March 31, 1987

820K87115

1,1-DICHLOROETHYLENE

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

I. INTRODUCTION

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

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

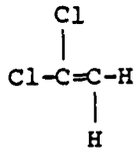
Health Advisories are developed for One-day, Ten-day, Longer-term (approximately 7 years, or 10% of an individual's lifetime) and Lifetime exposures based on data describing noncarcinogenic end points of toxicity. Health Advisories do not quantitatively incorporate any potential carcinogenic risk from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

This Health Advisory is based on information presented in the Office of Drinking Water's Health Effects Criteria Document (CD) for the dichloroethylenes (U.S. EPA, 1984a). The HA and CD formats are similar for easy reference. Individuals desiring further information on the toxicological data base or rationale for risk characterization should consult the CD. The CD is available for review at each EPA Regional Office of Drinking Water counterpart (e.g., Water Supply Branch or Drinking Water Branch), or for a fee from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161, PB #86-117785/AS. The toll-free number is (800) 336-4700; in the Washington, D.C. area: (703) 487-4650.

II. GENERAL INFORMATION AND PROPERTIES

CAS No. 75-35-4

Chemical structure



Synonyms

- Vinylidene chloride, 1,1-DCE, dichloroethene

Uses

- 1,1-Dichloroethylene has been used as a chemical intermediate and in the manufacture of polyvinylidene copolymers.

Properties (Irish, 1963; Windholz et al., 1976)

Chemical Formula	$C_2H_2Cl_2$
Molecular Weight	96.95
Physical State (room temp.)	clear, colorless liquid
Boiling Point	31.5 °C
Melting Point	-122.2 °C
Density	--
Vapor Pressure	591 torr (20°C)
Specific Gravity	1.3
Water Solubility	250 mg/L (20°C)
Log Octanol/Water Partition Coefficient	5.37
Taste Threshold (water)	--
Odor Threshold (water)	--
Odor Threshold (air)	2000-5500 mg/m^3
Conversion Factor	--

Occurrence

- 1,1-Dichloroethylene (1,1-DCE) is a synthetic chemical with no known natural sources (U.S. EPA, 1983).

- Approximately 200 million pounds of 1,1-DCE were produced in 1980. The major use of 1,1-DCE is as a co-monomer in the production of a number of polymers. Polymers of 1,1-DCE and vinyl chloride are used as food wrap (CEH, 1983).

- The major releases of 1,1-DCE to the environment are during its production and its use in the manufacture of polymers. Due to its volatile nature, the majority of releases are expected to be to air. Small amounts of 1,1-DCE may be released to water and land in industrial effluents and from the disposal of solid wastes (U.S. EPA, 1983). 1,1-Dichloroethylene may be a degradation product of trichloroethylene and perchloroethylene. While laboratory studies are currently inconclusive, 1,1-DCE has been found to co-occur in ground water with trichloroethylene and tetrachloroethylene and their other degradation products, cis- and trans-1,2-dichloroethylene and vinyl chloride.

- There is relatively little information on the behavior of 1,1-DCE in the environment. However, the behavior of this chemical has been estimated based upon the information on similar chlorinated compounds (U.S. EPA, 1979). 1,1-Dichloroethylene released to the atmosphere is expected to chemically degrade in hours; when released to surface waters, it is expected to volatilize rapidly. 1,1-DCE is chemically stable in water and mobile in soils and is expected to migrate with ground water. 1,1-Dichloroethylene is not believed to bioaccumulate in plants or animals.

- Available data suggest that 1,1-DCE is not a common contaminant of drinking water. It has not been reported to occur at levels higher than 0.1 ug/L in surface water. However, 1,1-DCE has been reported to occur at levels up to 40 ug/L in wells contaminated with other chlorinated solvents.

- No information is available on the occurrence of 1,1-DCE in food. While 1,1-DCE is used in the manufacture of food wrap, residual levels are expected to be very low because of its high volatility. Due to limited release and rapid degradation, little or no contamination of food by 1,1-DCE is expected.

- 1,1-Dichloroethylene contamination of air has been reported to occur in urban and suburban areas in the low ppt range. Levels in the ppb range have been reported in the areas where 1,1-DCE and its polymers are manufactured (U.S. EPA, 1983).

III. PHARMACOKINETICS

Absorption

- 1,1-Dichloroethylene is completely absorbed after gavage, since 96 to 100% of a single dose is excreted within 72 hours (Jones and Hathway, 1978a; McKenna et al., 1978b).

Distribution

- Distribution in rats following a single oral dose of 25 mg of 1,1-DCE/kg resulted in high concentrations in the liver and kidneys after 30 minutes with more general distribution throughout other soft tissues after 1 hour (Jones and Hathway, 1978a).

- Single oral doses of ^{14}C-1,1-DCE, at 1 or 50 mg/kg, were administered to rats (McKenna et al., 1978a,b). At 72 hours after dosing, the greatest percentage of radioactivity was found in the liver.

Metabolism

- The metabolic end products of chlorinated ethylenes are predominately alcohols and carboxylic acids. The known metabolites of 1,1-DCE are chloroacetic acid, chloroacetyl chloride and dichloroacetaldehyde (Liebler and Guengerich, 1983; Liebler et al., 1984). Toxic intermediates that are formed may interact with tissue macromolecules.

Excretion

- The rate of excretion is relatively rapid, since most of a dose is eliminated within the first 24-72 hours after administration (Jaeger et al., 1977). At low doses, a greater percentage of the metabolites are eliminated via renal and biliary excretion. Carbon dioxide formed during metabolism is expired through the lungs.

- As maximal metabolic capacity is approached at the higher dose levels, proportionally less of the compound is removed from the blood as it passes through the liver. As a result, increasing amounts of unchanged 1,1-DCE are eliminated via the lungs (McKenna et al. 1977).

IV. HEALTH EFFECTS

Humans

- At high concentrations ($\geq$ 4000 ppm; 15,880 mg/m^3), inhalation of 1,1-DCE results in rapid onset of CNS depression, with unconsciousness following if exposure is continued (Irish, 1963).

- Reports of effects on workers exposed to this chemical in combination with other vinyl compounds include liver function abnormalities, headaches, vision problems, weakness, fatigue and neurological sensory disturbances (NIOSH, 1979).

Animals

Short-term Exposure

- Reported oral LD_{50}s in adult rats range from 200 to 1800 mg/kg (NIOSH, 1978; Ponomarkov and Tomatis, 1980). Young or fasted rats are more sensitive to the acute effects of 1,1-DCE, with LD_{50}s of approximately 50 mg/kg (Andersen and Jenkins, 1977).

- The oral LD_{50}s in the mouse and the dog were reported to be 200 mg/kg (Jones and Hathway, 1978b) and 5750 mg/kg (NIOSH, 1978), respectively.

- The most sensitive end-point of 1,1-DCE toxicity is liver damage, ranging from fatty infiltration to necrosis (Reynolds et al., 1975; Chieco et al., 1982). In rats, after doses of 50 to 700 mg of 1,1-DCE/kg, the liver toxicity of 1,1-DCE followed a complex dose-response pattern, with a threshold level, a rapid increase in effect and an extended plateau where increasing doses caused slight increases in effect (Andersen and Jenkins, 1977).

- After a 90 day continuous exposure to 1,1-DCE (189 mg/m^3) liver and kidney lesions have been demonstrated (Prendergast et al., 1967).

- Since glutathione depletion increases toxicity (Jaeger et al., 1974; Andersen et al., 1980), the acute toxicity of the chemical is probably the result of a toxic metabolite.

Long-term Exposure

- As with acute exposure, the liver appears to be the principal target of 1,1-DCE toxicity following extended periods of exposure. Chronic exposure of rats to 0 to 200 ppm (0 to 26 mg/kg) in drinking water resulted in fatty changes and hypertrophy of liver cells in females and males at the highest dose (Rampy et al., 1977; Quast et al., 1983).

Reproductive Effects

- In a three-generation rat reproductive study, Nitschke et al. (1983) reported that, at concentrations of 0, 50, 100 or 200 ppm (0 to 26 mg/kg) in the drinking water, 1,1-DCE did not affect rat reproductive capacity.

Developmental Effects

- At levels producing no maternal toxicity (inhalation; 20 ppm in rats and 80 ppm in rabbits and ingestion; 200 ppm in rats) 1,1-DCE did not produce teratogenic effects in rats or rabbits following exposure of dams during organogenesis (Murray et al., 1979).

Mutagenicity

- With S-9 activation, 1,1-DCE was mutagenic in the Ames Salmonella test at concentrations of 3.3×10^{-4} to 3.3×10^{-2} M (Bartsch et al., 1975) or when exposed to an atmosphere containing 5% 1,1-DCE for 3 hours (Simmon et al., 1977). The chemical had no mutagenic activity in the absence of the S-9 fraction.

- 1,1-Dichloroethylene was mutagenic to E. coli K_{12} at a concentration of 2.5 mM with, but not without, microsomal activation (Greim et al., 1975).

- In mammalian assay systems, a mutagenic effect was not observed. Using the dominant lethal assay, it was reported that exposure to 1,1-DCE at 55 ppm for 6 hr/day for 11 weeks (Short et al., 1977) or to 10 to 50 ppm for 6 hr/day for 5 days (Anderson et al., 1977) did not produce germinal mutation. In addition, using V79 Chinese hamster ovary cells, exposed to 1,1-DCE at concentrations of 2 or 10%, Drevon and Kuroki (1979) did not observe any adverse effects.

- 1,1-Dichloroethylene binds with DNA to a slight degree in the liver and kidneys of both rats and mice after inhalation exposure to 10 or 50 ppm for 6 hours. However, massive tissue damage also occurred. In mice, the kidneys seem to be a more sensitive indicator of tissue damage than the liver (Reitz et al., 1980).

- The International Agency for Research on Cancer (IARC) concluded that there is sufficient evidence to state that 1,1-DCE is mutagenic (IARC, 1982).

- For a recent review of this area, the reader is referred to the article by Jacobson-Kram (1986).

Carcinogenicity

- The results of most studies of the carcinogenic potential of this substance fail to support a significant, treatment-related increase in tumor incidence (U.S. EPA, 1984a). No oral study has resulted in a significant tumor response (NTP, 1982; Quast et al., 1983). Some, but not all, of the inhalation studies have reported significant tumor increases (e.g., mammary tumors in female rats and mice and kidney adenocarcinomas in mice) (Maltoni et al., 1985).

- 1,1-Dichloroethylene was inactive as a whole mouse skin carcinogen when administered subcutaneously (Van Duuren et al., 1979). It was active as a skin tumor initiator following several topical applications of phorbol ester as a promotor.

V. QUANTIFICATION OF TOXICOLOGICAL EFFECTS

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

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

where:

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

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

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

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

One-day Health Advisory

The study by Chieco and coworkers (1981) has been selected to derive the One-day HA. The authors reported that when 200 mg/kg of 1,1-DCE was given in water containing 0.5% Tween 80, the chemical caused only a slight increase in the plasma levels of alanine, but not aspartate, transaminase. In addition, the pathological changes observed in the liver were limited to a few scattered microfoci of necrosis. Accordingly, the 200 mg/kg is taken to be the LOAEL.

The One-day HA for the 10 kg child is calculated as follows:

$$\text{One-day HA} = \frac{(200 \text{ mg/kg/day})\ (10 \text{ kg})}{(1{,}000)\ (1 \text{ L/day})} = 2.0 \text{ mg/L } (2{,}000 \text{ ug/L})$$

where:

200 mg/kg/day = LOAEL based on hepatic effects.

10 kg = assumed body weight of a child.

1,000 = uncertainty factor, chosen in accordance with NAS/ODW guidelines for use with a LOAEL from an animal study.

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

Ten-day Health Advisory

Appropriate studies for the calculation of the Ten-day HA are not available. However, evaluation of all toxicological data for 1,1-DCE suggests that the Longer-term Health Advisory for the 10-kg child of 1,000 ug/L would provide sufficient protection over a ten-day period.

Longer-term Health Advisory

A Longer-term HA can be calculated from a 90-day subchronic study in which rats of both sexes were given 1,1-DCE at nominal concentrations of 0, 50, 100 or 200 ppm (0 to 20 mg/kg bw/day) in their drinking water (Rampy, et al., 1977). Except for a decreased kidney:body weight ratio in males at the low dose, there were no statistically significant differences in organ weights or in organ:body weight ratios at the termination of the study. The only abnormal histopathology noted was an increased cytoplasmic vacuolization of hepatocytes

in the livers of both sexes exposed to the highest dose. A NOAEL of 100 ppm (10 to 12.6 mg/kg) was identified.

A Longer-term HA for the 10-kg child is calculated as follows:

$$\text{Longer-term HA} = \frac{(10 \text{ mg/kg/day})\ (10 \text{ kg})}{(100)\ (1 \text{ L/day})} = 1.0 \text{ mg/L } (1{,}000 \text{ ug/L})$$

where:

10 mg/kg/day = NOAEL based on the absence of liver effects.

10 kg = assumed body weight of a child.

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

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

A Longer-term HA for the 70-kg adult is calculated as follows:

$$\text{Longer-term HA} = \frac{(10 \text{ mg/kg/day})\ (70 \text{ kg})}{(100)\ (2 \text{ L/day})} = 3.5 \text{ mg/L } (3{,}500 \text{ ug/L})$$

where:

10 mg/kg/day = NOAEL based on the absence of liver effects.

70 kg = assumed body weight of an adult.

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

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

Lifetime Health Advisory

The Lifetime HA represents that portion of an individual's total exposure that is attributed to drinking water and is considered protective of noncarcinogenic adverse health effects over a lifetime exposure. The Lifetime HA is derived in a three step process. Step 1 determines the Reference Dose (RfD), formerly called the Acceptable Daily Intake (ADI). The RfD is an estimate of a daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime, and is derived from the NOAEL (or LOAEL), identified from a chronic (or subchronic) study, divided by an uncertainty factor(s). From the RfD, a Drinking Water Equivalent Level (DWEL) can be determined (Step 2). A DWEL is a medium-specific (i.e., drinking water) lifetime exposure level, assuming 100% exposure from that medium, at which adverse, noncarcinogenic health effects would not be expected to occur. The DWEL is derived from the multiplication of the RfD by the assumed body weight of an adult and divided by the assumed daily water consumption of an

adult. The Lifetime HA is determined in Step 3 by factoring in other sources of exposure, the relative source contribution (RSC). The RSC from drinking water is based on actual exposure data or, if data are not available, a value of 20% is assumed for synthetic organic chemicals and a value of 10% is assumed for inorganic chemicals. If the contaminant is classified as a Group A or B carcinogen, according to the Agency's classification scheme of carcinogenic potential (U.S. EPA, 1986), then caution should be exercised in assessing the risks associated with lifetime exposure to this chemical.

The Lifetime HA can be calculated from the 2-year chronic study in rats (Quast et al., 1983). 1,1-Dichloroethylene, at nominal concentrations of 0, 50, 100 or 200 ppm (0 to 20 mg/kg/day) in drinking water, was administered to animals of both sexes. No consistent treatment-related biochemical changes were observed in any parameter measured. The only abnormal histopathology observed was mid-zonal fatty accumulation in the livers of both sexes receiving the highest dose. No liver degeneration was noted. A LOAEL of 100 ppm (10 mg/kg) was identified, based upon a trend towards increased fatty deposition in the liver.

A Drinking Water Equivalent Level (DWEL) and Lifetime HA for the 70-kg adult are calculated as follows:

Step 1: Determination of the Reference Dose (RfD)

$$RfD = \frac{(10\ mg/kg/day)}{(1,000)} = 0.01\ mg/kg/day$$

where:

10 mg/kg/day = LOAEL for hepatic effects.

1,000 = uncertainty factor, chosen in accordance with NAS/ODW guidelines for use with a LOAEL from an animal study.

Step 2: Determination of the Drinking Water Equivalent Level (DWEL)

$$DWEL = \frac{(0.01\ mg/kg/day)\ (70\ kg)}{(2\ L/day)} = 0.35\ mg/L\ (350\ ug/L)$$

where:

0.01 mg/kg/day = RfD.

70 kg = assumed body weight of an adult.

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

Step 3: Determination of the Lifetime Health Advisory

$$Lifetime\ HA = \frac{(0.35\ mg/L)\ (20\%)}{(10)} = 0.007\ mg/L\ (7\ ug/L)$$

where:

0.35 mg/L = DWEL.

20% = assumed relative source contribution from water.

10 = additional uncertainty factor for class C carcinogens.

Evaluation of Carcinogenic Potential

- Qualitative and quantitative assessment of the carcinogenic potential of 1,1-DCE is complicated by the fact that there is only one positive bioassay (Maltoni et al., 1985) among the 18 oncogenic studies (U.S. EPA, 1985c).

- IARC (1982) reported that the data were inadequate to assess the carcinogenic potential in humans, but that it would reevaluate the assessment after reviewing the rat drinking water study (Rampy et al., 1977; Quast et al., 1983) and the NTP gavage bioassays (NTP, 1982). At the present time, this has not been done.

- Applying the criteria described in EPA's guidelines for assessment of carcinogenic risk (U.S. EPA, 1986), 1,1-dichloroethylene may be classified in Group C: Possible human carcinogen. Group C includes agents with limited evidence of carcinogenicity in animals in the absence of human data.

VI. OTHER CRITERIA, GUIDANCE AND STANDARDS

- In June, 1984, EPA proposed a Recommended Maximum Contaminant Level (RMCL) of zero for 1,1-dichloroethylene in drinking water (U.S. EPA, 1984b). In 1985, a RMCL of 7 was promulgated for 1,1-dichloroethylene. This value also was proposed for the MCL (U.S. EPA, 1985a).

- In 1980, EPA estimated a range of excess cancer risks for lifetime exposure to 1,1-dichloroethylene when developing ambient water quality criteria (U.S. EPA, 1980a). This range was 23 ug/L, 2.3 ug/L and 0.23 ug/L, respectively, for risks of 10^{-4}, 10^{-5} and 10^{-6}, assuming consumption of 2 liters of water and 6.5 grams of contaminated fish per day by 70-kg adult.

- The National Academy of Sciences calculated a chronic SNARL (Suggested-No-Adverse-Response-Level) of 100 ug/L, based upon non-carcinogenic effects only (NAS, 1983). The Academy identified a NOAEL of 2 mg/kg from the 1982 NTP bioassay in mice. An uncertainty factor of 100 was applied. It was assumed that a 70 kg adult consumes 2 liters of water daily and 20% of the exposure of most individuals would be from drinking water. In addition, a factor of 5/7 to correct from 5- to 7-day/week exposure was used.

- The World Health Organization has established a guideline for 1,1-DCE in drinking water of 0.3 ug/L, set on evidence of carcinogenicity (WHO, 1984).

° The threshold limit value (TLV) for 1,1-DCE in occupational settings is 5 ppm (20 mg/m^3) (ACGIH, 1982).

VII. ANALYTICAL METHODS

° Analysis of 1,1-DCE is by a purge-and-trap gas chromatographic procedure used for the determination of volatile organohalides in drinking water (U.S. EPA, 1985). This method calls for the bubbling of an inert gas through the sample and trapping 1,1-DCE on an adsorbant material. The adsorbant material is heated to drive off the 1,1-DCE onto a gas chromatographic column. This method is applicable to the measurement of 1,1-DCE over a concentration range of 0.03 to 1500 ug/L. Confirmatory analysis for 1,1-DCE is by mass spectrometry (U.S. EPA, 1985b). The detection limit for confirmation by mass spectometry is 0.2 ug/L.

VIII. TREATMENT TECHNOLOGIES

° Granular activated carbon (GAC) adsorption and aeration treatment technologies are available for the removal of 1,1-DCE from water and have been reported to be effective. Selection of individual or combinations of technologies to achieve chemical reduction must be based on a case-by-case technical evaluation and an assessment of the economics involved.

° Aeration has been shown to be effective in removing 1,1-DCE from water, based upon its carbon adsorption isotherm (Henry's Law Constant = 498 atm) and pilot and full-scale testing. The chemical was removed successfully from contaminated ground water at 12-14°C in an EPA pilot packed tower aerator containing 18 feet of 1-inch plastic saddle packing (ESE, 1984). The average percent removal varied with air-to-water volume ratio, from 90.6% to 99.99% at ratios of 5 to 80, respectively. Similarly, the concentration of 1,1-DCE in contaminated well water decreased from 122 ug/L to 4 ug/L (97%) using diffused aeration (ESE, 1984). Aeration was conducted in a pilot (1.5 inch diameter, 4-foot long) countercurrent glass column, using a 10-minute contact time and an air-to-water ratio of 4.

° Air stripping is an effective, simple and relatively inexpensive process for removing 1,1-DCE from water. However, the use of this process transfers the contaminant directly to the air stream. When considering use of air stripping as a traetment process, it is suggested that careful consideration be given to the overall environmental occurrence, fate, route of exposure and various hazards associated with the chemical.

IX. REFERENCES

ACGIH. 1982. American Conference of Government Industrial Hygienists. TLVs. Threshold limit values for chemical substances in work air.

Andersen, M.E., and L.R. Jenkins, Jr. 1977. Oral toxicity of 1,1-dichloroethylene in the rat: Effects of sex, age and fasting. Environ. Health Perspect. 21:157-163.

Andersen, M.E., O.E. Thomas, M.L. Gargas, R.A. Jones and L.J. Jenkins, Jr. 1980. The significance of multiple detoxification pathways for reactive metabolites in the toxicity of 1,1-dichloroethylene. Toxicol. Appl. Pharmacol. 52:422-432.

Anderson, D. 1977. Dominant lethal studies with the halogenated olefins vinyl chloride and vinylidene chloride in male CD-1 mice. Environ. Health Perspect. 21:71-78.

Bartsch, H., C. Malaveille, R. Montesano and L. Tomatis. 1975. Tissue-mediated mutagenicity of vinylidene chloride and 2-chlorobutadiene in Salmonella typhimurium. Nature. 255:641-643.

CEH. 1983. Chemical Economics Handbook, Stanford Research Institute, Menlo Park, California.

Chieco, P., M.T. Moslen and E.S. Reynolds. 1981. Effect of administrative vehicle on oral 1,1-dichloroethylene toxicity. Toxicol. Appl. Pharmacol. 57:146-155.

Chieco, P., M.T. Moslen and E.S. Reynolds. 1982. Histochemical evidence that plasma and mitochondrial membranes are primary foci of hepatocellular injury caused by 1,1-dichloroethylene. Lab. Invest. 46:413-421.

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

Drevon, C., and T. Kuroki. 1979. Mutagenicity of vinyl chloride, vinylidene chloride and chloroprene in V79 Chinese hamster cells. Mutat. Res. 67:173-182.

ESE. 1984. Environmental Science and Engineering. Draft technologies and costs for the removal of volatile organic chemicals from potable water supplies. ESE No. 84-912-0300. Prepared for the U.S. EPA, Science and Technology Branch, CSD, ODW, Washington, DC.

Greim, H., G. Bonse, Z. Radwan, D. Reichert and D. Henschler. 1975. Mutagenicity in vitro and potential carcinogenicity of chlorinated ethylenes as a function of metabolic oxirane formation. Biochem. Pharmacol. 24:2013-2017.

McKenna, M.J., P.G. Watanabe and P.J. Gehring. 1977. Pharmacokinetics of vinylidene chloride in the rat. Environ. Health Perspect. 21:99-105.

McKenna, M.J., J.A. Zempel, E.O. Madrid and P.J. Gehring. 1978a. The pharmacokinetics of (^{14}C) vinylidene chloride in rats following inhalation exposure. Toxicol. Appl. Pharmacol. 45:599-610.

McKenna, M.J., J.A. Zempel, E.O. Madrid, W.H. Braun and P.J. Gehring. 1978b. Metabolism and pharmacokinetic profile of vinylidene chloride in rats following oral administration. Toxicol. Appl. Pharmacol. 45:821-835.

Murray, F.J., K.D. Nitschke, L.W. Rampy and B.A. Schwetz. 1979. Embryotoxicity and fetotoxicity of inhaled or ingested vinylidene chloride in rats and rabbits. Toxicol. Appl. Pharmacol. 49:189-202.

NAS. 1983. National Academy of Sciences. Drinking Water and Health. Volume 5. National Academy Press, Washington, DC.

NIOSH. 1978. National Institute for Occupational Safety and Health. 1,1-Dichloroethylene. Registry of toxic effects of chemical substances. p. 563.

NIOSH. 1979. [C.D. for Occupational Standard]

Nitschke, K.D., F.A. Smith, J.F. Quast, J.M. Norris and B.A. Schwetz. 1983. A three-generation rat reproductive toxicity study of vinylidene chloride in the drinking water. Fund. Appl. Toxicol. 3:75-79.

NTP. 1982. National Toxicology Program. Carcinogenesis bioassay of vinylidene chloride (CAS No. 75-35-4) in F344 rats and B6C3F1 mice (gavage study). U.S. HHS. PHS. NIH NTP-80-2 NIH Publication No. 82-1784.

Ponomarkov, V., and L. Tomatis. 1980. Long-term testing of vinylidene chloride and chloroprene for carcinogenicity in rats. Oncology 37:136-141.

Prendergast, J.A., R.A. Jones, L.J. Jenkins, Jr. and J. Siegel. 1967. Effects on experimental animals of long-term inhalation of trichloroethylene, carbon tetrachloride, 1,1,1-trichloroethane, dichlorodifluoromethane, and 1,1-dichloroethylene. Toxicol. Appl. Pharmacol. 10:270-289.

Quast, J.F., C.G. Humiston, C.E. Wade, J. Ballard, J.E. Beyer, R.W. Schwetz and J.M. Norris. 1983. A chronic toxicity and oncogenicity study in rats and subchronic toxicity study in dogs on ingested vinylidene chloride. Fund. Appl. Toxicol. 3:55-62.

Rampy, L.W., J.F. Quast, C.G. Humiston, M.F. Blamer and B.A. Schwetz. 1977. Interim results of two-year toxicological studies in rats of vinylidene chloride incorporated in the drinking water or administered by repeated inhalation. Environ. Health Perspect. 21:33-43.

Reitz, R.H., P.G. Watanabe, M.J. McKenna, J.F. Quast and P.J. Gehring. 1980. Effects of vinylidene chloride on DNA synthesis and DNA repair in the rat and mouse: A comparative study with dimethylnitrosamine. Toxicol. Appl. Pharmacol. 52:357-370.

Reynolds, E.S., M.T. Moslen, S. Szabo, R.J. Jaeger and S.D. Murphy. 1975. Hepatotoxicity of vinyl chloride and 1,1-dichloroethylene. Amer. J. Pathol. 81:219.

Short, R.D., J.L. Minor, J.M. Winston and C.C. Lee. 1977. A dominant lethal study in male rats after repeated exposure to vinyl chloride or vinylidene chloride. J. Toxicol. Environ. Health. 3:965-968.

Simmon, V.F., K. Kauhanen and R.G. Tardiff. 1977. Mutagenic activity of chemicals identified in drinking water. Dev. Toxicol. Environ. Sci. 2:249-258.

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

U.S. EPA. 1980. U.S. Environmental Protection Agency. Ambient water quality criteria for dichloroethylenes. Office of Water Regulations and Standards. Criteria and Standards Division. Washington, D.C. EPA 440/5-80-041.

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

U.S. EPA. 1984a. U.S. Environmental Protection Agency. Draft criteria document for the dichloroethylenes. Criteria and Standards Division, Office of Drinking Water, Washington, DC.

U.S. EPA. 1984b. U.S. Environmental Protection Agency. National primary drinking water regulations; Volatile synthetic organic chemicals; Proposed rulemaking. Federal Register 49(114):24330-24355. June 12.

U.S. EPA. 1984c. U.S. Environmental Protection Agency. Method 501.1. Volatile halogenated organic compounds in water by purge and trap gas chromatography. Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 45268. June.

U.S. EPA. 1985a. U.S. Environmental Protection Agency. Final RMCL, proposed MCLs for VOCs. November 13, 1985.

U.S. EPA. 1985b. U.S. Environmental Protection Agency. Method 524.1. Volatile organic compounds in water by purge and trap gas chromatography/ mass spectrometry. Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. June.

U.S. EPA. 1985c. U.S. Environmental Protection Agency. Health assessment document for vinylidene chloride. August.

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

U.S. ITC. 1982. United States International Trade Commission. Synthetic organic chemicals United States production. 1983 USITC Publication 1422, Washington, D.C. 20436.

Van Duuren, B.L., B.M. Goldschmidt, G. Loewengart, A.C. Smith, S. Melchionne, I. Seldman and D. Roth. 1979. Carcinogenicity of halogenated olefinic and aliphatic hydrocarbons in mice. J. Natl. Cancer Inst. 63:1433-1439.

WHO. 1984. World Health Organization. Guidelines for drinking water quality. Volume 1. Recommendations. Geneva, Switzerland.

Windholz, M., ed. 1976. The Merck Index. 10th edition. Merck and Co., Inc. Rahway, NJ.