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Environmental Health Criteria 31

TETRACHLOROETHYLENE

Published under the joint sponsorship of
the United Nations Environment Programme,
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and the World Health Organization
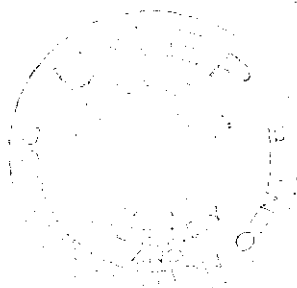
World Health Organization
Geneva, 1984

The **International Programme on Chemical Safety (IPCS)** is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. The main objective of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment. Supporting activities include the development of epidemiological, experimental laboratory, and risk-assessment methods that could produce internationally comparable results, and the development of manpower in the field of toxicology. Other activities carried out by IPCS include the development of know-how for coping with chemical accidents, coordination of laboratory testing and epidemiological studies, and promotion of research on the mechanisms of the biological action of chemicals.

ENVIRONMENTAL HEALTH CRITERIA 31: TETRACHLOROETHYLENE

CORRIGENDUM

Page 35, lines 17-18:

<u>Delete</u>: The WHO recommended guideline value in drinking-water is 10 mg/litre (WHO, 1983).

<u>Insert</u>: The WHO tentative guideline value for drinking-water is 10 μg/litre (WHO, 1983).

CONTENTS

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FOR TETRACHLOROETHYLENE

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The WHO Task Group for the Environmental Health Criteria
for Tetrachloroethylene met in Brussels from 19 to 22
September, 1983. Professor A. Lafontaine opened the meeting
and welcomed the participants on behalf of the host
government, and Dr. M. Mercier, Manager, IPCS, on behalf of
the heads of the three IPCS co-sponsoring organizations
(ILO/WHO/UNEP). The Group reviewed and revised the second
draft criteria document and made an evaluation of the health
risks of exposure to tetrachloroethylene.

The efforts of Dr. G.J. Van Esch and Dr. T. Vermeire, who
were responsible for the preparation of the draft, and of all
who helped in the preparation and the finalization of the
document are gratefully acknowledged.

* * *

PREFACE

A partly-new approach to develop more concise Environmental Health Criteria documents has been adopted with this issue. While the document is based on a comprehensive search of the available, original, scientific literature, only key references have been cited. A detailed data profile and a legal file on tetrachloroethylene can be obtained from the International Register of Potentially Toxic Chemicals, Palais des Nations, 1211 Geneva 10, Switzerland (Telephone No. 988400 - 985850).

The document focuses on describing and evaluating the risks of tetrachloroethylene for human health and the environment.

While every effort has been made to present information in the criteria documents as accurately as possible without unduly delaying their publication, mistakes might have occurred and are likely to occur in the future. In the interest of all users of the environmental health criteria documents, readers are kindly requested to communicate any errors found to the Manager, International Programme on Chemical Safety, World Health Organization, Geneva, Switzerland, in order that they may be included in corrigenda, which will appear in subsequent volumes.

1. SUMMARY

Tetrachloroethylene is widely used as a dry-cleaning and degreasing solvent under many different chemical, common, generic, and code names. Assessment of the toxicity of commercial tetrachloroethylene is frequently complicated by the presence of minor amounts of stabilizers that may themselves be toxic.

Man is exposed mainly to the vapour of tetrachloroethylene. Groups exposed to high concentrations include workers in dry-cleaning shops and factories; people living near these establishments may also be exposed to higher concentrations than the rest of the community. The general population is exposed to low levels of tetrachloroethylene in ambient air, food, and drinking-water.

An estimated 85% of man-made tetrachlorethylene is released into the ambient air, as a result of evaporation. In the troposphere, photodegradation takes place, ultimately leading to the formation of hydrogen chloride, trichloracetic acid, and carbon dioxide, in the presence of water. The significance of these findings for environmental conditions cannot be evaluated yet because of lack of consistent data. In surface water, photodegradation does not appear to be important in view of rapid volatilization. Available data concerning the process of microbial degradation are inadequate. Tetrachloroethylene is rather persistent in groundwater, which is one of the reasons for the present concern about the increasing incidence of contamination of groundwater through industrial spillage and waste dumps. No data are available concerning the behaviour of tetrachloroethylene in soil.

Tetrachloroethylene is absorbed via the skin, on direct contact, and via the lungs, after inhalation. Uptake is proportional to the exposure level and increases with exercise. Limited bioconcentration occurs in the lipid-rich tissues of both man and animals. All species are able to metabolize tetrachloroethylene, principally to trichloroacetic acid and sometimes also to trichloroethanol via the cytochrome P-450 mixed function oxidase system. However, the extent of metabolism differs in different species. In rat and man, most absorbed tetrachloroethylene is excreted unchanged via the lungs, whereas, in the mouse, the compound is metabolized to a much greater extent. In all species, metabolic capacity is limited, i.e., high exposures will not lead to higher concentrations of metabolites in the urine.

Because of accumulation in lipid-rich tissues, removal of tetrachloroethylene from blood and excretion in the breath are slow, both being proportional to the exposure level but not to

the length of exposure. The concentrations of
tetrachloroethylene in blood and breath can be used for
estimating exposure levels in man. Adequate analytical
methods are available.

Subjects exposed to tetrachloroethylene vapour will
experience eye irritation at approximately 500 mg/m^3 and
will begin showing signs of central and autonomic nervous
system depression, after both single exposure and short-term
repeated exposure to about 700 mg/m^3. At this
concentration, nose and throat irritation is reported. These
effects are reversible and increase in severity with the
concentration and length of exposure. Direct skin exposure
will result in irritation of the skin.

No effects were noted in man after repeated exposure (1,
3, or 7.5 h/day, 5 days/week) to approximately 140 mg/m^3,
but rats showed EEG changes at 100 mg/m^3. In mice, liver
and kidney damage first occurred at 1360 mg/m^3 with
short-term repeated inhalation exposure, and at 50 mg/kg body
weight during long-term oral exposure. In rats, short-term
oral exposure to 16 mg/kg body weight did not induce signs of
liver toxicity. The level of exposure at which effects on the
liver and/or kidneys might occur in man is not clear. Workers
in dry-cleaning plants did not show altered liver-enzyme
activity at exposure levels up to 2700 mg/m^3.

Embryotoxicity was observed in the progeny of experimental
animals exposed by inhalation to tetrachloroethylene
concentrations exceeding 2000 mg/m^3. It is possible that
similar effects might occur in human beings. However, there
was no indication of reproduction injury and only slight
evidence of teratogenicity in the animal studies reported.

Tetrachloroethylene was found to be carcinogenic for mice
but not for rats. Evidence from epidemiological studies among
dry-cleaning and laundry workers is insufficient to conclude
that exposure to tetrachloroethylene causes cancer in human
beings.

Tetrachloroethylene has been shown to be moderately toxic
for aquatic organisms in short-term studies and toxic in one
long-term study on fish.

2.   PROPERTIES AND ANALYTICAL METHODS

2.1 Chemical and Physical Properties of Tetrachloroethylene

Tetrachloroethylene (C_2Cl_4) is a nonflammable compound that is stable up to 500 °C in the absence of catalysts, moisture, and oxygen, but decomposes slowly in contact with moisture to yield trichloroacetic acid and hydrochloric acid.

Chemical structure:

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   Cl                 Cl
     \               /
      \C══C/
     /               \
   Cl                 Cl
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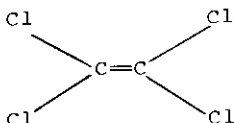
CAS registration number: 127-18-4
RTECS registration number: KX 385 0000

Common synonyms include: carbon dichloride, ethylene tetrachloride,   perchloroethylene,   tetrachloroethene, 1,1,2,2-tetrachloroethylene
Common trade names include: Ankilostin, Antisal 1, Antisol 1, Blancosolv No. 2, Dee Solve, Didakene, Dowper, Ent 1860, Fedal Un, Mid Solv, NeMa, Per, Perawin, Perc, Perclene, Per-Ex, Perk, Perklone, Perm-a-kleen, Persec, Phillsolv,   Tetlen,   Tetracap,   Tetraguer,   Tetraleno, Tetralex, Tetravec, Tetropil, Wacker-Per.

Some physical data on tetrachloroethylene

physical state	liquid
colour	colourless
odour	ethereal
relative molecular mass	165.82
melting point	-22 °C
boiling point	121 °C
water solubility	150 mg/litre, 20 °C
n-octanol-water partition coefficient	2.86
density	1.62 g/ml, 20 °C
relative vapour density	5.8
vapour pressure	1.9 kPa (14 mm Hg), 20 °C
surface tension	32.32 dyne/cm^2 20 °C

Conversion factor

tetrachloroethylene   1 ppm = 6.78 mg/m^3

Table 1 (contd).

Medium	Specification	Sampling method	Analytical method	Detection limit	Comments	Reference
air	ambient, breath	air, breath: sorption on XAD - 2	elution by pentane-ether	air: 0.01 µg/m³		Bauer (1981)
solids	food, tissues	solid and liquid samples: stripping by nitrogen, sorption on XAD - 2	elution by pentane gas chromatography with electron-capture detection	food: 0.2 µg/kg wet-weight		
liquids	water			water: 0.001 µg/litre		
water			gas chromatography with electron-capture detection	0.05 µg/litre	direct headspace analysis	Piet et al. (1978)
water	drinking		gas chromatography with electron capture detection	0.5 µg/litre	direct analysis	Nicholson et al. (1977)
food		extraction by steam distillation in presence of 25% sulfuric acid	gas chromatography with electron capture detection	2-5 µg/kg wet weight		Zimmerli et al. (1982a)
blood, breath			gas chromatography with electron capture detection	0.06 mg/litre blood 0.01 mg/m³ air	head space analysis (blood) direct analysis (breath)	Monster & Boersma (1975)

3. SOURCES IN THE ENVIRONMENT, ENVIRONMENTAL TRANSPORT AND DISTRIBUTION

3.1 Natural Occurrence

Tetrachloroethylene is not known to occur as a natural product (IARC, 1979).

3.2 Production Levels and Processes, and Uses

3.2.1 Production levels and processes

World production of tetrachloroethylene amounted to 680 kilotonnes in 1972 (Fishbein, 1979) and to 1000 kilotonnes in 1974 (Fuller, 1976).

The annual production is estimated to be 50-100 kilotonnes in Eastern Europe, about 55 kilotonnes in Japan (IARC, 1979), 100-250 kilotonnes in Western Europe (IARC, 1979), and about 350 kilotonnes in the USA (USITC, 1981).

Tetrachloroethylene is produced mainly by oxyhydro-chlorination, perchlorination, and/or dehydrochlorination of hydrocarbons or chlorinated hydrocarbons such as: 1,2 dichloroethane, methane, ethane, propane, propylene, propylene dichloride, 1,1,2-tri-chloroethane, and acetylene (Fuller, 1976; IARC, 1979).

Technical products contain stabilizers, believed to include amines or mixtures of epoxides, esters, and other chemicals such as acetone, acetylenic compounds, aniline, borate esters, n-butane, 2-cresol, diiosopropylamine, ethyl acetate, hydrazine derivatives, isobutyl alcohol, lactones, 2-nitrophenol, pyrazoles, stearates, and sulfur dioxide.

3.2.2 Uses

Tetrachloroethylene is mainly used as a solvent in dry cleaning and metal cleaning. It is also used for processing and finishing in the textile industry, as an extraction solvent, a veterinary anthelminthic, a heat-exchange fluid, in grain fumigation, and in the manufacture of fluorocarbons (IARC, 1979; NIOSH, 1976; Umweltbundesamt, 1978).

3.3 Occurrence and Transport in the Environment

3.3.1 Occurrence

In addition to being present in the air over rural and urban sites, tetrachloroethylene has also been found in the air over oceans (Murray & Riley, 1973). The concentrations

over the North East Atlantic ocean ranged between 1 and
9 ng/m^3, the concentration in the water being
0.2–0.8 ng/litre. Bay water along the coast of the United
Kingdom contained 0.12–2.6 µg/litre, while the sediment
contained 0.02–4.8 µg/litre (Pearson & McConnell, 1975).
Not surprisingly, marine organisms were also found to contain
residues of tetrachloroethylene. Pearson & McConnell measured
0.05–15 µg/kg wet weight in vertebrates, 13–20 µg/kg wet
weight in algae, and 0–19 µg/kg wet weight in seal blubber
and shrew. Organs and eggs of birds contained 0.7–39 µg/kg
wet weight.

Surface water in Western Europe was found to contain
tetrachloroethylene levels of 0.01–46 µg/litre (Correia et
al., 1977; Bauer, 1981). Maximum levels of 22 µg/litre,
measured in groundwater in the Netherlands, were probably
caused by leaching of tetrachloroethylene through the soil
after industrial spillage (Zoeteman et al., 1980).

3.3.2   Transport

About 85% of the tetrachloroethylene used annually in the
USA is lost to the atmosphere (Fuller, 1976), and the
world-wide emission of tetrachloroethylene has been estimated
to be about 450 kilotonnes per year (Singh et al., 1975).
Volatilization also appears to be the major pathway by which
tetrachloroethylene is lost from water. Zoeteman et al.
(1980) estimated the half-life of tetrachloroethylene to be
3–30 days for river water and 30–300 days for lake- and
groundwater, on the basis of field experiments.

Photodegradation of tetrachloroethylene in water does not
appear to be important as a sink, in view of the rapid
volatilization from water. Hydrolysis also seems to be of
minor importance (Dilling, 1975).

Once tetrachloroethylene enters the troposphere, hydroxyl
radicals can attack the double bond, yielding intermediate
products likely to be hydrolized in the aqueous phase mainly
to trichloroacetic acid, which, in turn, is slowly decomposed
to carbon dioxide and chloride ions (Pearson & McConnell,
1975).

Reports about microbial biodegradation are few and
conflicting. Bouwer et al. (1981) did not find aerobic or
anaerobic degradation using primary sewage effluent and a
mixed methanogenic culture, respectively. However, recently,
Bouwer et al. (1983) reported almost complete anaerobic
transformation using a mixed methanogenic culture. The first
step appeared to be reductive dechlorination to
trichloroethylene. Tabak et al. (1981) found significant
aerobic degradation in water, inoculated by settled domestic
waste water.

4. ENVIRONMENTAL LEVELS AND EXPOSURES

Tetrachloroethylene is mainly used in dry-cleaning and degreasing operations. Consequently, the main human exposure is through vapour inhalation, sometimes accompanied by skin and eye contact, at the place of work. People living nearby may be exposed to higher levels than the general population elsewhere. Maximum concentrations have been found not to exceed about 50 µg/m³ in the urban atmosphere, 35 µg/litre in drinking-water, and about 3.5 mg/kg wet weight in foodstuffs. A point of concern is the contamination of groundwater through spillage, as tetrachloroethylene is remarkably persistent in water.

4.1 Occupational Exposure

Exposures in dry-cleaning establishments can be as high as an 8-h time-weighted average of 4000 mg/m³ (Shipman & Whim, 1980). However, in the United Kingdom, over 90% of 493 8-h measurements in 131 dry-cleaning establishments revealed concentrations below 680 mg/m³, and over 50% of these samples revealed concentrations below 200 mg/m³ (Shipman & Whim, 1980). Similar results were obtained in a survey of 46 dry-cleaning establishments in the Federal Republic of Germany (Franke & Eggeling, 1969). Between 1977 and 1979, breathing-zone air samples were collected from 144 workers at 44 out of an estimated 25 000 dry-cleaning establishments in the USA (Anon, 1983). Machine-operators received the highest exposures with 8-h time-weighted averages between 27 and 1010 mg/m³. Machine-operators in 9 plants had 8-h time-weighted-average exposures exceeding 340 mg/m³. In 7 plants, 15-min peak exposures exceeded 680 mg/m³. Other workers received a maximum 8-h time-weighted average of 251 mg/m³. At railway works, where tetrachloroethylene was used as a cleaning agent, 6% of 104 8-h measurements were below 680 mg/m³ with peaks up to 1290 mg/m³ (Essing, 1975).

4.2 General Population Exposure

Individuals living near dry-cleaning shops can be exposed to concentrations of tetrachloroethylene high enough to show measurable uptake. The breath of residents, living above 12 dry-cleaning shops in the Netherlands, was found to contain a mean concentration of 5 mg/m³, while the breath of residents, living adjacent to the shops, contained 1 mg/m³ (Verberk & Scheffers, 1979). People, living elsewhere, can also be exposed. However, at rural sites, exposure will be low and air concentrations ranging from 8 ng/m³ to 500

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ng/m^3 have been measured (Murray & Riley, 1973; Lillian et al., 1975). At a similar site, a concentration of 337 ng/m^3 was reported by Singh et al. (1982). Surveys of the air in 9 cities in the USA showed concentrations between 0.2 and 51.55 µg/m^3 with averages between 1.98 and 3.99 µg/m^3 (Simmons et al., 1974; Lillian et al., 1975; Singh et al., 1982). In 14 cities in the Federal Republic of Germany, average concentrations were between 1.7 and 6.1 µg/m^3 (Bauer, 1981; Düszeln et al., 1982).

Municipal drinking-water in the Federal Republic of Germany, the United Kingdom, and the USA contained an average of 1.3 µg of tetrachloroethylene per litre, or less (Pearson & McConnell, 1975; Saunders et al., 1975; Fujii, 1977; Düszeln et al., 1982). In the Federal Republic of Germany, the maximum concentration found in a drinking-water survey in 100 cities was 35.3 µg/litre in 1977, the average being 0.6 µg/litre (Bauer, 1981).

In foodstuffs, McConnell et al. (1975) measured 0.01 - 19 µg/kg wet weight. In milk (products) or meat (products), average concentrations were recorded ranging from 0.003 to 3.49 mg/kg in Switzerland, and a total daily intake via food was calculated of 160 µg per day (Zimmerli et al., 1982). In the Federal Republic of Germany, the daily intake via food was calculated to be 160 µg per day (Bauer, 1981) and 87 µg per day (Düszeln et al., 1982)

The total human intake of tetrachloroethylene from air, water, and food was calculated by Bauer and Düszeln to be, respectively, 113 and 144 µg/day. When human tissues of 15 deceased persons from an industrialized area in the Federal Republic of Germany were analysed, maximum concentrations of tetrachloroethylene in fat of up to 36.9 µg/kg wet weight were found, the average being approximately 14 µg/kg (Bauer, 1981).

5.   CHEMOBIOKINETICS AND METABOLISM

5.1   Absorption

5.1.1   Animal studies

Dermal absorption was rapid in both mice and guinea-pigs, peak concentrations of tetrachloroethylene in the blood of guinea-pigs being reached 30 min after application (Tsuruta, 1975; Jakobson et al., 1982).   The level of tetrachloroethylene in the blood of rats reached a maximum 1 h after oral ingestion, or immediately after 6 h inhalation (Pegg et al., 1979).

5.1.2   Human studies

Dermal exposure to liquid tetrachloroethylene resulted in measurable levels of the compound in the breath, reaching a maximum 10 min after exposure (Steward & Dodd, 1964). Absorption via the lungs is also rapid.   Within 3 h of exposure to tetrachloroethylene vapour, concentrations in the blood appeared to reach equilibrium (Steward et al., 1961a). The exposure level had a greater effect on blood concentrations than the exposure time (Hake & Steward, 1977). The total uptake over 4 h increased 2.1 times when the exposure concentration was doubled.   Body mass influenced this uptake more than respiratory minute volume or the amount of adipose tissue.   Due to decreased retention, the uptake decreased in the course of the exposure to 60% of the initial uptake.   Uptake increased with exercise (Monster et al., 1979).   The venous blood concentration also increased during exercise (Hake & Steward, 1977).

5.2   Distribution

5.2.1   Animal studies

Seventy-two hours after either oral administration (once by gavage, or for 12 h in the drinking-water) or 6-h inhalation of labelled tetrachloroethylene by rats (Pegg et al., 1979; Frantz & Watanabe, 1983) and mice (Schumann et al., 1980), less than 5% of the radioactivity was retained by the body.   Most radioactivity was found in body fat, kidneys, and liver of rats.   Some radioactivity was also found in the lung, heart, and adrenals.   Tetrachloroethylene was bound irreversibly to liver macromolecules more rapidly, and to a greater extent, in mice than in rats.   No binding to DNA was found (Schumann et al., 1980).

In short-term exposures of laying hens, via the feed, tetrachloroethylene was mainly deposited in fat and fat-containing tissues. The concentration of tetrachloroethylene in eggs and tissues increased proportionally with the concentration in the feed up to 575 mg/kg of feed (Zimmerli et al., 1982b).

5.2.2   Human studies

Evidence of limited accumulation of tetrachloroethylene in the human body was found by Hake & Steward (1977). Exposure of volunteers to 678 mg/m^3 for 7.5 h per day, 5 days/week, resulted in a slightly higher alveolar excretion after each daily exposure.

5.3   Metabolic Transformation

5.3.1   Animal studies

Tetrachloroethylene, ingested or inhaled by rats, is mainly excreted unchanged via the lungs, particularly at high exposures. Pegg et al. (1979) (section 5.2.1) recovered 60-70% of labelled tetrachloroethylene in the breath after low oral and inhalation exposures and about 90% after a high exposure. Mice metabolized tetrachloroethylene to a greater extent than rats. After inhaling a low concentration of the labelled compound, 12% was excreted unchanged in the breath (Schumann et al., 1980), while 70% was excreted unchanged after inhalation of a high concentration (Yllner, 1961). Most of the balance was found as metabolites in the urine. At a very high oral dose (8300 mg/kg body weight), only 1.6% of the radioactivity was found in the urine of rats (Daniel, 1963). The above values indicate saturable metabolism.

The major metabolite, found in the urine of rats, mice, and hamsters, was trichloroacetic acid (Yllner, 1961; Daniel, 1963; Ikeda & Imamura, 1973; Moslen et al., 1977). Other metabolites found were oxalic acid and ethylene glycol. Pegg et al. (1979) found only oxalic acid in the urine of rats.

Yllner (1961) and Daniel (1963) suggested a metabolic pathway in which epoxidation was the first step. After a chloride shift, trichloroacetyl chloride could be formed, which hydrolyses to trichloroacetic acid. The involvement of a mixed-function oxidase was demonstrated in rats and hamsters, when inducers of these enzymes increased the excretion of trichlorocompounds as much as 7 times (Ikeda & Imamura, 1973; Moslen et al., 1977). The results of in vitro experiments showed that cytochrome P-450 binds tetrachloroethylene and metabolizes it to mainly trichloroacetic acid, stimulated by inducers of mixed-function oxidases. Binding

between metabolites and liver macromolecules (Schumann et al., 1980) is believed to occur via an acylation reaction (Bonse et al., 1975; Leibmann & Ortiz, 1977; Costa & Ivanetich, 1980). The formation of radicals, presumably trichloroacetyl radicals, was established in vivo in rats and mice (Schmid & Beuter, 1982).

5.3.2   Human studies

Trichlorocompounds in the urine of workers exposed to 70-2710 mg/m³ for a few hours or repeatedly over several days were identified as metabolites of tetrachloroethylene. Mainly trichloroacetic acid was found (Weiss, 1969; Ikeda & Ohtsuji, 1972; Ikeda et al., 1972; Ikeda & Imamura, 1973; Münzer & Hecter, 1973), but also trichloroethanol (Ikeda & Ohtsuji, 1972; Ikeda et al., 1972). After controlled exposures to tetrachloroethylene concentrations of 488-1356 mg/m³ for 1-8 h, less than 2% of the uptake was found as trichloroacetic acid in the urine (Fernandez et al., 1976; Hake & Steward, 1977; Monster et al., 1979). Monster et al. (1979) calculated that 80-100% of the uptake was excreted unchanged via the lungs. Ikeda et al. (1972) found that the trichloroacetic acid concentration in the urine reached a plateau with repeated exposures above 340 mg/m³.

5.4   Excretion

5.4.1   Animal studies

Tetrachloroethylene was still detectable in the breath of rats 16 h after a single exposure to levels of 339 - 3390 mg/m³ for 1 - 40 h. The excretion was proportional to the exposure level and not directly to the exposure time (Boettner & Muranko, 1969). This excretion followed first-order kinetics with a half-life of 7 h (Pegg et al., 1979; Frantz & Watanabe, 1983). Excretion of tetrachloroethylene in cows' milk was found after oral ingestion of 100 mg/day with the feed. One percent of the intake was recovered in the milk (Wanner et al., 1982). Tetrachloroethylene was also recovered in hen eggs at a rate of 0.6%, when the hens were repeatedly exposed via the feed (Zimmerli et al., 1982b).

5.4.2   Human studies

The elimination of tetrachloroethylene from the body has been reported to be slow (Steward et al., 1970; Monster et al., 1979). Excretion of tetrachloroethylene in breath was proportional to the exposure level (Steward et al., 1961a; Fernandez et al., 1976), but not to the length of exposure

(Fernandez et al., 1976). A prolonged exponential decay was found (Steward et al., 1961a) with a biological half-life of 65 h (Ikeda & Imamura, 1973). Contrary to the rapid excretion of tetrachloroethylene found by Steward et al. (1961a), Monster et al. (1979) found a slow excretion. The excretion via blood and lungs occurred at 3 different rate constants with half-lives of 12-16 h, 30-40 h, and about 55 h, respectively, 20, 50, and 100 h after exposure. Trichloroacetic acid was excreted from blood with a half-life of 75-80 h (Monster et al., 1979). Ikeda & Imamura (1973) estimated the half-life of this metabolite in urine to be about 6 days. One case was reported of excretion of tetrachloroethylene in breast milk (Bagnell & Ellenberger, 1977).

6.   EFFECTS ON ORGANISMS IN THE ENVIRONMENT

A summary of the acute toxicity of tetrachloroethylene for
aquatic organisms and plants is presented in Table 2.

In a 60-day study, 3 groups of black mollies (Poecilia
sphenops), each comprising 3 females and 3 males, were
exposed, respectively, to 0, 0.001, and 0.005 ml
tetrachloroethylene per litre water. Weights declined by 30 -
40% in the exposed groups and increased in the control group.
Survival was 100%, 17%, and 0% at 0, 0.001, and 0.005
ml/litre, respectively. The livers of exposed fish showed
fatty degeneration (Loekle et al., 1983).

Pearson & McConnell (1975) estimated bioconcentration
factors from levels in sea water and biota (fish, birds' eggs,
seal blubber) to be less than 100. A steady-state
bioconcentration factor of 49 was found in bluegill sunfish
with a half-life of less than 1 day for depuration (Barrows et
al., 1980).

Table 2. Acute aquatic toxicity

Organism	Description	t(°C)	pH	Dissolved oxygen (mg/litre)	Hardness (mgCaCO₃/litre)	Flow/stat [1]	Parameter	Concentration mg/litre	Reference
crustacea	water flea, Daphnia magna	22	6.7-8.1	6.5-9.1	72	stat	48-h LC$_{50}$ no-observed adverse-effect level	18 10	Le Blanc (1980)[2]
crustacea	water flea, Daphnia magna	20	8.0	>2		stat	24-h EC$_{50}$ 24-h ECO	147 65	Dringmann & Kühn (1982)[3]
fish	fathead minnow, Pimephales promelas	12	7.8-8.0	>5.0		stat	96-h LC$_{50}$	21.4	Alexander et al. (1978)[4]
fish	fathead minnow, Pimephales promelas	12	7.8-8.0	>5.0		flow	96-h LC$_{50}$	18.4	Alexander et al. (1978)[4]
fish	bluegill sunfish, Lepomis macrochirus	21-23	6.5-7.9	9.7-0.3	32-48	stat	96-h LC$_{50}$ 24-h LC$_{50}$	13 46	Buccafusco et al. (1981)[5]
fish	rainbow trout, Salmo gairdneri	12	7.1		44	stat	96-h LC$_{50}$	5	Shubat et al. (1982)[11]
algae	unicellular Phaeodactylum tricornutum						EC$_{50}$	10.5	Pearson & McConnell (1975)[7]
plankton	phytoplankton	18	7.8			flow	lowest observable effect level	2.0	Erickson & Hawkins (1980)[8]

Table 2 (contd).

inverte-brate	barnacle Elminius modestus		stat	48-h LC_{50}	3.5	Pearson & McConnell (1975)[9]
fish	dab, Limanda limanda		flow	96-h LC_{50}	5	Pearson & McConnell (1975)[10]
fish	sheepshead minnow, Cyprinodon variegatus	25-31	stat	96-h LC_{50}	>29, <52	Heitmuller et al. (1981)[11]

Notes

1) Flow through or static method.
2) 15 daphnias/concentration, < 24 h old.
3) 20 daphnias/concentration, < 24 h old; standardised synthetic medium was aerated up to saturation before the test; the sum of calcium and magnesium ions was 2.5 mmol/litre.
4) dechlorinated, sterilised lake water.
5) 10 juvenile fish/concentration, deionized reconstituted fresh water; no aeration.
6) 20 fish/concentration, lake water.
7) ^{14}C uptake inhibition during photosynthesis in sea water.
8) sea water; phytoplankton included Chlorophyceae, Cyanophyceae and Bacillariophyceae; salinity 1.6-1.7%.
9) sea water.
10) sea water; 5 fish/concentration.
11) sea water; salinity 1.0-3.1%; 10 juvenile fish/concentration; no aeration.

7.   EFFECTS ON ANIMALS

7.1   Short-term studies

7.1.1   Oral exposure

Fatty infiltration of the liver and heart was observed in dogs after oral ingestion of tetrachloroethylene at 306-398 mg/kg body weight along with depressed heart and respiration rates (Christensen & Lynch, 1933).

Rats receiving 405 mg of tetrachloroethylene per kg body weight in arachis oil, for 5 days per week, during 4 weeks, showed an increased relative liver weight and increased liver aniline hydroxylase activity. No histopathological abnormalities were found. At 16 mg/kg body weight, no effects on the liver were noted (de Vries et al., 1982).

7.1.2   Inhalation exposure

No macroscopic lesions were found in surviving rats at the 6-h LC_{50} value of 27 800 mg/m^3, 14 days after exposure (Bonnet et al., 1980). Inhalation by rats of tetrachloroethylene at concentrations of 3390 mg/m^3 or more caused increased activity in the following enzymes in blood: serum glutamic oxaloacetic transaminase (SGOT) (EC 2.6.1.1), serum glutamic pyruvic transaminase (SGPT) (EC 2.6.1.2), glucose-6-phosphatase (EC 3.1.3.9), and ornithine carbamoyl-transferase (EC 2.1.3.3). These changes are indicative of liver injury (Drew et al., 1978). Neurotoxic effects were noted in rats following a single exposure to 2000 mg/m^3. Rats exhibited an intensified motor reaction and there were distinct alterations in the EEG, an increased impedance of the cerebral cortex and decreased biopotentials and EEG voltage. Serum acetylcholinesterase (EC 3.1.1.7) activity was decreased (Dmitrieva, 1966).

In mice, SGPT-activity increased by 100% after inhalation of 25 100 mg/m^3 for 7 h (Gehring, 1968). Moderate fatty infiltration was noted in the livers of mice after a 4-h exposure to a tetrachloroethylene concentration of 1366 mg/m^3. Massive infiltrations occurred at higher exposures. No liver necrosis was found (Kylin et al., 1963).

After 8 weeks of exposure to 1356 mg/m^3, for 4 h per day and 5 days per week, rats showed fatty infiltration in the liver and an increase in extractable fat, but no cirrhosis or necrosis (Kylin et al., 1965). The kidneys were not affected in this study.

Rats, rabbits, and monkeys did not exhibit any adverse effects, including neurotoxic and behavioural effects during

or after repeated exposure to levels of tetrachloroethylene up to 2720 mg/m^3 for about 200 days. Guinea-pigs, however, showed increased liver weight and a few liver cells containing fat vacuoles at 680 mg/m^3. At levels of 1360 mg/m^3 or more, fatty degeneration without cirrhosis was found. Loss of equilibrium, coordination, and strength were observed in rats at 10 900 mg/m^3, and rabbits at 1700 mg/m^3. Kidney damage appeared after 24 days of exposure to 17 000 mg/m^3. The weight was increased and the tubular epithelium was swollen (Rowe et al., 1952).

Rabbits exposed repeatedly to 15 000 mg/m^3 for 45 days showed increased SGOT, SGPT, and glutamate dehydrogenase (EC 1.4.1.2) activity and signs of adrenal injury (Mazza & Brancaccio, 1971; Mazza, 1972).

Neurotoxic effects were observed in rats exposed to 100 mg of tetrachloroethylene per m^3 air, for 5 h per day, for 5 months. There were EEG changes together with an increased electrical impedance of cerebral tissue. The protoplasm of some cortex cells was swollen and there were isolated cells with vacuoles and karyolysis. Acetylcholinesterase activity was reduced. Fatty infiltration of the liver was also noted. At 10 mg/m^3, only changes in impedance and a slight decrease in acetylcholinesterase activity were found (Dmitrieva & Kuleshov, 1971). In 1937, Carpenter did not find any pathological changes in rats exposed repeatedly to tetrachloroethylene at 475 mg/m^3 for 7 months. At concentrations of 1559 and 3187 mg/m^3, congestion and swelling were the major changes in liver and kidneys.

Relevant acute mortality data are shown in Table 3.

Table 3. Acute mortality after oral intake or
inhalation of tetrachloroethylene

Species	Route	Vehicle	Parameter studied	Value	Reference
rat	oral	none	LD_{50}	13 000 mg/kg body weight	Smyth et al. (1969)
rat	inhalation	-	6-h LC_{50}	27 800 mg/m^3	Bonnet et al. (1980)
mouse	oral	herring oil	LD_{50}	10 300 mg/kg body weight	Dybing & Dybing (1946)
mouse	oral	none	LD_{50}	8400 mg/kg body weight	Dybing & Dybing (1946)
mouse	inhalation	-	4-h LC_{50}	35 000 mg/m^3	Friberg et al. (1953)
mouse	inhalation	-	6-h LC_{50}	20 200 mg/m^3	Gradisky et al. (1978)

The slope of the regression line giving the probability units of the percentage mortality after inhalation as a function of the logarithm of the concentration is rather steep for both rats and mice, the difference between the LC_{10} and the LC_{90} being less than 14 000 mg/m^3 (Gradiski et al., 1978; Bonnet et al., 1980).

7.1.3   Exposure of eyes and skin

Duprat et al. (1976) exposed New Zealand rabbits once, either by ocular instillation or dermal application. The ensuing conjunctivitis and epithelial abrasion of the eye was reversible and qualified as slight. Severe erythema and oedema with necrosis of the skin was noted. In a study on guinea-pigs, 1 ml (1.62 g) of undiluted tetrachloroethylene applied to the skin caused severe karyolisis, oedema, spongiosis, and pseudoeosinophilic infiltration (Kronevi et al., 1981).

7.2 Long-term studies

7.2.1   Oral exposure

B6C3F1 mice and Osborn Mendel rats were given tetrachloroethylene (more than 99% pure) in corn oil, by gavage, 5 days per week, for 78 weeks (NCI, 1977). Two groups each consisting of 50 male and 50 female animals received doses of approximately 500 and 1000 mg/kg body weight, respectively. Treated and untreated control groups were each made up of 20 male and 20 female animals. A dose-related increase in mortality was found in both species. Kidney damage observed at both dose levels, showing degenerative changes of the convoluted tubules with cloudy swelling, fatty degeneration, and necrosis of the tubular epithelium was not seen in the control animals. No effects on behaviour were observed, but rats developed a hunched appearance.

7.2.2   Inhalation exposure

Two groups each consisting of 96 male and 96 female Sprague Dawley rats were exposed to 2100 and 4010 mg tetrachloroethylene (96%) per m^3 air, for 6 h per day, 5 days per week, during 12 months. A control group consisted of 192 male and 192 female rats (Rampy et al., 1978). The rats were observed throughout their lifetime. At the highest exposure, increased mortality in males was related to an earlier onset of advanced chronic renal disease, which was also noted in females and controls. No significant effects

were found on body weight, or on the gross- and histopathology of major organs and tissues, other than the kidneys.

7.3 Carcinogenicity

7.3.1 Oral exposure

In the study by NCI (1977) (section 7.2.1), a significant increase in the incidence of hepatocellular carcinomas was found in mice at dose levels of both 500 and 1000 mg/kg body weight. No other significant effects were observed in the liver.

No evidence of an increased incidence of tumours was found in rats exposed to 500 and 1000 mg/kg body weight (NCI, 1977, section 7.2.1). However, survival was poor.

7.3.2 Inhalation exposure

There were no clear differences in the incidence of the different tumour types between exposed and control animals in the study by Rampy et al. (1978) (section 7.2.2) in which male and female rats were exposed to tetrachloroethylene (96%) at 2100 and 4010 mg/m^3 for 6 h/day, 5 days/week, for 12 months. The animals were kept for their lifetime.

7.3.3 Dermal exposure

Two groups, each consisting of 30 male and 30 female Ha:ICR Swiss mice, received 18 and 54 mg, respectively, of tetrachloroethylene in acetone applied to the shaven dorsal skin, 3 times per week for 440-594 days. In a third group, each mouse received one application of 163 mg of tetrachloroethylene followed after 2 weeks by a promotor in acetone, 3 times per week for 428-576 days. There were 3 control groups, one for the promotor, one for acetone, and one for no treatment. Tetrachloroethylene did not initiate or induce dermal tumours (Van Duuren et al., 1979).

7.4 Mutagenicity

Tetrachloroethylene, of undisclosed purity, induced base substitutions and frameshift mutations in plate tests with several strains of Salmonella typhimurium without metabolic activation (Cherna & Kypenova, 1977), but the response was dose-dependent only in TA 100.

With Escherichia coli K12, tetrachloroethylene was non-mutagenic in vitro, with or without metabolic activation (Greim et al., 1975).

In a 2-h test with Saccharomyces cerevisiae D7, no
mutagenic alterations were found in vitro or in vivo, with or
without metabolic activation (Bronzetti et al., 1983).
However, Callen et al. (1980) did find dose-related mutagenic
effects with strain D7 at the same loci and at similar
concentrations without additional metabolic activation in 1-h,
but not in 4-h suspension tests. Strain D4 did not show
mutagenic activity in vitro. Both groups of authors suggest a
possible toxic effect on the cytochrome P-450 system. Strain
D4 contains much less cytochrome P-450 than strain D7.

In bone-marrow cells of mice and rats, no chromosomal
aberrations were induced after single, repeated, or long-term
exposure to tetrachloroethylene in vivo (Cherna & Kypenova,
1977; Rampy et al., 1978).

In host-mediated assays with Salmonella typhimurium
strains TA 1950, TA 1951, and TA 1952 and female ICR mice as
hosts, an increase in mutagenic effects was observed. No dose
dependence was found (Cherna & Kypenova, 1977).

7.5 Reproduction and Teratogenicity

Seventeen rats exposed to 2060 mg of tetrachloroethylene
per m^3 air on days 6-15 of pregnancy showed reduced body
weight and a slightly increased number of resorptions (Schwetz
et al., 1975). No teratogenic effects were found.

In the same study, pups of 17 mice, exposed to
2060 mg/m^3 on days 6-15 of pregnancy showed a reduced body
weight. Out of 17 litters, all showed delayed ossification of
skull bones, 10 litters showed an increase in the incidence of
subcutaneous oedema, and 4, split sternebrae. Tetrachloro-
ethylene did not exhibit any reproductive toxicity or
teratogenic potential when rats and rabbits were exposed to
3390 mg/m^3 during pregnancy. Histopathology and weight of
maternal organs were also not affected (Hardin et al., 1981).
Several behavioural and neurochemical effects were observed in
the offspring of 75 rats, exposed to 6100 mg
tetrachloroethylene per m^3 air between the 7th and 13th day
or between the 14th and 20th day of pregnancy (Nelson et al.,
1979). Neuromuscular ability was affected. Decreased levels
of acetylcholine and dopamine were found in the brains of
21-day-old pups but not in the newborn. At 680 mg/m^3, no
behavioural effects were found in pups, but the mothers
consumed less food and gained less weight at both
concentrations.

8. EFFECTS ON MAN

8.1 Controlled Human Studies

Rowe et al. (1952) exposed six volunteers to tetrachloroethylene. Between exposure levels of 560 and 880 mg/m^3, only eye irritation was noted; from 1400 mg/m^3 upwards, reversible signs of central nervous system depression were observed, which increased in severity with higher exposures. The most frequently reported subjective complaints of central nervous system depression in this study were, in order of severity: light-headedness, dizziness, drowsiness, headache, nausea, fatigue, and impaired coordination.

Two groups of 6 male volunteers were exposed to concentrations of tetrachloroethylene ranging from 508 to 1654 mg/m^3. After several min of exposure to 508 mg/m^3, slight eye irritation was reported and, after 30 min of exposure to 1424 mg/m^3 the subjects experienced slight light-headedness and impaired motor coordination. No liver or kidney damage was found (Steward et al., 1961a).

Irritation of the eyes, nose, or throat and central nervous system depression were experienced by 17 subjects, exposed to 685 mg of tetrachloroethylene per m^3 air. Coordination was impaired within 3 h of exposure. No liver or kidney damage was found (Steward et al., 1970).

Hake & Steward (1977) exposed 19 subjects for 1, 3, or 7.5 h per day, for 5 days per week. At 136 mg/m^3, no effects were found. At 678 and 1017 mg/m^3, coordination was slightly impaired in males. No general relationship was found between subjective complaints and exposure. Adaptation occurred for odour perception and the subjective feelings reported earlier by Steward et al. (1970).

The odour threshold for tetrachloroethylene has been established as 32 mg/m^3 (Leonardos et al., 1969).

8.2 Accidental Exposures

A man accidentally exposed to 1860 mg/m^3 for 3 h, followed by 7460 mg/m^3 for 30 min, experienced light-headedness and eye irritation and finally became unconscious reversibly after the first 3 h. Liver damage was indicated by the clinical report (Steward et al., 1961b). Saland (1967) reported reversible elevated SGOT values in 8 out of 9 men after accidental exposures. Another accident resulted in unconsciousness in one man (Patel et al., 1977). No liver damage was noted, but the principal clinical feature was pulmonary oedema. It can be presumed that the oedema was an effect secondary to hypoxia induced by circulatory failure.

A girl of 6 weeks was exposed to tetrachloroethylene through excretion in breast milk. Jaundice was diagnosed. SGOT and alkaline phosphatase activities and bilirubin were increased in the serum of the baby, but not in that of the parents (Bagnell & Ellenberger, 1977).

8.3 Occupational Exposure

Münzer & Heder (1972) carried out further studies on 40 workers in dry-cleaning plants found to have more than 40 mg/litre of trichloroacetic acid in the urine. Exposures ranged from 678 to 2712 mg/m^3. Sixteen subjects showed signs of central nervous system depression and, in 21 cases, the autonomic nervous system was also affected. Liver malfunction was not observed.

Examination of 113 dry-cleaning workers (Franke & Eggeling, 1969), revealed that 35% of them experienced symptoms of central nervous system depression, while the autonomic nervous system was affected in 40%. Slight liver function disturbances were revealed. Out of 326 measurements, 75% revealed average 8-h concentrations below 678 mg/m^3.

Neurotoxic effects, including differences in the proximal motor latency of nerve cells and electrodiagnostic and neurological rating scores, were found in 20 dry-cleaning workers, exposed for an average of 7.5 years to time-weighted-average concentrations of between 9 and 252 mg/m^3. A correlation was found between years of exposure and some behavioural variables (Tuttle et al., 1976).

Chmielewski et al. (1976) identified 6 pseudoneurotic syndrome cases and 4 subjects with pathological EEG recordings among 16 factory employees exposed to tetrachloroethylene concentrations ranging from 400 to 3000 mg/m^3 for periods of 2 years to more than 20 years. The altered EEG was accompanied by a reduced cholinesterase activity in the serum of 3 workers and an increased alanine aminotransferase activity in the serum of 2 workers, which could point to liver damage. Subjective complaints of irritation and neurological disorders were related to length of exposure. Adrenal gland damage was also noted.

Essing (1975) did not find significant differences in the incidence of liver and kidney malfunctions between a group of 112 railway workers, exposed to tetrachloroethylene, and a control group of 101 workers, over an average period of 11.5 years. Three-quarters of all 8-h measurements revealed concentrations below 340 mg/m^3. Liver dysfunction after short-term tetrachloroethylene exposure was found in a number of case studies (Hughes, 1954; Meckler & Phelps, 1966; Trense & Zimmerman, 1969). In two of these cases, liver cell necrosis was found and, in one case, pulmonary oedema. One

case of liver cirrhosis was reported by Coler & Rosmiller (1953). They examined a total of 7 men, exposed for 2-6 years. Three of the men, including the cirrhosis case, showed significantly changed clinical chemistry measurements, indicative of liver disease.

Cytogenic and cytokinetic studies of lymphocytes were performed on 10 factory workers, who had been exposed to tetrachloroethylene vapour concentrations between 68 and 270 mg/m^3 air or between 200 and 1490 mg/m^3 air for periods ranging from 3 months up to 18 years. No significant dose-related changes were found in chromosome aberrations, sister-chromatid-exchange rates, the proportion of M2 + M3 metaphases, and the mitotic index (Ikeda et al., 1980).

8.4 Mortality Studies

The causes of death of 330 laundry- and dry-cleaning workers in the USA, deceased in the period 1957-77, were analysed by the proportionate mortality method (Blair et al., 1979). The workers had mainly been exposed to tetrachloro-ethylene, but also to carbon tetrachloride, trichloro-ethylene, and other petroleum solvents, including benzene. An excess of lung, cervical, and skin cancer was the main cause of the increase in the observed number of deaths due to carcinogenic effects, compared with the proportionate mortality data of the USA population.

In another study, the death certificates of 671 female workers in the laundry- and dry-cleaning industry, deceased in the period 1963-77, were examined for the causes of death (Katz & Jowett, 1981). These data were compared with the mortality data of working females and with those of a population derived from low-wage occupations. Results failed to show an overall increase in malignant neoplasms, but an elevated risk of genital and kidney cancer was observed, together with a smaller excess of bladder and skin cancer and lymphosarcoma. Exposure data were not given.

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9. EVALUATION OF HEALTH RISKS FOR MAN

On the basis of results of repeated short-term, human exposure studies, it is considered that no acute effects will occur at tetrachloroethylene concentrations of approximately 140 mg/m^3 or less (Hake & Steward, 1977).

The results of human exposure studies indicate that, after single or short-term exposures to tetrachloroethylene, human beings are likely to begin experiencing eye irritation at air concentrations of approximately 500 mg/m^3 (Rowe et al., 1952) and depression of the central nervous system, and nose and throat irritation, at approximately 700 mg/m^3 (Steward et al., 1970). Such effects are reversible on cessation of exposure, but increase in severity with both increasing concentration and duration of exposure. Because the excretion rate is relatively slow, a large dose in the target tissue is likely to remain high for several days after exposure. Direct skin exposure will result in irritation of the skin.

Observations after repeated exposure to tetrachloroethylene over months or years indicate that human beings inhaling tetrachloroethylene are likely to begin to exhibit depression of the central- and autonomic nervous systems at concentrations exceeding approximately 700 mg/m^3 (Münzer & Heder, 1972; Hake & Steward, 1977). Results of studies on rats indicate that inhalation exposure to tetrachloroethylene concentrations of approximately 1300 mg/m^3 or more appears to be associated with definable liver injury (Kylin et al., 1965). However, the level at which similar effects in the liver might occur in human beings is not clear. Workers in dry-cleaning plants, exposed to concentrations up to 2700 mg/m^3 did not show alterations in liver enzyme activity (Münzer & Heder, 1972).

Embryotoxicity was observed in the progeny of experimental animals exposed by inhalation to tetrachloroethylene concentrations exceeding 2000 mg/m^3 (Schwetz et al., 1975). It is possible that similar effects might occur in human beings. However, there was no indication of reproduction injury and only slight evidence of teratogenicity in the animal studies reported.

Tetrachloroethylene was found to be carcinogenic for mice but not for rats (NCI, 1977). Evidence from epidemiological studies (Blair et al., 1979; Katz & Jowett, 1981) among dry-cleaning and laundry workers is insufficient to conclude that exposure to tetrachloroethylene can cause cancer in human beings.

10. CURRENT REGULATIONS, GUIDELINES, AND STANDARDS

10.1 Occupational Exposure

Maximum allowable concentrations[a] range from 10 mg/m³ (1.5 ppm, ceiling value) in the USSR, 140 mg/m³ (20 ppm, TWA) in Sweden, and 250 mg/m³ (37 ppm) in Czechoslovakia to 340 mg/m³ (50 ppm) in the Federal Republic of Germany, Japan, and the USA. Short-term exposure limits range from 340 mg/m³ (50 ppm) in Sweden to 1250 mg/m³ (183 ppm) in Czechoslovakia and 1340 mg/m³ (200 ppm) in the USA. The acceptable limit in Brazil is 525 mg/m³ (78 ppm) for 48 h per week (IRPTC, 1983).

10.2 Ambient Air Levels

Maximum allowable concentrations are 1.0 mg/m³ average per day or 4.0 mg/m³ average per 0.5 h in Czechoslovakia and 0.06 mg/m³ average per day in the USSR (IRPTC, 1983).

10.3 Drinking-Water

The WHO recommended guideline value in drinking-water is 10 mg/litre (WHO, 1983).

10.4 Use

The European Economic Commission prohibits the use of tetrachloroethylene in cosmetic products (IRPTC, 1983).

10.5 Labelling and Packaging

The European Economic Commission regulations state that the label should read that tetrachloroethylene is harmful if inhaled or swallowed, and should be kept out of reach of children. Contact with the eyes must be avoided (IRPTC, 1983).

10.6 Storage and Transport

The United Nations Committee of Experts (1977) on the Transportation of Dangerous Goods qualifies tetrachloroethylene as a toxic substance (Class 6.1) with minor danger for packing purposes (Packing Group III).

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[a] Values quoted from national lists.

Packing methods and a label are recommended. The Inter-governmental Maritime Consultative Organization (1981) also qualifies tetrachloroethylene as a toxic substance (Class 6.1) and recommends packing, storage, and labelling methods for maritime transport in glass bottles, cans, and metal drums. The label recommended by both organizations is:

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