
Manganese
Zinc
Coal tar linings (chlorine + coal tar pitch)
Polyethylene pipe (alkathene)
2,6-di-*tert*-butyl-p-benzoquinone (DBQ) (chlorine on antioxidant Irganox 1010, 1035, 1076, 1330, 3112, 1425 WL, MD 1024)
2-*tert*-butyl-5-methyl-1,4-benzoquinone (chlorine on antioxidant Santanox)
2,2,4,-trimethylpentane-1,3-diol di*iso*butyrate
Oleate-based pipe joint lubricants

- Hexanal
- Heptanal
- Octanal
- Nonanal

Solvents (compounds are included in section 3.)

APPENDIX B TOP TWENTY PRIORITY COMPOUNDS ASSOCIATED WITH TASTE AND ODOUR CONSUMER COMPLAINTS

C2 and C3 Alkylbenzenes

- Ethylbenzene
- *iso*Propylbenzene
- *n*-Propylbenzene
- Trimethylbenzenes (1,2,3-; 1,2,4-; 1,3,5-trimethylbenzene)
- Xylenes (*m*-xylene, *o*-xylene, *p*-xylene)

Benzene

Bromochlorophenols

- 4-Bromo-2-chlorophenol
- 4-Bromo-2,6-dichlorophenol

Bromophenols

- 2-Bromophenol
- 4-Bromophenol
- 2,4-Dibromophenol
- 2,6-Dibromophenol
- 2,4,6-Tribromophenol

Chloramines

- Monochloramine
- Dichloramine
- Trichloramine (nitrogen trichloride)

Chlorine

Chloroanisoles

- 2-Chloroanisole
- 4-Chloroanisole
- 2,4-Dichloroanisole
- 2,6-Dichloroanisole
- 2,3,6-Trichloroanisole
- 2,4,6-Trichloroanisole
- 2,3,4,6-Tetrachloroanisole
- 2,3,4,5,6-Pentachloroanisole

Chlorobenzenes

- Monochlorobenzene
- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 1,2,3-Trichlorobenzene
- 1,2,4-Trichlorobenzene
- 1,3,5-Trichlorobenzene

Chlorophenols

- 2-Chlorophenol

- 4-Chlorophenol
- 2,4-Dichlorophenol
- 2,6-Dichlorophenol
- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol

Cresols and chlorinated cresols

- *o*-Cresol
- *m*-Cresol
- *p*-Cresol
- 4-Chloro-*o*-cresol
- 6-Chloro-*o*-cresol
- 4-Chloro-*m*-cresol
- 6-Chloro-*m*-cresol
- 2-Chloro-*m*-cresol
- 2-Chloro-*p*-cresol

2-Ethyl-5,5-dimethyl-1,3-dioxane (EDD)
Geosmin
Iron
2-*iso*Butyl-3-methoxypyrazine
2-*iso*Propyl-3-methoxypyrazine
p-*iso*Propyltoluene
2-Methylisoborneol
Naphthalene
Styrene
Sulphides

- Alkyl sulphides (e.g diphenyl sulphide, ethyl sulphide, methyl sulphide)
- Dimethyltrisulphide
- Hydrogen sulphide
- Dimethyldisulphide

Toluene

N.B. Creosote, Diesel fuel, Fuel oil, Hydraulic fluid, Kerosene, Petrol, White spirit are common causes of taste and odour complaints. Their composition can vary widely, but they are generally a complex mixture of a range of hydrocarbons and additives. The components most likely to cause taste or odour in water are the alkylaromatics and low molecular weight polycyclic aromatics and these have been covered in the 'top twenty' priority compounds.

APPENDIX C DATA SUMMARIES FOR THE TOP TWENTY PRIORITY COMPOUNDS

BENZENE

Benzene is most likely to occur in drinking water as a result of contamination by petroleum products or raw water pollution.

Health Effects

Benzene is readily absorbed following ingestion but is poorly absorbed through intact skin[10]. It is excreted predominantly in the urine as phenol sulphate and to a lesser extent glucuronide conjugates [1].

In man, most toxicity data relate to the inhalation route of exposure. Symptoms of acute exposure include central nervous system effects such as dizziness, visual disturbances, nausea, vomiting, headache, drowsiness, loss of balance and at very high doses, narcosis, coma and death[1,2]. The single acute oral lethal dose in humans has been estimated at 8.8 g of benzene[10]. Repeated exposure to low levels of benzene is well known to cause toxic effects on the bone marrow resulting in blood disorders e.g. anaemia and different forms of leukaemia, and immune suppression [1,2,5,10].

Based on studies in laboratory animals, benzene is of low acute oral toxicity (rat oral LD_{50} 3.0-8.1 g kg^{-1})[10]. Oral administration of benzene to rats, 5 days per week for 6 months, was reported to produce a 'minimal' toxic effect at 10 mg kg^{-1} body weight[11]. Benzene is a well recognised carcinogen in humans and laboratory animals and has been shown to have mutagenic activity[3]. It does not appear to be teratogenic but may be fetotoxic at high doses based on inhalation studies in rodents[2,4,10].

Short-term health guideline values

The USEPA have established 1- and 10-day health advisories of 200 µg l^{-1} based on a 10 kg child drinking 1 litre of water per day. These were derived by applying an uncertainty factor of 100 to a NOAEL identified in a 31-week inhalation study in rats[1].

Taste and odour Effects

A very wide range of odour threshold concentrations have been reported in the literature. The lowest odour threshold concentrations of 24 and 120 µg l^{-1} were reported at 60°C[6], but higher threshold concentrations of 170, 2000, 10,000 and 31,300 µg l^{-1} have also been reported[1,7,8]. An odour threshold of 190 µg l^{-1} was reported at 40°C based on 8/10 panellists detecting an odour (at 77 µg l^{-1} none of the panellists detected an odour)[9]. Taste threshold concentrations of 400 and 600 µg l^{-1} have also been reported at 40°C[6].

Overall Evaluation

A very wide range of odour threshold concentrations have been reported in the literature making it difficult to determine the exact odour threshold for benzene. However, it would appear that the odour threshold concentration is most likely to be around 200 µg l^{-1} which is the same as the USEPA 1- and 10-day health advisories of 200 µg l^{-1}.

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BROMOCHLOROPHENOLS

Bromochlorophenols can be formed during the chlorination of raw water containing phenol and bromide ion[1]. This data summary has reviewed *4-bromo-2-chlorophenol* and *4-bromo-2,6-dichlorophenol* as examples of bromochlorophenols which have been detected in drinking water at ng l^{-1} levels[2] and implicated in taste and odour problems.

Health Effects

No toxicity data were located specifically for the two bromochlorophenols under review. However, toxicity data were located for the structurally similar compound 4-bromo-2,5-dichlorophenol which indicates that it is of low acute oral toxicity in laboratory animals (oral rat LD_{50} 1350 mg kg^{-1})[3].

Short-term health guideline values

There are no health-based guideline values for bromochlorophenols.

Taste and odour Effects

Although no published taste or odour thresholds were located for the two bromochlorophenols under review they were detected in drinking water at low ng l^{-1} levels during a taste and odour incident. In view of the low taste and odour thresholds which have been published for a variety of bromo- and chlorophenols, it is likely that these compounds will be detected by taste or odour at concentrations at, or below 1 µg l^{-1}.

Overall Evaluation

Although there are no toxicity data available for the bromochlorophenols under review, based on a structurally similar bromochlorophenol, it is considered unlikely that they will result in any significant health effects in the short-term, other than possibly through palatability, at the very low concentrations at which they are likely to cause taste and odour problems.

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BROMOPHENOLS

Bromophenols can be formed during the chlorination of raw water containing phenol and bromide ion[3] and a number have been detected in drinking water at trace ng l^{-1} levels[4,10]. This data summary has reviewed *2-bromophenol, 4-bromophenol, 2,4-dibromophenol, 2,6-dibromophenol and 2,4,6-tribromophenol* as examples of bromophenols which are most likely to be detected in drinking water.

Health Effects

The toxicity database for this class of compounds is limited but based on studies in laboratory animals, they appear to be of moderate to low acute oral toxicity. Oral LD_{50} values have been reported in the mouse as follows: 2-bromophenol 652 mg kg^{-1}; 4-bromophenol 523 mg kg^{-1}; 2,4-dibromophenol 282 mg kg^{-1}; 2,4,6-tribromophenol 2000 mg kg^{-1}[5]. An oral LD_{50} of 1900 mg kg^{-1} has also been reported in the rat for 2,4,6-tribromophenol[9]. Symptoms of acute exposure include increased respiratory rate, loss of muscle tone, collapse and death for 2,4,6-tribromophenol[6].

2,6-Dibromophenol and 2,4,6-tribromophenol do not appear to be mutagenic based on bacterial studies[7,8,9]. There are no toxicological data concerning the carcinogenic potential for the bromophenols reviewed. In a pilot teratology study, oral administration of 2,4,6-tribromophenol in pregnant rats resulted in fetotoxic effects but only at a maternally toxic dose. No such effects were seen at doses at or below 300 mg kg^{-1}[9].

Short-term health guideline values

There are no short-term health guideline values established for bromophenols.

Taste and odour Effects

	Taste threshold (μg l^{-1})	Odour threshold (μg l^{-1})
2-Bromophenol	0.03, 0.17[1,2]	0.1[1]
4-Bromophenol	23, 250[1,2]	160[1]
2,4-Dibromophenol	4[2]	No data located
2,6-Dibromophenol	0.0005[2]	No data located
2,4,6-Tribromophenol	0.6[2]	No data located

Overall Evaluation

Some of the bromophenols reviewed are likely to cause taste effects at extremely low concentrations. In particular, 2-bromophenol, 2,6-dibromophenol and 2,4,6-tribromophenol are likely to cause taste effects at levels which are less than 1 μg l^{-1}. Although only

limited toxicity data are available, it is considered that the bromophenols reviewed are unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low concentrations at which they cause taste and odour problems.

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CHLORAMINES

Mono-, di- and trichloramines are formed in water which contains ammonia and undergoes chlorination. The type of chloramine formed is dependent on the chlorine to ammonia ratio, pH, temperature and contact time. Monochloramine is also used as a disinfectant.

Health Effects

Of the chloramines, monochloramine has been the most extensively studied toxicologically. In rodents, it is readily absorbed from the gastrointestinal tract and metabolised to the chloride ion which is excreted primarily in the urine and to a lesser extent in the faeces[1]. In a controlled human trial, monochloramine was administered at increasing doses of up to 24 mg l^{-1} to 10 healthy adult males over a 16 day period. No adverse health effects were observed based on clinical signs, urinalysis, haematology and clinical chemistry. When 10 healthy adult males were exposed to 500 ml of water containing 5 mg l^{-1} of monochloramine for 12 weeks again no adverse health effects were observed[2].

The main short-term toxic effect of monochloramine is its ability to induce haemolytic anaemia and this has been reported in haemodialysis patients when tap water containing chloramines was used for dialysis[3].

There have been a number of short- and long-term drinking water studies carried out in laboratory animals for monochloramine and no specific, clearly adverse treatment effects have been observed. The lowest NOAEL identified in these studies was 5.2 mg kg^{-1} body weight day^{-1} reported in a 2 year drinking water study in rats. The NOAEL was based on lowered body weights which may have been attributable to the unpalatability of the drinking water[4].

Based on laboratory animal studies, monochloramine has shown no evidence of causing reproductive, teratogenic or embryotoxic effects[5,6]. The balance of evidence indicates that monochloramine does not appear that to be mutagenic or carcinogenic.

No relevant toxicity data were located for di- or trichloramine.

Short-term health guideline values

The USEPA have established draft 1- and 10-day health advisories of 1 mg l^{-1} for monochloramine based on a 10 kg child drinking 1 litre of water per day. These were derived by applying an uncertainty factor of 100 to a NOAEL identified in a 6-week study in monkeys which was based on the absence of effects on the blood. However, in view of the data available in humans and the World Health Organization (WHO) guideline value of 3 mg l^{-1} based on lifetime exposure, these values appear to be highly conservative.

It should be noted that dialysis patients are a particularly sensitive population and that chloraminated tap water has been shown to cause acute haemolytic anaemia in such patients. A dialysis water standard of 0.1 mg l^{-1} (measured as chlorine) has been established for chloramine in the USA[7].

Taste and odour Effects

Trichloramine has the lowest odour threshold of the chloramines with an odour threshold of 0.02 mg NCl_3 l^{-1} being reported[8,10,11]. (The original source and hence derivation of this value is not given in these references).

For dichloramine, one study found the organoleptic effects between 0.1 and 0.5 mg l^{-1} to be 'slight' and 'acceptable', the concentration being expressed as mg l^{-1} chlorine (Cl_2). Odour and taste thresholds of 0.15 and 0.13 mg Cl_2 l^{-1} were reported, respectively, although the authors considered that a concentration at, or below 0.5 mg Cl_2 l^{-1}, is likely to be of adequate organoleptic quality[9]. This study used a minimum of four trained panellists in each session and samples were tested at 25°C. Another study reported that an odour is noticeable in drinking water containing dichloramine at levels above 0.8 mg $NHCl_2$ l^{-1} [10].

By comparison, monochloramine has a much higher odour threshold than di- or trichloramine. In one study, most panellists perceived no odour or taste at concentrations between 0.5 to 1.5 mg Cl_2 l^{-1}. Sensitive panellists detected a slight organoleptic effect in this range and for such individuals an odour and taste threshold of 0.65 and 0.48 mg Cl_2 l^{-1} were reported, respectively[9]. However, the authors concluded that monochloramine would not be very odorous at concentrations of up to 3 mg l^{-1} for the majority of individuals.

Overall Evaluation

Of the chloramines, monochloramine is the species most likely to be found in drinking water. Monochloramine has the highest taste and odour thresholds of the chloramines and is unlikely to be detected organoleptically at concentrations below 1 mg l^{-1} other than by extremely sensitive individuals. Concentrations above 3 mg l^{-1} are more likely to impart effect on taste and odour which is lower than concentrations likely to be of significant risk to health in the short-term. No adverse health effects were observed following short-term exposure to 24 mg l^{-1} in a controlled human study and no specific, clearly adverse treatment effects have been observed in studies undertaken in laboratory animals.

Dichloramine is likely to be detected by odour at concentrations above 0.5 mg l^{-1} by most individuals whereas trichloramine can be detected at levels as low as 0.02 mg l^{-1}. Although no relevant toxicity data were identified for these two compounds, based on monochloramine, there is no evidence to suggest that such concentrations are likely to be of significant risk to health in the short-term.

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CHLORINE

Chlorine is present in drinking water as a result of its use as a disinfectant and oxidant in drinking water treatment.

Health Effects

Chlorine is an irritant and in man, most toxicity data relate to effects following inhalation of chlorine gas. Clinical cases of toxicity following ingestion of chlorine have been few and short-term exposure concentrations of up to 50 mg l^{-1} and above, appear to have caused no adverse health effects in man. Momentary throat and mouth irritation have been observed following the ingestion of water containing 90 mg l^{-1}[2,3]. Ingestion of very high doses is likely to cause symptoms such as burning sensation, thirst, abdominal cramps, nausea and vomiting.

Lubbers *et al*[4] investigated the effects of chronic exposure of healthy male volunteers, aged 21 to 35 years, to chlorine in drinking water. In Phase I, progressively increasing doses of chlorine were administered in water every 3 days, for a total of 18 days, at concentrations of 0, 0.1, 1, 5, 10, 18 and 24 mg l^{-1}. In Phase II, 10 subjects ingested chlorine at a daily concentration of 5 mg l^{-1} (500 ml per day) for 12 consecutive weeks and no significant adverse toxic effects were observed.

Chlorine appears to be of low oral toxicity to laboratory animals and when exposed to chlorine in drinking water, no specific adverse treatment-related effects have been observed[1]. No adverse effects were seen in rats when exposed to a chlorine dose of 15 mg kg^{-1} body weight day^{-1} in drinking water for 2 years[1].

The reactive nature of chlorine makes it difficult to assess its mutagenicity. The tests which have been carried out show evidence of mutagenicity *in vitro* but not *in vivo*. Chlorine does not appear to be carcinogenic[5,6] nor does it appear to cause adverse reproductive effects including teratogenicity[6,7].

Short-term health guideline values

There are no short-term health-based guideline values for chlorine. However, there is evidence from studies in humans that short-term exposure to concentrations of up to 50 mg l^{-1} cause no adverse effects. It should also be noted that in 1993, the World Health Organization derived a conservative health-based guideline value of 5 mg l^{-1} based on lifetime exposure and at this concentration most individuals are able to taste chlorine[1].

Taste and odour Effects

Taste and odour thresholds for chlorine in distilled water are reported as 5 and 2 mg l^{-1}, respectively[1]. Most individuals are able to taste chlorine or its by-products (e.g. chloramines) at concentrations below 5 mg l^{-1}. Bryan *et al*[8] studied the taste threshold of residual chlorine in odour-free distilled and demineralised water at different pH values with a panel size of 11. Threshold concentrations of 0.075, 0.156 and 0.45 mg l^{-1} were reported at pH 5, pH 7 and pH 9. These tests indicate a wide range of sensitivity of the

panellists with, for example, 95% confidence limit at pH 7 was 0.02-0.29 mg l^{-1}. Another study reported that a chlorine concentration of 0.8 mg l^{-1} in mineralised water at 25°C had a distinct taste and odour[9] but this value was not an estimate of a threshold concentration.

Overall Evaluation

It is generally considered that a residual chlorine concentration of between 0.2 and 0.3 mg l^{-1} can begin to cause taste problems. However, experience suggests that changes in chlorine concentrations from normal levels are a frequent cause of complaints. These concentrations are well below those considered to be of significant risk to health in the short-term and are also below the WHO health-based drinking water guideline value of 5 mg l^{-1} for chlorine which is based on lifetime exposure.

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CHLOROANISOLES

Chloroanisoles are most likely to occur in drinking water as a result of bacterial methylation of chlorophenols during water distribution[6,7]. This data summary has reviewed *2-chloroanisole, 4-chloroanisole, 2,4-dichloroanisole, 2,6-dichloroanisole, 2,3,6-trichloroanisole, 2,4,6-trichloroanisole, 2,3,4,6-tetrachloroanisole and 2,3,4,5,6-pentachloroanisole* as examples of chloroanisoles which may be detected in drinking water.

Health Effects

Practically no toxicity data were located for the chloroanisoles. Pentachloroanisole appears to be of moderate acute oral toxicity in laboratory animals (oral LD_{Lo} 500 mg kg^{-1} in the rat; mouse oral LD_{50} 318 mg kg^{-1})[8,9]. Only very limited mutagenicity data are available for pentachloroanisole but it appears to have some mutagenic activity[8,9]. In a 181 day study, pentachloroanisole was given to male and female rats at doses of 0, 4, 12 or 41 mg kg^{-1} body weight through mating and pregnancy. At the highest dose, females showed a decreased body weight gain. There was evidence of fetotoxicity at the highest dose but no evidence of teratogenicity was found[10].

It should be noted that anisole is used in perfumes and is considered to be of low short-term oral acute toxicity in laboratory animals (rat oral LD_{50} 3700 mg kg^{-1}; mouse oral LD_{50} 2800 mg kg^{-1})[9] .

Short-term health guideline values

There are no short-term health guideline values for the chloroanisoles.

Taste and odour Effects

Chloroanisole	Odour threshold (ng l^{-1})	Taste threshold (ng l^{-1})
4-Chloroanisole	<2000, 20000[1]	6200, 10000[1]
2,4-Dichloroanisole	210[1] 400 [5,11] 500[1]	80, 400[1]
2,6-Dichloroanisole	40[5,11]	No data located
2,3,6-Trichloroanisole	4[12] 7[4] 7.4, 24.5[3]	No data located
2,4,6-Trichloroanisole	0.03[11] 0.08, 0.9 [1]	20[2] 25, 50[1]
2,3,4,6-Tetrachloroanisole	4[11]	200[2]
2,3,4,5,6-Pentachloroanisole	4000[11]	3200[2]

Overall Evaluation

Chloroanisoles have been involved in a number of taste and odour incidents and are most likely to occur in drinking water as a result of biological methylation of chlorophenols during water distribution. In general, they have very low taste and odour thresholds in the low ng l^{-1} range and usually below 1 $\mu g\ l^{-1}$. 4-Chloroanisole and pentachloroanisole have higher taste and odour threshold concentrations which are more likely to be around a few $\mu g\ l^{-1}$. Although the toxicological data are limited for the chloroanisoles, they are considered unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low concentrations at which they cause taste and odour problems.

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CHLOROBENZENES

Chlorobenzenes are common industrial chemicals which are most likely to contaminate drinking water as a result of raw water pollution. This data summary has reviewed *monochlorobenzene, 1,2-; 1,3-; 1,4-dichlorobenzene and 1,2,3-; 1,2,4- and 1,3,5-trichlorobenzene* as examples of chlorobenzenes which may be detected in drinking water.

Health Effects

The chlorobenzenes are readily absorbed following ingestion and are metabolised principally to phenols. Following conjugation, they are rapidly and predominantly excreted in the urine as glucuronides or sulphates[1,2,10].

In man, most toxicity data on chlorobenzenes relate to exposure following inhalation either from occupational exposure or solvent abuse. The main toxic effect is central nervous system (CNS) depression and irritation of the eye and respiratory tract [1,2]. In some cases, effects on the liver and blood may develop[1,2].

Based on laboratory animal studies, mono- and dichlorobenzenes are of low acute oral toxicity and the trichlorobenzenes are of moderate acute oral toxicity[1,2,3]. Numerous short- and long-term oral studies have been carried out in laboratory animals for the chlorobenzenes and the target organs following exposure to high doses are predominately the liver and kidney[1,2,3].

For monochlorobenzene, doses which have caused no adverse toxic effects in 13-week studies in animals include 27.25 mg kg^{-1} body weight day^{-1} in dogs and 60 mg kg^{-1} body weight day^{-1} in rats and mice when administered 5 days/week[1,10].

Studies in rats and mice have reported no adverse effects when given doses of 125 mg kg^{-1} body weight day^{-1} of 1,2-dichlorobenzene (5 days/week) for 13 weeks[1,10]. In the case of 1,4-dichlorobenzene doses of 150 and 337.5 mg kg^{-1} body weight day^{-1} (5 days/week) caused no adverse effects in rats and mice, respectively, in a 13-week study[1].

For trichlorobenzenes, no adverse effects were seen in rats when given a dose of 7.7 mg kg^{-1} body weight day^{-1} in a 90-day study[3]. In all these studies, the primary effect seen at higher doses was liver toxicity.

The balance of evidence indicates that the chlorobenzenes are not mutagenic[1,2,3]. Carcinogenicity studies have not been undertaken for trichlorobenzenes or 1,3-dichlorobenzene but 1,2-dichlorobenzene does not appear to be carcinogenic in laboratory animals. However, no carcinogenic effects were observed in rats when exposed to 11 volatile halogenated hydrocarbons including trichlorobenzenes, in their drinking water for a lifetime[6]. In the case of monochlorobenzene and 1,4-dichlorobenzene there is some evidence for carcinogenicity in rodents, although in both cases the relevance for humans is highly doubtful[3]. There is no evidence for teratogenicity for the chlorobenzenes [5,10].

Short-term health guideline values

The following health advisories (HAs) have been established by the USEPA:

Chlorobenzene	1 day ($mg\ l^{-1}$)	10 day ($mg\ l^{-1}$)	Basis
Monochlorobenzene	2	2	90 day study in dogs, NOAEL: $\cong 27\ mg\ kg^{-1}$ (5 days/week) UF = 100
1,2-Dichlorobenzene	9	9	90 day study in rats, mice NOAEL: $125\ mg\ kg^{-1}$ (5 days/ week) UF = 100
1,3-Dichlorobenzene	9	9	Based on HAs for 1,2-isomer
1,4-Dichlorobenzene	10	10	90 day study in rats, NOAEL: $150\ mg\ kg^{-1}$ (5 days/week) UF = 100
1,2,4-Trichlorobenzene	0.1	0.1	13 week inhalation study in rats NOAEL: $22.3\ mg\ m^{-3}$ UF = 100
1,3,5-Trichlorobenzene	0.6	0.6	13 week inhalation study in rats NOAEL: $97\ mg\ m^{-3}$ UF = 100

* UF = uncertainty factor

1,2,3-Trichlorobenzene

Short-term SNARLs can be derived for 1,2,3-trichlorobenzene. In a 90 day study in rats no adverse effects were seen at 7.7 $mg\ kg^{-1}$ body weight day^{-1}. By applying an uncertainty factor of 100, a short-term tolerable daily intake of 77 $\mu g\ kg^{-1}$ body weight day^{-1} is derived for man. Assuming a 10 kg child drinking 1 litre of water per day, SNARLs are as follows;-

24 hour SNARL allowing 100% of the TDI to water = 0.77 $mg\ l^{-1}$

7 day SNARL allowing 50% of the TDI to water = 0.38 $mg\ l^{-1}$

Taste and odour Effects

Chlorobenzene	Taste threshold ($\mu g\ l^{-1}$)	Odour threshold ($\mu g\ l^{-1}$)
Monochlorobenzene	190[4]	40[3] 80[8] 100[11] 120[3] 190[4]
1,2-Dichlorobenzene	1[3] 200[4]	2-10[3] 10-30[1] 200[4]
1,3-Dichlorobenzene	190[4]	10-30[1] 20[11] 77, 170[4]
1,4-Dichlorobenzene	6[3] 11, 32[4]	0.3-30[3] 4.5, 18[4]
1,2,3-Trichlorobenzene	No data located	10[3]
1,2,4-Trichlorobenzene	No data located	5-30[3] 64[7]
1,3,5-Trichlorobenzene	No data located	50[3]

Odour threshold concentrations of 8 and 12 μg l^{-1} have been reported at 60°C for trichlorobenzene (isomer unspecified)[8].

Overall Evaluation

Concentrations most likely to give consumer complaints based on taste and odour are between 5 to 50 μg l^{-1} for the di- and trichlorobenzenes. For monochlorobenzene it appears the taste and odour threshold is higher and more likely to be between 100-200 μg l^{-1}. Such concentrations are below those considered to be of significant risk to health in the short-term by at least an order of magnitude.

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CHLOROPHENOLS

Chlorophenols can be formed during the chlorination of raw water containing phenol and a number have been detected in drinking water at trace $\mu g\ l^{-1}$ levels. This data summary has reviewed *2-chlorophenol, 4-chlorophenol, 2,4-dichlorophenol, 2,6-dichlorophenol, 2,4,5-trichlorophenol and 2,4,6-trichlorophenol* as examples of chlorophenols most likely to be detected in drinking water.

Health Effects

Chlorophenols are well absorbed following ingestion and readily penetrate the skin. They are rapidly metabolised and excreted mainly as glucuronide conjugates in the urine and lesser extent the faeces[3]. In man, acute toxicity of chlorophenols is characterised by CNS effects, increased respiratory rate, sweating, nausea and vomiting [4].

Based on studies in laboratory animals, the chlorophenols under review are of low to moderate acute and chronic oral toxicity[4]. Symptoms of acute exposure to high doses are similar and include effects on the central nervous system (CNS)[2,3]. Short-term oral studies indicate that the liver, kidney and spleen are target organs for the chlorophenols and that 2,4-dichlorophenol may also cause adverse effects on the immune system and blood [3,15]. The USEPA have established a reference dose of 0.1 mg kg day^{-1} for the 2,4,5-isomer by applying an uncertainty factor of 1000 to a NOAEL of 100 mg kg^{-1} day^{-1} identified in a 98-day study in rodents [14].

The chlorophenols under review are considered not to be mutagenic other than 2,4,6-trichlorophenol which is thought to possess weak mutagenic activity[1,3]. IARC have reviewed 2,4,5- and 2,4,6-trichlorophenol and concluded that there was 'inadequate evidence of carcinogenicity in laboratory animals' for 2,4,5-TCP. However, IARC concluded that there was sufficient evidence for carcinogenicity in laboratory animals for 2,4,6-TCP[3]. 2,4-DCP does not appear to be carcinogenic[3], and there are inadequate information available for the other chlorophenols under review. The WHO (1993) drinking water guideline value for 2,4,6-trichlorophenol is 200 $\mu g\ l^{-1}$ based on an excess cancer risk of 10^{-5} following a lifetime of exposure.

Chlorophenols do not appear to be teratogenic based on studies in laboratory animals [3,4].

Short-term health guideline values

The USEPA have derived draft 1- and 10-day health advisories (HAs) for the following chlorophenols:

Chlorophenol	1 day ($\mu g\ l^{-1}$)	10 day ($\mu g\ l^{-1}$)	Basis
2-Chlorophenol	500	500	Transplacental exposure in rats[16] NOAEL≅ 5mg kg day^{-1} UF = 100
2,4-Dichlorophenol	30	30	90 day drinking water study in rats[15] NOAEL = 0.3 mg kg day^{-1} UF = 100

UF= uncertainty factor

Suggested No Adverse Response Levels (SNARLs) are proposed for the remaining chlorophenols under review as follows:

Chlorophenol	24 hour ($\mu g\ l^{-1}$)	7 day ($\mu g\ l^{-1}$)	Basis
4-Chlorophenol	500	500	USEPA HA for 2-chlorophenol
2,6-Dichlorophenol	30	30	USEPA HA for 2,4-isomer
2,4,5-Trichlorophenol	3000	1500	USEPA RfD: 0.1 mg kg^{-1} day^{-1} 60 kg adult, 2 litres day^{-1}
2,4,6-Trichlorophenol	3000	1500	SNARL for 2,4,5-isomer

Taste and odour Effects

The following taste and odour thresholds have been reported for the chlorophenols under review:

Chlorophenol	Taste threshold ($\mu g\ l^{-1}$)	Odour threshold ($\mu g\ l^{-1}$)
2-Chlorophenol	0.1[1] 0.14[6] 1[7] 50[10]	0.09, 0.36[6] 0.33, 0.5[13] 1,2,3 [12] 2.5, 5 [10] 10[1] 19[13]
4-Chlorophenol	0.1 [3,11] 1[7] 39[6] 50[11]	1[13] 5 [11] 10[6] 20[6] 50, 250[12]
2,4-Dichlorophenol	0.3[1] 1[6,7,] 2.5 [6]	2 [12] 5[6], 29[6] 40[1] 210 [12]
2,6-Dichlorophenol	1[7] 0.006[6] 0.02 [6]	3 [12] 6[6] 7.5[13] 10[7] 22[6]
2,4,5-Trichlorophenol	1[5,7] 100[6]	11[8] 25[9] 63[6] 100[7] 200[5] 333[8] 350[6]
2,4,6-Trichlorophenol	1[7] 2[1]	100[7] 300[1] 380[6]

Overall Evaluation

Chlorophenols are well known for their low taste and odour thresholds. In general, taste thresholds are lower than those reported for odour and tend to be around 1 $\mu g\ l^{-1}$ for mono-, di- and trichlorophenols, although lower concentrations may be detected by more sensitive individuals. To avoid organoleptic effects it is generally accepted that the total sum of the concentrations of chlorophenols should not be higher than 0.1 $\mu g\ l^{-1}$ in drinking water. Such concentrations are well below those considered to be of significant risk to health in the short-term.

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CRESOLS AND CHLORINATED CRESOLS

Cresols (methylphenols) are widely used in the chemical industry and are present in petroleum, coal-tar, creosote, synthetic resins and as additives in lubricating oils and therefore have a variety of means by which they can contaminate drinking water. In addition, a number of chlorinated cresols may be formed during chlorination. This data summary has reviewed *o-*, *m-* and *p-cresol* and *4-chloro-o-cresol*, *6-chloro-o-cresol*, *4-chloro-m-cresol*, *6-chloro-m-cresol*, *2-chloro-m-cresol* and *2-chloro-p-cresol* as examples of cresols and chlorinated cresols which may be detected in drinking water.

Health Effects

Cresols

Cresol behaves much like phenol. It is readily absorbed following ingestion and can be absorbed through the skin[6]. Cresols are rapidly metabolised via oxidation and conjugated with sulphates and glucuronic acids and excreted predominantly in the urine[6]. It should be noted that cresols, particularly *p*-cresol, are normally present in human urine[6].

The acute toxicity of cresols is similar to but less severe than that of phenol. Symptoms of acute poisoning are similar to phenol and include gastrointestinal disturbances, muscular weakness, effects on the central nervous system (CNS) and collapse[6]. Cresols can also induce methaemoglobinaemia and at very high oral doses, injury to the lungs, kidneys, liver, pancreas and spleen may also occur. In man, the lowest oral toxic dose for cresol has been reported at 177 mg kg^{-1} based on effects on the blood [7]. An oral dose of 8 g of cresol produced rapid circulatory collapse and death[6,10]. Cresols can cause irritation to the skin and eyes and following repeated exposure may induce allergic dermatitis[6].

Cresol and its various isomers are considered to be of moderate acute oral toxicity in laboratory animals. Generally, *m*-cresol is considered the least toxic isomer (rat oral LD_{50} 242 -2020 mg kg^{-1}; mouse oral LD_{50} 828 mg kg^{-1}) compared to *o*-cresol (rat oral LD_{50} 121-1350 mg kg^{-1}; mouse oral LD_{50} 344 mg kg^{-1}) and *p*-cresol (rats oral LD_{50} 207-1800 mg kg^{-1}; mouse oral LD_{50} 344 mg kg^{-1})[2,6,7,10].

In a short-term dietary study involving cresol (mixed isomers) no adverse effects were observed at a dose of 0.1% (about 50 mg kg^{-1} body weight) in rats, whereas higher doses caused gastrointestinal irritation and effects on the liver and kidney[18]. In a 90-day gavage study in rats, no toxic effects were observed at a dose of 50 mg kg^{-1} body weight day^{-1} for both *o-* and *m*-cresol. At higher doses, toxic effects included CNS effects, decreased body weight and increased mortality[16].

There is some evidence for mutagenicity[7] and also some evidence of carcinogenicity when applied to the skin at high doses in laboratory animals, although this is probably as a result of an irritant effect on the skin[7] .

Chlorocresols

Based on laboratory animal data for 4-chloro-*m*-cresol, it is likely that the chlorocresols will be absorbed following ingestion and rapidly excreted in the urine[8]. Chlorocresols appear to be of similar or slightly lower acute oral toxicity in laboratory animals than the corresponding cresol[6] and symptoms of acute exposure are similar to those seen with cresols. Target organs following exposure to high oral doses include the CNS, gastrointestinal tract, kidney, liver and spleen[8]. They are also skin and eye irritants and can cause allergic dermatitis[8].

Chlorocresol	Rat oral LD_{50} (mg kg^{-1})	Mouse oral LD_{50} (mg kg^{-1})
4-Chloro-*o*-cresol	1194[8]	1330[8]
6-Chloro-*o*-cresol	No data located	710[8]
6-Chloro-*m*-cresol	500[11] (LD_{Lo})	No data located
4-Chloro-*m*-cresol	1830-5130[8,9]	600[7]

One 90-day dietary study reported that no toxic effects were seen in rats when given 150 ppm 4-chloro-*m*-cresol (≅7.5 mg kg^{-1} body weight day^{-1}) but that slight growth retardation occurred at doses of 500 and 1500 ppm[8]. In a 28-day study with 4-chloro-*m*-cresol, no adverse effects were seen in rats given 200 mg kg^{-1} body weight day^{-1} by stomach tube whereas 400 mg kg^{-1} day^{-1} resulted in weight loss, although no other toxic effects were observed[8].

Based on limited data, chlorocresols do not appear to be mutagenic[8,9] but no data on their carcinogenic potential were located.

Short-term health guideline values

No short-term health guideline values were located for cresols or chlorinated cresols.

Cresols

Suggested No Adverse Response Levels (SNARLs) can be determined as follows for *o*-, *m*- and *p*-cresol based on laboratory animal studies. No adverse effects were seen at a *o*- and *m*-cresol dose of 50 mg kg^{-1} body weight day^{-1} in a 90-day gavage studies in rats. By applying an uncertainty factor of 1000, the USEPA have derived a chronic reference dose of 0.05 mg kg^{-1} body weight day^{-1} for man. Assuming a 60 kg adult drinking 2 litres of water per day, conservative short-term SNARLs are as follows;-

24 hour SNARL allowing 100% of the RfD to water = 1.5 mg l^{-1}

7 day SNARL allowing 50% of the RfD to water = 0.75 mg l^{-1}

Chlorocresols

In a well reported 28-day gavage study, no adverse effects were observed at a dose of 200 mg kg^{-1} body weight day^{-1} for 4-chloro-*m*-cresol. No adverse effects were reported in a 90 day dietary study at 7.5 mg kg^{-1} body weight day^{-1} for this same compound. By taking the more conservative approach, by applying an uncertainty factor of 100 to the NOAEL of 7.5 mg kg^{-1} body weight day^{-1}, a short-term tolerable daily intake of 0.075 mg kg^{-1} is derived. Assuming a 60 kg adult drinking 2 litres of water per day, SNARLs are as follows:-

24 hour SNARL allowing 100% of the TDI to water = 2.25 mg l^{-1}

7 day SNARL allowing 50% of the TDI to water = 1.1 mg l^{-1}

Although there are only limited toxicity for chlorinated cresols, they appear to be of moderate acute oral toxicity and of similar toxicity. Therefore, the above short-term SNARLs are likely to be appropriate for total chlorinated cresols.

Taste and odour Effects

	Odour threshold (µg l^{-1})	**Taste threshold (µg l^{-1})**
o-cresol	16, 90, 260, 650, 4100[2-5,12,14]	1[10] 3[2]
m-cresol	16,200,250, 680, 4000[4,5,12-14]	2[2]
p-cresol	55,100, 250, 680, 800[2,3,12,14]	2[2]
4-chloro-*o*-cresol	62[1]	2.5,10[1] 120 [8]
6-chloro-*o*-cresol	0.1[15]	0.08[8]
4-chloro-*m*-cresol	2.5[1] 100 [17]	0.2[15] 2.5, 9[1]
6-chloro-*m*-cresol	3000[11]	No data located
2-chloro-*p*-cresol	0.15[1]	<0.05, 0.3[1]

Overall Evaluation

Cresols are reported to have low taste thresholds of around 1-3 µg l^{-1} which are lower than their odour thresholds which are more likely to be between 50-250 µg l^{-1}. Cresols are expected to cause taste effects at concentrations which are well below those considered to be of significant risk to health in the short-term. Cresols may react with chlorine to form chlorocresols some of which can have even lower taste thresholds at concentrations below 0.1 µg l^{-1}. Again, chlorocresols are unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low concentrations at which they cause taste problems.

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ETHYLBENZENE

Ethylbenzene is most likely to occur in drinking water through its use as a solvent or as a result of contamination by petroleum products or raw water pollution.

Health Effects

Ethylbenzene is readily absorbed by via ingestion or through the skin. In man, it is readily converted into soluble metabolites (mainly mandelic acid and phenylglyoxylic acid) which are excreted rapidly in the urine[1,2,6,7]. Most toxicity data relate to the inhalation route of exposure and high doses it can cause irritation of the eyes, nose and throat and CNS depression [1,2].

Based on laboratory animal studies, ethylbenzene is of very low acute oral toxicity (rat oral LD_{50} 3.5 g kg^{-1}). Short-term oral studies have been carried out in laboratory animals which indicate that it is of low chronic oral toxicity and the target organs are the liver and kidney. In a 6-month oral study in rats, no adverse effects were seen at a dose of 136 mg kg^{-1} (5 days/week), whereas higher doses had slight effects on the liver and kidney [1,2,3].

Ethylbenzene is considered not to be mutagenic[1,2,6] but there are inadequate data to assess its carcinogenicity. It can cross the placenta but it is not fetotoxic in rodents[7] and although poorly studied is unlikely to be teratogenic based on inhalation studies in rodents[1].

Short-term health guideline values

The USEPA have established 1- and 10-day health advisories of 30 and 3 mg l^{-1} based on a 10 kg child drinking 1 litre of water per day. The 1-day health advisory was derived from a NOAEL identified in a controlled human inhalation study. An extra uncertainty factor of 10 was incorporated to derive the 10-day health advisory.

Taste and odour Effects

A number of odour threshold concentrations have been reported in the literature ranging from 1.6, 3.2, 10, 29, 100, 140, 150, 200 and 550 µg l^{-1}[1-5]. The lowest odour concentrations were reported at 60°C[4], whereas the threshold value of 150 µg l^{-1} was reported at 40°C[5].

Taste threshold concentrations of 29, 64, 72, 80, 200, 390 and 780 µg l^{-1} have been reported[1,4,5,6]. The taste concentrations of 64 and 80 µg l^{-1} were reported at 40°C[4] whereas the value of 390 µg l^{-1} was reported at 25°C [5].

Overall Evaluation

The taste and odour threshold concentration for ethylbenzene is most likely to be between 20 to 200 µg l^{-1} which is approximately two to three orders of magnitude below those concentrations considered to be of significant risk to human health in the short-term.

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2-ETHYL-5,5-DIMETHYL-1,3-DIOXANE

2-Ethyl-5,5-dimethyl-1,3-dioxane (2-EDD) is most likely to occur in drinking water through raw water contamination by waste products from resin manufacturing factories. It has been involved in a number of incidents causing major taste and odour problems in the USA[1,2], UK[3] and Spain[5] .

Health Effects

An epidemiological study investigating the short-term health effects of 2-EDD was rapidly initiated following a taste and odour incident in the UK (peak 2-EDD concentration in drinking water was 130 ng l^{-1})[4]. The authors found that for the exposed population there was a significant increase in incidence of the following symptoms: nausea, headache, skin irritation, diarrhoea, itchy eyes, stomach pains and tiredness. However, apart from nausea, these symptoms appeared to be associated with the ability to detect an unusual taste or odour in the water rather than with the degree of chemical contamination. The authors concluded that the observed increase of nausea in exposed subjects which was irrespective of whether subjects detected an unusual taste or odour or not, was probably due to anxiety caused by the incident.

There are no toxicity data available for 2-EDD specifically. However, several other 1,3-dioxane derivatives have been shown to be of low acute oral toxicity in experimental animals with LD_{50} values of 2-5 g kg^{-1} being reported. The most structurally similar compound for which toxicity data could be located was 2,4-dimethyl-1,3-dioxane which is likely to be of similar toxicity. This compound appears to be of very low oral short-term toxicity in laboratory animals, with an oral LD_{50} of 5.57 g kg^{-1} being reported in mice[6].

Short-term health guideline values

There are no short-term health guideline values for 2-EDD.

Taste and odour Effects

2-EDD is extremely odorous with an odour threshold of 5-10 ng l^{-1} being reported in the literature[1,5]. This is supported by taste and odour incidents in which the 2-EDD concentrations measured in treated drinking water have been in the ng l^{-1} range. For example, in the US incident, concentrations in the treated drinking water were 20 ng l^{-1} and were up to 130 ng l^{-1} in the UK[1,3]. The mean concentration of 2-EDD found in water samples in the Spanish incident was 950 ng l^{-1} [5].

Overall Evaluation

2-EDD is an extremely odorous compound which is most likely to be detected by odour at concentrations between 5-20 ng l^{-1}. This is supported by data generated in incidents in which it has caused severe taste and odour problems. An epidemiology study which investigated the short-term health effects of 2-EDD following the UK incident found that there was no serious risk to the health of the public, although there was an increase in the incidence of nausea which may have been due to the anxiety caused by the incident, as well as symptoms such as headache and gastrointestinal symptoms which appeared to be associated with the ability to detect an unusual taste or odour in the water. Although there are no data specifically for 2-EDD, studies in laboratory animals on similar compounds indicate that it is likely to be of low short-term toxicity and unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low concentrations at which it causes taste and odour effects.

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GEOSMIN

Geosmin is a naturally occurring contaminant of drinking water which is produced by some species of actinomycetes and blue-green algae.

Health Effects

The only toxicological data located specifically for geosmin indicate that it is not mutagenic in bacterial test systems[1,2].

Short-term health guideline values

There are no short-term health guideline values for geosmin.

Taste and odour Effects

Odour threshold concentrations of 1, 4, 10, 15, 21, 50, 130 and 200 ng l^{-1} have been reported in the literature[3-8]. The value of 130 ng l^{-1} was reported at room temperature (panel size 7-14) [8] and the values of 1 and 4 ng l^{-1} were reported when tested at 40°C based on a panel size of 10[7]. In one study, trained *vs.* consumer panels determined the threshold odour concentration of geosmin. Threshold odour concentrations of 94 and 360 ng l^{-1} were reported for the trained and consumer panels, respectively[9]. (This was a Japanese study and it has been suggested that Japanese people are less sensitive to geosmin than other populations). It should be noted that in practice the odour may be masked to some extent by the addition of chlorine.

Taste threshold concentrations of 16 and 7.5 ng l^{-1} were reported at 25°C based on a panel size of 10[7].

Overall Evaluation

The taste and odour threshold of geosmin has been reported to be as low as 1 ng l^{-1} and it is highly likely to be detectable below 50 ng l^{-1} . Although no toxicity data have been located specifically for geosmin, it is considered unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low ng l^{-1} concentrations at which it causes taste and odour problems.

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IRON

Iron is most likely to occur in drinking water as a result of the corrosion of steel and cast iron pipes during water distribution or through the use of iron coagulants[1].

Health Effects

Iron is an essential element in human nutrition and because it is so important in physiological function the body tends to conserve iron. Estimates of the minimum daily requirement depend on age, sex, physiological status, and iron bioavailablility but range from 10 to 50 mg day^{-1}[1].

Iron absorption depends on an individual's iron status and is regulated so that excessive iron is not stored in the body. It is predominantly present in haemoglobin, myoglobin and haem-containing enzymes. Iron excretion in the urine and sweat are negligible and it is mainly lost from the body due to cell exfoliation from the gastrointestinal tract and, in women, there is an additional iron loss via menstruation[3] .

In man, the average lethal dose of iron has been reported as 200-250 mg kg^{-1} body weight per day, although death has occurred from ingestion of smaller doses ranging from 180 mg kg^{-1} upwards [4,9]. The ingestion of iron-containing tablets by children is the most common form of iron poisoning and it has been estimated that a 'mild to moderately' toxic dose is between 20-60 mg Fe kg^{-1}[3,8]. Symptoms of acute oral iron intoxication include irritability, gastrointestinal irritation and damage, abdominal pain, vomiting and diarrhoea. It has been reported that a dose of 77 mg Fe kg^{-1} produced signs of behavioural irritability and vomiting in a child[6]. Central nervous system depression as well as cardiovascular symptoms, such as pallor, increased heart rate and hypotension may also occur. Individuals with only mild to moderate poisoning do not usually progress past this first phase[9]. Following severe poisoning, the patients may appear to recover, although 12 to 48 hours after the ingestion, life-threatening symptoms can appear. These include gastrointestinal perforation, liver damage, renal failure, coma, convulsions, vasomotor collapse, cyanosis and pulmonary edema[3,7] .

Iron or iron salts do not appear to be mutagenic nor carcinogenic via the oral route[3]. They do not appear to cause adverse reproductive effects or be teratogenic[5].

Short-term health guideline values

There are no short-term health guideline values for iron. In 1993, the World Health Organization did not specify a health-based guideline for iron in drinking water but indicated that a concentration of 2 mg l^{-1} would not present a hazard to health in the long-term. For short-term exposure, it has been estimated that doses expected to cause mild to moderate toxicity are between 20 and 60 mg Fe kg^{-1} body weight. By applying an uncertainty factor of 10 to the lower dose, assuming a 10 kg child drinking 1 litre of water per day and 50% allocation of exposure to drinking water, concentrations of up to 10 mg l^{-1} are unlikely to be of significant risk to health in the short-term.

Taste and odour effects

Iron can affect the taste of drinking water and its threshold is dependent on its form in that the ferrous iron (Fe^{2+}) tends to impart a more noticeable taste than ferric iron (Fe^{3+})[10]. In drinking water supplies, iron is predominantly present in drinking water in the oxidised ferric form.

The taste threshold of iron can vary widely depending on the sensitivity of an individual. In one study, ferrous iron (Fe^{2+}) concentrations of 0.04 mg l^{-1} and 0.12 mg l^{-1} were detected by taste in distilled and spring water, respectively, by the most sensitive 5% of the panellists[10]. Higher ferrous iron concentrations of 3.4 and 1.8 mg l^{-1} were detected by taste by 50% of the panel for distilled and spring water, respectively. Ferric iron (Fe^{3+}) was detectable by taste at concentrations of 0.7 and 8.8 mg l^{-1} by 5 and 50% of the panellists, respectively, when tested in distilled water[10]. In other studies involving distilled water, taste thresholds of 0.2 mg l^{-1} and 10 mg l^{-1} were reported for ferric iron whereas ferrous iron was detected at 0.1 mg l^{-1} [10].

It should be noted that ferric iron can give a objectionable reddish-brown colour to water and discoloration may develop at concentrations above 0.1 mg l^{-1}[4]. Staining of laundry and plumbing may also occur at concentrations above 0.3 mg l^{-1} [1].

Overall evaluation

The taste threshold of iron can vary widely depending on the sensitivity of an individual. It is generally considered that there is no noticeable taste at iron concentrations below 0.3 mg l^{-1} [1]. Although the taste threshold concentration of iron can vary between above 0.3 mg l^{-1} to up to a few mg l^{-1}, discoloration of drinking water will be expected at these levels. Concentrations of up to 10 mg l^{-1} are considered unlikely to be of significant risk to health in the short-term. This is above concentrations at which the taste and appearance of drinking water will be affected.

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2-*ISO*BUTYL-3-METHOXYPYRAZINE

2-*iso*Butyl-3-methoxypyrazine is a naturally occurring contaminant of drinking water which is believed to be produced by actinomycetes.

Health Effects

No toxicity data have been located which related specifically to 2-*iso*butyl-3-methoxypyrazine. However, toxicity data from laboratory animal studies indicate that other related compounds such as alkylpyrazines are of low to moderate acute oral toxicity[3]. A mouse intraperitoneal LD_{50} of 1300 mg kg^{-1} has been reported for the related compound 5-methyl-2-hydroxypyrazine[3].

Short-term health guideline values

No short-term health guideline values were located for 2-*iso*butyl-3-methoxypyrazine.

Taste and odour Effects

2-*iso*Butyl-3-methoxypyrazine has extremely low odour and taste thresholds. Odour threshold concentrations of <0.05 and 1 ng l^{-1} (tested at 40°C) and 2 ng l^{-1} have been reported in the literature. Taste threshold concentrations of 0.4 and 3 ng l^{-1} have been reported when tested at 25 °C[1,2,4].

Overall Evaluation

2-*iso*Butyl-3-methoxypyrazine causes taste and odour at extremely low concentrations most likely to be around 1-2 ng l^{-1}. Although no toxicity data have been located specifically for this compound, it is considered unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low ng l^{-1} concentrations at which it causes taste and odour problems.

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*ISO*PROPYLBENZENE

*iso*Propylbenzene (cumene) is most likely to be detected in drinking water as a result of contamination by petroleum or other raw water pollution.

Health Effects

In man, most toxicity data relate to the inhalation route of exposure and symptoms include irritation of the respiratory tract and general central nervous system (CNS) depression e.g. dizziness, drowsiness and incoordination following exposure to high doses[1,4]. Following ingestion, *iso*propylbenzene is rapidly absorbed and can also be absorbed through the skin. It can be irritating to the skin and eyes [1,4].

Based on studies in laboratory animals, *iso*propylbenzene is of low acute toxicity (rat LD_{50} 1400 mg kg^{-1}[1]. As in man, at high levels it is a membrane irritant and causes CNS depression. It is of low chronic oral toxicity and unlike benzene, there is no evidence that is causes adverse effects on the blood. It has been reported that no adverse effects were seen in rats when dosed 154 mg kg^{-1} body weight day^{-1} in olive oil (5 days/week) for 194 days whereas higher doses resulted only in increased kidney weights[1-3,5].

No data were located which related to its mutagenicity or carcinogenicity but based on inhalation studies it does not appear to cause any adverse reproductive effects[6].

Short-term health guideline values

No short-term health guideline values were located for *iso*propylbenzene. However, the USEPA have derived a long-term oral reference dose of 0.04 mg kg^{-1} body weight day^{-1} for man by applying an uncertainty factor of 3000 to the NOAEL of 110 mg kg^{-1} day^{-1} (adjusted for 7 day dosing) reported in a 194-day study in rats. Assuming a 60 kg adult drinking 2 litres of water per day, conservative SNARLs are as follows:-

24 hour SNARL allowing 100% of the TDI from water = 1.2 mg l^{-1}

7 day SNARL allowing 50% of the TDI from water = 0.6 mg l^{-1}

Taste and odour Effects

Odour threshold concentrations of 70 µg l^{-1}[8] and 100 µg l^{-1}[7] have been reported in the literature, although it may be possible for sensitive individuals to detect an odour at concentrations as low as 8 or 10 µg l^{-1}[8,9]. It is less likely to be detected by taste although sensitive individuals may detect it at concentrations as low as 60 µg l^{-1} [8].

Overall Evaluation

*iso*Propylbenzene is most likely to be detected by odour at concentrations of around 70 µg l^{-1} or above, although it may be possible for sensitive individuals to detect an odour at concentration as low as 10 µg l^{-1}. Such concentrations are at least an order of magnitude below those considered to be of significant risk to health in the short-term.

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2-*ISO*PROPYL-3-METHOXYPYRAZINE

2-*iso*Propyl-3-methoxypyrazine is a naturally occurring contaminant of drinking water which is produced by actinomycetes and Lysobacter *sp.*[5] .

Health Effects

No toxicity data have been located which related specifically to 2-*iso*propyl-3-methoxypyrazine. However, toxicity data from laboratory animal studies indicate that other related compounds such as alkylpyrazines are of low to moderate acute oral toxicity[3]. A mouse intraperitoneal LD_{50} of 1300 mg kg^{-1} has been reported for the related compound 5-methyl-2-hydroxypyrazine[3] .

Short-term health guideline values

No short-term health guideline values were located for 2-*iso*propyl-3-methoxypyrazine.

Taste and odour Effects

2-*iso*Propyl-3-methoxypyrazine has extremely low odour and taste thresholds in the ng l^{-1} range. Odour threshold concentrations of <0.03 and 0.2 ng l^{-1} (tested at 40°C) and 2 ng l^{-1} have been reported. Taste threshold concentrations are reported as 10 and 20 ng l^{-1} when tested at 25°C[1,2,4].

Overall Evaluation

2-*iso*Propyl-3-methoxypyrazine causes taste and odour effects at extremely low concentrations most likely to be as low as 1-10 ng l^{-1}. Although no toxicity data have been located specifically for this compound, it is considered unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low ng l^{-1} concentrations at which it causes taste and odour problems.

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*P-ISO*PROPYLTOLUENE

*p-iso*Propyltoluene (cymene) is a solvent which is most likely to occur in drinking water through raw water pollution.

Health Effects

Based on laboratory animal studies, *p-iso*propyltoluene is rapidly absorbed following ingestion and primarily metabolised via hydroxylation and excreted in the urine[1,4]. It is also rapidly absorbed through the skin[1,4].

*p-iso*Propyltoluene is a mild skin irritant[4] and can cause nausea, headache and vomiting following high oral doses[1]. In man, the lowest toxic oral dose reported to cause affects on the central nervous system was 86 mg kg^{-1}[3]. It has also been reported that daily administration of 3-4 g (about 50-66 mg kg^{-1} body weight) for 2-3 days caused nausea, headache and vomiting[4].

Based on laboratory animal studies, it is of low oral acute toxicity (rat oral LD_{50} of 4750 mg kg^{-1})[2]. Symptoms of acute toxicity include central nervous system (CNS) effects, diarrhoea and blood and respiratory effects[4]. There are only limited toxicity data following repeated exposure which is poorly reported but a dose of 200 mg kg^{-1} body weight day^{-1} caused no adverse effects in dogs apart from diarrhoea[4].

Short-term health guideline values

No short-term health guideline values were located for *p-iso*propyltoluene. However, a Suggested No Adverse Response Level (SNARL) can be proposed based on the available data in humans. Daily administration of 3-4 g for 2 to 3 days in man caused minor symptoms of toxicity. By applying an uncertainty factor of 100 to allow for differences between individuals and the fact that the dose was not a no-effect-level, a short-term tolerable daily intake of 0.5 mg kg^{-1} body weight day^{-1} is derived for man. This value is also supported by toxicity data in laboratory animals. Assuming a 60 kg adult drinking 2 litres of water per day, SNARLs are as follows:

24 hour SNARL allowing 100% of the TDI to water = 15 mg l^{-1}

7 day SNARL allowing 50% of the TDI to water = 7.5 mg l^{-1}

Taste and odour effects

An odour threshold concentration of 400 µg l^{-1} has been reported at 40°C based on a panel size of 8. However, one panellist was able to detect an odour at a concentration as low as 25 µg l^{-1}[5]. An odour threshold of 100 µg l^{-1} has also been reported[6]. No taste effects were reported at concentrations of 1000 µg l^{-1} when tested at 25°C[5]

Overall evaluation

*p-iso*Propyltoluene is most likely to have an odour threshold concentration of around 100-400 $\mu g\ l^{-1}$, although very sensitive individuals may be able to detect an odour at concentrations as low as 25 $\mu g\ l^{-1}$. Such concentrations are well below those considered to be of significant risk to health in the short-term.

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2-METHYLISOBORNEOL

2-Methylisoborneol is a naturally occurring contaminant of drinking water which is produced by some species of actinomycetes and blue-green algae.

Health Effects

The only toxicological data located specifically for 2-methylisoborneol indicate that it is not mutagenic in bacterial test systems[8]. However, toxicity data are available for the structurally similar compound isoborneol which indicate that this compound is of low acute oral toxicity in laboratory animals. Oral LD_{50} values of 5200 and 3830 mg kg^{-1} have been reported for the rat and mouse, respectively [1,9].

Short-term health guideline values

No short-term health guideline values were located for 2-methylisoborneol.

Taste and odour Effects

Odour threshold concentrations of 4, 6, 9, 12, 15, 20, 29, 42, and 100 ng l^{-1} and taste threshold concentrations of 18 and 2.5 ng l^{-1} have been reported in the literature [2-7]. It should be noted that in practice the odour may be masked to some extent by the addition of chlorine.

Overall Evaluation

2-Methylisoborneol can cause taste and odour at concentrations as low as 5 ng l^{-1} and is most likely to be detectable below 50 ng l^{-1}. Although no toxicity data have been located specifically for 2-methylisoborneol, it is considered unlikely to result in any significant health effects in the short-term, other than possibly through palatability, at the extremely low ng l^{-1} concentrations at which it causes taste and odour problems.

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NAPHTHALENE

Naphthalene is most likely to occur in drinking water as a result of leaching from coal-tar pitch linings or through contamination by diesel fuel or petroleum products.

Health Effects

Naphthalene is absorbed via the gastrointestinal tract although quantitative data were not available. It is metabolised to a number of intermediates (e.g. naphthols, phenols, dihydrodiols) or can be conjugated with glutathione and is primarily excreted in the urine and to a lesser extent the faeces[1] .

Naphthalene is considered to be of low oral short-term toxicity. Symptoms of acute human poisoning with naphthalene are characterised by gastrointestinal and neurological disturbances and toxicity to the eye at very high doses [1,3] . Oral acute doses of 2-3 g and 5-15 g have been reported to be lethal in a child and adult, respectively[1,2] . It has also been reported that naphthalene caused near blindness, cataract formation and optic atrophy in one human who ingested 5 g in oil[1]. In some cases, haemolytic anaemia and toxicity to the kidney may also develop[2,3]. It should be noted that infants and adults with congenital glucose-6-phosphate dehydrogenase deficiency will be more susceptible to naphthalene-induced haemolytic anaemia. At high doses, naphthalene is also considered to be a eye and skin irritant[1,2].

Naphthalene is of low to moderate short-term oral toxicity in laboratory animals (oral LD_{50}s in rats 1780-9430 mg kg^{-1}; mice 533, 710 mg kg^{-1}) [1,2]. Like man, the principal toxic effects following short-term exposure to high doses are haemolytic anaemia and toxic effects on the eye, in particular cataract formation. Based on a number of short- and longer-term studies, no-observed-adverse-effect-levels (NOAELs) of 35, 41, 53 and 200 mg kg^{-1} body weight have been identified[1] .

Naphthalene is not considered to be mutagenic nor does it appear to be carcinogenic[2]. It has been reported to cross the human placenta and can be fetotoxic but is not considered to be a teratogen [1,3].

Short-term health guideline values

The USEPA have established 1- and 10-day health advisories of 500 µg l^{-1} based on a 10 kg child drinking 1 litre of water per day. These were derived by applying an uncertainty factor of 1000 to a NOAEL of 53 mg kg^{-1} body weight identified in a 14-day gavage study in mice.

Taste and odour effects

Various odour threshold concentrations have been reported in the literature: 1 µg l^{-1}[3]; 2.5 µg l^{-1}[4]; 5 µg l^{-1}[5]; 6 µg l^{-1}[4]; 6.8 µg l^{-1}[6]; 21 µg l^{-1}[1] and 500 µg l^{-1}[5]. A taste concentration of 50 and 25 µg l^{-1} has also been reported[4].

Overall Evaluation

Naphthalene is most likely to be detected by odour at concentrations around 5 $\mu g\ l^{-1}$ which is two orders of magnitude below the USEPA 1-day and 10-day health advisories.

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n-PROPYLBENZENE

n-Propylbenzene is most likely to be present in drinking water as a result of contamination by petroleum products or through raw water pollution.

Health Effects

n-Propylbenzene is likely to be readily absorbed following ingestion and is primarily metabolised via side chain hydroxylation forming alcohols (e.g. 1-phenylpropan-1ol), followed by conjugation with glucuronic acid or glycine[2]. It is mainly excreted in the urine[3].

n-Propylbenzene is of low acute oral toxicity in laboratory animals (oral LD_{50} 6040 mg kg^{-1} in rats; LD_{50} in mice 5200 mg kg^{-1})[1,3]. Like other similar solvents at high doses, *n*-propylbenzene is irritating to mucous membranes, eyes, nose, throat and skin and causes CNS depression[2]. Unlike benzene, *n*-propylbenzene does not appear to exhibit toxic effects on the blood[2].

In a poorly reported 6 month oral study, rabbits were fed *n*-propylbenzene at 0, 0.25 or 2.5 mg kg^{-1} day. No effects on general appearance, body weight, organ weights and protein function of the liver were observed, although there were some non-significant effects on the blood at the high dose[3]. Based on limited very data, *n*-propylbenzene does not appear to be mutagenic[4].

Short-term health guideline values

No short-term health guideline values were located for *n*-propylbenzene.

Taste and odour Effects

n-Propylbenzene has been reported to have an odour threshold concentration of 200 $\mu g\ l^{-1}$[5].

Overall Evaluation

n-Propylbenzene is likely to cause odour at concentrations of around 200 $\mu g\ l^{-1}$ which is similar to the odour threshold concentration of benzene. Based on studies in laboratory animals, it is of very low short-term oral toxicity and there is no evidence to suggest it will result in any significant health effects in the short-term, other than through palatability, at the concentrations at which it causes odour effects.

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STYRENE

Styrene is most likely to occur in drinking water as a result of leaching from resins (e.g. acrylonitrile-butadiene-styrene) or from raw water pollution by industrial effluents.

Health Effects

Styrene is rapidly and well absorbed following ingestion after which it is widely distributed in the body and relatively rapidly metabolised by the liver. In man, almost all of an absorbed dose is excreted via the urine as mandelic acid and phenylglyoxylic acid. Most toxicity data relate to exposure following inhalation, the most common symptoms of acute exposure being central nervous system (CNS) depression and irritation of the skin, eyes, nose and respiratory tract[7] .

Based on laboratory animal studies, it is considered to be of low acute oral toxicity (rat oral LD_{50} 2.65 g kg^{-1})[8]. A number of short- and long-term oral studies have been carried out in laboratory animals and a dose of 133 mg kg^{-1} per day (5 days/week) was identified as having no adverse effects in a 6 month oral study in rats[7].

Styrene is considered to be mutagenic which is thought to be due to the formation of the reactive intermediate styrene-7,8-oxide. In 1994, the International Agency for Research on Cancer (IARC) re-evaluated styrene and classified it as 'possibly carcinogenic to humans' based on inadequate evidence in humans and limited evidence in laboratory animals. Styrene has been observed to cross the placenta and a few studies have investigated reproductive and/or teratogenic effects in women occupationally exposed to styrene. However, the studies were limited and no definite conclusions could be drawn[9]. Studies in laboratory animals indicate that styrene is not teratogenic[10].

Short-term health guideline values

The USEPA have established 1- and 10-day health advisories of 20 and 2 mg l^{-1}, respectively, based on a 10 kg child drinking 1 litre of water per day. The 1-day health advisory was derived from a NOAEL observed in a controlled human inhalation study whereas the 10-day health advisory was derived from a NOAEL identified in a 18 month gavage study in dogs[11].

Taste and odour Effects

In the literature, threshold odour concentrations of 3.2, 4, 10, 11, 20, 37, 50, 65, 730 and 2600 µg l^{-1} have been reported [1-6,11]. The two lowest odour threshold concentrations were reported at 60°C and are likely to be conservative[3], whereas the odour threshold reported as 37 µg l^{-1} was tested at 40°C[5]. Taste threshold concentrations of 80, 94 and 160 µg l^{-1} have been reported [3,5]. The taste threshold of 94 µg l^{-1} was reported at 25°C[5] compared to the other two thresholds reported at 40°C[3]. However, a proportion of the population is expected to be insensitive to any taste or odour of styrene.

Overall Evaluation

Styrene is most likely to be detected by odour at concentrations as low as 40-50 $\mu g\ l^{-1}$ which are about two to three orders of magnitude below the USEPA short-term health advisories. However, it should be noted that a proportion of the population is expected to be insensitive to any taste or odour of styrene.

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SULPHIDES

Sulphides are most likely to be found in stagnant drinking-water in distribution as a result of oxygen depletion and the action of sulphate-reducing bacteria. Point of use devices have also been reported to generate 'bad egg' odours which are probably caused by low molecular weight alkyl sulphides. The data summary has reviewed *hydrogen sulphide*, *dimethyldisulphide* and *dimethyltrisulphide* as examples of sulphides which may cause odour effects in drinking water[10,11].

Health Effects

Nearly all toxicity data available for hydrogen and organic sulphide compounds relate to exposure via inhalation. In general, symptoms include nausea, headache, dizziness, fatigue, coughing, irritation to the eyes, nose, skin and respiratory system. At higher doses CNS depression occurs which can lead to asphyxia and death. Hydrogen sulphide is much more acutely toxic than organic sulphides via inhalation, for example hydrogen sulphide has been estimated to be more toxic than dimethyl sulphide by a factor of 50 [12].

Hydrogen sulphide is rapidly absorbed following ingestion, oxidised by the liver and is rapidly excreted as sulphide and sulphate via the kidneys in laboratory animals[6]. No oral toxicity data were located for hydrogen sulphide but sodium and other soluble sulphides are promptly and completely hydrolysed in body fluids and so in terms of their systemic effects no toxicological distinctions are recognised between them and hydrogen sulphide [13]. Alkaline sulphides are reported to irritate the epithelium of mucous membranes and oral ingestion produces nausea, vomiting and epigastric pain. An oral dose of 10-15 g sodium sulphide is fatal[8].

In general, organic sulphides are of moderate acute oral toxicity in laboratory animals. Oral LD_{50} values of 535 and 3700 mg kg^{-1} have been reported in the rat and mouse, respectively for dimethyl sulphide[6]. For dimethyldisulphide and diphenyl sulphide, oral LD_{50} values of 190 and 490 mg kg^{-1} have been reported in rats[6,9]. Daily oral doses of 2.5, 25 and 250 mg body weight kg^{-1} of dimethyl sulphide for 14 weeks caused no adverse effects in rats[6]; this dose equates to a daily intake of 17.5 g by a 70 kg adult [8]. Some sulphides can cause skin and eye irritation [6,7].

No evidence of carcinogenicity was located for the sulphides under review and dimethyldisulphide does not appear to be mutagenic[6,9]. Based on limited animal data, hydrogen sulphide does not appear to be teratogenic [7].

Short-term health guideline values

There are no short-term health-based guideline values for the sulphides under review. In 1993, the World Health Organization (WHO) did not establish a health-based guideline for hydrogen sulphide but concluded that it was unlikely that a person could consume a harmful dose of hydrogen sulphide from drinking water because of the unpleasant taste and odour which occur at concentrations much lower than toxic levels.

Taste and odour Effects

Sulphide	Odour threshold (μg l^{-1})	Taste threshold (μg l^{-1})
Hydrogen sulphide	1.1[1] 0.029[3]	50[5]
Methyl sulphide	1.1[1] 12, 20, 300[4]	No data located
Ethyl sulphide	0.25[1]	No data located
Dimethyltrisulphide	0.01[1]	No data located
Dimethyldisulphide	1.2, 0.29[2] 3.3[4] 5[4] 50[2] 90[2]	No data located
Diphenyl sulphide	0.048[1] 5[2,4]	No data located

Overall Evaluation

The taste and odour thresholds of the sulphides varies widely. It is generally thought that the taste and odour threshold of hydrogen sulphide in water is between 50 and 100 μg l^{-1}, although other low molecular weight sulphides e.g. dimethyltrisulphide and diphenyl sulphide may have lower odour thresholds of below 1 μg l^{-1}. It is considered that the sulphides under review will cause odour effects at much lower concentrations than those considered to result in any significant health effects in the short-term.

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TOLUENE

Toluene is likely to occur in drinking water as a result of contamination through its use as a solvent or by contamination of water by petroleum products.

Health Effects

Toluene is rapidly and well absorbed following ingestion. It is rapidly metabolised and mainly excreted via the urine as hippuric acid or benzoyl glucuronide. In man, most toxicity data on toluene relate to exposure following inhalation either from occupational exposure or solvent abuse. In such situations there is little evidence to suggest that exposure to toluene results in toxicity to any particular organ apart from causing central nervous system (CNS) depression. Symptoms following acute exposures to high concentrations include mental confusion, fatigue, incoordination, nausea and insomnia, although these symptoms are generally reversible. It has been reported that a death occurred following ingestion of 625 mg kg^{-1} body weight of toluene[8].

Based on studies in laboratory animals, toluene is of very low acute oral toxicity (rat oral LD_{50} 2.6-7 g kg^{-1}), the toxic endpoint again being CNS depression[8]. A number of short- and long-term oral studies have been carried out in laboratory animals and a dose of 80 mg l^{-1} was reported as causing no adverse effects in a 4-week drinking water study in mice[6]. A dose of 312 mg kg^{-1} body weight day^{-1} was reported to cause marginal effects on the liver in a 13-week gavage study in female mice but did not result in any toxic effects in rats[7].

The balance of evidence indicates that toluene is not mutagenic nor is it carcinogenic. It has been shown to have embryotoxic and fetotoxic effects but only at high doses, and there is no clear evidence that it is teratogenic in laboratory animals or humans.

Short-term health guideline values

The USEPA have established 1- and 10-day health advisories of 20 and 2 mg l^{-1} based on a 10 kg child drinking 1 litre of water per day. The 1-day health advisory was derived from a NOAEL observed in a controlled human inhalation study whereas the 10-day health advisory was derived from a NOAEL identified in a 2 year inhalation study in rats[1].

Taste and odour Effects

A wide range of taste and odour threshold concentrations have been reported in the literature. These include 24, 40, 170, 500, 960 and 1000 µg l^{-1}[1-5,9,10], the lowest odour concentration being reported at 60°C. Taste threshold concentrations of 40, 120, 160 and 960 µg l^{-1} have also been reported[3,4,5].

Overall Evaluation

The wide range of taste and odour threshold concentrations quoted in the literature make it difficult to determine the concentration at which toluene will cause taste and odour complaints. It appears that toluene is most likely to be detected by taste and odour at concentrations above 200 $\mu g\ l^{-1}$ and certainly at 1 $mg\ l^{-1}$ which are below the concentrations considered to be of risk to human health in the short-term.

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TRIMETHYLBENZENES

There are three trimethylbenzene isomers (1,2,3-; 1,2,4- and 1,3,5-) and they are likely to occur in drinking water as a result of contamination through their use as a solvents or by contamination of water by petroleum products or paint thinners.

Health Effects

Trimethylbenzenes are readily absorbed from the gastrointestinal tract and also are readily excreted, mainly as glycine conjugates [1]. In man, most toxicity data on trimethylbenzenes relate to exposure following inhalation either from occupational exposure or solvent abuse. The main toxic effect is central nervous system (CNS) depression and symptoms following acute exposures to high concentrations include mental confusion, tension, nausea and drowsiness, although these symptoms are generally reversible[1].

Based on studies in laboratory animals, trimethylbenzenes are of very low acute oral toxicity (rat oral LD_{50} 3.4-6 g kg^{-1} for the 1,2,4-isomer), the toxic endpoint again being CNS depression. Limited short- term oral studies have been carried out in laboratory animals but a dose of 500 mg kg^{-1} body weight day^{-1} (5 days/week) was reported as having no adverse effects in a 4-week study in rats for the 1,2,4-isomer [1] .

Limited data indicate that trimethylbenzenes are not mutagenic[1], although no studies investigating their carcinogenic potential or reproductive effects were located.

Short-term health guideline values

There are no short-term health guideline values for trimethylbenzenes. Based on a 4 week gavage study in rats, no adverse effects were observed when the 1,2,4-isomer was administered a dose of about 357 mg kg^{-1} day^{-1}. By applying an uncertainty factor of 500 to allow for inter- and intraspecies differences and the limited database, a short-term tolerable daily intake of 0.7 mg kg^{-1} body weight is derived. Assuming a 60 kg adult drinking 2 litres of water per day, SNARLs are as follows;-

24 hour SNARL allowing 100% of the TDI to water = 20 mg l^{-1}

7 day SNARL allowing 50% of the TDI to water = 10 mg l^{-1}

Since it is likely that the three isomers are of similar toxicity, the SNARLs relate to total trimethylbenzenes.

Taste and odour Effects

A range of odour threshold concentrations have been reported in the literature. These include 3, 15, 27 and 500 µg l^{-1} for 1,3,5-trimethylbenzene[2-6]. A threshold odour concentration of 500 µg l^{-1} has also been reported for 1,2,4-isomer[2].

Overall Evaluation

The odour threshold concentration for trimethylbenzenes is most likely to be between 10 and 30 $\mu g\ l^{-1}$ which is three orders of magnitude below those concentrations considered to be of significant risk to human health in the short-term.

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XYLENES

The three xylene isomers (*ortho-*, *meta-* and *para-*) are most likely to occur in drinking water through their use as solvents or via contamination by petroleum products and are likely to be present as a mixture of the three isomers.

Health Effects

Xylenes are likely to be rapidly absorbed via ingestion and can be absorbed to some extent via the skin[3]. They are readily metabolised and rapidly excreted in the urine[1,2].

In man, most toxicity data on xylenes relate to exposure following inhalation either from occupational exposure or solvent abuse. Following inhalation to high doses, the main toxic effects are central nervous system (CNS) disturbances as well as respiratory effects[3]. The lowest oral lethal dose for humans has been reported as 50 mg kg^{-1} [2].

Based on laboratory animal studies, xylene is of low acute oral toxicity (rat oral LD_{50}s range from 4300 to 5000 mg kg^{-1})[2,3]. A number of short- and long-term oral studies have been carried out in laboratory animals which indicate that it is also of low chronic toxicity. No adverse effects were observed in rats when dosed 500 mg kg^{-1} body weight day^{-1} (5 days/week) by gavage for 13 weeks and 1000 mg kg^{-1} day^{-1} only caused slight toxicity as indicated by decreased body weight[2]. In a 103-week gavage study in rats no adverse effects were observed at a dose of 250 mg kg^{-1} day^{-1} (5 days/week) and 500 mg kg^{-1} day^{-1} only resulted in decreased body weight [2].

Xylenes are considered not to be mutagenic or carcinogenic and no convincing evidence for teratogenicity has been found [1,2].

Short-term health guideline values

The USEPA have established 1 and 10-day health advisories of 40 mg l^{-1} for xylenes based on a 10 kg child drinking 1 litre of water per day. These were derived by applying an uncertainty factor of 100 to a NOAEL of 500 mg kg^{-1} (dosed 5 days/week) which was identified in a 13-week gavage study in rats.

Taste and odour Effects

Odour threshold concentrations reported in the literature for xylene vary widely. These include 20, 300, 1000, 1800 µg l^{-1}[1,2,5]. Based on a panel size of 16, an average odour threshold concentration of 2.21 mg l^{-1} was reported for xylene (mixed isomers) whereas the range was between 0.26 to 4.13 mg l^{-1} [4]. Odour threshold reported for the individual isomers are as follows: *o*-xylene 1.8 and 2.2 mg l^{-1}[7,8]; *m*-xylene 0.05, 1.1 mg l^{-1} [8]; *p*-xylene 0.53, 1 mg l^{-1}[8].

A threshold taste concentration of 0.3-1 mg l^{-1} has been reported for xylene[2]. Taste threshold for individual isomers are reported as follows: *o*-xylene 0.3 mg l^{-1}[6], *m*-xylene 0.17 mg l^{-1}[2]; *p*-xylene 0.47 mg l^{-1} [9].

Overall Evaluation

The wide range of taste and odour threshold concentrations quoted in the literature make it difficult to determine the concentration at which xylenes will cause taste and odour complaints. It appears that xylene is most likely to be detected by taste and odour at concentrations above 300 $\mu g\ l^{-1}$ although there may be more sensitive individuals who will be able to detect xylene concentrations as low as 20 $\mu g\ l^{-1}$. Xylene will certainly be detected by taste and odour well below the concentrations considered to be of risk to human health in the short-term.

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APPENDIX D SUMMARY TABLE OF SHORT-TERM HEALTH BASED GUIDELINE VALUES AND TASTE AND ODOUR THRESHOLDS

The following table summarises information only for those data summaries for which USEPA health advisories or WRc SNARLs have been derived. Reference should be made to the individual data summaries for further guidance and also for those chemicals not included in the summary table.

Table D.1 Summary table

Compound	USEPA 1-day Health Advisory ($\mu g\ l^{-1}$)	USEPA 10-day Health Advisory ($\mu g\ l^{-1}$)	WRc SNARL 24-hour ($\mu g\ l^{-1}$)	WRc SNARL 7-day ($\mu g\ l^{-1}$)	Most likely taste/odour threshold ($\mu g\ l^{-1}$)
Benzene	200	200	-	-	≅200
Chlorocresols (*total)	-	-	2250	1100	0.1-3
2-Chlorophenol	500	500	-		0.1-1
4-Chlorophenol	-	-	500	500	0.1-1
Cresols (*total)	-	-	1500	750	1-3
1,2-Dichlorobenzene	9000	9000	-	-	5-50
1,3-Dichlorobenzene	9000	9000	-	-	5-50
1,4-Dichlorobenzene	10,000	10,000	-	-	5-50
2,4-Dichlorophenol	30	30	-	-	0.1-1
2,6-Dichlorophenol	-	-	30	30	0.1-1
Ethylbenzene	30,000	3000	-	-	20-200
Isopropylbenzene	-	-	1200	600	10-70
p-Isopropyltoluene	-	-	15000	7500	100-400
Monochlorobenzene	2000	2000	-	-	100-200
Naphthalene	500	500	-	-	5-20
Styrene	20,000	2000	-	-	45-50
Toluene	20,000	2000	-	-	200-1000
1,2,3-Trichlorobenzene	-	-	770	380	5-50
1,2,4-Trichlorobenzene	100	100	-	-	5-50
1,3,5-Trichlorobenzene	600	600	-	-	5-50
2,4,5-Trichlorophenol	-	-	3000	1500	0.1-1
2,4,6-Trichlorophenol	-	-	3000	1500	0.1-1
Trimethylbenzenes (*total)	-	-	20,000	10,000	10-30
Xylenes (*total)	40,000	40,000	-	-	20-300

APPENDIX E INDEX TO DATA SUMMARIES

APPENDIX F CONTACTS FOR FURTHER ADVICE

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