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The Installation Restoration Program Toxicology Guide

Volume 2

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Harry G. Armstrong Aerospace Medical Research Laboratory
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio
45433-6573

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THE INSTALLATION RESTORATION PROGRAM TOXICOLOGY GUIDE

Volume 2

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PREFACE

One of the objectives of the U.S. Air Force Installation Restoration Program (IRP) is to provide individuals responsible for the management and implementation of the IRP with information to evaluate the health hazards associated with actual or potential contamination of drinking water supplies. The Harry G. Armstrong Aerospace Medical Research Laboratory was requested by HQ USAF/SGPA to develop health and environmental information for each potential contaminant of drinking water supplies associated with USAF installations. This IRP Toxicology Guide consists of four volumes which were initially issued in 1985-1987. The original Toxicology Guide was produced under contract F33615-81-D-0508 by Arthur D. Little, Inc. for the Biochemical Toxicology Branch, Toxic Hazards Division, Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL), Wright-Patterson AFB, OH. The updated volumes of the Toxicology Guide include new regulatory requirements and recently published toxicology information. The updated Toxicology Guide was produced under an Interagency Agreement with the U.S. Department of Energy, Oak Ridge National Laboratory (87-TH-0002) for the Hazard Assessment Branch, Toxic Hazards Division, AAMRL, Wright-Patterson AFB, OH.

For each chemical in the IRP Toxicology Guide, the environmental fate, exposure pathways, toxicity, sampling and analysis methods and state and federal regulatory status are outlined. The material provided is intended as an overview of key topic areas; no attempt was made to provide a comprehensive review. Users are encouraged to read the Introduction to Volume 1 of the IRP Toxicology Guide before applying chemical-specific information.

Candidate chemicals for inclusion in subsequent Toxicology Guide updates should be forwarded through MAJCOM bioenvironmental engineers to HQ USAF/SGPA. Consultant service for current toxicological information should be obtained from the USAF OEHL/ECO, Brooks AFB, TX 78235-5000.

Substantial effort was made to assure that the information contained in the Toxicology Guide was current and reliable at the time of publication. Users are encouraged to report apparent discrepancies or errors to AAMRL/THA, Wright-Patterson AFB, OH 45433-6573. Copies of this document are available from: National Technical Information Services, 5285 Port Royal Road, Springfield, VA 22161. Federal Government agencies and their contractors registered with Defense Technical Information Center should direct requests for copies to: Defense Technical Information Center, Cameron Station, Alexandria, VA 22314.

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LIST OF ABBREVIATIONS, ACRONYMS, TERMS AND SYMBOLS

This list of abbreviations, acronyms, terms and symbols is selected from the pages of the Guide. Words and phrases defined here include those occurring in more than one chapter, those indispensable to understanding the material in a chapter and those that may help clarify some of the definitions themselves. Not listed are chemical synonyms which can be found in the chemical index and words adequately defined at the point of use.

A	Acre
AA	Atomic absorption spectroscopy
ACGIH	American Conference of Governmental Industrial Hygienists
Active metals	This refers to metals such as aluminium, calcium, magnesium, potassium, sodium, tin, zinc, and their alloys.
ADI	Acceptable daily intake
ADL	Arthur D. Little, Inc.
Adenocarcinoma	A malignant tumor originating in glandular or ductal epithelium.
Adenoma	A benign growth of glandular tissue.
ae	Acid equivalent
Aerosol	A suspension or dispersion of small solid or liquid particles in air or gas.
AFOSH	Air Force Occupational Safety and Health Standard
Alkali metals	Metals (in Group 1A of the Periodic Table,) such as lithium, sodium, potassium, rubidium, cesium, and francium. The alkali metals react vigorously, at times violently, with water. These metals present a dangerous fire risk when in contact with moisture or oxidizing materials.

Alkaline earth metals	Calcium, barium, strontium, and radium (Group IIA of Periodic Table). Alkaline earth metals are less reactive than sodium and potassium and have higher melting and boiling points.
Ambient water	Surface water
Ambient water criterion	That concentration of a pollutant in a navigable water that, based upon available data, will not result in adverse impact on important aquatic life, or on consumers of such aquatic life, after exposure of that aquatic life for periods of time exceeding 96 hours and continuing at least through one reproductive cycle; and will not result in a significant risk of adverse health effects in a large human population based on available information such as mammalian laboratory toxicity data, epidemiological studies of human occupational exposure data, or any other relevant data.
Amines	A class of organic compounds of nitrogen that may be considered as derived from ammonia (NH_3) by replacing one or more of the hydrogen atoms (H) with straight or branched hydrocarbon (alkyl) groups. All amines are basic in nature and usually combine readily with hydrochloric or other strong acids to form salts.
API	American Petroleum Institute
Aquifer	An underground, permeable saturated strata of rock, sand or gravel containing ground water.
Aromatic	A major group of hydrocarbons containing one or more rings like benzene, which has a six-carbon ring containing three double bonds. Most compounds in this group are derived from petroleum and coal tar and are reactive and chemically versatile. The name characterizes the strong and pleasant odor of most substances of this group. NOTE: The term "aromatic" is often used in perfume and fragrance industries to describe essential oils, which are not aromatic in the chemical sense.
atm	Atmosphere (760 Torr)
ATP	Adenosine triphosphate, a nucleotide cofactor important in many biological reactions where energy is transferred.
Autoignition temperature	The minimum temperature at which the material will ignite without a spark or flame being present. Along with the flash point, autoignition temperature gives an indication of relative flammability.

BCF	Bioconcentration factor, a measure of the cumulative build-up of a specific compound sequentially through a food chain.
Benign	A term meaning noncancerous.
BOD	Biochemical oxygen demand
BUN	Blood urea nitrogen
bw	Body weight
C	Celsius (Centigrade)
CAA	Clean Air Act
CAG	Cancer Assessment Group of the U.S. Environmental Protection Agency
Calc	A number calculated by Arthur D. Little, Inc.
Carcinogen	Any cancer-producing substance.
Carcinoma	A malignant epithelial tumor.
CAS REG NO	Numeric designation assigned by the American Chemical Society's Chemical Abstract Service which uniquely identifies chemical compound.
cc	Cubic centimeter(s)
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
CL	Ceiling limit value
cm	Centimeter(s) (1E-02 meter)
Chemically active metals	This phrase generally refers to metals such as, calcium, magnesium, potassium, sodium, tin, zinc, and their alloys.

CNS	Central nervous system which consists of the brain and spinal cord. The CNS controls mental activity plus voluntary muscular activity. It also coordinates the parasympathetic and sympathetic nervous systems, which command the body's involuntary functions.
CO	Carbon monoxide
CO_2	Carbon dioxide
Cp	Centipoise
CPSA	Consumer Product Safety Act
C*t	Product of concentration multiplied by time of exposure
CWA	Clean Water Act
d	Density
da	Day(s)
°	Degrees, as in 37°C
DNA	Deoxyribonucleic acid
DOT	U.S. Department of Transportation
Drinking Water	Water which meets the specifications of the water quality standards and is therefore suitable for human consumption and for all usual domestic purposes.
ECD	Electron capture detector
EEC	European Economic Community
EEG	Electroencephalogram, it detects abnormalities in the electrical waves emanating from different areas of the brain.
EKG	Electrocardiogram, a recording of the changes in electrical potential that occur during a cycle of heart muscle activity, producing a characteristic series of waves.
EPA	Environmental Protection Agency
Epithelium	The covering of internal and external surfaces of the body, including the lining of vessels and small cavities.

Epoxide	An organic compound containing a reactive group resulting from the union of an oxygen atom with other atoms (usually carbon) that are joined as shown below: O / \ -C - C- This group, commonly called "epoxy", characterizes the epoxy resins. Epichlorohydrin and ethylene oxide are well-known epoxides.
estim	Estimated value
F	Fahrenheit
FDA	Food and Drug Administration (U.S.A.)
FDCA	Food, Drug and Cosmetic Act
FID	Flame ionization detector
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
Finished	Tap water, i.e., water that has undergone drinking water treatment
Flammable limits in air	The range of gas or vapor concentrations in air, generally expressed in units percent by volume, capable of supporting combustion when ignited. The lower end of the range is commonly referred to as the lower flammable limit (LFL) and sometimes as the lower explosive limit (LEL). The upper end of the range is called the upper flammable limit (UFL) or the upper explosive limit (UEL).
f_{oc}	Fraction organic carbon in soil ($0 \leq f_{oc} \leq 1$)
FR	Federal Register
ft	Foot
g	Gram(s)
Gavage	Forced feeding through a tube passed into the stomach.
GC	Gas chromatography

GI	Gastro-intestinal
Ground water	Subsurface water that occurs beneath the water table in soils and geologic forms that are fully saturated.
H	Henry's law constant ($atm \cdot m^3/mol$)
^3H	Chemical symbol for the radioactive isotope of hydrogen of atomic mass 3.
ha	Hectare, a unit of area equal to 10,000 square meters.
HA	EPA's Health Advisory (formerly termed SNARL), an estimate of the no adverse response level for short and long-term exposures to a chemical via drinking water.
Half-life	Time required for removal or degradation of one-half of the original quantity.
Halogen	One of the electronegative elements of Group VIIA of the Periodic Table: fluorine, chlorine, bromine, iodine, and astatine. Fluorine is the most active of all chemical elements.
Halogenated	Containing one or more atoms of halogens.
Hemangioma	A tumor composed of blood vessels.
Hemangiosarcoma	A malignant tumor composed of endothelial cells which line the heart and vessels of the circulatory system.
Hg	Mercury
HMTA	Hazardous Materials Transportation Act
HPLC	High-pressure liquid chromatography
hr	Hour(s)
HSDB	Hazardous Substances Data Bank
Hydrocarbon	An organic compound (as acetylene or benzene) consisting exclusively of the elements carbon and hydrogen and often occurring in petroleum, natural gas, coal, and bitumens.

Hydrolysis	The addition of the hydrogen and hydroxyl ions of water to a molecule, with its consequent splitting into 2 or more simpler molecules.
IARC	International Agency for Research on Cancer
IDLH	Immediately dangerous to life or health concentration; represents the maximum level from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects.
im	Intramuscular
in	Inch
intradermal	Situated or applied within the skin
in vitro	Describes biological experiments in laboratory apparatus rather than in a living organism.
in vivo	Describes process that occurs within a living organism.
ip	Intraperitoneal
IR	Infrared spectroscopy
IRP	Installation Restoration Program
IU	International units
iv	Intravenous
K_d (or K_p)	Soil sorption coefficient
kg	kilogram(s) (1E+03 grams)
K_{oc}	Soil absorption coefficient normalized to represent amount sorbed per unit weight of organic carbon in soil.
L	Liter(s)
lb	Pound(s)
LC_{50}	The concentration required to kill 50% of test individuals.
LC_{Lo}	Lowest reported lethal concentration.

LC^*t_{50}	Product of the concentration times time which causes lethality in 50% of the exposed population.
LD_{50}	The dose required to kill 50% of test individuals.
LD_{Lo}	Lowest reported lethal dose.
Lesion	An abnormal change in an organ because of injury or disease.
log K_{ow}	Log of the octanol-water partition coefficient.
Lower flammable limit	The lowest concentration of the material in air which will support combustion.
m	Meter
m^3	Cubic meter(s)
MAC	Maximum allowable concentration
Malignant	Pertaining to the growth and proliferation of certain tumors which terminate in death if not checked by treatment.
MCL	Maximum contaminant level
MDL	Minimum detection limit(s)
mEq	Milliequivalent (1/1000 of an equivalent)
mg	Milligram(s) (10E-3 gram)
mg%	The concentration of a solution expressed in milligrams per 100 mL.
min	Minute(s)
Mineral acids (non-oxiding)	Examples include boric, disulfuric, fluosilicic, hydriodic, hydrobromic, hydrochloric, hydrocyanic, hyfluoric, permonosulfuric, phosphoric, and selenous acids as well as chlorosulfonic acid and various fluorophosphoric acids.
Mineral acids (oxidizing)	Examples include bromic, chloric, chromic, acids hypochlorous, nitric, nitrohydrochloric, perbromic, perchloric, perchlorous, periodic, and sulfuric acids as well as oleum.

mL	Milliliter (1E-03 liter)
MLD	Minimum lethal dose
mm	Millimeter(s) (1E-03 meter)
mM	Millimoles
mol	Gram mole
MPRSA	Marine Protection Research and Sanctuaries Act
MS	Mass spectrometry
Mutagen	A material that induces genetic damage.
MW	Molecular weight
n	Normal (isomer), as in n-butyl.
N	Normal (equivalents per liter, as applied to concentration); nitrogen (as in N-methylpyridine).
Narcosis	A state of stupor, unconsciousness or arrested activity.
NCI	National Cancer Institute
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NIOSH	The National Institute for Occupational Safety and Health
NIOSH No.	A unique, nine-position accession number assigned to each substance listed in the Registry of Toxic Effects of Chemical Substances published by NIOSH.
NIPDWR	National interim primary drinking water regulation
Nitride	Compounds of nitrogen with N≡ as the anion. These compounds may react with moisture to evolve flammable ammonia gas.
NOEL/NOAEL	No observed (adverse) effect level
NPL	National Priority List
NTP	National Toxicology Program

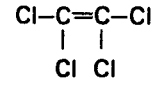
ng	Nanogram(s) (1E-09 gram)
OHM/TADS	Oil and Hazardous Materials Technical Assistance Data System
OSHA	Occupational Safety and Health Act (or Administration)
Oxidation	Any process involving the addition of oxygen, loss of hydrogen, or loss of electrons from a compound.
Oxidizing materials	Any compound that spontaneously evolves oxygen either at room temperature or under slight heating. The term include such chemicals as peroxides, chlorates, perchlorates, nitrates, and permanganates. These can react vigorously at ambient temperatures when stored near or in contact with reducing materials such as cellulosic (i.e., cotton, paper, rayon) and other organic compounds. In general, storage areas for oxidizing materials should be well ventilated and kept as cool as possible.
PEL	Permissible exposure limit, as found in 29CFR 1910.1000.
Percutaneous	Penetration of the skin
pg	picogram(s) (1E-12 grams)
pH	A measure of acidity or alkalinity of a solution on a scale of 0-14; log of the reciprocal of the hydrogen ion concentration.
PID	Photo ionization detector
Pk	Peak concentration.
Plasma	The straw-colored, fluid portion of blood that remains when all cells are removed.
po	By mouth
Polymerizable material	A substance capable of self-polymerization under appropriate conditions. Polymerization reactions are often violent, exothermic, and capable of causing violent rupture of sealed containers.

Polymerization	A chemical reaction, usually carried out with a catalyst, heat, or light, and often under high pressure. In this reaction, a large number of relatively simple molecules combine to form a chain-like macromolecule. This reaction can occur with the release of heat. In a container, the heat associated with polymerization may cause the substance to expand and/or release gas and cause the container to rupture, sometimes violently. The polymerization reaction occurs spontaneously in nature; industrially it is performed by subjecting unsaturated or otherwise reactive substances to conditions that will bring about the combination.
POTWs	Publicly owned treatment works
ppb	Part(s) per billion
ppm	Part(s) per million
ppt	Part(s) per thousand
PVA	Polyvinyl acetate
PVC	Polyvinyl chloride
Raw	Applied to water or waste water that has undergone no treatment.
RCRA	Resource Conservation and Recovery Act
Reactivity (chemical)	Relating to the potential for a substance to undergo chemical transformation or change in the presence of other materials. Such chemical reactions often (but not always) are hazardous and involve evolution of heat, toxic or flammable gases, fires, or expolsions. The products formed by the reaction may have properties or hazards different from those of the chemical reactants.
RBC	Red blood cells

Reducing agents	These agents act to extract and liberate hydrogen from organic substances and may generate toxic and/or flammable gases and heat in contact with water. Many reducing agents may be pyrophoric and may ignite combustible materials in the presence of air. Contact with oxidizing materials may result in violent or explosive reactions. Examples of reducing agents include calcium, phosphorus, sodium, hydrazine, arsine, and metallic acetylides, aluminates, boranes, bromides, carbides, chlorides, hydrides, hydroborates, hyposulfites, iodides, phosphides, selenides, and silanes, as well as metal alkyls such as triethyl aluminum and diethyl zinc.
Reduction	Decreasing the oxygen content or increasing the proportion of hydrogen in a chemical compound or adding an electron to an atom or ion.
REL	Recommended exposure limit
Rf	Retardation factor, i.e., the ratio of the velocity of the interstitial water to the velocity of a pollutant in soil.
RfD	Reference dose
RMCL	Recommended maximum contaminant level
RNA	Ribonucleic acid
RQ	Reportable quantities
SAE	Society of Automotive Engineers
sc	Subcutaneous, beneath the skin
SD	Standard deviation, a measure of the spread of individual measurements of a normally distributed variable.
SDWA	Safe Drinking Water Act
sec	Second(s)
Serum	The clean amber fluid that remains after blood has clotted; plasma without any of the substances involved in clotting.
SGOT	Serum glutamic oxalacetic transaminase, an enzyme released into the serum as the result of tissue injury, especially injury to the heart and/or liver.

SGPT	Serum glutamic pyruvic transaminase, an enzyme released into the serum as a result of tissue injury, especially damage to liver cells.
SH	Sulfhydryl group
SNARL	Suggested no adverse response level
STEL	Short-term exposure limit
STP	Standard temperature and pressure
Subcutaneous	Beneath the skin
Surface water	That water contained on the exterior or upper portion of the earth's surface; it does not include ground water.
Sym	Symmetrical
$t_{1/2}$	Half-life
TD_{Lo}	Lowest reported toxic dose
Teratogen	A material that induces nontransmissible changes (birth defects) in the offspring.
TLV®	Threshold limit value; an ACGIH-recommended time-weighted average concentration of a substance to which most workers can be exposed without adverse effect.
TNT	Trinitrotoluene, an explosive used in the munitions industry.
Toxic metals and their compounds	These include antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, indium, lead, manganese, mercury, molybdenum, nickel, osmium, selenium, thallium, thorium, titanium, zinc, and zirconium; compounds containing these metals; and metallic compounds containing arsines, boron, calcium, cesium, magnesium, silver, strontium, tellurium, tin, tungsten, or vanadium, among others.
TSCA	Toxic Substances Control Act
TWA	Time-weighted-average
μg	Microgram(s) (1E-06 gram)
μL	Microliter(s) (1E-06 liter)

uns	Unsymmetrical
Upper flammable limit	The highest concentration of the material in air which will support combustion.
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
Vol.%	The number of milliliters of a substance in 100 milliliters of the medium.
Water quality standard	Legally enforceable provisions of state or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses.
WHO	World Health Organization
wk	Week(s)
w/v	Weight per unit volume
w/w	Weight per unit weight
%	Percent
>	Greater than
≥	Greater than or equal to
<	Less than
≤	Less than or equal to
~	Approximately
->	Yields or causes
+	Plus

COMMON SYNONYMS:	CAS REG.NO.: 127-18-14 FORMULA: C_2Cl_4 NIOSH N0: KX3850000 STRUCTURE:	AIR W/V CONVERSION FACTOR at 25°C (12) 6.78 mg/m^3 ≈ 1 ppm; 0.147 ppm ≈ 1 mg/m^3 MOLECULAR WEIGHT: 165.85
Carbon dichloride Ethylene tetrachloride PCE PERC Perchloroethylene Tetrachloroethene Tetrachloroethylene		

REACTIVITY	Reactions of halogenated organic materials such as tetrachloroethylene with cyanides, mercaptans or other organic sulfides typically generate heat, while those with amines, azo compounds, hydrazines, caustics or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, zinc or magnesium, organic peroxides or hydroperoxides, strong oxidizing agents, or strong reducing agents typically result in heat generation and explosions and/or fires (511).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Ether-like	
	• Odor Threshold: 50.000 ppm	(38)
	• Density: 1.6250 g/mL (at 20°C)	(23)
	• Freeze/Melt Point: -22.40°C	(23)
	• Boiling Point: 121.00°C	(23)
	• Flash Point: None	
	• Flammable Limits: Nonflammable	

PHYSICO-CHEMICAL DATA (Cont.)	• Autoignition Temp.: Nonflammable	
	• Vapor Pressure: 1.40E+01 mm Hg (at 20°C)	(38)
	• Satd. Conc. in Air: 1.2600E+05 mg/m^3 (at 20°C)	(67)
	• Solubility in Water: 1.50E+02 mg/L (at 20°C)	(38)
	• Viscosity: 0.890 (estimate)(at 20°C)	(21)
	• Surface Tension: 3.1300E+01 dyne/cm (at 20°C)	(59)
	• Log (Octanol-Water Partition Coeff.): 3.14	(29)
	• Soil Adsorp. Coeff.: 6.65E+02	(652)
	• Henry's Law Const.: 2.27E-02 $atm \cdot m^3/mol$ (at 20°C)	(74)
	• Bioconc. Factor: 4.90E+01 (bluegill) 6.60E+01 (estim)	(170,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems, including transport of vapor through air-filled pores as well as transport in solution. Chemical is resistant to hydrolysis and to biodegradation (except by acclimated mixed cultures); it may thus persist for months to years (or longer).

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of tetrachloroethylene to ground-water used as sources for drinking water. There is substantial evidence that such migration has occurred in the past. Inhalation resulting from volatilization from surface soils and drinking water may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (45) Ingestion and inhalation cause nausea, vomiting, headache, dizziness, drowsiness and tremors. Skin contact with liquid causes irritation and blistering. Both liquid and vapor are irritating to the eyes. Acute Toxicity Studies: (3504) INHALATION: LC_{50} 5200 ppm · 4 hr — Mouse LC_{50} 5040 ppm · 8 hour — Rat ORAL: LD_{50} 8850 mg/kg — Rat LD_{50} 8100 mg/kg — Mouse SKIN: LD_{50} 64680 mg/kg · 10-day — Mouse Long-Term Effects: Liver and kidney toxicity Pregnancy/Neonate Data: Negative Genotoxicity Data: Negative Carcinogenicity Classification: IARC - Group 2B (possibly carcinogenic to humans) NTP - Clear evidence in mice, male rats, some evidence in female rats EPA - Group B2 (sufficient evidence in animals and inadequate evidence in humans)
HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation. • Vapor concentrations of 100-500 ppm: any supplied-air respirator or self-contained breathing apparatus with full facepiece; gas mask with organic vapor canister; chemical cartridge respirator with full facepiece and organic vapor cartridge. • Above 500 ppm: self-contained breathing apparatus with full facepiece operated in positive-pressure mode. • Chemical goggles if there is probability of eye contact. • Butyl, natural rubber, neoprene or PVC gloves/apron/boots to prevent repeated or prolonged skin contact with the liquid.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 25 ppm;
- AFOSH PEL (8-hr TWA): 25 ppm; STEL (15-min): 37.5 ppm

Criteria
- NIOSH IDLH (30 min): deleted: NIOSH has recommended that the substance be treated as a potential human carcinogen.
- NIOSH REL: Lowest feasible limit
- ACGIH TLV® (8-hr TWA): 50 ppm
- ACGIH STEL (15 min): 200 ppm

WATER EXPOSURE LIMITS:

Drinking Water Standards (3742)
MCLG: 0 μg/L (proposed)
MCL : 5 μg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 2 mg/L
- 10-day (child): 2 mg/L
- longer-term (child): 1 mg/L
- longer-term (adult): 5 mg/L
- 1E-04 cancer risk: 70 μg/L

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WHO Drinking Water Guideline (666)

A tentative health-based guideline for drinking water of 10 μg/L has been proposed for tetrachloroethylene. A daily per capita consumption of two liters was assumed.

EPA Ambient Water Quality Criteria

- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms (1E-05, 1E-06, 1E-07 cancer risk), 8 μg/L, 0.8 μg/L, 0.08 μg/L.
  - Based on ingestion of drinking water only, (1E-04, 1E-05, 1E-06 cancer risk), 70 μg/L, 7 μg/L, 0.7 μg/L.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 5280 μg/L.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 840 μg/L.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 10,200 μg/L.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 450 μg/L.

REFERENCE DOSES:

ORAL: 1.000E+01 μg/kg/day (3744)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Tetrachloroethylene is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations have been set for tetrachloroethylene effluent in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), iron and steel manufacturing (354), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Tetrachloroethylene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 (3781). It is listed as an unregulated contaminant requiring monitoring in all community water systems and non-community non-transient water systems (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of tetrachloroethylene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Tetrachloroethylene is identified as a toxic hazardous waste (U210) and a hazardous waste constituent (3783,3784). Non-specific sources of tetrachloroethylene-containing waste are solvent use (or recovery) activities, chlorinated aliphatic hydrocarbon production, and spent solvent mixtures containing 10% or more tetrachloroethylene (325). Waste streams from the following industries contain tetrachloroethylene and are listed as specific sources of hazardous waste: organic chemicals (production of carbon tetrachloride, 1,2-dichloroethane, vinyl chloride, and toluene diisocyanate) and inorganic chemicals (chlorine production) (3774, 3765). Effective July 8, 1987, the land disposal of hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances exist until May, 1990 for land and injection well disposal of some wastewaters and non-wastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). Tetrachloroethylene is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors, or importers who possess health and safety studies on tetrachloroethylene must submit them to EPA (3789).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
Tetrachloroethylene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 0.454 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing tetrachloroethylene but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of tetrachloroethylene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
Tetrachloroethylene is exempt from a tolerance requirement when used as a solvent or cosolvent at a level of no more than 0.6% in pesticide formulations applied to growing crops or to raw agricultural commodities after harvest. Exemptions also apply when it is used as a solvent in pesticide formulations applied to animals (315).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to tetrachloroethylene shall not exceed an 8-hour time-weighted average (TWA) of 25 ppm (3539).

Clean Air Act (CAA)
EPA lists tetrachloroethylene as a hazardous air pollutant for which it will establish national emission standards under Section 112 of the Clean Air Act (3803).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated tetrachloroethylene as a hazardous material with a reportable quantity of 0.454 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Tetrachloroethylene is approved for use as an indirect food additive as a component of adhesives (3209).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additonal or more stringent criteria:

CALIFORNIA
California has an action level of 4 μg/L for drinking water (3098).

CONNECTICUT
Connecticut has a quantification limit of 2 μg/L and an action level of 20 μg/L for drinking water (3137,3138).

FLORIDA
Florida has set an MCL of 3 μg/L for drinking water (3219).

KANSAS
Kansas has an action level of 7 μg/L for ground-water (3213).

NEW HAMPSHIRE
New Hampshire has set an enforceable Toxic Contaminant Level (TCL) for tetrachloroethylene in drinking water of 2.3 mg/L (assumes a child weighing 10 kg who drinks one liter of water per day) (3710).

NEW JERSEY
New Jersey has set an MCL of 1 μg/L (ppb) for drinking water (3497).

OKLAHOMA
Oklahoma has a water quality criterion of 1.6 μg/L for ground-water, and has set a nonenforceable Toxic Substance Goal of zero for public and private surface waters (3534).

PENNSYLVANIA
Pennsylvania has set a human health criterion (cancer risk level) of 0.7 μg/L for surface waters (3561).

RHODE ISLAND

Rhode Island has an acute freshwater quality guideline of 240 μg/L and a chronic guideline of 5.3 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA

South Dakota requires tetrachloroethylene to be nondetectable, using designated test methods, in ground-water (3671).

VERMONT

Vermont has a preventive action limit of 0.07 μg/L and an enforcement standard of 0.70 μg/L for tetrachloroethylene in ground-water (3682).

WISCONSIN

Wisconsin has a preventive action limit of 0.1 μg/L and an enforcement standard of 1 μg/L for tetrachloroethylene in ground-water (3840).

Proposed Regulations

- Federal Programs

Safe Drinking Water Act (SDWA)

EPA has proposed a maximum contaminant level goal (MCLG) of zero and a maximum contaminant level (MCL) of 5 μg/L for tetrachloroethylene as part of the National Primary Drinking Water Regulations. This action is expected in May, 1989, with promulgation scheduled for December, 1990 (3759).

Resource Conservation and Recovery Act (RCRA)

EPA has proposed that solid wastes be listed as hazardous because they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 0.1 mg/L tetrachloroethylene. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565). EPA has proposed listing wastestreams from the following industries as specific sources of tetrachloroethylene-containing wastes: organic chemicals (1,1,1-trichloroethane production), and inorganic chemicals (2,4-D production) (3795).

- State Water Programs

MOST STATES

Most states are in the process or revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officer is advised. Changes are projected for 1989-90 (3683).

CALIFORNIA

California has proposed an MCL of 5 μg/L for drinking water (3096).

MINNESOTA

Minnesota has proposed a Recommended Allowable Limit (RAL) of 6.6 μg/L for tetrachloroethylene in drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 2110 μg/L for designated surface waters, and chronic criteria of 6.6 μg/L for designated ground-waters and 3.8 μg/L for designated surface waters for the protection of human health (3452).

NEW JERSEY

New Jersey has proposed a water quality criterion of 1 μg/L for class FW2 surface waters (3496).

EEC Directives

Directive on Ground-Water(538)

Direct discharge into ground-water (i.e. without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Quality Required of Shellfish Waters (537)

The mandatory specifications for organohalogenated substances specify that the concentration of each substance in the shellfish water or in shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The specifications for organo-halogenated substances state that the concentration of each substance in shellfish flesh must be so limited that it contributes to the high quality of the shellfish product.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Tetrachloroethylene is listed as a Class II/b harmful substance and is subject to packaging and labeling regulations.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials an other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Tetrachloroethylene is classified as a harmful substance and is subject to packaging and labeling regulations. Tetrachloroethylene may contain a stablizer and if the stablizer changes the dangerous properties of this substance should be labeled in accordance with rules in Annex I.

17.1 MAJOR USES

The major application for tetrachloroethylene, approximately 68% of annual domestic production, is in the dry cleaning industry. Some 80% of all dry cleaners use it as their primary cleaning agent (21). Its popularity in this area is due to its nonflammability, ease of recovery for reuse and its compatibility with various fabrics. Cold cleaning and vapor degreasing of metals account for 15% of its use, while 14% is used as a chemical intermediate in the synthesis of fluorocarbons. Minor applications account for 3% of its use. These include various manufacturing and industrial processes as well as medicinal uses (6, 21, 25).

17.2 ENVIRONMENTAL AND EXPOSURE PATHWAYS

17.2.1 Transport in Soil/Ground-water Systems

17.2.1.1 Overview

Tetrachloroethylene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways for low soil concentrations can be assessed by using an equilibrium partitioning model as shown in Table 17-1. These calculations predict the partitioning of tetrachloroethylene among soil particles, soil water and soil air. The tetrachloroethylene associated with soil air and soil water is more mobile than the sorbed portion.

The estimates for the unsaturated topsoil model indicate that most of the chemical (about 97%) is sorbed to the soil. The amount of the chemical in soil air (2.2% at 20°C, 0.7% at 10°C) is, however, large enough to make volatilization an important transport pathway. The amount in soil water (0.8%) indicates solution transport is a relatively minor transport pathway unless the water content is higher.

In saturated deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of tetrachloroethylene (26%) is in the soil water; this portion would be transported with flowing ground-water.

A number of laboratory and field studies have documented the mobility of tetrachloroethylene in soil/ground-water systems. Wilson et al. (82) showed in a laboratory test that most of the chemical was lost from the soil column via volatilization and a smaller amount via leaching. Field studies by Piet et al. (226), Schneider et al. (227) and Schwarzenbach and Westall (228) have demonstrated the

TABLE 17-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR TETRACHLOROETHYLENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c]			
(i) at 20°C	97	0.8	2.2
(ii) at 10°C	98.5	0.8	0.7
Saturated deep soil[d] at 20°C	73.6	26.4	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 660 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 0.154 atm · m^3/mol at 20°C (74). This datum seems to be in error.
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

mobility of tetrachloroethylene through river sediments and aquifers near the Rhine River. The velocity of tetrachloroethylene relative to that of water in one study was 0.1 for the river sediments and 0.6 for the aquifer (228).

17.2.1.2 Sorption on Soils

As with other neutral organic molecules, the extent of tetrachloroethylene sorption on soil is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil (the salting-out coefficient, k, for tetrachloroethylene in KCl solutions is 0.56 L/mol (18)); and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of about 1400, the soil sorption coefficient (per unit weight of organic carbon in the soil), K_{oc}, is estimated to be 660. Sabljic (230) reports a measured value of K_{oc} as 360; the original source of this datum is not clearly identified. The equilibrium partition calculations described above (with results shown in Table 17-1) used K_{oc} = 660. The results showed extensive (97%) sorption in the unsaturated zone and major (74%) sorption in the saturated zone.

17.2.1.3 Volatilization from Soils

Transport of tetrachloroethylene vapors through the air-filled pores of unsaturated soils is an important transport mechanism for near-surface soils. This has been demonstrated in laboratory tests by Wilson et al. (82).

In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant (H), the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31). The temperature dependence of H for tetrachloroethylene has been measured by Gossett and Lincoff (18):

$$H(atm \cdot m^3/mol) = \exp [11.32 - 4622/T\ (°K)].$$

Using this equation, values at 20°C and 10°C are calculated to be 0.0117 and 0.00666 $atm \cdot m^3/mol$, respectively. The influence of salt concentration and dissolved organic matter on the value of H is also provided by Gossett and Lincoff (18); the effects are smaller than those associated with normal temperature changes (e.g., a 10°C change).

17.2.2 Transformation Processes in Soil/Ground-water Systems

17.2.2.1 Overview

The persistence of tetrachloroethylene in soil/ground-water systems is not well documented. In most cases, it should be assumed that it will persist for months to years (or more).

Tetrachloroethylene that has been released into the air will eventually undergo photochemical oxidation; a tropospheric lifetime on the order of days to weeks has been reported for the chemical (229). Photolytic degradation in surface waters has also been demonstrated in laboratory tests (231). Tetrachloroethylene undergoes hydrolysis very slowly in the presence of water. At elevated temperatures (150°C), the products of hydrolysis are trichloroacetic acid (CCl_3COOH) and hydrochloric acid (HCl). Available data from laboratory tests indicate that the half-life of tetrachloroethylene due to aqueous hydrolysis in natural waters is on the order of several months (232) to several years (75). Losses (in the laboratory study) in the first study due to volatilization and/or reaction with dissolved oxygen may be

responsible for the lower half-life. Mabey et al. (33) indicate that hydrolysis is not an environmentally-significant degradation pathway for tetrachloroethylene.

Literature references to microbial degradation of compounds such as tetrachloroethylene are few and conflicting; the majority report that low molecular weight chloroaliphatics are not metabolized (10). However, significant degradation may be achieved in biological wastewater treatment plants where the microbes have become acclimated to the chemical. Tabak et al. (55), for example, showed significant tetrachloroethylene biodegradation with gradual adaptation at levels of 5 and 10 mg/L in a static-culture flask-screening procedure. Other, less-direct data indicating biodegradation in wastewater treatment plants are summarized by Gilbert et al. (229). However, in most soil/ground-water systems such aerobic degradation would be of minimal importance because of the low concentration of microorganisms and the low dissolved oxygen (anaerobic) conditions.

Evidence of anaerobic microbiological degradation of tetrachloroethylene has been reported by Haider (233), and Bouwer and McCarty (234). Bouwer et al. (235) had previously reported that no anaerobic degradation was observed in their mixed culture tests. Wilson et al. (236) tried to assess the extent of biodegradation in laboratory soil columns and found that, for tetrachloroethylene, the percent of the original amount degraded per week was about 1. However, the authors indicated that hydrolysis could have been the cause of degradation.

17.2.3 Primary Routes of Exposure From Soil/ Systems

The above discussion of fate pathways suggests that tetrachloroethylene is highly volatile in aqueous solutions, moderately adsorbed by soil and has a low potential for bioaccumulation. This compound may volatilize from soil surfaces, but that portion not removed by volatilization may eventually migrate to ground-water. These fate characteristics suggest several potential exposure pathways.

Volatilization of tetrachloroethylene from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. In addition, the potential for ground-water contamination is high, particularly in sandy soils. Mitre Corp. (83) reported that tetrachloroethylene has been found at 57 of the 546 National Priority List (NPL) sites. It was detected at 47 sites in ground-water, 17 sites in surface water and 3 sites in air. The potential for exposure through drinking water is confirmed by the pervasiveness of tetrachloroethylene in ground-water sources of drinking water in the United States. The USEPA (62, 64) reported the following results from a variety of surveys of drinking water supplies:

Survey	No. Sampled	No. Positive	Range of Positives
State Data	3636	628	Trace - 1000 μg/L
NOMS	113	48	0.2 - 3.1 μg/L
NSP	142	24	Trace 0 3.2 μg/L
CWSS	452	22	0.5 - 30 μg/L
GWSS (Random Data)	466	34	0.2 - 23 μg/L

The state data include only ground-water sources and were compiled from various state reports on local contamination problems. The state data are not considered to be statistically representative of national occurrence. The National Organics Monitoring Survey (NOMS) included data from both ground and surface water supplies, as did the National Screening Program (NSP) and the Community Water Supply Study (CWSS). The USEPA (531) Ground-water Supply Survey (GWSS) is the most recent study. This survey sampled a total of almost 1000 drinking water systems using ground-water; 466 selected at random, and about 400 selected by the state as potentially contaminated. The random results suggest that tetrachloroethylene is a common contaminant in drinking water, particularly in ground-water as evidenced by the state reports of contamination problems. The USEPA (64) estimates about 3.6% of the nation's ground-water supplies are contaminated with tetrachloroethylene (≥0.5 μg/L).

These results indicate that tetrachloroethylene has the potential for movement in soil/ground-water systems. This compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure.
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposure.
- Recreational use of these waters may result in dermal exposure.
- Domestic animals may consume or be dermally exposed to contaminated ground- or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposure from drinking, or showering in contaminated ground-water. The Henry's law constant for tetrachloroethylene suggests that it will volatilize upon reaching surface waters. In addition, the bioconcentration factor for this compound is low, suggesting limited bioaccumulation in aquatic organisms or domestic animals.

17.2.4 Other Sources of Exposure

Tetrachloroethylene is a widely used organic solvent, predominantly in the drycleaning industry, by textile manufacturers, and in metal degreasing operations. As a result of emissions during production, use, and disposal, and because of its high volatility, tetrachloroethylene has become pervasive in the environment. The data reported in the previous section show that this is a common contaminant in drinking water. In addition to its presence in ground-water, Coniglio et al. (223) reported that tetrachloroethylene was found in surface water supplies. In a summary of data available as of 1980, these authors reported that 24.4% of the 180 finished surface water samples were contaminated with a mean concentration of 1.49 μg/L of tetrachloroethylene.

The volatility of this compound suggests that it may be found in air as well. Brodzinsky and Singh (84) compiled all available atmospheric monitoring data for a number of volatile organics. For tetrachloroethylene, they had data for 2553 locations. In rural and remote locations, the median concentration was 1.4 $\mu g/m^3$. In urban and suburban locations, the median concentration was 2.3 $\mu g/m^3$, and in source-dominated areas, the median concentration was 4.8 $\mu g/m^3$. These results suggest that inhalation exposure occurs even in rural and remote areas.

17.3 HUMAN HEALTH CONSIDERATIONS

17.3.1 Animal Studies

17.3.1.1 Carcinogenicity

Tetrachloroethylene is an apparent liver carcinogen in mice. In a study conducted by the National Cancer Institute, USP-grade tetrachloroethylene was administered in corn oil by gavage to male and female B6C3F$_1$ mice and Osborne-Mendel rats 5 days per week for 78 weeks. The high and low time-weighted average doses were 941 and 471 mg/kg/day for male rats, 949 and 474 mg/kg/day for female rats, 1072 and 536 mg/kg/day for male mice and 772 and 386 mg/kg/day for female mice. Hepatocellular carcinoma was found in 40% to 65% of all treated mice compared to 0-10% incidence in controls. A high rate of toxic nephropathy was observed in both species. The high incidence of early dose-related deaths in rats of both sexes due to toxic nephropathy rendered the bioassay inconclusive for rats (163).

In a recently completed NTP inhalation study, F344/N rats and B6C3F$_1$ mice were exposed to vapor concentrations of 200 or 400 ppm and 100 or 200 ppm of tetrachloroethylene (99.9% pure), respectively, 6 hours daily, 5 days per week, for 103 weeks (793). Clear evidence of carcinogenicity was noted for both rats and mice (793, 802). Both male and female B6 mice at both treatment levels exhibited increased incidences of hepatocellular carcinoma. In rats (both sexes), tetrachloroethylene exposure was associated with increased incidences of mononuclear

cell leukemia. There was also a low incidence (6-8%) of renal tubular cell adenomas/adenocarcinomas (combined), rare tumors in F344/N rats.

In an inhalation study, male and female rats were exposed to 300 and 600 ppm (2010 or 4020 mg/m^3) for 12 months. Increased mortality was observed in male rats exposed to 600 ppm. This was attributed to chronic renal disease brought about by the tetrachloroethylene exposure. No statistically significant increase in tumor incidence was seen, although there was a slight increase in adrenal pheochromocytoma in low-dose females (165).

IARC (3317) currently lists tetrachloroethylene in category 2B (inadequate human evidence and sufficient animal evidence) in its weight-of-evidence ranking for potential carcinogens. EPA (3808) lists the chemical in Group B2 (inadequate human evidence and sufficient animal evidence). The USEPA SAB, however, concluded that the chemical should be listed in Group C. The USEPA is soliciting public comments on this issue.

17.3.1.2 Genotoxicity

Negative findings for tetrachloroethylene have been reported in bacterial mutagenicity assays with Salmonella typhimurium (149, 3276) with and without activation and with Escherichia coli K12 (156) with microsomal activation. Positive findings were reported by Cerna and Kypenova (153), who found increased mutagenic activity in one strain of Salmonella typhimurium without metabolic activation. They also reported positive results in a host-mediated assay in mice with three strains of S. typhimurium at 1/2 LD_{50} and LD_{50} levels. No evidence of dose-dependence was seen.

High purity tetrachloroethylene produced no reversions in Salmonella when vapor phase exposure was used in two strains (TA100 and TA1535) of the five standard strains usually tested with or without metabolic activation. The other three strains were also negative (3644). In this same study, tetrachloroethylene with stabilizers induced revertants but only at toxic doses.

No significant increase in unscheduled DNA synthesis activity was observed in rat hepatocytes with any sample of tetrachloroethylene used, pure or stabilized (3644). Chinese hamster ovary cells treated with tetrachloroethylene with and without metabolic activation showed no increase above controls for sister chromatid exchanges or chromosomal aberrations (3235), nor did it induce sex-linked recessive lethals in the germ cells of Drosophila when it was injected or fed to males (3976).

Negative results were also obtained in an in vivo cytogenetics study of peripheral blood lymphocytes obtained from workers exposed to 10-92 ppm tetrachloroethylene for periods ranging from 2 months to 18 years (582).

17.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Schwetz et al. (115) examined the teratogenic effects of tetrachloroethylene in rats and mice. The animals were exposed to vapor levels of 300 ppm 7 hours/day on days 6 through 15 of gestation. The investigators concluded that tetrachloroethylene had little effect on embryonic and fetal development and that it was not teratogenic. However, there were a number of modest but statistically significant deviations from controls. These included increased incidences of subcutaneous edema, delayed ossification of skull bones and split sternebrae in mice. Rats exhibited a significant decrease in maternal weight gain and an increase in the percentage of fetal resorptions. In a study to determine embryotoxicity during the preimplantation period, Spielmann et al. (3678) observed that the maternal LD_{50} and embryonic LD_{50} for tetrachloroethylene in mice had the same value, 4.3 mg/kg. This indicates that there is no risk of embryolethality in early gestation. No teratogenicity was observed in this study. Pregnant rats were exposed by inhalation to 900 ppm tetrachloroethylene for 7 hours/day during gestational days 7-13 or 14-20 in a study by Nelson et al. (3492). Seven behavioral tests were selected as measures of CNS functions at several stages of development. The dams consumed less food and gained less weight during the exposure period than did the controls. The treated pups performed more poorly on some tests; however, in later tests the pups exposed on days 14-20 were found superior in the rotorod and open field tests. The investigators stated that there were generally few behavioral or neurochemical differences observed between the offspring of the treated and control animals.

17.3.1.4 Other Toxicologic Effects

17.3.1.4.1 Short-term Toxicity

Animals exposed to tetrachloroethylene by inhalation exhibit central nervous system depression as well as effects on the cardiovascular system, liver and kidney. Rats did not survive longer than 12 to 18 minutes when exposed to vapor concentrations of 12,000 ppm. Concentrations of 200 ppm were tolerated for up to 14 hours while 3000 ppm was tolerated for 4 hours with no deaths. Unconsciousness was observed within a few minutes at concentrations of 6000 ppm or above and after several hours at 3000 ppm. The predominant response at these levels was CNS depression along with slight changes in the liver (167). LC_{50} values of 5200 ppm · 4 hr (25) and 5040 · 8 hr (12) have been reported for mice and rats, respectively.

Eleven consecutive daily oral doses at levels of 100, 250 or 1000 mg/kg resulted in liver changes in mice at all dose levels and in rats at the 1000 mg/kg level (581). Oral LD_{50} values of 8100 mg/kg (mouse) and 8850 mg/kg (rat) have been recorded in the literature (59, 47).

Kylin et al. (160) noted moderate fatty degeneration of the liver in mice after a single 4-hour exposure to 200 ppm. Exposure to the same concentration 4 hours daily, 6 days per week for 8 weeks, increased the severity of the lesions caused by tetrachloroethylene.

Rabbits exposed to 2790 ppm 4 hours daily, 6 days per week for 45 days, exhibited reduced glomerular filtration and renal plasma flow and a significant decrease in tubular excretion (151).

Tetrachloroethylene also produces cardiac depression and decreased blood pressure but has not been found to sensitize the myocardium to epinephrine (578).

Duprat et al. (155) have shown tetrachloroethylene to be a primary eye and skin irritant in rabbits. Instillation into the eye produced conjunctivitis and epithelial abrasion. However, the eyes recovered completely within 2 weeks. Tetrachloroethylene also produced a severe irritant effect when a single application was made to the skin of rabbits.

The role of metabolism in the hepatotoxicity of tetrachloroethylene has been investigated by Buben and O'Flaherty (3089). Male Swiss-Cox mice were administered tetrachloroethylene (0-2000 mg/kg/day) by gavage for 6 weeks. The extent of metabolism was estimated by quantification of the urinary metabolites. Hepatotoxicity was assayed by changes in liver weight, triglyceride level, glucose-6-phosphate activity, and SGPT activity. All four parameters were affected by tetrachloroethylene. Plots of the hepatotoxicity data against total urinary metabolites were linear suggesting that the hepatotoxicity of the agent is related to the extent of metabolism.

In another study by Hayes et al. (3277), a NOEL of 14 mg/kg/day was established in rats. Groups of 20 Sprague-Dawley rats of both sexes were administered tetrachloroethylene at doses of 14, 400, or 1400 mg/kg/day in drinking water. Depressed body weights were observed in the two high-dose groups. Equivocal evidence of hepatotoxicity was also observed at the higher doses.

17.3.1.4.2 Chronic Toxicity

Carpenter (152) exposed rats by inhalation, 8 hour per day, 5 days per week for up to 7 months, to concentrations of 70, 230 or 470 ppm. All animals survived with growth comparable to that of the controls. At 70 ppm, no pathological effects were observed. At 230 ppm, pathological changes occurred in both the liver and kidney. These included congestion and slight swelling. At 470 ppm, the injury to liver and kidney was more severe.

In another chronic inhalation study, Rowe et al. (167) exposed rabbits, monkeys, rats and guinea pigs to concentrations ranging from 100 to 2500 ppm for 7 hours daily, 6 days per week for up to 6 months. Rabbits, rats and monkeys showed no effects from repeated exposures to concentrations up to 400 ppm. In contrast, guinea pigs showed a marked susceptibility to tetrachloroethylene. They exhibited loss of coordination, weight loss, increased liver and kidney weights and fatty degeneration of the liver after being exposed from 10 to 236 days to 100 to 2500 ppm, 7 hours per day. Rabbits exposed to 2500 ppm, 7 hours per day for 39 days, exhibited central nervous system depression and slight liver toxicity.

17.3.2. Human and Epidemiologic Studies

17.3.2.1 Short-term Toxicologic Effects

In man, the predominant effect of short-term inhalation exposure to tetrachloroethylene levels above 200 ppm (1340 mg/m^3) is depression of the central nervous system characterized by dizziness, impaired memory, confusion, irritability, "inebriation-like" symptoms, tremors and numbness. Kidney impairment, hepatitis and enlargement of the liver and spleen have also been reported, but are not well documented (6, 578).

Individuals exposed to 215-280 ppm tetrachloroethylene vapor for up to 2 hours experienced eye irritation, dizziness and incoordination; recovery was complete within one hour after exposure ceased (167). Five-minute exposures to 2000 ppm produced mild CNS depression. Exposures of ten minutes at 600 ppm resulted in dizziness and incoordination (46). In an industrial exposure to an average concentration of 275 ppm for 3 hours followed by 1100 ppm for 30 minutes, a worker lost consciousness. There was apparent clinical recovery 1 hour after exposure. A blood level of 2.5 mg/L tetrachloroethylene was reported (168). A fatality resulting from acute inhalation of tetrachloroethylene has been reported by Levine et al. (583). Post-mortem blood levels of 4.5 mg/L indicate a sustained exposure above 200 ppm.

Skin contact with the liquid may cause dryness, irritation, blistering and burns. In one case, a drycleaning worker who came into direct contact with tetrachloroethylene was found unconscious; redness and blistering covered over 30% of his body. He regained full consciousness within 24 hours and his burns gradually healed over 3 weeks (161). In another case, a worker was discovered lying in a pool of the solvent. He had been unconscious for approximately 12 hours. He was experiencing hypotension and cyanosis and underwent a mild seizure. First and second degree burns were seen where skin had been in direct contact with the liquid. There was also evidence of mild liver and kidney damage. Recovery was complete after 21 days (157).

Permanent eye injury is not likely, although liquid tetrachloroethylene splashed in the eye may cause pain and lacrimation (12). Moderate eye irritation is apparent at vapor concentrations of 200 ppm (19, 12).

No data are available on accidental ingestion. Oral doses of 2.8 to 4.0 mL tetrachloroethylene were formerly used as intestinal anthelmintics; inebriation was the only troublesome side effect noted in 46,000 treated patients (43).

17.3.2.2 Chronic Toxicologic Effects

Very little data are available concerning the effects of long-term exposure to tetrachloroethylene. Medak and Kovarik (162) noted subjective complaints such as headache, fatigue and dizziness in a group of workers occupationally exposed to 60

ppm vapor for up to 15 years. Stewart et al. (169) noted the same symptoms after exposing subjects 5.5 hours daily for 55 days to vapor levels of 25 or 100 ppm.

Hepatotoxic effects resulting from long-term exposure to tetrachloroethylene have been documented by a number of investigators (578, 579). In most studies, the concentration was greater than 100 ppm. Effects observed include hepatitis, cirrhosis, liver-cell necrosis and enlarged liver (579). Chronic kidney disease has also been noted (579).

Epidemiology studies have linked tetrachloroethylene exposure with cancer. A study of 330 deceased laundry and drycleaning workers by Blair et al. (154) indicated an increased number of cancer deaths, particularly of lung cancer and cervical cancer. This proportional mortality analysis has many pitfalls. Indeed, many of the workers examined by Blair and his colleagues may not have been exposed to tetrachloroethylene at all, but rather, to other petroleum-based solvents such as Stoddard solvent (580). Kaplan (580), citing unpublished results, states that a significant increase in the number of deaths from cancer of the colon, pancreas and urinary organs were found in a retrospective cohort mortality study of 1597 drycleaning workers exposed to tetrachloroethylene for at least one year. In a study of 67 women working in 53 dry cleaning shops in the city of Rome, Italy, Bosco et al. (3079) found no overt reproductive pathology. Exposure to the prevalent dry cleaning solvent, tetrachloroethylene, was evaluated by the trichloroacetic acid concentrations in the urine. Exposure of the workers was found to be 4 times higher than that of the controls. All values for live births, birth weights, and occurrence of malformations in the worker's children were similar to those of the control group. The percentage of spontaneous abortions was increased (8.9% vs 2.2% for controls); however, this difference was not statistically significant. While the reproductive outcome indicates the absence of reproductive pathology, the small sample size causes the findings to be considered merely tentative.

17.3.3 Levels of Concern

For the maximum protection of human health from the potential carcinogenic effects due to exposure to tetrachloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the USEPA (355) has specified an ambient water quality criterion of zero for this compound. Since attainment of a zero level may be infeasible in some cases, the concentrations of tetrachloroethylene in water calculated to result in incremental lifetime cancer risks of 1E-05, 1E-06 and 1E-07 from ingestion of both water and contaminated aquatic organisms were estimated to be 8, 0.8 and 0.08 μg/L, respectively (355). Risk estimates are expressed as a probability of cancer after a lifetime daily consumption of two liters of water and 6.5 g of fish that have bioaccumulated the compound. Thus, a risk of 1E-05 implies that a lifetime consumption of two liters of drinking water and 6.5 g of contaminated fish at the criterion level of 8 ug tetrachloroethylene per liter would be expected to produce one excess case of cancer above the normal background incidence for every

100,000 people exposed. It should be emphasized that these extrapolations are based on a number of assumptions and should be taken as crude estimates of human risk at best.

The NTP (793, 802) categorizes tetrachloroethylene as providing clear evidence of carcinogenic activity in both mice and rats. IARC (3317) currently lists tetrachloroethylene in category 2B (inadequate human evidence, sufficient animal evidence) in its weight-of-evidence ranking of potential carcinogens.

USEPA (3808) lists the chemical in Group B2 (inadequate human evidence, sufficient animal evidence). The USEPA (3808) has proposed the following drinking water standards: Maximum Contaminant Level Goal (Proposed) 0 μg/L; Maximum Contaminant Level (Proposed) 5 μg/L. The following health advisories are in effect: 10-kg child: one-day, 2 mg/L, ten-day, 2 mg/L, longer-term, 1 mg/L. 70-kg adult: longer-term, 5 mg/L. They also reported that drinking water containing 70 μg/L would increase the risk of cancer by one individual/10,000 people exposed.

The World Health Organization (666) has proposed a tentative health-related guideline of 10 μg/L tetrachloroethylene for drinking water; daily per capita consumption of drinking water was assumed to be two liters.

OSHA (3539) currently permits exposure to 25 ppm (170 mg/m^3) averaged over an 8-hour work-shift. The ACGIH (3005) recommends a threshold limit value of 50 ppm (335 mg/m^3). These exposure limits were selected to prevent toxic effects other than cancer.

17.3.4 Hazard Assessment

Tetrachloroethylene exposure has been linked to liver carcinoma in B6C3F$_1$ mice at a dose of 386 mg/kg given by gavage; test results were negative for rats, but were confounded by poor survival (163). Based on the ingestion data in mice, the USEPA (667) calculated an upper-limit incremental unit cancer risk of 6E-02[(mg/kg/day)E-01] for tetrachloroethylene. A recently completed inhalation study conducted with F344/N rats and B6C3F$_1$ mice provided clear evidence of carcinogenic activity for tetrachloroethylene, inducing hepatocellular carcinomas in mice and mononuclear cell leukemia in rats (793).

The chief target organs of tetrachloroethylene toxicity in animals are the liver and kidney. Liver enlargement, fatty degeneration and abnormal liver function tests as well as kidney damage, particularly to the proximal convoluted tubules, have been linked to tetrachloroethylene exposure. Disruption of the central nervous system has also been reported. However, dose-response relationships for these effects are unclear. Mutagenic findings are for the most part, negative. There are no indications of reproductive toxicity for tetrachloroethylene in humans.

The predominant effect of acute exposure to high concentrations of tetrachloroethylene vapor is depression of the central nervous system, characterized by vertigo, confusion, inebriation-like symptoms, tremors and numbness. Kidney impairment and hepatotoxic effects have been reported after accidental exposures, but are not well documented. The lack of long-term exposure data makes assessment of long-term, low-level exposure to tetrachloroethylene in drinking water difficult. However, the pronounced toxic nephropathy observed in rodents chronically exposed to tetrachloroethylene by ingestion and the increased incidences of liver carcinoma in mice and leukemia in rats raise concerns of possible human health effects associated with prolonged exposure to tetrachloroethylene.

17.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of tetrachloroethylene concentrations in soil and water requires collection of a representative field sample and subsequent laboratory analysis. Due to the volatility of tetrachloroethylene, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight containers with no headspace; analysis should be completed within 14 days of sampling. However, recent studies (3430) show large losses of volatiles from soil handling. At the present, the best procedure is to collect the needed sample in an EPA VOA vial, seal with a foil-lined septum cap, and analyze the entire contents in the vial using a modified purge and trap apparatus. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of tetrachloroethylene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 601, 624, and 1624 (65), and Methods 8010 and 8240 (65). The sample introduction technique most useful for aqueous samples is the purge and trap method. An inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the tetrachloroethylene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the tetrachloroethylene and transfer it onto a gas chromatographic (GC) column. The GC column is programmed to separate the volatile organics; tetrachloroethylene is then detected with a halide specific detector (Methods 601 and 8010) or a mass spectrometer (Methods 624, 1624, and 8240). For samples that contain high concentrations, direct injection may also be used. The generalized procedure for sample preparation for the analysis of volatile organics by purge and trap (Method 5030) (63) also recommends that samples be screened prior to the purge and trap step to prevent contamination of the system. The recommended screening techniques involve the analysis of a headspace sample by GC with photo-ionization or electrolytic conductivity detectors or the analysis of a solvent extract by GC with flame ionization or electrolytic conductivity detectors.

The EPA procedures recommended for tetrachloroethylene analysis in soil and waste samples, Methods 8010 and 8240 (63), differ from the procedures for aqueous

samples primarily in the method by which the analyte is introduced into the GC. The recommended method for low level samples (< 1 mg/kg) involves dispersing the soil or waste sample in water and purging in a heated purge and trap device. The trap is desorbed and analyzed as described above. Recently introduced wide bore capillary columns show promise for increasing the performance of the GC analysis (3402, 3184, 3443).

Other methods that have been used to quantitate tetrachloroethylene in soil and water include purge and trap with flame ionization detection (3263) and solvent extraction with electron capture detection (3352).

Typical tetrachloroethylene detection limits that can be obtained in aqueous samples (including wastewaters without interferences) and in non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.03 μg/L (Method 601)	5.0 μg/kg (Method 8240)
4.1 μg/L (Method 624)	0.3 μg/kg (Method 8010)
10.0 μg/L (Method 1624)	
5.0 μg/L (Method 8240)	
0.3 μg/L (Method 8010)	

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COMMON SYNONYMS:	CAS REG. NO.: 71-43-2 FORMULA: C_6H_6 NIOSH NO: CY1400000 STRUCTURE:	AIR W/V CONVERSION FACTORS at 25°C (12) 3.19 mg/m³ ≈ 1 ppm 0.313 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT 78.11
Benzene Benzol Benzole Carbon Oil Coal Naphtha Phenylhydride Pyrobenzol		

REACTIVITY	Benzene may generate heat, react vigorously, and possibly ignite or explode in contact with oxidizing mineral acids or other strong oxidizing agents (507, 511, 505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless to light yellow	(23)
	• Odor: Aromatic	(23)
	• Odor Threshold: 4.680 ppm (15 mg/m³)	(263)
	• Density: 0.8765 g/mL (at 20°C)	(68)
	• Freeze/Melt Point: 5.50°C	(14)
	• Boiling Point: 80.10°C	(23)
	• Flash Point: -11.00°C closed cup	(23)
	• Flammable Limits: 1.30 to 7.90 % by volume	(60,504,506)
	• Autoignition Temp.: 560.0 to 592.0°C	(60,504,510)
	• Vapor Pressure: 7.60E+01 mm Hg (at 20°C)	(67)
	• Satd. Conc. in Air: 3.1900E+05 mg/m³ (at 20°C)	(67)
	• Solubility in Water: 1.78E+03 mg/L (at 20°)	(67)
	• Viscosity: 0.647 cp (at 20°C)	(21)
	• Surface Tension: 2.9000E+01 dyne/cm (at 20°C)	(23)
	• Log (Octanol-Water Partition Coeff.): 2.13	(29)
	• Soil Adsorp. Coeff.: 6.50E+01	(652)
	• Henry's Law Const.: 5.43E-03 atm · m³/mol (at 25°C)	(74)
	• Bioconc. Factor: 6.50E+00 (estim)	(659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Benzene is expected to be fairly mobile in the soil/ground-water system. Transport with infiltration water is expected particularly in sandy soils and soils of low organic content. Volatilization of material near the surface or in the soil-air compartment may be important. Transformation processes such as hydrolysis and biodegradation are not expected to be significant in natural soils; however, biodegradation by acclimated populations has been reported.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of benzene to groundwater drinking water supplies. Migration has commonly occurred in the past. Inhalation resulting from volatilization from surface soils may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (12, 45) The primary effects of inhalation and ingestion are on the central nervous system. Symptoms include headache, dizziness, drowsiness and nausea which may progress to convulsions, respiratory paralysis and death with high vapor concentrations. Benzene causes irritation of the eyes and skin. Acute Toxicity Studies: (3504) INHALATION: LC_{Lo} 6380 mg/m^3 · 5 min — Human TC_{Lo} 319 mg/m^3 — Human LC_{50} 31900 mg/m^3 · 7 hr — Rat LC_{Lo} 146000 mg/m^3 — Dog LC_{Lo} 170000 mg/m^3 — Cat LC_{50} 31836 mg/m^3 — Mouse LC_{Lo} 65 mg/m^3 · 5 year — Human TC_{Lo} 670 mg/m^3 — Human ORAL: LD_{Lo} 50 mg/kg — Man LD_{50} 2000 mg/kg — Dog LD_{50} 4700 mg/kg — Mouse LD_{50} 3306 mg/kg — Rat

HEALTH HAZARD DATA (Cont.)	Long-Term Effects: Pancytopenia, leukemia Pregnancy/Neonate Data: Embryotoxicity and fetotoxicity at maternally toxic doses. Genotoxicity Data: Mixed results Carcinogenicity Classification: IARC - Group 1 (carcinogenic to humans) NTP - Clear evidence EPA - Group A (human carcinogen)

HANDLING PRECAUTIONS (54,52)	Handle chemical only with adequate ventilation. • Vapor concentrations of 10-50 ppm: supplied-air respirator or self-contained breathing apparatus • 50-1000 ppm: supplied-air respirator or self-contained breathing apparatus with full facepiece. • 1000-2000 ppm: supplied-air respirator operated in pressure- demand, positive-pressure or continuous flow mode. • Butyl, natural rubber, neoprene, nitrile, viton, PE, PVC or other protective clothing to prevent prolonged or repeated skin contact with the liquid. • Chemical goggles if there is possibility of eye contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 1 ppm; STEL (15 min): 5 ppm
- AFOSH PEL 1 ppm; STEL (15-min): 5 ppm

Criteria
- NIOSH IDLH (30-min): 2000 ppm (15 min)
- NIOSH REL (8-hr TWA): 0.1 ppm; 1 ppm ceiling (15-min)
- ACGIH TLV® (8-hr TWA): 10 ppm (A2, suspected human carcinogen)
- ACGIH STEL (15-min): deleted

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (3742)
MCLG: 0 μg/L
MCL: 5 μg/L

EPA Health Advisories and Cancer Risk Levels
In the absence of formal drinking water standards the EPA has developed the following Health Advisories which provide specific advice on the levels of contamionants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 200 μg/L
- 10-day (child): 200 μg/L
- 1E-04 cancer risk level: 100 μg/L

WHO Drinking Water Guideline
A health based guideline for drinking water of 10 μg/L is recommended for benzene. A daily per capita consumption of two liters was assumed.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of ingestion of contaminated water and aquatic organisms (1E-05, 1E-06, 1E-07 cancer risk), 6.6 g/L, 0.66 μg/L 0.066 μg/L.
  - Based on ingestion of contaminated aquatic organisms only, (1E-05, 1E-06, 1E-07 cancer risk), 400 μg/L, 40.0 μg/L, 4 μg/L.
  - Based on ingestion of drinking water only (1E-05, 1E-06, 1E-07 cancer risk) 6.7 μg/L, 0.67 μg/L, 0.067 μg/L.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 5300 μg/L.
    chronic toxicity:
    no criterion established due to insufficient data.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 5100 μg/L.
    chronic toxicity:
    no criterion, but adverse effects occur at concentrations as low as 700 μg/L with a fish species exposed for 168 days.

REFERENCE DOSES:
No reference dose available.

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Benzene is designated a hazardous substance. It has a reportable quantity (RQ) limit of 454 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations have been set for benzene in the following point source categories: iron and steel manufacturing (354), electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802, metal molding and casting (892), and metal finishing (3768). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Benzene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 (3781). Benzene has a maximum contaminant level (MCL) of 0.005 mg/L and a maximum contaminant level goal (MCLG) of zero (3773, 3772). In states with an approved Underground Injection Control program, a permit is required for the injection of benzene- containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Benzene is identified as a toxic ignitable hazardous waste (U019) and listed as a hazardous waste constituent (3783, 3784). Non-specific sources of benzene- containing waste are the production of chlorinated aliphatic hydrocarbons, and spent solvents containing 10% or more of benzene (325). Waste streams from the following industries contain benzene and are listed as specific sources of toxic hazardous waste: organic chemicals (production of chlorobenzenes, nitrobenzenes and aniline), petroleum refining, and coking operations (3116, 3117). Benzene is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective November 8, 1988, the land disposal of certain untreated benzene-containing hazardous wastes is prohibited. These wastes must be treated according to Best Demonstrated Available Technology (BDAT) treatment standards before they can be disposed. Certain variances exist until May, 1990 for other benzene-containing hazardous wastes for which BDAT treatment standards have not been promulgated by EPA (3786). Benzene is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Benzene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 454 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing benzene but these depend upon the concentration of the chemicals present in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of benzene must report annually, to EPA and state officials, their releases of this chemical to the environment (3787).

Clean Air Act (CAA)
Benzene is a hazardous air pollutant and is subject to national emission standards for fugitive emission sources (3803).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to benzene shall not exceed an 8-hour time-weighted average (TWA) of 1 ppm or STEL (15-min) of 5 ppm shall not be exceeded at any time during an 8-hour work-shift. Some industries may be exempt from these standards (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated benzene as a hazardous material with a reportable quantity of 454 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Benzene is approved for use as an indirect food additive as component of adhesives (3209).

- State Water Programs
  ALL STATES
  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

ALABAMA
Alabama requires that the annual average maximum contaminant level of benzene not exceed 5 μg/L in drinking water. This applies to all community water systems and non-community non-transient water systems (3015).

CALIFORNIA
California has an action level of 0.7 μg/L and an MCL of 1 μg/L for benzene in drinking water (3098, 3096).

CONNECTICUT
Connecticut has an action level and a quantification limit of 1 μg/L for drinking water (3138, 3137).

DISTRICT OF COLUMBIA
The District of Columbia has a human health criterion of 0.8 μg/L for public water supply surface waters (3828).

FLORIDA
Florida has set an MCL of 1 μg/L for drinking water (3219).

NEW JERSEY
New Jersey has set an MCL of 1 μg/L for benzene in drinking water (3497).

NEW MEXICO
New Mexico has a water quality criterion of 0.01 mg/L for ground-water (3499).

OKLAHOMA
Oklahoma has set a nonenforceable Toxic Substance Goal of 0.66 μg/L for surface waters used for public and private water supply, a water quality criterion of 2200 μg/L for fish and wildlife propagation surface waters, and a maximum contaminant level of 0.2 μg/L for ground-water (3534).

PENNSYLVANIA
Pennsylvania has a human health criterion (cancer risk level) of 1 μg/L for surface waters (3561).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 265 μg/L and a chronic guideline of 5.9 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

WISCONSIN
Wisconsin has a preventive action limit of 0.067 μg/L and an enforcement standard of 0.67 μg/L for benzene in ground-water (3840).

Proposed Regulations

- Federal Programs

  Clean Air Act (CAA)
  EPA has proposed four different NESHAPs for benzene emissions, depending on the source of emissions: 14 kg/day for equipment leaks (fugitive emission sources), 0.34 kg/day for coke by-product recovery plants, 0.47 kg/day for benzene storage vessels, and 5.5 kg/day for ethylbenzene/styrene plants. Final action on the proposal is expected by August, 1989 (3788, 3683).

  Resource Conservation and Recovery Act (RCRA)
  EPA has proposed listing wastestreams from the production of acrylonitrile in the organic chemicals industry as specific sources of benzene-containing hazardous waste (3795). EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 0.07 mg/L benzene. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565, 3683).

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA
  Minnesota has proposed a Sensitive Acute Limit (SAL) of 2792 μg/L for designated surface waters, and chronic criteria of 5 μg/L for ground-water, 5.2 μg/L for cold surface waters, and 6.1 μg/L for other designated surface waters. These criteria are for the protection of human health (3452).

  NEW JERSEY
  New Jersey has proposed a water quality criterion of 1 μg/L for class FW2 surface waters (3496).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic,mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Benzene is listed as a Class I/a toxic substance and is subject to packaging and labeling regulations.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Marketing and Use of Dangerous Substances (541)
Benzene is not permitted in toys or parts of toys as placed on the market where the concentration of benzene in the free state is in excess of 5 mg/kg of the weight of the toy or part of toy.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto- pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Benzene is classified as a flammable, toxic substance and is subject to packaging and labeling regulations.

Directive on the Approximation of the Laws, Regulations and Administrative Provisions Relating to the Classification, Packaging and Labeling of Dangerous Preparations (3980)
The labels on packages containing preparations classified as very toxic, toxic or corrosive must bear the safety advice S1/S2 and S46 in addition to the specific safety advice. If it is physically impossible to give such information, the package must be accompanied by precise and easily understood instructions.

EEC Directive-Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
Benzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

18.1 MAJOR USES

In the past, benzene was widely used as a solvent. As its adverse health effects became known, usage declined to the point where it is now minimal. At present, most benzene is consumed in the chemical industry where it is used as a starting material for the synthesis of other organic compounds (2, 518, 3887). Prior to World War II, the major use for benzene was as an octane-raising additive in gasoline. When benzene is used in this manner, it is not added to the gasoline pool as pure benzene but rather as a mixture of benzene, toluene and xylene (21, 43, 518). Presently, its use in this area is minor. However, benzene remains an important contaminant of gasoline. Gasoline used in the U.S. contains from 0.8 to 2.0% benzene.

18.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

18.2.1 Transport in Soil/Ground-water Systems

18.2.1.1 Overview

Benzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by equilibrium partitioning, as shown in Table 18-1.

These calculations predict the partitioning of benzene among soil particles, soil water and soil air. The portions of benzene associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that most of the benzene (88%) is expected to be sorbed to the soil. A much smaller (yet significant) amount (7%) will be present in the soil water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the portion of benzene in the gaseous phase of the soil (5%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, will be a significant loss pathway. There is no significant difference in the partitioning calculated for 25°C and 10°C.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the benzene (79%) is likely to be present in the soil-water phase (Table 18-1) and transported with flowing ground-water.

TABLE 18-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR BENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c]			
at 25°C	88.1	7.1	4.8
at 10°C	89.7	7.2	3.1
Saturated deep soil[d]	21.4	78.6	-

a) Calculations based on Mackay's equilibrium partitioning model (34,35,36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 65. (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 0.00543 atm · m^3/mol at 25°C/10°C ratio of H values from Brown and Wasik (521).
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: $K_p = 0.001 \times K_{oc}$.

18.2.1.2 Sorption on Soils

The mobility of benzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 135 (log P = 2.13), the soil sorption coefficient (K_{oc}) is estimated to be 65. This is a relatively low number indicative of weak sorption to soils.

18.2.1.3 Volatilization from Soils

Transport of benzene vapors through the air-filled pores of unsaturated soils is an important transport mechanism for near-surface soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

There are no data from laboratory or field tests showing actual soil volatilization rates. Sorption of the benzene vapors on the soil may slow the vapor phase transport; Politzki et al. (516) have shown, for example, that the vapor pressure of benzene in the presence of (thus partially sorbed to) silica gel was decreased by a factor of 10E+04 from the pure compound value.

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, increases significantly with increasing temperature (28). Moderate increases in H are also observed with increasing salinity due to a decrease in benzene's solubility (517).

18.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of benzene in soil/ground-water systems is not well documented. Based on a rate constant for the reaction of benzene with OH (3892) and the concentration of OH radical concentration in water of 10E-17 mol/L (3901), a half-life of 0.71 year has been calculated (3887). In most cases, it should be assumed that the chemical will persist for months to years (or more).

Benzene under normal environmental conditions is not expected to undergo hydrolysis (10,33). Further, benzene is not expected to be susceptible to oxidation or reduction reactions in the soil/ground-water environment.

There is evidence that benzene can undergo aerobic and anaerobic degradation (3887); however, the rate of degradation is dependent upon several factors such as whether communities of degrading microorganisms are established and acclimated, nutrient levels, temperature and concentration of benzene (3916), and the number of organisms present (3887). Aerobic biodegradation in acclimated wastewater treatment plants (e.g., activated sludge) would be expected to be relatively easy based upon the data of Tabak et al. (55). However, in most soil/ground-water systems such aerobic degradation would be of minimal importance because of the low concentration of microorganisms (at depth) and the low dissolved oxygen (anaerobic) conditions. Anaerobic degradation has been demonstrated in the laboratory by Wilson et al. (3958), but degradation was relatively slow, particularly during the first 20 weeks of incubation. By 40 weeks, however, 72% of the benzene was degraded and by 120 weeks, 99% was degraded. In another study, in situ treatment of a hydrocarbon

contaminated aquifer resulted in complete anaerobic degradation of benzene after only 6 months (3895).

18.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that benzene is highly volatile, weakly adsorbed by soil and has a limited potential for bioaccumulation. This compound may volatilize from soil surfaces, but that portion not subject to volatilization is likely to be mobile in ground-water. These fate characteristics suggest several potential exposure pathways. [It should be noted, however, that benzene released into the air can be degraded via reaction with atmospheric hydroxy radical (3887), or may eventually undergo photochemical degradation. Tropospheric lifetimes on the order of a few hours to a few days have been estimated (10).]

Volatilization of benzene from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. The potential for ground-water contamination is high, particularly in sandy soils. Mitre (83) reported that benzene has been found at 94 of the 546 National Priority List (NPL) sites. It was detected at 72 sites in ground-water, 31 sites in surface water, and 17 sites in air. The USEPA (64) reported that in state occurrence data with 646 total number of samples, 4 were positive with a range between trace-17 μg/L. The National Organic Monitoring Survey (NOMS) (90) found that out of 113 samples, 7 were positive with a mean of positives at 0.4 μg/L.

The results of the USEPA (531) Ground-water Supply Survey (GWSS) are as shown below:

Sample Type	Occurrences* No.	%	Median of Positives (μg/L)	Maximum (μg/L)
Random				
Supplies serving <10,000 people (280 samples)	1	0.4	0.61	0.61
Supplies serving >10,000 people (186 samples)	2	1.1	9.0	15.0
Non-Random				
Supplies serving <10,000 people (321 samples)	5	1.6	1.6	12.0
Supplies serving >10,000 people (158 samples)	3	1.9	2.7	12.0

*Samples having levels over quantification limit of 0.5 μg/L.

The state data include only ground-water sources and were compiled from various state reports on local contamination problems. The state data are not considered to be statistically representative of national occurrence. The National Organic Monitoring Survey (NOMS) included data from both ground- and surface water supplies. The 1982 Ground-water Supply Survey (GWSS) is the most recent study (531). This study sampled a total of almost 1000 drinking water systems using ground-water, 466 selected at random, and about 500 selected by the state as potentially contaminated. The USEPA (64) estimates that 1.5% of the nation's ground-water supplies are contaminated with benzene (>10.5 μg/L).

These results indicate that benzene has the potential for movement in soil/ground-water systems. This compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure.
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposure through bioaccumulation.
- Recreational use of these waters may result in dermal exposure.
- Domestic animals may consume or be dermally exposed to contaminated ground- or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower then exposures from drinking contaminated ground-water. The Henry's law constant for benzene indicates that it will volatilize upon reaching surface waters. Secondly, the octanol/water partition coefficient (log P) for benzene is 2.13 (29) and the bioconcentration factor is expected to be low, suggesting limited bioaccumulation in aquatic organisms or domestic animals.

18.2.4 Other Sources of Exposure

Benzene is widely used in the synthesis of other organic compounds (ethyl-benzene, cumene, cyclohexane, and other benzene derivatives), as a solvent, and as a pesticide among other uses. It is also an important constituent of gasoline. As a result of emissions during production, use, and disposal and because of its high volatility, benzene has become pervasive in the aquatic and atmospheric environments, in spite of the effects of environmental degradative processes.

Coniglio et al. (223), in a summary of data from SRI, NOMS and NORS, reported that benzene was found at a frequency of 21.6% in finished surface water.

Brodzinsky and Singh (84) compiled all available atmospheric monitoring data for a number of volatile organics. For benzene, they had data for 2789 locations. In rural and remote locations, the median concentration was 4.5 $\mu g/m^3$. In urban and suburban locations, the median concentration was 8.9 $\mu g/m^3$, and in source-dominated areas, the median concentration was 9.6 $\mu g/m^3$. These results suggest that ambient benzene, via inhalation exposure, contributes significantly to the total body burden of the chemical for the general population.

18.3 HUMAN HEALTH EFFECTS

18.3.1 Animal Studies

18.3.1.1 Carcinogenicity

Although an appropriate laboratory animal model for the study of the carcinogenicity of benzene has not been developed, recent studies suggest that benzene is carcinogenic in animals. In an oral carcinogenicity study, administration of benzene (99.7% pure) by gavage to groups of 50 F344/N rats and 50 $B6C3F_1$ mice of each sex and for each dose, 5 days per week for 103 weeks, produced clear evidence of carcinogenicity in both species. Doses of 0, 25, 50 or 100 mg/kg bw benzene (in corn oil) were administered to male and female mice and female rats; male rats were given doses of 0, 50, 100 or 200 mg/kg bw. Dose-related lymphocytopenia was observed in treated mice and rats. An increased incidence of Zymbal gland carcinomas was seen in both sexes for both species and both male and female rats exhibited elevated incidences of squamous-cell carcinomas of the oral cavity. Male rats also displayed an increased incidence of squamous-cell carcinomas of the skin. Both sexes of $B6C3F_1$ mice had elevated incidences of malignant lymphomas and alveolar/bronchiolar carcinomas. For female mice, benzene treatment also induced increased incidences of ovarian granulosa cell tumors and carcinomas and carcinosarcomas of the mammary gland (3519).

Maltoni et al. (201) recently completed a series of studies which show that benzene is carcinogenic in rats by both the oral and inhalation routes. In the oral studies, Sprague-Dawley rats were administered benzene (purity 99.93%) in olive oil at doses of 50 or 250 mg/kg/day, 4-5 days weekly for 52 weeks and then kept under observation until death. Mortality was higher in the benzene-treated groups and was dose-correlated. There was also a dose-related increase in the incidence of hemolymphoreticular neoplasias ("leukemias") and of mammary carcinomas. The incidence of "leukemias" was 7.7% in the high-dose group, 3.4% in the low-dose group and 1.7% in controls. The incidence of mammary carcinomas was 10.8% and 6.9% in the high and low-dose groups, respectively, and 5.2% in the controls. There was also a 12.3% incidence of Zymbal-gland carcinomas, 3.1% incidence of carcinoma of the oral cavity and a 1.5% incidence of both angiosarcomas and hepatomas, all in the high-dose group.

In the inhalation studies, Sprague-Dawley rats were exposed to vapor concentrations of 200-300 ppm, 4-7 hours daily for 104 weeks. The investigators found a 2.3% incidence of hepatomas and a 26.6% and 1.4% incidence of mammary carcinoma and leukemia, respectively (201).

The carcinogenicity of benzene by inhalation has also been demonstrated in mice. C.A. Snyder et al. (197) observed an increased incidence of thymic lymphoma in C57BL/J6 mice that were exposed to vapor concentrations of 300 ppm, 6 hours daily, 5 days per week for life. In contrast, AKR/J mice that were exposed to 100 ppm on the same dosing schedule experienced no change in the induction of lymphoma. Poor survival of this strain at 300 ppm necessitated the lower exposure level. It should be noted that both of these strains carry a virus which can result in a high incidence of lymphoma following exposure to radiation, carcinogens or immunosuppressive agents (203). In a similar study, Cronkite reported increased incidences of leukemia, lymphoma, and solid tumors in C57Bl/BNL mice exposed to benzene levels of 300 ppm, 6 hours/day, 5 days/week for only 16 weeks and observed over several months for tumor development (3904, 3903). The patterns of lymphoma and solid tumors in the Cronkite studies were significantly different than those observed after lifetime exposures.

IARC (202) believes there is sufficient evidence that benzene is carcinogenic to animals, as well as to man. A discussion of human data can be found in Section 18.3.2.2, Chronic Toxicologic Effects.

18.3.1.2 Genotoxocity

Benzene is not mutagenic in bacterial systems. Studies with five standard strains of Salmonella typhimurium in the presence or absence of hamster or rat liver microsomes were negative in the plate incorporation assay (3519); and additional studies in three strains of Salmonella were negative when care was taken to assure exposure of the bacteria to benzene vapors (3077). Attempts to induce genotoxic effects in Bacillus subtilis, Saccharomyces cerevisiae, and Escherichia coli have all proved negative (202).

Chromosomal abnormalities in bone marrow cells resulting from subcutaneous or intraperitoneal administration of benzene have been reported in various species of animals including rats, rabbits and mice (203). The animals were treated with single or multiple daily doses of benzene ranging from 0.2 to 2.0 mL/kg/day. Most of the induced abnormalities were chromatid breaks or deletions. Male rats exposed to benzene vapor at concentrations of 1, 10, 100 or 1000 ppm for 6 hours showed a significant increase in chromosomal abnormalities in their bone marrow cells at the 2 higher exposure levels (192).

Tice et al. (3716) exposed mice via inhalation to benzene and observed a significant increase in sister chromatid exchanges but not chromosomal aberrations in bone marrow cells of the treated animals. In a subsequent experiment Tice et al.

(3717) were able to induce chromosomal aberrations in mice with enhanced liver metabolism by treating the mice with phenobarbital before exposure to benzene.

Benzene has also proved to be an effective inducer of micronuclei in the mouse, in both bone marrow-derived and peripheral erythrocytes (3124, 3463). Male mice appear to be more sensitive to the clastogenic effects of benzene than do females (202, 192, 3124). Erexson et al. (3203) observed significant increases sister chromatid exchanges in peripheral blood lymphocytes as well as in the bone marrow micronucleus test with rats and mice exposed to benzene via inhalation.

That benzene can cross the placenta was shown by Ciranni et al. (3902) who treated pregnant mice orally with 880 mg/kg and found an increase in micronuclei in fetal liver as well as in bone marrow cells of the treated adult.

Chromosomal aberrations were found in the lymphocytes of humans occupationally exposed to low concentrations (0.2 to 12.4 ppm) of benzene. Twenty-two workers with 3 to 35 years of company service were studied, and each subject was paired with a suitable control. There was no evidence for increased sister chromosome exchange activity in these same subjects (3609). Forni et al. (3223) also studied workers of a rotogravure plant and found a significant increase in chromosome aberrations in their lymphocytes compared.

18.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effect

Benzene, administered orally to pregnant mice at doses of 0.5 and 1.0 ml/kg body weight, did not induce malformations, but did cause maternal lethality and resorptions (3487), and at the dose of 1.47 ml/kg/day caused significant reductions in fetal body weights (3634).

Widely tested by inhalation in rats, rabbits, and mice, benzene was not teratogenic (i.e., did not produce birth defects) in test animals even at 125 to 940 ppm, levels that were toxic to the mother as evidenced by her reduced weight gain (3887). However, benzene induced increased incidences of fetotoxic effects such as resorptions, reduced fetal weight, and skeletal variations at concentrations of 100 to 940 ppm. Benzene fetotoxicity appears to be a function of maternal toxicity. Benzene is not teratogenic or embryotoxic at 1 ppm (3887), the current OSHA standard.

In subchronic inhalation studies, benzene affected the ovaries (bilateral cysts) and testes (atrophy/degeneration, decrease in spermatozoa, moderate increase in abnormal sperm forms) of adult mice at 300 ppm, but not at 30 ppm (3957), and caused histopathological testicular changes of adult rabbits at 80 ppm (210).

Dermal application of benzene to rats for 4 months at doses of 64 or 320 mg/kg/day did not affect the fertilizing ability of males or the conceptional capacity of females when either sex was mated with untreated rats (3973). Both levels caused a

decrease in the number of spermatogonia in the males and an increase in the mortality of the first generation offspring.

18.3.1.4 Other Toxicologic Effects

18.3.1.4.1 Short-term Toxicity

Benzene causes central nervous system depression, narcosis, and death in various species of animals. An LC_{50} value of 10,000 ppm · 7 hr was recorded for the rat (59). Rabbits exposed to vapor concentrations ranging from 35,000 to 45,000 ppm underwent slight anesthesia after 4 minutes. They experienced other CNS effects such as excitation, tremors and loss of pupil reflexes. Death occurred within 22 to 71 minutes (628). Forty percent of rats exposed to 40,000 ppm for five 20-25 minute periods died within 24 hours (202). Oral LD_{50} values in the rat varied from 3.4 to 5.6 mL/kg depending on the age and strain (12). Oral LD_{50} values of 4700 mg/kg and 3800 mg/kg have also been reported for the mouse and rat, respectively (59).

More subtle central nervous system effects have been induced in animals by short-term exposure to benzene. For example, impaired learning ability was observed in Sprague-Dawley rats given 550 mg/kg of benzene orally on days 9, 11, and 13 postpartum (3911); and behavioral disturbances in mice, characterized by increased milk-licking, were demonstrated after one and five day exposures to benzene concentrations of 100 ppm and 300 ppm, respectively (3907).

In addition to neurotoxicity, hematotoxicity and immunotoxicity have been observed following short-term exposure to benzene. For example, $B6C3F_1$ mice exposed to benzene 6 hours/day for 6 days exhibited statistically significant depressions ($p<0.05$) in peripheral blood lymphocyte counts at 10.2 ppm and in erythrocyte counts at 100 ppm (3938). Lymphocytes are essential to the cellular and humoral immune responses and, consequently, benzene concentrations that reduced the lymphocyte counts depressed the B- and T-lymphocyte functions as well [3938]. Injury to the immune system can result in serious health consequences, including the suppression of host resistance to bacterial infections and tumor growth. In one study, the resistance of mice to the bacterium, Listeria monocytogenes, was significantly ($p<0.05$) lowered during exposure to benzene concentrations of 30 ppm or greater (6 hours/day for 12 days) (3936). In another study, 90% of the mice exposed to 100 ppm benzene (6 hours/day, 5 days a week for 20 exposures) and inoculated with tumor cells developed lethal tumors, in comparison to 30% of the controls that were inoculated with tumor cells but not exposed to benzene (3937).

The local effects of benzene liquid or vapor on the eye are slight. In the rabbit eye, it is a moderate irritant, causing conjunctival irritation and transient corneal injury. Fifty percent of rats exposed to vapor concentrations of 50 ppm developed cataracts after more than 600 hours of exposure (19). When applied to the skin of laboratory animals, benzene is slightly to moderately irritating (210).

18.3.1.4.2 Chronic Toxicity

The target cells for benzene-induced toxicity appear to be the cells of the bone marrow. The events that occur in the bone marrow and circulating blood cells following benzene exposure are described in section 18.3.2.2, Human and Epidemiological Studies, Chronic Toxicologic Effects.

Leukopenia (i.e. reduction of white blood cells) is the most common manifestation of chronic benzene toxicity in laboratory animals. Leukopenia was observed in rats given 132 daily oral doses ranging from 10 to 100 mg/kg bw. The no-effect level for blood changes was determined to be 1 mg/kg bw (210).

Similar results were reported in a more recent oral subchronic and chronic studies (3519). F344/N rats and B6C3F$_1$ mice were administered benzene (0, 25, 50, 100, 200, 400, 600 mg/kg) in corn oil for 17 weeks (3519). The rats exhibited dose-related leukopenia, lymphoid depletion in the spleen at 200 mg/kg, and increased extramedullary hematopoiesis in the spleen at 600 mg/kg (120 days of exposure). Mice in the 400 and 600 mg/kg groups had a dose-related leukopenia. In the chronic study, oral administration of 0, 50, 100, or 200 mg of benzene/kg, 5 days/week, for 103 weeks resulted in dose-related lymphocytopenia and leukocytopenia in both species. The mice, in addition, had lymphoid depletion of the splenic follicles and thymus and hyperplasia of the bone marrow.

After inhalation of 17.5 ppm for 127 days, no blood changes were observed in rats, guinea pigs and dogs. Slight leukopenia has been reported in rats exposed to 44 ppm, 5 hours per day, 4 days weekly for 5 to 7 weeks (202).

Changes were observed in the blood and bone marrow of CD-1 mice and Sprague-Dawley rats exposed to 300 ppm 6 h/day, 5 days/wk for 13 weeks (3957). In mice, the effects included increased mean cell volumes and mean cell hemoglobin values, and decreased hematocrit, hemoglobin, RBC count, leukocyte count, platelet count, and percent lymphocytes. Histological findings included: myeloid hypoplasia of the bone marrow, splenic periarteriolar lymphoid sheath depletion, lymphoid depletion in the mesenteric lymph node, increased extramedullary hematopoiesis in the spleen, and plasma cell infiltration in the mandibular lymph node. The rats, less severely affected, exhibited decreased leukocyte counts and decreased femoral marrow cellularity. Hematological effects were not observed in either species exposed to 1, 10, or 30 ppm.

The immune system is another target for benzene toxicity. For example, Rozen and Snyder (3938) demonstrated that benzene concentrations of 300 ppm, 6 hours/day for 115 exposures reduced the abilities of T- and B-cells to respond to mitogenic stimuli and markedly reduced the numbers of B-lymphocytes in the bone marrow and spleen and the number of T-lymphocytes in the thymus and spleen. In addition, a compensatory proliferation was observed in cells of the bone marrow and thymus in response to the benzene exposures.

18.3.2 Human and Epidemiologic Studies

18.3.2.1 Short-term Toxicologic Effects

Benzene is a central nervous system depressant at high concentrations and may cause acute narcotic reactions. Depending upon the concentration and duration of exposure, these effects may range from mild manifestations such as headache and lightheadedness to more severe effects such as convulsions, respiratory paralysis and death (200). Death has resulted from single 5 to 10 minute exposures of benzene in air at concentrations of 20,000 ppm. Concentrations of 3000 to 7500 ppm may result in toxic signs within 1 hour. Exposures of 50 to 250 ppm may produce headache, lassitude and dizziness which may become more exaggerated at higher levels. No effects are reported after acute exposure to 25 ppm (12).

Ingestion of 2 mL may produce symptoms while 10 mL may be fatal (56). Ingestion of 9 to 12 g (10-14 mL) has been noted to cause staggering gait, vomiting, loss of consciousness, delirium and death (12). In acute poisoning, death may be due to respiratory arrest or cardiac failure. Excessive physical activity at the time of acute exposure predisposes individuals to cardiac failure (56).

Direct contact with the liquid may cause redness and dermatitis. Absorption through human skin has been reported to be 0.004 to 0.052%, the highest absorptions occurring through the palm (194). Therefore, skin absorption has not been considered to be an important route of entry in occupational situations (633). However, the results of recent studies have indicated that benzene absorption through the skin may, in fact, be considerable. For example, Susten et al. (3945) calculated, from the results of dermal absorption studies in hairless mice and observations of workers, that 20-40% of the total benzene dose received by humans in tire-building operations could be absorbed dermally. These findings are supported by the work of Blank and McAuliffe (3896) whose calculations (from their own in vitro experiments with human skin and the inhalation data of others) indicate that approximately 17% of the total dose of ambient benzene could be absorbed dermally.

The local effects of benzene vapor on the human eye are slight. Occasionally, hemorrhages in the retina and conjunctiva are found after systemic benzene poisoning. In rare instances these may be accompanied by edema of the retina and optic nerve. It has been suggested but not firmly established that benzene may induce inflammation of the optic nerve (19).

18.3.2.2 Chronic Toxicologic Effects

Workers exposed to benzene for 0.5 to 4 years have exhibited signs of neurotoxicity as evidenced by EEG changes and atypical sleep activity (3921). However, the most important effect resulting from chronic benzene exposure is hematotoxicity, the targets being the cells of the bone marrow. At the early stages,

leukopenia, anemia or thrombocytopenia (i.e. a decrease in platelet count) may be seen as well as any combination of these (195). The effects appear to be reversible at this stage (202).

Many observers agree that the lowest air levels of benzene capable of producing a decrease in human circulating blood cells are in the range of 40 to 50 ppm (195). However, one investigator estimated, from a study of 119 workers exposed to benzene concentrations of ~20 ppm, that hematological changes may occur at levels as low as 10.1 ppm (3900). The initial symptoms of benzene poisoning tend to be non-specific and include fatigue, headache, nausea and loss of appetite (46). With continued exposure there is severe bone marrow damage which results in pancytopenia, a deficiency of all cellular elements of the blood. Human benzene toxicity is often described as aplastic or hypoplastic anemia. However, in some cases of benzene-induced hematotoxicity, hyperplastic bone marrows have been reported. It has been suggested that hyperplasia is an early bone marrow response to benzene and that hypoplasia follows after continued exposure (196). The direct, life-threatening consequences of pancytopenia result from leukopenia and thrombocytopenia which will cause an increased susceptibility to infection or hemorrhagic conditions, respectively. There is also evidence that the circulating cells contain morphological or functional abnormalities which may contribute to these effects (203).

Numerous studies indicate that benzene metabolism is required for toxicity (3920, 3942). The major site for the biotransformation of benzene is the liver; however, bone marrow, the target organ, possesses a limited capacity to metabolize the chemical. Phenol, hydroquinone, catechol, and benzene oxide represent the major metabolites of benzene. Of these, the potential toxic metabolite is generally considered to be the quinone or semiquinone derived from hydroquinone (3920), but the open-ring product, trans,trans-muconaldehyde, has also been implicated (3959). The ultimate mechanism of benzene-induced hematotoxicity is the subject of extensive research. Proposed molecular mechanisms include: suppression of RNA and DNA synthesis (3931), alkylation of cellular sulfhydryl groups (3919), disruption of the cell cycle (3943), free radical formation (3919), and covalent binding of benzene metabolites to cellular macromolecules (3924).

There is a correlation between benzene exposure and chromosomal aberrations in the bone marrow and peripheral lymphocytes of exposed individuals. Although aberrations have been reported following chronic, low-level exposures (<10 ppm), it has not been a consistent finding. Aberrations due to high exposure levels (>100 ppm) may persist for many years after exposure has been discontinued (202). Some investigators have associated irreversible chromosome damage with the eventual development of leukemia (195).

Leukemia is defined as a neoplastic condition in which there are increased numbers of white blood cells or their precursors in the blood or bone marrow. Acute myelogenous leukemia is the form most frequently related to benzene exposure although other types have also been observed. In one study, for example, three cases of chronic leukemia (two chronic lymphoid and one hairy cell) were identified among

58 leukemia patients with histories of chronic exposure to benzene (3889). In another study of benzene-exposed workers, none of the seven deaths from leukemia were from acute myelogenous leukemia, but were related to either lymphatic leukemia, chronic myelogenous leukemia, or acute (unspecified) leukemia (3962).

The relationship between benzene exposure and the development of leukemia has been established in numerous epidemiological studies. The International Agency for Research on Cancer believes there is sufficient evidence that benzene is carcinogenic to man (202). Studies by Aksoy and coworkers in Turkey support the causal relationship between benzene exposure and leukemia. These investigators found 26 cases of leukemia or pre-leukemia in a group of 28,500 shoe-manufacturing workers observed over an 80-month period from 1966 to 1973. The exposures were in the range of 210 to 650 ppm with durations ranging from 1 to 15 years. These cases were calculated to give an annual incidence rate of 13 per 100,000 as opposed to a rate of 6 per 100,000 for the general population (629). The latter rate was derived from countries more developed than Turkey and is believed to be high. The investigators recently estimated the incidence of leukemia in the general population in Turkey to be 2.5 to 3 per 100,000 (630) making the increased incidence of leukemia in exposed workers more significant.

Infante and associates (631) conducted a study in 2 populations of workers engaged in the production of rubber products from 1940 through 1949. Benzene was the only material in their work environment known to be associated with blood disorders (43). This group of 748 white males was followed for vital status from 1950 through 1975. A statistically significant excess of leukemia was found in comparison to 2 control groups, the white male American population and the workers in another industry not using benzene. Nine deaths resulted from all forms of leukemia in the 2 exposed groups where the expected incidence was 1.25 (518). The critical issue in this study was the estimation of the air levels of benzene in the work environments. The investigators suggested that the plants functioned within the recommended standards of 100 ppm in 1941, 50 ppm in 1947 and 35 ppm in 1948, and that the actual air concentrations were in the range of 10 - 15 ppm. These exposure levels have been refuted by other investigators who have suggested that the levels were probably greater than the prevailing standards and more likely were in the range of 95 to 950 ppm. It was also argued that environmental exposures at the plants could not have been the same since different rubber products were being manufactured at each location (631). It is also probable that there is a wide variation in absorbed doses due to variations in work habits and also due to the fact that benzene, being volatile, could drift to various locations causing actual exposures to workers thought to be unexposed. These factors make a dose-response relationship difficult to establish (518).

Recently, however, a dose-response relationship between benzene exposure and lymphatic and hematopoietic cancers was described in a historical prospective mortality study of chemical workers (3962). The cohort of the study consisted of 4602 male workers from seven plants who had been occupationally exposed to benzene (3536 continually, 1066 intermittently) for at least six months, between the

years of 1946 and 1975, and a comparison group of male chemical workers from the same plants who had been employed for at least six months during the same period, but were never occupationally exposed to benzene. The internal comparison group was included to minimize the effects of exposure to the chemicals, in addition to benzene, that were present in the plants. This control group also served to avoid several other problems that could result from comparison to national mortality statistics.

The risk of death was assessed using the standard mortality ratio (SMR) (actually observed deaths expressed as percentages of the expected); relative risk was calculated using the Mantel-Haenszel chi-square procedure. When compared to the national norm, the SMRs from all lymphatic and hematopoietic cancer combined and non-Hodgkin's lymphoma and leukemia for the exposed group were slightly, but not significantly, increased. However, when compared to the internal comparison group, the SMR's were considerably higher.

The relative risk for lymphopoietic cancer in the exposed groups (continuous and intermittent) compared with the internal comparison group was 2.99, of borderline significance, while the relative risk for the continuously exposed group alone was 3.2 ($p<0.05$). The chi-square test showed that the association between continuous exposure to benzene and leukemia alone was statistically significant ($p<0.05$). Cohort members were divided into three categories according to benzene exposure: <180 ppm-months, 180-719 ppm-months, and ≥ 720 ppm-months. The dose-response relationships between the cumulative exposure to benzene (in ppm-months) and mortality from all lymphopoietic cancer combined and from leukemia were statistically significant ($p=0.02$ and $p=0.01$, respectively), while the dose response relationship between cumulative exposure and non-Hodgkin's lymphopoietic cancer was of borderline statistical significance ($p=0.06$). The investigator concluded, in spite of several limitations of the study, most of which are typical of a historical mortality study of industrial populations, that chemical workers occupationally exposed to benzene experienced significant mortality from leukemia and from all lymphatic and hematopoietic cancer when compared with chemical workers who were not occupationally exposed to benzene. The significant dose response relationships add strength to the association between benzene exposure in the workplace and these effects.

Controversy has arisen over whether it is necessary for some degree of bone marrow damage to occur before leukemia develops. Many observers believe that this is indeed the case. Yin et al. (3962) observed that seven of twenty-five cases of benzene-induced leukemia had a history of chronic benzene poisoning (leukopenia or aplastic anemia) before the leukemia developed and conjectured a close relationship between leukemia and benzene poisoning. This type of correlation suggests a yet to be proven assumption that there is a threshold for benzene-induced leukemia (195). Others argue that exposure to a carcinogen at any level carries the threat of cancer and in the case of benzene, exposures as low as 10 ppm pose a significant probability of leukemia developing (195). Most cases of leukemia have been observed in those industries where benzene has been used as a solvent; whereas, industries in which benzene is either produced or used as a chemical reactant, such as the petroleum

industry, usually have not exhibited an increased incidence of leukemia (518). This has been attributed to the fact that solvent exposure occurs indoors, in unventilated areas, whereas workers in the petrochemical industries are in largely outdoor situations where the probability of benzene levels exceeding 1 ppm TWA is less than 5% (198).

18.3.2.3 Teratogenicity, Embryotoxicity and Reproductive Effects

A definite association between low-level benzene exposure and human reproduction can not be shown because human exposure to benzene has often occurred along with exposure to many other chemicals. Benzene crosses the human placenta and is present in the cord blood in amounts equal to those in maternal blood (3182). Barlow and Sullivan (3053) reviewed the literature on the effect of acute benzene exposures on human reproductive organs and offspring. Menstrual disturbances and reduced fertility have been reported. A normal infant survived when the mother died at parturition because of severe anemia caused by benzene (3972). No statistically significant clusters of birth defects were found when analyzing data from Drake Superfund Site, Pennsylvania, an area where benzene has been identified (3971). Heath (3282) conducted a study at Love Canal in New York, an area contaminated with benzene and other chemicals and found no clear increased incidence of abortion, birth defects, or low infant birth weight among women living next to the Canal.

18.3.3 Levels of Concern

The USEPA (355), using epidemiological data for cancer in humans (202, 630, 631) and supportive experimental data showing carcinogenicity in rats (201), has established an ambient water quality criterion of zero for benzene. Because the attainment of a zero concentration level may be infeasible in some cases, the concentrations of benzene in water calculated to result in incremental lifetime cancer risks of 1E-05, 1E-06 and 1E-07 from ingestion of both water and contaminated aquatic organisms were estimated to be 6.6, 0.66 and 0.066 μg/L, respectively. Risk estimates are expressed as a probability of cancer after a lifetime daily consumption of two liters of water and 6.5 g of fish that have bioaccumulated benzene. Thus, a risk of 1E-05 implies that a lifetime daily consumption of two liters of drinking water and 6.5 g of contaminated fish at the criterion level of 6.6 μg/L of benzene would be expected to produce one excess case of cancer above the normal back- ground incidence for every 100,000 people exposed. It should be emphasized that these numerical values represent extrapolations that are based on a number of assumptions.

The EPA Office of Drinking Water recently promulgated the Maximum Contaminant Level (MCL) for benzene of 5 μg/L (3952).

The WHO (666) recommends a level of 10 μg/L for benzene in drinking water.

OSHA (3539) currently permits exposure to 1 ppm for an 8-hour TWA and a short-term exposure level (STEL) of 5 ppm, although some industries are exempt.

The ACGIH (3005) has set a TLV (threshold limit value) of 10 ppm, with the notation that benzene is a suspected human carcinogen.

18.3.4 Hazard Assessment

There is sufficient evidence that benzene is carcinogenic in animals and man. Several case reports (202) as well as two cohort studies (630, 631) established a relationship between benzene exposure and leukemia. IARC (518) lists benzene in category 1 (sufficient evidence of human carcinogenicity) in its weight-of-evidence ranking for potential carcinogens. The NTP (801) has categorized benzene as providing clear evidence of carcinogenic activity (multiple sex/species/tumor sites).

A correlation between benzene exposure and chromosomal aberrations in bone marrow and lymphocytes of exposed individuals has also been observed at levels above 100 ppm; results are inconsistent at lower levels (202). A recent report (710) noted chromosome damage in animals at levels as low as 1 ppm. Additional studies regarding the mutagenic capability of benzene are needed to clarify the lowest effective dose.

Retardation of fetal development accompanied by a decrease in maternal weight gain have been seen in reproductive toxicity studies but there is no pattern suggestive of teratogenic activity for benzene.

Aside from the reported hematological effects of long-term benzene exposure (e.g., leucopenia, thrombocytopenia, pancytopenia), most adverse effects associated with benzene exposure are of an acute nature and occur at considerably higher concentrations (e.g., 3000-7500 ppm for one hour). Ingestion of about 10 mL is fatal (56, 12) and symptoms of CNS depression have been noted following ingestion of 2 mL (56).

18.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of benzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of benzene, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight containers with no headspace; analysis should be completed within 14 days of sampling. However, recent studies (3430) show large losses of volatiles from soil handling. At the present, the best procedure is to collect the needed sample in an EPA VOA vial, seal with a foil-lined septum cap, and analyze the entire contents in the vial using a modified purge and trap apparatus. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended method.

EPA-approved procedures for the analysis of benzene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 602, 624, 1624 (65), 8020 and 8240 (63). An inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the benzene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the benzene and transfer it onto a gas chromatographic (GC) column. The GC column is programmed to separate the volatile organics; benzene is then detected with a photo-ionization detector (Methods 602 and 8020) or a mass spectrometer (Methods 624, 1624, and 8240). Direct injection may also be used for samples containing elevated concentrations.

The EPA procedures recommended for benzene analysis in soil and waste samples, Methods 8020 and 8240 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The recommended method for low level soils (< 1 mg/kg) (Method 5030) involves dispersing the soil of waste sample and purging in a heated purge and trap device. Other sample introduction techniques include direct injection and a headspace method.

Coherent anti-stokes raman scattering (CARS) has also been used to quantitate benzene in aqueous solutions (3862). Detection limits are in the 1 to 10 ppb range.

Typical benzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.2 μg/L (Method 602)	2 μg/kg (Method 8020)
4.4 μg/L (Method 624)	5 μg/kg (Method 8240)
10 μg/L (Method 1624)	
2 μg/L (Method 8020)	
5 μg/L (Method 8240)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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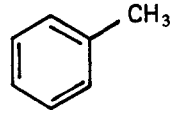
COMMON SYNONYMS:	CAS REG. NO.: FORMULA:	AIR W/V CONVERSION FACTORS at 25°C (12)
Methyl Benzene Methyl Benzol Phenyl Methane Toluene Toluol	108-88-3 C_7H_8 NIOSH NO: XS5250000 STRUCTURE: 	3.77 mg/m3 ≈ 1 ppm; 0.2652 ppm ≈ 1 mg/m^3 MOLECULAR WEIGHT: 92.14

REACTIVITY	Toluene may generate heat, react vigorously, and possibly ignite or explode in contact with oxidizing mineral acids or other strong oxidizing agents (507, 38, 511, 505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Benzene-like	(23)
	• Odor Threshold: 2.900 ppm	(384)
	• Density: 0.8669 g/mL (at 20°C)	(68)
	• Freeze/Melt Point: -95.00°C	(68)
	• Boiling Point: 110.60°C	(68)
	• Flash Point: 4.40°C closed cup	(23)
	• Flammable Limits: 1.20 to 7.10% by volume	(38,51,506)
	• Autoignition Temp.: 480.0 to 536.0°C	(504,506,510)
	• Vapor Pressure: 2.20E+01 mm Hg (at 20°C)	(67)
	• Satd. Conc. in Air: 1.1000E+05 mg/m^3 (at 20°C)	(67)
	• Solubility in Water: 5.15E+02 mg/L (at 20°C)	(67)
	• Viscosity: 0.580 cp (at 20°C)	(1219)
	• Surface Tension: 2.9000E+01 dyne/cm (at 20°C)	(59)
	• Log (Octanol-Water Partition Coeff.): 2.73	(29)
	• Soil Adsorp. Coeff.: 2.59E+02	(652)
	• Henry's Law Const.: 6.61E-03 atm · m^3/mol (at 25°C)	(74)
	• Bioconc. Factor: 2.60E+01 (estim), 2.71E+01 (estim)	(659,207)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems, including transport of vapor through air-filled pores as well as transport in solution. Chemical is resistant to hydrolysis but will probably biodegrade easily if microbiological populations are sufficiently numerous and active. It may persist for months to years (or more) if biodegradation is not possible.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of toluene to groundwater drinking water supplies. Data from NPL sites indicate that migration of this compound has occurred in the past, although survey data do not show extensive contamination of drinking water. Inhalation resulting from volatilization from surface soils may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (54) Acute exposure to toluene results in CNS depression. Symptoms include headache, dizziness, fatigue, muscular weakness, drowsiness and incoordination with staggering gait. The liquid splashed in the eyes may cause irritation and reversible corneal damage. Prolonged or repeated skin contact may cause drying and dermatitis. Acute Toxicity Studies: (3504) INHALATION: LC_{50} 5320 ppm · 8 hr — Mouse LC_{Lo} 4000 ppm · 4 hr — Rat TC_{Lo} 100 ppm — Human LC_{Lo} 1600 ppm — Guinea Pig ORAL: LD_{50} 5000 mg/kg — Rat LD_{Lo} 50 mg/kg — Human SKIN: LD_{50} 12,124 mg/kg — Rabbit

HEALTH HAZARD DATA (Cont.)	Long-Term Effects: Inhalation: respiratory tract lesions; conflicting data on kidney effects; chronic abuse: CNS impairment. Pregnancy/Neonate Data: Insufficient data to determine teratogenic potential. Genotoxicity Data: Insufficient data to determine genotoxic potential. Carcinogenicity Classification: IARC - No data NTP - No evidence of carcinogenicity in F344 rats and $B6C3F_1$ mice by inhalation. EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation. • Vapor concentrations of 200-500 ppm: any supplied-air respirator, self-contained breathing apparatus or chemical cartridge respirator with an organic vapor cartridge. • 500-1000 ppm: chemical cartridge respirator with full facepiece and organic vapor canister. • 1000-2000 ppm: any supplied-air respirator or self-contained breathing apparatus with full facepiece. • Chemical goggles if there is probability of eye contact with the liquid. • Impervious clothing to prevent prolonged or repeated skin contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 100 ppm; STEL (15-min): 150 ppm
- AFOSH PEL (8-hr TWA): 100 ppm; STEL (15-min): 100 ppm

Criteria
- NIOSH IDLH (30-min): 2000 ppm
- NIOSH REL (10-hr TWA): 100 ppm
- NIOSH Ceiling Limit (10 min): 200 ppm

- ACGIH TLV® (8-hr TWA): 100 ppm
- ACGIH STEL (15-min): 150 ppm

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA
(Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (3883)
MCLG: 2 mg/L (proposed)
MCL : 2 mg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 20 mg/L
- 10-day (child): 3 mg/L
- longer-term (child): 3 mg/L
- longer-term (adult): 10 mg/L
- lifetime (adult): 2 mg/L

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, 14.3 mg/L. Based on ingestion of contaminated aquatic organisms only, 424 mg/L. Based on ingestion of contaminated water only, 15.0 mg/L.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity: no criterion, but lowest effect level occurs at 17,500 μg/L.

    chronic toxicity:
    no criterion established due to insufficient data.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 6300 μg/L.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 5000 μg/L.

REFERENCE DOSES:
3.000E+02 μg/kg/day (3744)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Toluene is designated a hazardous substance under the CWA. It has a reportable quantity (RQ) limit of 454 kg (347, 3764). It is also listed as a toxic pollutant subject to general pretreatment regulations for new and existing sources, and to effluent guidelines and standards (351, 3763). Effluent limitations for toluene have been set in the following point source categories: electroplating (3767), organic chemicals, plastics and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Toluene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 (3781). Toluene is one of 36 unregulated organic chemicals requiring special monitoring in all community water systems and non-community, non-transient water systems (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of toluene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Toluene is identified as a toxic waste (U220) and listed as a hazardous waste constituent (3783, 3784). Non-specific sources of toluene-containing waste are solvent use (or recovery) activities, chlorinated aliphatic hydrocarbon production, and spent solvents containing 10% or more toluene (325). Waste streams from the following industries contain toluene and are listed as specific sources of hazardous wastes: organic chemicals (benzyl chloride production, phenol/acetone production, toluene diisocyanate production), pesticides (disulfoton production), petroleum refining, ink formulation, and coking operations (3774, 3765). Toluene is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Certain variances exist until May, 1990 for land and injection well disposal of some wastewaters and nonwastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). Toluene is included on EPA's groundwater monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their groundwater for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of toluene must report production usage, disposal, and exposure-related information to EPA (334). They, as well as others who possess health and safety studies on toluene, must submit them to EPA (3789).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Toluene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 454 kg (3766). Reportable quantities have also been issued for RCRA hazardous waste streams containing toluene but these depend upon the concentration of the chemicals present in the waste stream (3766). Under SARA Title III, manufacturers, processors, importers, and users of toluene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
Toluene is exempt from a tolerance requirement when used as a solvent or cosolvent in pesticide formulations applied to growing crops (315).

Occupational Safety and Health Act (OSHA)
Employee exposure to toluene shall not exceed an 8-hour time-weighted average (TWA) of 100 ppm. An employee 15-minute short term exposure limit (STEL) of 150 ppm shall not be exceeded at any time during a work-day (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated toluene as a hazardous material with a reportable quantity of 454 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Toluene is approved for use as an indirect food additive as a component of adhesives (3209).

- State Water Programs

  ALL STATES

  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

  CALIFORNIA

  California has an action level of 100 μg/L for drinking water (3098).

  CONNECTICUT

  Connecticut has an action level of 1000 μg/L and a Quantification limit of 2 μg/L for drinking water (3138, 3137).

  DISTRICT OF COLUMBIA

  The District of Columbia has a human health criterion of 1000 μg/L for public water supply surface waters (3828).

  NEW HAMPSHIRE

  New Hampshire has set an enforceable Toxic Contaminant Level (TCL) for toluene in drinking water of 1 mg/L for a ten-day exposure (assume a child weighing 10 kg who drinks one liter of water per day) (3710).

  NEW MEXICO

  New Mexico has a water quality criterion of 750 μg/L for toluene in ground-water (3499).

  NEW YORK

  New York has an MCL of 5 μg/L for drinking water, and a non-enforceable water quality guideline of 50 μg/L for surface and ground-waters (3501).

  OKLAHOMA

  Oklahoma has a water quality standard of 0.5 μg/L for ground-water (3534).

  RHODE ISLAND

  Rhode Island has an acute freshwater quality guideline of 635 μg/L and a chronic guideline of 14 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

  SOUTH DAKOTA

  South Dakota requires toluene to be nondetectable, using designated test methods, in ground-water (3671).

VERMONT
Vermont has a preventive action limit of 1.21 mg/L and an enforcement standard of 2.42 mg/L for toluene in ground-water (3682).

WISCONSIN
Wisconsin has a preventive action limit of 68.6 μg/L and an enforcement standard of 343 μg/L for toluene in ground-water (3840). Wisconsin also has set a human threshold criterion of 7.6 mg/L for public water supply surface waters (3842).

Proposed Regulations

- Federal Programs

Resource Conservation And Recovery Act (RCRA)
EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 14.4 mg/L toluene. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565).

Safe Drinking Water Act (SDWA)
EPA has proposed an MCL and MCLG of 2 mg/L for toluene (as well as Health Advisories). Final promulgation is expected in December, 1990 (3759).

- State Water Programs

MOST STATES
Are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the State Officers is advised. Changes are projected for 1989-90 (3683).

IOWA
Iowa has proposed acute criteria of 7500 μg/L for Class B (limited resource warm water) surface waters and 2500 μg/L for all other Class B surface waters. Iowa has also proposed chronic criteria of 150 μg/L for Class B (limited resource warm water) surface waters, and 50 μg/L for all other Class B surface waters. These criteria are for the protection of aquatic life (3326).

KANSAS
Kansas has proposed a water quality criterion of 2000 μg/L for toluene in ground-water (3213).

MINNESOTA
Minnesota has proposed a Recommended Allowable Limit (RAL) of 2420 μg/L for toluene in drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 3044 μg/L for surface waters, and chronic criteria of 68 μg/L for designated surface waters and 2420 μg/L for designated ground-waters. These criteria are for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Toluene is listed as a Class II/c harmful substance and is subject to packaging ad labeling regulations.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto- pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Toluene is classified as a flammable, harmful substance and is subject to packaging and labeling regulations. Toluene may contain a stablizer. If the stablizer changes the dangerous properties of this substance, sunstance should be labeled in accordance with rules in Annex I and EEC 88/490, 22 July 1988.

EEC Directive-Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
Toluene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

19.1 MAJOR USES

Toluene is an important raw material for organic syntheses. It is used in the production of benzene, benzyl chloride, benzoic acid, phenol, cresols, vinyl toluene, TNT and toluene diisocyanate. It is also used as a solvent for paints, rubber and resins and as a component of motor and aviation fuels (206). Toluene may be encountered as a relatively pure substance or it may be contaminated with as much as 25% benzene (206).

19.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

19.2.1 Transport in Soil/Ground-water Systems

19.2.1.1 Overview

Toluene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by estimating equilibrium partitioning, as shown in Table 19-1. These calculations predict the partitioning of toluene among soil particles, soil water and soil air. The toluene associated with the water and air phases of the soil is more mobile than the adsorbed compound.

The estimates for the unsaturated topsoil model indicate that nearly all of the toluene (97%) is sorbed to the soil. A much smaller amount (2%) will be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the portion of toluene in the gaseous phase of the soil (1.6%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, will be a significant loss pathway. There is no significant difference in the partitioning calculated for 25°C and 10°C.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the toluene (48%) is likely to be present in the soil-water phase (Table 19-1) and transported with flowing ground-water.

Wilson et al. (82) investigated the transport and fate of toluene in solutions applied to sandy soils. In a soil column receiving solutions with less than 1 mg/L toluene, approximately 40-70% was volatilized and 2-13% percolated through the soil column with minimal retardation. Between 20-60% was either degraded or not accounted for in the study. The retardation factor for toluene in the soil columns (i.e., interstitial water velocity/velocity of toluene) was determined to be <2.

Demirjian et al. (522) found that land treatment of sewage sludge containing toluene (applied at 0.0092 kg toluene/ha) led to undetectable levels of the chemical in the soil at the end of the study. Volatilization was presumably an important pathway. In a field study on the removal of organics from water by dune-infiltration (using water from the Rhine River), Piet et al. (226) actually found increases in the toluene concentration in the water after infiltration. While the reason for the increase is not known, and may have been due to some artifact of the study, the results do indicate that toluene is easily transported by infiltrating water.

TABLE 19-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR TOLUENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c]			
at 25°C	96.5	1.9	1.6
at 10°C	97.0	2.0	0.96
Saturated deep soil[d]	52.1	47.9	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 259 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 6.61E-03 atm · m^3/mol at 25°C (74), and 0.00385 atm · m^3/mol at 10°C [latter calculated using 25°C/10°C ratio of H values from Brown and Wasik (521)].
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

19.2.1.2 Sorption on Soils

The mobility of toluene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to: increase with increasing soil organic matter content; increase slightly with decreasing temperature; increase

moderately with increasing salinity of the soil water; and decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 537, the soil sorption coefficient (K_{oc}) is estimated to be 259. This number is indicative of moderate sorption to soils.

Nathwani et al. (523) found that toluene sorption on soils followed a Freundlich isotherm in the concentration range of 1-100 mg/L. The typical Freundlich equations for toluene sorption on various soils were:

(1) $S = KC^n = 3.52C^{1.008}$
Wendover silty clay (pH 5.4, 16.2% organic matter)

(2) $S = 2.69C^{1.002}$
Vandreil sandy loam (pH 5.1, 10% organic matter)

(3) $S = 0.9C^{0.996}$
Grimsby silt loam (pH 4.4, 1% organic matter)

where S = μg toluene sorbed/g soil and
C = equilibrium solution concentration (mg/L).

19.2.1.3 Volatilization from Soils

Transport of toluene vapors through the air-filled pores of unsaturated soils is an important transport mechanism for near-surface soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physico-chemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31). The studies of Wilson et al. (82) and Demiryian et al. (522) provide fairly strong evidence that volatilization is an important loss mechanism for near surface soils. Sorption of toluene vapors on the soil may slow the vapor phase transport; Politzki et al. (516) have shown, for example, that the vapor pressure of toluene in the presence of (and thus partially sorbed to) silica gel was decreased by a factor of almost 1E+04 from the pure compound value.

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, increases significantly with increasing temperature (28). Moderate increases in H are also expected with increasing salinity due to a decrease in toluene's solubility (517).

19.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of toluene in soil/ground-water systems is not well documented. In most cases, it should be assumed that the chemical will persist for months to years (or more). Toluene that has been released into the air will eventually undergo photochemical oxidation; a tropospheric lifetime of 15 hours has been estimated (10).

Toluene under normal environmental conditions is not expected to undergo hydrolysis (10, 33). Further, toluene is not expected to be susceptible to oxidation or reduction reactions in the soil/ground-water environment.

Available data indicate that toluene is biodegradable in the soil/ground-water environment (10, 524, 525, 236, 55, 519). A number of species of microorganisms are capable of using toluene as the sole carbon source. Toluene is easily degraded in adaptable mixed cultures (55). However, in most soil/ground-water systems such aerobic degradation would be of minimal importance because of the low concentration of microorganisms (at depth) and the low dissolved oxygen (anaerobic) conditions. No data are available on the susceptibility of toluene to anaerobic biodegradation.

19.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The properties of toluene and the above discussion of fate pathways suggest that toluene is highly volatile from aqueous solutions, moderately adsorbed by soil and has a low potential for bioaccumulation. This compound may volatilize from soil surfaces; however, the portion not removed by volatilization may eventually migrate to ground-water. These fate characteristics suggest several potential exposure pathways.

Volatilization of toluene from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. The potential for ground-water contamination is high, particularly in sandy soil. Mitre (83) reported that toluene has been found at 95 of the 546 National Priority List (NPL) sites. It was detected at 74 sites in ground-water, 41 sites in surface water and 12 sites in air.

This compound was also reported in the USEPA (531) Ground-water Supply Survey (GWSS). This survey examined 945 finished water supplies that use ground-water sources. The results for toluene are summarized in the following table.

The random results are intended to statistically represent the U.S. ground-water drinking water supplies. The non-random samples were chosen by the states as being potentially contaminated. Toluene was also detected in the National Organic Monitoring Survey (NOMS) (90).

Sample Type	Occurrences* No.	%	Median of Positives (μg/L)	Maximum (μg/L)
Random				
Supplies serving <10,000 people (280 samples)	4	1.4	0.62	0.85
Supplies serving >10,000 people (186 samples)	2	1.1	2.6	2.9
Non-Random				
Supplies serving <10,000 people (321 samples)	4	1.2	0.67	0.79
Supplies serving >10,000 people (158 samples)	1	0.6	1.5	1.5

*Samples having levels over quantification limit of 0.5 μg/L.

The properties of toluene and the results described above indicate that this compound has the potential for movement in soil/ground-water systems. This compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure.
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures through bioaccumulation.
- Recreational use of these waters may result in dermal exposures.
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposure from drinking contaminated ground-water for two reasons. First, the Henry's law constant for toluene suggests that it will volatilize upon reaching surface waters. Secondly, the bioconcentration factor for this compound is low, suggesting limited bioaccumulation in aquatic organisms or domestic animals.

19.2.4 Other Sources of Exposure

Toluene is a widely used chemical, predominantly in gasoline, chemical synthesis (benzene, phenol and others), and as a solvent. As a result of emissions during

production, use, and disposal, and because of high volatility, toluene has become pervasive in the environment.

The data presented above on the Ground-water Supply Survey (531) suggest that toluene is found in a limited number of ground-water supplies used as drinking water. Coniglio et al. (223), in a summary of data from SRI, NOMS and NORS, found that toluene was detected at a frequency of 19.4% in finished surface water.

The volatility of toluene suggests that it may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric monitoring data for a number of volatile organics. For toluene, they had data for 3498 locations. In rural and remote areas, the median concentration was 2.5 $\mu g/m^3$. In urban and suburban areas, the median concentration was 41 $\mu g/m^3$. In source-dominated locations, the median concentration was 17 $\mu g/m^3$. These results indicate that individuals are exposed via inhalation even in rural and remote areas.

Toluene has also been identified in cigarette smoke. According to the NRC (743), the average toluene exposure is 0.1 mg per cigarette. This route would likely represent the greatest source of exposure for smokers.

19.3 HUMAN HEALTH CONSIDERATIONS

19.3.1 Animal Studies

19.3.1.1 Carcinogenicity

An increased incidence of neoplasms has been observed in rats and mice exposed to toluene by dermal application and gavage; however, the evidence is insufficient to determine the carcinogenic potential of toluene by these routes. Toluene applied to the skin of mice for 1 year failed to elicit skin neoplasms or an increased frequency of systemic tumors. However, it was not clear whether the toluene was allowed to evaporate or was applied under an occlusive dressing (619). Skin cancers were observed in 2 mice out of a group of 30 who were subjected to topical application of 16 to 20 μl of toluene twice weekly for 72 weeks (43). In a gavage study conducted by Maltoni et al. (3423), 40 male and 40 female Sprague Dawley rats were given 500 mg/kg of toluene in olive oil 4 to 5 days/week for 2 years. Hemolymphoreticular neoplasms were reported in 3 of 37 exposed males and in 7 of 40 exposed females compared with 3 of 45 and 1 of 40 controls, respectively.

However, results from two long-term carcinogenicity studies indicate that toluene is clearly not carcinogenic in rats and mice by inhalation at concentrations up to 1200 ppm. In an inhalation study conducted by Gibson and Hardisty (3245), no increased incidence of neoplasms was observed in male and female Fischer 344 rats (120 animals/exposure group) following exposure to 30, 100, or 300 ppm of toluene, 6 hours/day, 5 days/week for 2 years. Results of a 2-year NTP inhalation

carcinogenicity study indicated no evidence of carcinogenic activity in male and female Fischer 344 rats exposed to toluene at concentrations of 600 and 1200 ppm (6.5 hours/day, 5 days/week) or in male and female B6C3F$_1$ mice exposed to toluene at concentrations of 120, 600, or 1200 ppm (6.5 hours/day, 5 days/week) (3485).

19.3.1.2 Genotoxicity

Cytogenetic data in lymphocytes of toluene-exposed workers are contradictory. Bauchinger et al. (622) observed a statistically significant number of chromatid breaks, exchanges and gaps among workers employed for 16 years in a rotogravure plant. Vapor concentrations ranged from 200-300 ppm. However, this data is questionable because the investigators failed to separate the data from smokers and nonsmokers. In a follow-up study, Schmid et al. (3622) examined the lymphocytes of these workers after they had been in a toluene-free environment for a period of 4 months to 5 years. Chromatid aberrations were at a higher incidence compared with controls for up to 2 years after cessation of exposure to toluene. After longer post-exposure periods, aberrations yields were at background levels. Other investigators reported negative results in chromosomal analysis of workers exposed to vapor concentrations in the 7-200 ppm range (623, 724).

Toluene did not induce recessive lethals in germ cells of Drosophila melanogaster males exposed to 500 or 1000 ppm by feeding for 24 hours nor did it induce chromosomal aberrations in male Wistar rats exposed to 300 ppm by inhalation, 6 hr/day, 5 days/week for 15 weeks (624). Toluene was also negative in inducing histidine reversions in the Salmonella/microsome assay with or without activation (3276, 3233).

Conflicting results have been reported for the induction of micronuclei in bone marrow cells of mice. Negative results were found with oral treatment of CD-1 males (3232) and of CD-1 males and females (3233), but significant positive results were observed when NMRI males were injected with toluene (3462, 3463). No chromosomal aberrations were observed in the study with oral treatment of male and female mice (3233).

19.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

There are many recent studies in which toluene has been administered by inhalation to pregnant test animals. Ghantous and Danielsson (3243) found toluene levels in the fetal mouse much lower than levels in the maternal tissues. Ungvary (3754) noted signs of skeletal retardation in offspring of pregnant rats exposed to 1000 mg/m^3. Tests with mice resulted in weight reduction and skeletal retardation of fetuses at this level but not at 500 mg/m^3 (3753). Their tests with pregnant rabbits showed no statistically significant effect on the offspring at the 500 mg/m^3 level, but 1000 mg/m^3 caused spontaneous abortion. Courtney et al. (3143) administered toluene at 1500 mg/m^3 to mice from days 6 to 16 of gestation and called it teratogenic at that level due to a significant shift in the fetal rib profile. There also

was increased body weight in the neonates on day 1 postpartum. Shigeta et al. (3643) exposed rats to 100 ppm toluene from the 13th day of gestation to 48 days of age. There were no effects on developmental signs of offspring, but in one group of male offspring learning acquisition was slow.

Tested orally in pregnant mice, toluene doses of 0.3, 0.5 or 1.0 mL/kg caused embryonic lethality, while reduction in fetal weight occurred in the two higher dose groups (3488). A statistically significant increase in the incidence of cleft palate occurred at the 1.0 mL/kg level. No fetotoxic effects of toluene were noted by oral dosing of pregnant mice by Seidenberg et al. (3634) at 1,800 mg/kg/day or by Hardin et al. (3271) at 3,000 mg/kg/day.

19.3.1.4 Other Toxicologic Effects

19.3.1.4.1 Short-term Toxicity

The oral LD_{50} for rats is 5 g/kg (47). The minimum lethal vapor concentration for mice was found to be 5300 ppm in an 8-hour exposure (206). The inhalation LC_{50} value for mice is 5320 ppm · 8hr (47). Dermal LD_{50} values of 12.1 and 14 g/kg have been reported for the rabbit (12,47).

Inhalation appears to be the most frequent and most important route of exposure to toluene. Animal experiments indicate that the main toxic effects of acute inhalation exposure are upon the central nervous system (CNS). This is not surprising based on the high lipid solubility of toluene and the high lipid content of the brain. Therefore, uptake in the various brain regions is widespread and correlated with the total lipid content of each brain region. The CNS response is biphasic, with an initial excitable phase followed by CNS depression. Hinman (3291) reported that inhalation exposure to concentrations of 10,000 to 15,000 ppm for 60 minutes resulted in an initial increase in locomotor activity; however, with continued exposure at these levels, locomotor activity decreased and eventually spontaneous activity ceased.

Inhalation exposure to concentrations ranging from 1000 to 2000 ppm can result in instability, incoordination, light narcosis and tremors (206). Concentrations ranging from 100 to 4000 ppm can produce effects on behavioral patterns and on the electrical activity of the brain of rats. Rats exposed by inhalation to concentrations of 1000, 2000, and 4000 ppm for 4 hours exhibited disturbed sleep-wake patterns (3698). Concentrations ranging from 100 to 1000 ppm, 6 hours/day for 20 days resulted in reduced wheel-turning activity in rats (3298). Ikeda and Miyake (3320) found that learning was impaired in rats exposed to 4000 ppm of toluene, 2 hours/day for 60 days.

Recent studies have found that toluene induces hearing loss in rats after short-term, high-level inhalation exposures. Based on behavioral and electrophysiologic changes, Pryor et al. (621) observed hearing loss in male Fischer 344 rats following three-day exposures to 1500 ppm for 14 hours daily or 2000 ppm

for 8 hours daily. Single exposures to 4000 ppm for 4 hours or 2000 ppm for 8 hours were without effect. Exposure to vapor concentrations of 400-700 ppm were without effect even after 16 weeks of exposure (621). Johnson et al. (3342) also observed high-frequency auditory impairment in rats following inhalation exposure to 1000 ppm of toluene, 16 hours/day, 5 days/week for 2 weeks. The authors suggested that the major cause of the impairment was cochlear damage. This is supported by data from an oral gavage study in which Fischer 344 and Sprague Dawley rats were provided 620 mg/kg of toluene once per day for 4 weeks. In this study, hearing loss resulted from damage to the outer hair cells of the inner ear (3691).

Other toxicological effects have been observed following short-term inhalation exposure to toluene, with the primary target organs being the kidney, brain, and lung. Concentrations of 200 and 5000 ppm, 7 hours/day, 5 days/week for 5 to 15 weeks resulted in decreased leukocyte counts, pulmonary lesions, and casts in renal tubules in the kidneys of rats. Increased mortality was observed in the 5000 ppm dose-group (3820). von Oettingen et al. also observed similar effects in dogs exposed by inhalation to 200 to 600 ppm, 8 hours/day for 20 days, followed by exposure at 7 hours/day for 5 days, and then 850 ppm for 1 hour. The effects included appreciable fat in the convoluted tubules and hyaline casts in the collecting tubules of the kidneys and congestion in the lungs. In male Sprague-Dawley rats and ICR mice, reduced body weight gain and depression of kidney, brain, and lung weights were observed following intermittent inhalation exposure to 12,000 ppm of toluene. Rats and mice were exposed to 7 daily consecutive cycles of 10 minutes of 12,000 ppm of toluene followed by 20 minutes of toluene-free recovery 5 days/week for 8 weeks (3085). Kyrklund et al. (3386) also observed decreased body weights and decreased weight of the whole brain and the cerebral cortex in male Sprague Dawley rats following continuous inhalation exposure to 320 ppm opf toluene for 30 days.

When instilled into rabbit eyes, toluene causes transient conjunctival irritation (19). A single application of 0.005 mL of toluene, in excess of 15 percent, produced severe ocular irritation when instilled into the cornea of albino rabbits (3102); however, no reports of corneal damage in animals have been found (206).

Guillot et al. (3256) found that 0.5 mL of undiluted toluene applied to intact and abraided skin of male albino rabbits for 24 hours produced moderate skin irritation.

19.3.1.4.2 Chronic Toxicity

Information on the effects of oral exposure to toluene are limited. Rats given oral doses of 118 to 590 mg/kg/day for 193 days exhibited no effects (210). In a 13-week study in which Fischer 344 rats and B6C3F$_1$ mice were given 0, 312, 625, 1250, 2500, or 5000 mg/kg of toluene in corn oil by gavage (5 days/week), adverse effects were observed at the three highest doses (3485). All rats and mice receiving 5000 mg/kg died during the first week of the study. Relative liver, kidney (rats only), and heart (female rats only) weights were increased at the highest dose, and necrosis of

the brain and hemorrhage of the urinary bladder occurred with increased incidence in dosed rats at 1250 and 2500 ppm.

Similar effects were observed in the same strains of rats and mice following inhalation exposure to 1250, 2500, and 3000 ppm of toluene, 6.5 hours/day, 5 days/week for 14 (mice) to 15 (rats) weeks (3485). Eight of 10 male rats, 5 of 10 male mice, and all female mice exposed to 3000 ppm died during week 2 of the study; mean body weights were decreased; and relative liver, kidney, lung (mice only), and heart (rats only) weights were increased compared with controls in rats following exposure to 2500 and 3000 ppm and in mice exposed to 1250, 2500, and 3000 ppm. Centrilobular hypertrophy of the liver was observed in male mice at the two highest concentrations. Matsumoto et al. (3434) also observed increased liver, kidney, and heart weights in DONRYU male rats exposed by inhalation to 2000 ppm of toluene for 18 weeks. These investigators also observed hyaline droplets in the renal tubular epithelium of DONRYU male rats exposed to 100, 200, or 2000 ppm of toluene, 6 days/week for 43 weeks. However, the significance of this finding is questionable due to the uncertainty concerning the length of time from the last exposure to the time of killing of the test animals.

In 15-month and 2-year inhalation studies conducted by NTP (3485) to determine the carcinogenicity of toluene, nonneoplastic lesions of the respiratory tract were observed in Fischer 344 rats exposed to 600 or 1200 ppm of toluene, 6.5 hours/day, 5 days/week. At 15 months, degeneration of olfactory and respiratory epithelium and goblet cell hyperplasia were increased in exposed rats. At 2 years, erosion of the olfactory epithelium and degeneration of respiratory epithelium were significantly increased in both sexes. Inflammation of nasal mucosa and metaplasia of olfactory epithelium were significantly increased in exposed female rats. In addition, $B6C3F_1$ mice exposed to 1200 ppm of toluene, 6.5 hours/day, 5 days/week exhibited minimal hyperplasia of bronchial epithelium. No other biologically important increases in nonneoplastic lesions were observed in exposed mice. The lesions observed in this study were of mild severity and are not unusual with solvent exposures.

Several investigators have observed no histopathologic or hematologic effects in rats (various strains), guinea pigs, dogs and primates exposed by inhalation to concentrations of toluene ranging from 103 to 1481 ppm, 6-8 hours/day, 5 days/week for 90-180 days. (3339, 3248, 3022)

19.3.2 Human and Epidemiologic Studies

19.3.2.1 Short-term Toxicologic Effects

No reports involving human ingestion of toluene were found. The primary hazard associated with acute inhalation exposure to high levels of toluene is CNS depression (207). Controlled exposure of human subjects to 200 ppm (750 mg/m^3) for 8 hours produced mild fatigue, weakness, confusion, lacrimation and tingling of the skin. At 600 ppm, additional effects including euphoria, headache, dizziness,

dilated pupils, convulsions and nausea became evident. After 8 hours at 800 ppm, symptoms were more pronounced; after-effects included nervousness, muscular fatigue and insomnia persisting for several days (46). Exposure to very high concentrations (10,000 to 30,000 ppm) could lead to narcosis and death (3850).

Toluene is frequently used as a solvent of abuse due to the euphoria and inebriation-like symptoms associated with inhalation of its vapors either from paint or glue or in its pure form. Exposure levels in these cases have been estimated to be as high as 5000 ppm (12). Long-term abuse of toluene (3 to 15 years) has resulted in emotional and intellectual disturbances as well as central nervous system impairment (70). Symptoms include tremors, weakness, diminished reflexes, sensory loss, visual impairment (204), cerebellar dysfunction (3222), and brain atrophy (3620). Other complaints involve gastrointestinal disorders (17). Several deaths due to toluene abuse have been reported. Although most have been attributed to cardiac arrhythmias or asphyxiation, a recent case report of toluene abuse attributed death to severe fluid volume depletion and electrolyte abnormalities (decreased serum potassium, calcium and phosphorus) (205). These effects result from long-term, high-level inhalation exposures. Information concerning the effects of toluene abuse on the kidney are conflicting. Several investigators, including Patel and Benjamin (3555), have reported cases of severe distal renal tubular acidosis following abusive exposure to toluene-containing solvents. However, most persons exhibiting signs of renal damage from toluene sniffing are also exposed to other solvents, and therefore the effect cannot be clearly attributed to toluene alone.

Impairment of reaction time was observed in humans after 20 minutes exposure to 300 ppm (1125 mg/m^3) and after 7 hours exposure to 200 ppm (750 mg/m^3) (70, 206).

Grant (19) reports that eye irritation is noticeable at vapor levels of 300 to 400 ppm. Toluene splashed in the eyes of workers resulted in transient corneal damage and conjunctival irritation from which they recovered within 48 hours (19).

Prolonged or repeated skin contact may cause drying and dermatitis. For liquid toluene, the rate of percutaneous absorption ranges from 14 to 23 mg/m^3 per hour (206). Dermal absorption of the vapor is negligible (70).

19.3.2.2 Chronic Toxicologic Effects

The industrial experience with toluene has generally been good. In one study, occupational exposure to vapor concentrations ranging from 80 to 160 ppm produced no changes in the blood or liver of workers exposed for "several years." One worker exposed to mean vapor levels of 250 ppm experienced conjunctival irritation, insomnia, and nervousness (625). Hepatomegaly (liver enlargement) has been observed in workers following occupational exposure (2 to 14 years) to toluene at concentrations ranging from 53 to 1115 ppm (3254, 3696). However, no pathological changes occurred in the liver and no clinical signs of liver dysfunction were observed

in any of the workers. Other early studies also implicated toluene as the cause of various blood disorders. The current view is that these effects were entirely attributable to benzene contamination (206).

19.3.2.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Recreational toluene sniffing by 3 pregnant women resulted in the birth of babies with microcephaly, central nervous system dysfunction, and minor craniofacial and limb abnormalities (3288). Syrovadko (3618) found a higher incidence of low birth weight in the offspring of women working with organosilicon varnishes containing toluene. Exposure averaged 55 ppm. There was no detectable effect on fertility, course of pregnancy, and perinatal mortality. Heath (3282) conducted a study at Love Canal in New York, an area contaminated with toluene and other chemicals. No clear increased incidence of abortion, birth defects, or low infant birth weight was observed in women living next to the Canal.

19.3.3.3 Levels of Concern

The USEPA (355) has established an ambient water quality criterion for the protection of human health for toluene of 14.3 mg/L. This criterion was developed based on the no-observed-effect level of 590 mg/kg/day for rats ingesting toluene for 193 days (210), an uncertainty factor of 1000, 100% absorption, a bioconcentration factor of 10.7 for fish and the assumption the two liters of drinking water and 6.5 g of contaminated fish are consumed by a 70-kg adult per day. A MCLG and MCL of 2 mg/L for toluene in drinking water has been proposed by the USEPA (3883).

A reference dose of 300 μg/kg/day has been derived for toluene (3744).

OSHA (3539) permits exposure to 100 ppm (375 mg/m^3) averaged over an 8-hour work-shift, with a short-term exposre limit (STEL) of 150 ppm for 15 minutes. The ACGIH (3005) recommends a threshold limit value of 100 ppm (375 mg/m^3), with a short-term exposure limit of 150 ppm.

19.3.3.4 Hazard Assessment

Toluene acts primarily on the central nervous system. Uptake in the various brain regions is widespread due to the high lipid solubility of toluene and the high lipid content of the brain. CNS effects are noted with high acute inhalation exposures (>1000 ppm) in experimental animals (206). A recent report (621) has also linked hearing loss in rats to high-level toluene exposures (e.g., 1500 ppm, 14 hr/day for 3 days). Rats and dogs exposed to concentrations ranging from 200 to 5000 ppm for 5 to 15 weeks have also exhibited renal effects and pulmonary lesions (3820). Chronic inhalation exposure (15 months to 2 years) to 600 or 1200 ppm has resulted in lesions in the respiratory tract of rats and mice (3485). Ingestion of 590 mg/kg/day for 7 months produced no effects in rats (210); however, rats given 1250 or 5000 mg/kg by gavage for 13 weeks exhibited weight increases in the liver and kidney

at the high dose and necrosis of the brain at both doses (3485). No human ingestion data were found. Chronic abusive inhalation (3 to 15 years) of toluene vapors by humans produces CNS impairment and emotional and intellectual disturbances (70).

Results of an NTP (3485) carcinogenicity study indicate that toluene exhibits no evidence of carcinogenic activity in F344 rats and B6C3F$_1$ mice via inhalation at concentrations of 600 or 1200 ppm for rats and 120, 600, or 1200 ppm for mice.

Toluene has been inadequately tested to permit assessment of its carcinogenic potential via the dermal or oral route. Cytogenetic data in lymphocytes of toluene-exposed workers are contradictory (623, 724, 3622). Conflicting results have been reported in the micronucleus test in mice (3462, 3232, 3463). Negative genotoxic effects have been reported for bacteria (3675, 3276), a rat chromosomal study, and a test in Drosophila (624). One study noted an increased incidence of cleft palate in mice, given 1 mL/kg toluene by gavage during gestation (620). No teratogenic effects were observed in either rats or mice exposed to 375-400 ppm by inhalation (53).

The USEPA has estimated an acceptable daily intake of 30 mg of toluene per day for a 70-kg individual based on a no-effect-level in rats ingesting toluene for 7 months (670). Toluene exposure should be avoided by pregnant women because of possible teratogenic and embryotoxic effects.

19.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of toluene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of toluene, care is required to prevent losses during sample collection and storage. By EPA protocols, soil and water samples should be completed within 14 days of sampling. However, recent studies (3430) show large losses of volatiles from soil handling. At the present, the best procedure is to collect the needed sample in an EPA VOA vial, seal with a foil-lined septum cap, and analyze the entire contents in the vial using a modified purge and trap apparatus. In addition to the targeted samples, quality control samples, such as field blanks, duplicates, and spiked matrices, may be specified in the recommended methods.

EPA-approved procedures for the analysis of toluene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 602, 624, and 1624 (65, A,B). An inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the toluene from the aqueous phase to the vapor phase and into a sorbent trap. The trap is then heated and backflushed to desorb the toluene and transfer it into a gas chromatographic (GC) packed column. The GC column is temperature programmed to separate the volatile organics; toluene is then detected with a photo-ionization detector (Method 602) or a mass spectrometer (Methods 624 and 1624). Recently introduced wide bore capillary columns show considerable

promise for increasing the performance of the gas chromatographic analysis. (3402, 3184)

The EPA procedures recommended for toluene analysis in soil and waste samples, Methods 8020 and 8240 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the trap. The recommended method 5030 for low level samples (<1 mg/kg) involves dispersing the soil or waste sample in water and purging in a heated purge and trap apparatus. The trap is desorbed and analyzed for toluene as described above.

Other sample introduction techniques include direct injection and a headspace method (3355, 3660, 3570). EPA SW-846 Method 3810 (63) describes a generic headspace procedure. In analyses for toluene, a water (3184) or soil sample (suspended in aqueous solution (3355, 3660) or organic solvent (3570) is transferred into a sealed vial that is placed in a thermostatted bath. After an equilibration period, an aliquot of the headspace vapor in the vial is taken (e.g., by gas-tight syringe) for toluene analysis using GC and the flame ionization detector. Far-ultra-violet laser-induced fluorescence has also been used to detect "environmentally significant" levels of toluene in ground water (3128). This method allows determinations to be made remotely by using a fiber-optic probe.

Typical toluene detection limits that can be obtained in waters and nonaqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Nonaqueous Detection Limit
0.2 μg/L (Method 602)	2 μg/kg (Method 8020 with purge and trap)
6.0 μg/L (Method 624)	0.1-0-2 μg/g (3355)
6.0 μg/L (Method 624)	5 μg/kg (Method 8240)
10 μg/L (Method 1624)	
10 μg/L (3355)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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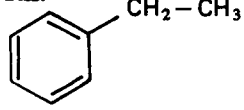
COMMON SYNONYMS:	CAS REG.NO: 100-41-4 FORMULA: C_8H_{10} NIOSH NO: DA0700000 STRUCTURE: 	AIR W/V CONVERSION FACTORS at 25°C (12) 4.34 mg/m³ ≈ 1 ppm 0.2304 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 106.16
Ethyl Benzene Ethyl Benzol Phenyl Ethane EB		

REACTIVITY	Ethyl benzene may generate heat, react vigorously, and possibly ignite or explode in contact with oxidizing mineral acids or other strong oxidizing agents (507, 51, 54, 511).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Sweet, gasoline-like	(59)
	• Odor Threshold: 2.300 ppm	(384)
	• Density: 0.8670 g/mL (at 20°C)	(23)
	• Freeze/Melt Point: -95.00°C	(23)
	• Boiling Point: 136.19°C	(21)
	• Flash Point: 15.00°C closed cup	(23)
	• Flammable Limits: 1.00 to 6.70% by volume	(51,504,506)
	• Autoignition Temp.: 432.0°C	(504,506,510)
	• Vapor Pressure: 7.00 mm Hg (at 20°C)	(67)
	• Satd. Conc. in Air: 4.0000E+04 mg/m³ (at 20°C)	(67)
	• Solubility in Water: 1.52E+02 mg/L (at 20°C)	(67)
	• Viscosity: 0.640 cp (at 25°C)	(599)
	• Surface Tension: 3.1500E+01 dyne/cm (at 20°C)	(21)
	• Log (Octanol-Water Partition Coeff.): 3.15	(29)
	• Soil Adsorp. Coeff.: 6.81E+02	(652)
	• Henry's Law Const.: 7.90E-03 atm · m³/mol (at 25°C)	(74)
	• Bioconc. Factor: 6.80E+01 (estim), 9.50E+01 (estim)	(659,211)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Somewhat mobile in soil-water systems, especially in aqueous phase if sufficient water is present. Volatilization losses through air-filled pores may be a minor loss pathway. Chemical is resistant to hydrolysis, but will probably biodegrade easily if microbiological populations are sufficiently numerous and active. May persist for months to years (or more) if biodegradation is not possible.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of ethyl benzene to groundwater drinking water supplies. It is commonly found in ground water at NPL sites, illustrating the importance of this pathway. Inhalation from surface soils may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (38, 54) Ethyl benzene primarily causes irritation of the eyes, nose, throat and skin. Irritating effects are more pronounced at higher concentrations. Narcosis can occur with very high concentrations; dizziness, drowsiness and weakness may occur. Prolonged or repeated skin contact with the liquid is defatting and may cause dermatitis. Acute Toxicity Studies: (3504) INHALATION: LC_{Lo} 4000 ppm · 4 hr — Rat ORAL: LD_{50} 3500 mg/kg — Rat SKIN: LD_{50} 5000 mg/kg — Rabbit LD_{50} 17800 mg/kg — Rabbit

HEALTH HAZARD DATA (Cont.)	Long-Term Effects: Limited data suggest possible liver and kidney injury Pregnancy/Neonate Data: Teratogenic at high levels Genotoxicity Data: Negative Carcinogenicity Classification: IARC - No data NTP - Study in progress EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation • Vapor concentrations of 100-1000 ppm: chemical cartridge respirator with full facepiece and organic vapor canister • 1000-2000 ppm: any supplied-air respirator or self-contained breathing apparatus with full facepiece; gas mask with organic vapor canister • Chemical goggles if there is probability of eye contact • Impervious clothing and gloves should be used to prevent repeated or prolonged skin contact with liquid.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 100 ppm; STEL (15-min): 125 ppm
- AFOSH PEL (8-hr TWA): 100 ppm; STEL (15-min): 125 ppm

Criteria
- NIOSH IDLH (30-min): 2000 ppm
- ACGIH TLV® (8-hr TWA): 100 ppm
- ACGIH STEL (15-min): 125 ppm

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (3883)
MCLG: 700 μg/L (proposed)
MCL : 700 μg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 30 mg/L
- 10-day (child): 3 mg/L
- longer-term (child): 1 mg/L
- longer-term (adult): 3 mg/L
- lifetime (adult): 0.7 mg/L

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, 1.4 mg/L. Based on ingestion of contaminated aquatic organisms only, 3.28 mg/L.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 32,000 μg/L.

    chronic toxicity:
    no criterion established due to insufficient data.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 430 μg/L.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES: (3744)
ORAL: 1.000E-01 mg/kg/day

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Ethyl benzene is designated a hazardous substance under CWA. It has a reportable quantity (RQ) limit of 454 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), and steam electric power generating (3802). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

EPA lists ethyl benzene as an unregulated contaminant requiring monitoring in all community water systems and non-community non-transient water systems (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of ethyl benzene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

EPA lists spent solvent mixtures containing 10% or more ethyl benzene as non-specific sources of ignitable, toxic hazardous wastes (325). Effective November 8, 1988, land disposal of spent solvent wastes containing 10% or more ethyl benzene is prohibited. Certain variances exist until May, 1990 for some wastewaters, nonwastewaters, and contaminated soils for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). Ethyl benzene is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)

Manufacturers, processors or distributors of ethyl benzene must report production, usage and disposal information to EPA (334). They and others who possess health and safety studies on ethyl benzene must submit them to EPA (3789).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Ethyl benzene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 454 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing ethyl benzene but these depend upon theconcentration of the chemicals present in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of ethyl benzene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Occupational Safety and Health Act (OSHA)
Employee exposure to ethyl benzene in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time- weighted average (TWA) of 100 ppm or a 15-minute short-term exposure limit (STEL) in any 8-hour work-day of 125 ppm (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated ethyl benzene as a hazardous material with a reportable quantity of 454 kg, subject to requirements for packaging,labeling and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

CALIFORNIA
California has set an MCL and an action level of 680 μg/L for drinking water (3096, 3098).

CONNECTICUT
Connecticut has set a quantification limit of 2 μg/L for ethyl benzene in drinking water (3137).

NEW MEXICO
New Mexico has a human health criterion of 0.75 mg/L for ground-water (3499).

NEW YORK
New York has set an MCL of 5 μg/L for drinking water, and a nonenforceable water quality guideline of 50 μg/L for surface and ground-waters (3501).

OKLAHOMA
Oklahoma has a water quality criterion of 0.4 μg/L for ground-water (3534).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 1600 μg/L and a chronic guideline of 36 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires that ethylbenzene be nondetectable, using designated test methods, in ground-water (3671).

VERMONT
Vermont has a preventive action limit of 340 μg/L and an enforcement standard of 680 μg/L for ground-water (3682).

WISCONSIN
Wisconsin has a preventive action limit of 272 μg/L and an enforcement standard of 1360 μg/L for ground-water (3840).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)
  EPA proposed an MCL and MCLG of 0.7 mg/L for ethyl benzene in May, 1989, with final action scheduled for December, 1990 (3759).

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officers is advised. Changes are projected for 1989-90 (3683).

  KANSAS
  Kansas has proposed a water quality standard of 680 μg/L for ethyl benzene in ground-water (3213).

  MINNESOTA
  Minnesota has proposed a Recommended Allowable Limit (RAL) of 680 μg/L for drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 7867 μg/L for surface waters, and chronic criteria of 680 μg/L for designated ground-waters and 175 μg/L for designated surface waters. These criteria are for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water(i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Ethyl benzene is listed as a Class II/c harmful substance and is subject to packaging and labeling regulations.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert poly-meric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Ethyl benzene is classified as a harmful substance and is subject to packaging and labeling regulations.

EEC Directive-Proposed Resolution

Resolution on a Revised List of Second-Category Pollutants (545)
Ethylene benzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

20.1 MAJOR USES

The major application of ethyl benzene is as an intermediate in the production of styrene. It is also used in the manufacture of cellulose acetate and synthetic rubber. Significant quantities are consumed in connection with xylene, which may contain as much as 20% ethyl benzene as a solvent or diluent. These xylene/ethyl benzene mixtures are used as diluents in the paint industry, in agricultural sprays for insecticides and in gasoline blends (54, 21).

20.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

20.2.1 Transport in Soil/Ground-water Systems

20.2.1.1 Overview

Ethyl benzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways for low soil concentrations can be assessed by using an equilibrium partitioning model, as shown in Table 20-1. These calculations predict the partitioning of ethyl benzene among soil particles, soil water and soil air. Ethyl benzene associated with the water and air phases of the soil is more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that nearly all of the ethyl benzene (98%) is sorbed to the soil. A much smaller amount (0.75%) is expected to be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the portion of ethyl benzene in the gaseous phase of the soil (0.7%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, will be a significant loss pathway. There is no significant difference in the partitioning calculated for 25°C and 10°C.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the ethyl benzene (26%) is likely to be present in the soil-water phase (Table 20-1) and transported with flowing ground-water.

TABLE 20-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR ETHYL BENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c]			
at 25°C	98.5	0.75	0.74
at 10°C	98.8	0.76	0.42
Saturated deep soil[d]	74.1	25.9	-

a) Calculations based on Mackay's equilibrium partitioning model (34,35,36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 681 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 0.00790 atm · m^3/mol at 25°C (74), and 0.00430 atm · m^3/mol at 10°C (latter calculated using 25°C/10°C ratio of H values from Brown and Wasik (521)).
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

20.2.1.2 Sorption on Soils

The mobility of ethyl benzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 1410, the soil sorption coefficient (K_{oc}) is estimated to be 681. This number is indicative of a moderate soil sorption potential.

20.2.1.3 Volatilization from Soils

Transport of ethyl benzene vapors through the air-filled pores of unsaturated soils is an important transport mechanism for near-surface soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31). No data are available from laboratory or field studies to indicate the actual rate of volatilization, but the rate should not be much different than for toluene (see Chapter 19).

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, is expected to increase significantly with increasing temperature. Moderate increases in H are also expected with increasing salinity due to a decrease in ethyl benzene's solubility (517).

20.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of ethyl benzene in soil/ground-water systems has not been studied. In most cases, it should be assumed that the chemical will persist for months to years (or more).

Ethyl benzene that has been released into the air will eventually undergo photochemical oxidation; an estimated tropospheric lifetime of 15 hours has been reported (10). Ethyl benzene under normal environmental conditions is not expected to undergo hydrolysis (10, 33).

The available data indicate that ethyl benzene would be biodegradable in the soil/ground-water environment (10, 55). Some species of soil bacteria are capable of using ethyl benzene as the sole carbon source. The data from Tabak et al. (55) indicate that the chemical would be fairly easily biodegraded in a biological wastewater treatment plant. However, in most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as ethyl benzene is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in landfills with active microbiological populations.

20.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The properties of ethyl benzene and the above discussion of fate pathways suggest that ethyl benzene is highly volatile in aqueous solutions, may be moderately adsorbed by soil and has a moderate potential for bioaccumulation. This compound may volatilize from soil surfaces. The portion of the compound not removed by volatilization may be adsorbed, but some of the ethyl benzene may migrate to groundwater. These fate characteristics suggest several potential exposure pathways.

Volatilization of ethyl benzene from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. In addition, the potential for ground-water contamination is high, particularly in sandy soils. Mitre (1983) reported that ethyl benzene has been found at 47 of 546 National Priority List (NPL) sites. It was detected at 32 sites in ground-water, 13 sites in surface water and 7 sites in air.

This compound was also reported in the USEPA (531) Ground-water Supply Survey (GWSS). This survey examined 945 finished water supplies that use ground-water sources. The results for ethyl benzene are shown below:

Sample Type	Occurrences* No	%	Median of Positives (μg/L)	Maximum (μg/L)
Random				
Supplies serving <10,000 people (280 samples)	2	0.7	0.94	1.1
Supplies serving >10,000 people (186 samples)	1	0.5	0.74	0.74
Non-Random				
Supplies serving <10,000 people (321 samples)	5	1.6	1.6	12.0
Supplies serving >10,000 people (158 samples)	0	0	-	-

*Samples having levels over quantification limit of 0.5 μg/L.

The random results are intended to statistically represent the U.S. ground-water drinking water supplies. The non-random samples were chosen by the states as being potentially contaminated. Ethyl benzene has also been detected in the National Organic Monitoring Survey (NOMS) (90).

These survey results indicate that this compound has the potential for movement in soil/ground-water systems. This compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may bioaccumulate this chemical and be consumed, also resulting in ingestion exposures;
- Recreational use of these waters may result in dermal exposures;

- Domestic animals may consume or be dermally exposed to contaminated ground- or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposure from drinking contaminated ground-water. The Henry's law constant for ethyl benzene suggests that it will volatilize upon reaching surface waters. However, if ethyl benzene is available, the bioconcentration factor for this compound suggests moderate bioaccumulation in aquatic organisms or domestic animals.

20.2.4 Other Sources of Exposure

The volatility of ethyl benzene suggests that it may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric monitoring data for a number of volatile organics. For ethyl benzene, they had data for 861 locations. In rural and remote areas, the median concentration was 2.0 $\mu g/m^3$. In urban and suburban areas, the median concentration was 5.2 $\mu g/m^3$ and in source-dominated locations, the median concentration was 2.7 $\mu g/m^3$. These results suggest there are inhalation exposures to individuals, even in remote areas.

20.3 HUMAN HEALTH CONSIDERATIONS

20.3.1 Animal Studies

20.3.1.1 Carcinogenicity

Maltoni et al. (3423) reported on carcinogenicity studies in Sprague-Dawley rats (40 of each sex) administered 500 mg/kg ethyl benzene (in olive oil) by gavage once daily, 4-5 days/week for 104 weeks. Controls received olive oil alone. At the end of the experiment (141 weeks) there was 40.3% total malignant tumors in treated males and females combined (35% in males, 45.9% in females), compared with 24% in control males and female combined (26.7% in males and 22.4% in females).

20.3.1.2 Genotoxicity

The number of sister chromatid exchanges in human lymphocytes treated in culture with ethyl benzene was essentially at control levels (209). Dean et al. found ethyl benzene negative in a battery of tests including the five standard Salmonella strains, two strains of E. coli, a strain of yeast designed to test for gene conversion at two loci, and two rat liver cell lines designed to detect chromosomal aberrations (3163). Ethyl benzene was also found negative in two yeast strains, one designed to detect gene conversion at two loci, and the other to detect reversions at three loci (3493). Nestmann et al. (3494) found ethyl benzene to be negative in the five standard Salmonella strains with or without metabolic activation.

When ethyl benzene was injected intraperitoneally in male mice, no increase was detected in the incidence of micronuclei in bone marrow cells of the treated animals (3462). Ethyl benzene did not induce sex-linked recessive lethals in the germ cells of males treated with this compound (3178).

20.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Hardin et al. (208) exposed rats and rabbits to 100 or 1000 ppm ethyl benzene for 6 to 7 hours daily. No significant maternal or fetal toxicity was seen in rabbits. In rats, a possible reduction in fertility was noted at both exposure levels, but no dose-response was evident. Maternal toxicity in the form of increased spleen, liver and kidney weights was seen in the 1000 ppm group. In the fetuses, there was a significant increase in the incidence of extra ribs at both exposure levels.

Ungvary and Tatrai (3753) used rats, mice, and rabbits to test the embryotoxicity of ethyl benzene by inhalation. In rats exposed to 600, 1200 or 2400 mg/m^3, maternal toxicity was moderate and dose-dependent. There was an increase in postimplantation loss and skeletal retardation of the fetuses at all levels. The highest concentration resulted in an increased incidence of extra ribs, anomalies of the uropoietic (production of urine) apparatus, malformations of the skeleton, and weight retardation. Mice exposed at the 500 mg/m^3 level produced offspring with an increased incidence of anomalies of the uropoietic apparatus. Ethyl benzene was very toxic to pregnant rabbits at the 1000 mg/m^3 level, causing abortion, resorption or death of the mother in all eight does. At 500 mg/m^3, pregnancy was normal except for a slight decrease in mean weight of female fetuses.

20.3.1.4 Other Toxicologic Effects

20.3.1.4.1 Short-term Toxicity

Acute toxicity data on oral and dermal routes in both rats and rabbits indicate a low toxicity for ethyl benzene. An oral LD_{50} in rats of 3500 mg/kg has been reported; dermal LD_{50} values in rabbits of 500 mg/kg (59) and 17,800 mg/kg (47) have been recorded.

Wolf et al. (210) evaluated the ability of ethyl benzene to produce injury to the eye and skin of rabbits. They found that two drops applied to the eye produced slight conjunctival irritation but no corneal injury. Ten to twenty applications to the ear and abdomen for 2 to 4 weeks produced moderate redness, swelling, superficial necrosis and blistering.

20.3.1.4.2 Chronic Toxicity

Chronic inhalation exposure of guinea pigs, monkeys, rabbits and rats at concentrations ranging from 400 to 2200 ppm for 7 to 8 hours per day, 5 days per week for 6 months produced no effects in guinea pigs, monkeys and rabbits; rats exhibited a slight increase in liver and kidney weights (210). The same investigators noted changes in the liver and kidney in rats administered 408 or 680 mg/kg/day ethyl benzene in olive oil, 5 days per week for 6 months. No effects on the bone marrow were observed (210).

Elovaara et al. (3198) reported on the effects of ethyl benzene on drug-metabolizing enzymes in the liver and kidney of male Wistar rats and also on accompanying ultrastructural changes in the liver. The rats were exposed for 6 hours/day, 5 days/week to 50, 300, or 600 ppm of ethylbenzene vapor, and killed after 2, 5, 9 or 16 weeks of exposure. Microsomal protein content was increased significantly ($p < 0.01$ at 2 weeks, and $p < 0.05$ at 5 and 9 weeks) in rats exposed to 600 ppm of ethylbenzene, and also in the 300 ppm and 50 ppm exposure groups at 9 weeks ($p < 0.01$). NADPH-cytochrome c reductase activity was increased by 30% (≤1.3-fold) after exposure to 300 or 600 ppm of the chemical, but microsomal cytochrome P-450 concentration was only marginally affected. In the kidneys, 7-ethoxycoumarin O-deethylase (≤3.5-fold) and UDPG-transferase (≤1.8-fold) showed dose-related increases. Electron microscopic examination revealed changes in hepatocyte ultrastructure at all three concentrations of ethyl benzene after 2, 5, and 9 weeks: the smooth endoplasmic reticulum showed proliferation and the rough endoplasmic reticulum was partly split and shortened with slight degranulation; some mitochondria were enlarged and branched. After 16 weeks, these changes were mainly in the 600 ppm group.

20.3.2 Human and Epidemiologic Effects

Ethyl benzene is primarily an irritant to the skin, eyes and upper respiratory tract. Systemic absorption causes central nervous system depression (38). Inhalation of ethyl benzene might exacerbate the symptoms of obstructive airway diseases (e.g., emphysema) due to its irritant properties or reflex bronchospasm. Aspiration of small amounts causes extensive edema and hemorrhage of lung tissue (38).

No human ingestion data are available and inhalation data are limited. At 200 ppm (870 mg/m^3), the vapor has a transient irritant effect on the eyes. At 2000 ppm, eye irritation and lacrimation are immediate and severe and are accompanied by moderate nasal irritation. Tolerance to these effects develops after several minutes. Central nervous system effects begin after about 6 minutes at this level. At 5000 ppm, the irritation of the eyes, nose and throat becomes intolerable (19, 2, 211). Redness and inflammation may result from skin contact with the liquid (51). The rate of absorption through the skin of the hand and forearm is 22 to 33 mg/cm^2. per hour (46). Ethyl benzene is not known to be toxic to the liver or kidneys; however,

concern for these organs has been expressed since they are the primary routes of metabolism and excretion, respectively (54).

Angerer and Wulf (3029) examined 35 spraymen who used varnishes dissolved in solvent mixtures containing mainly o-, m-, p-xylene, and ethylbenzene. The average concentrations of the solvents in air were 2.1, 7.9, 2.8, and 4.0 ppm respectively. The spraymen were between 24 and 52 years (average 38.8 years) and had been employed for between 2 and 24 years (average 8.2 years) at that firm. The concentration of ethylbenzene found in the blood of the workers was 61.4 ± 62.3 μg/L. Alterations of blood counts were observed in the workers exposed to the various solvent mixtures. (They were also exposed to n-butanol, 1,1,1-trichloroethane, some C9-aromatic hydrocarbons, and lead pigments). On the average, the number of lymphocytes was higher than that of segmented granulocytes. Erythrocytes and hemoglobin levels of the spraymen were lower than those of controls.

20.3.3.3 Levels of Concern

The USEPA (355) has established an ambient water quality criterion for the protection of human health for ethyl benzene of 1.4 mg/L. This criterion is based on the threshold limit value (100 ppm) for occupational exposure to vapors, which was set to prevent irritation rather than chronic effects. An uncertainty factor of 1000, 50% absorption (assumed), a bioconcentration factor of 37.5 for fish and consumption of two liters of water and 6.5 g of contaminated fish per day were also utilized to calculate the criterion. A MCL for ethyl benzene in drinking water of 700 μg/L has been proposed by the USEPA (3883).

Both OSHA (3539) and the ACGIH (3005) have set an occupational exposure limit (8-hr TWA) of 100 ppm (435 mg/m^3) for ethyl benzene, based on preventing eye irritation.

20.3.3.4 Hazard Assessment

The extent and quality of health effects data available for ethyl benzene are inadequate. Available data deal primarily with the irritant properties of ethyl benzene. The limited nature of these studies, linked with the sparse information on chronic and subchronic toxicity, and carcinogenic activity, make estimation of the hazards of long-term low-level human exposure to this compound difficult to define. Almost all short-term tests for genotoxicity have found ethyl benzene to be negative. In the only carcinogenic study found in the literature, there was an increase in malignant tumors in rats treated with high concentrations of ethyl benzene.

20.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of ethyl benzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of ethyl benzene, care is required to prevent losses during sample collection

and storage. Soil and water samples should be collected in airtight containers with no headspace; analysis should be completed within 14 days of sampling. However, recent studies (3430) show large losses of volatiles from soil handling. At the present, the best procedure is to collect the needed sample in an EPA VOA vial, seal with a foil-lined septum cap, and analyze the entire contents in the vial using a modified purge and trap apparatus. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of ethyl benzene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 602, 624, 1624 (65), 8020 and 8240 (63). An inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the ethyl benzene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the ethyl benzene and transfer it onto a gas chromatographic (GC) column. The GC column is programmed to separate the volatile organics; ethyl benzene is then detected with a photo-ionization detector (Methods 602 and 8020) or a mass spectrometer (Methods 624, 1624, and 8240). Direct injection may also be used for samples containing elevated concentrations.

The EPA procedures recommended for ethyl benzene analysis in soil and waste samples, Methods 8020 and 8240 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The recommended method for low level samples (<1 mg/kg) (Method 5030) involves dispersing the soil or waste sample in water and purging in a heated purge and trap device. Other sample introduction techniques include direct injection and a headspace method.

Typical ethyl benzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.2 μg/L (Method 602)	2 μg/kg (Method 8020)
7.2 μg/L (Method 624)	5 μg/kg (Method 8240)
10 μg/L (Method 1624)	
5 μg/L (Method 8240)	
2 μg/L (Method 8020)	

20.5 REFERENCES

Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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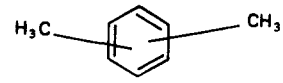
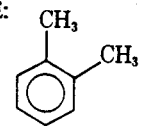
COMMON SYNONYMS:	CAS REG NO: 1330-20-7 FORMULA: C_8H_{10} NIOSH NO: ZE2190000 STRUCTURE: 	AIR W/V CONVERSION FACTORS at 25°C (12) 4.34 mg/m³ ≈ 1 ppm 0.2304 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 106.17

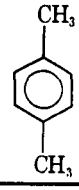
PHYSICO-CHEMICAL DATA (mix)	• Isomer, grade, or form: Mixed	
	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Aromatic	(2)
	• Odor Threshold: 1.100 ppm	(384)
	• Density: No data	
	• Freeze/Melt Point: No data	
	• Boiling Point: No data	
	• Flash Point: No data	
	• Flammable Limits: No data	
	• Autoignition Temp.: No data	
	• Vapor Pressure: No data	
	• Satd. Conc. in Air: No data	
	• Solubility in Water: No data	
	• Viscosity: No data	
	• Surface Tension: No data	
	• Log (Octanol-Water Partition Coeff.): 3.16 (avg)	(29)
	• Soil Adsorp. Coeff.: No data	(652)
	• Henry's Law Const.: No data	(74)
	• Bioconc. Factor: 7.00E+01 (average estim; o-,m-,p-)	(659)

Note: Throughout this chapter, the term xylene refers to the mixed isomers unless otherwise specified. Where appropriate, the isomers are identified by the prefixes o-(ortho), m-(meta) or p-(para).

COMMON SYNONYMS:	CAS REG NO.: 95-47-6 FORMULA: C_8H_{10} NIOSH NO: ZE2450000	AIR W/V CONVERSION FACTORS at 25°C (12)
o-Dimethylbenzene o-Xylene o-Xylol	STRUCTURE: 	4.34 mg/m³ ≈ 1 ppm 0.2304 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 106.17

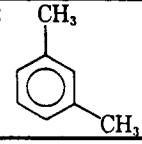
PHYSICO-CHEMICAL DATA (ortho)	• Isomer, grade, or form: o	
	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Aromatic	(2)
	• Odor Threshold: 1.100 ppm	(384)
	• Density: 0.8802 g/mL (at 25°C)	(21)
	• Freeze/Melt Point: -25.20°C	(21)
	• Boiling Point: 144.40°C	(21)
	• Flash Point: 31.00°C	(21)
	• Flammable Limits: 1.00 to 7.00% by volume	(504,12)
	• Autoignition Temp.: 464.0°C	(51,506)
	• Vapor Pressure: 7.00 mm Hg (at 20°C)	(38)
	• Satd. Conc. in Air: 4.0750E+04 mg/m³ (at 20°C)	(ADL. est.)
	• Solubility in Water: 3.00E-01 mg/L (at 20°C)	(38)
	• Viscosity: 0.802 cp (at 20°C)	(48)
	• Surface Tension: 3.2500E+01 dyne/cm (at 20°C)	(21)
	• Log (Octanol-Water Partition Coeff.): 3.12	(29)
	• Soil Adsorp. Coeff.: 6.91E+02	(652)
	• Henry's Law Const.: 4.94E-03 atm · m³/mol (at 25°C)	(74)
	• Bioconc. Factor: 7.00E+01 (average estim; o-,m-,p-)	(659)

Note: Throughout this chapter, the term xylene refers to the mixed isomers unless otherwise specified. Where appropriate, the isomers are identified by the prefixes o- (ortho), m-(meta) or p-(para).

COMMON SYNONYMS:	CAS REG NO: 106-42-3 FORMULA: C_8H_{10} NIOSH NO: ZE2625000 STRUCTURE: 	AIR W/V CONVERSION FACTORS at 25°C (12) 4.34 mg/m³ ≈ 1 ppm 0.2304 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 106.17

PHYSICO-CHEMICAL DATA (para)	• Isomer, grade, or form: p	
	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Aromatic	(2)
	• Odor Threshold: 1.100	(384)
	• Density: 0.8610 g/mL (at 25°C)	(21)
	• Freeze/Melt Point: 13.30°C	(21)
	• Boiling Point: 138.70°C	(21)
	• Flash Point: 27.00°C	(21)
	• Flammable Limits: 1.00 to 7.00% by volume	(504,12)
	• Autoignition Temp.: 529.0°C	(513)
	• Vapor Pressure: 9.00 mm Hg (at 20°C)	(38)
	• Satd. Conc. in Air: 5.2400E+04 mg/m³ (at 20°C)	(ADL. est.)
	• Solubility in Water: 3.00E-01 mg/L (at 20°C)	(38)
	• Viscosity: 0.635 cp (at 20°C)	(48)
	• Surface Tension: 2.8300E+01 dyne/cm (at 20°C)	(21)
	• Log (Octanol-Water Partition Coeff.): 3.15	(29)
	• Soil Adsorp. Coeff.: 6.91E+02	(652)
	• Henry's Law Const.: 7.01E-03 atm · m³/mol (at 25°C)	(74)
	• Bioconc. Factor: 7.00E+01 (average estim; o-,m-,p-)	(659)

Note: Throughout this chapter, the term xylene refers to the mixed isomers unless otherwise specified. Where appropriate, the isomers are identified by the prefixes o- (ortho), m-(meta) or p-(para).

COMMON SYNONYMS:	CAS REG NO: 108-38-3 FORMULA: C_8H_{10} NIOSH NO: ZE2275000 STRUCTURE: 	AIR W/V CONVERSION FACTORS at 25°C (12) 4.34 mg/m³ ≈ 1 ppm 0.2304 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 106.17

PHYSICO-CHEMICAL DATA (meta)	• Isomer, grade, or form: m	
	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Aromatic	(2)
	• Odor Threshold: 1.100 ppm	(384)
	• Density: 0.8642 g/mL (at 25°C)	(21)
	• Freeze/Melt Point: -47.90°C	(21)
	• Boiling Point: 139.10°C	(21)
	• Flash Point: 29.00°C	(21)
	• Flammable Limits: 1.00 to 7.00% by volume	(504,12)
	• Autoignition Temp.: 528.0 to 530.0°C	(506,60)
	• Vapor Pressure: 9.00 mm Hg (at 20°C)	(38)
	• Satd. Conc. in Air: 5.2400E+04 mg/m³ (at 20°C)	(ADL. est)
	• Solubility in Water: 3.00E-01 mg/L (at 20°C)	(32)
	• Viscosity: 0.061 cp (at 20°C)	(48)
	• Surface Tension: 3.1200E+01 dyne/cm (at 20°C)	(21)
	• Log (Octanol-Water Partition Coeff.): 3.20	(29)
	• Soil Adsorp. Coeff.: 6.91E+02	(652)
	• Henry's Law Const.: 6.91E-03 atm · m³/mol (at 25°C)	(74)
	• Bioconc. Factor: 7.00E+01 (average estim; o-,m-,p-)	(659)

Note: Throughout this chapter, the term xylene refers to the mixed isomers unless otherwise specified. Where appropriate, the isomers are identified by the prefixes o- (ortho), m-(meta) or p-(para).

REACTIVITY	Xylenes may generate heat, react vigorously, and possibly ignite or explode in contact with oxidizing mineral acids or other strong oxidizing agents (512, 507, 38, 511).

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems, especially in aqueous phase. Volatilization through air-filled pores is also possible. Chemical is resistant to hydrolysis but is probably biodegradable. Should assume chemical could persist for months to years (or longer).

PATHWAYS OF EXPOSURE	The primary pathway of concern from soil-water systems is the migration of xylene to groundwater drinking water supplies. Data from NPL sites indicate that migration of this compound has occurred in the past. Inhalation resulting from volatilization from surface soils may also be important.

HEALTH HAZARD DATA (Cont.)	Signs and Symptoms of Short-term Human Exposure: (54) Acute exposure to high concentrations of xylene vapors in air may cause CNS depression with symptoms including dizziness, drowsiness, nausea, vomiting, abdominal pain, loss of appetite, pulmonary edema, and unconsciousness, as well as reversible effects on the liver and kidneys. Liquid xylene and high vapor concentrations are irritating to the eyes and the vapor may cause transient, reversible damage to the cornea. Aspiration of liquid into the lungs may cause chemical pneumonitis, pulmonary edema and hemorrhage.

HEALTH HAZARD DATA	Acute Toxicity Studies: (47) INHALATION: LC_{50} 5000 ppm · 4hr Rat ORAL: LD_{50} 4300 mg/kg Rat Long-Term Effects: Possible damage to liver and kidneys, but such effects have not been demonstrated with certainty Pregnancy/Neonate Data: Negative in rats; cleft palates in mice but only at near lethal levels Genotoxicity Date: Negative Carcinogenicity Classification: IARC - No data NTP - No evidence in mice and rats EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (38, 52)	Handle xylene only with adequate ventilation • Vapor concentrations of 100-1000 ppm: chemical cartridge respirator with full facepiece and organic vapor cartridge • 1000-5000 ppm: any supplied-air respirator or self-contained breathing apparatus with full facepiece or NIOSH-approved respirator with organic vapor canister • Chemical goggles if there is probability of eye contact • Natural rubber, neoprene, PVA, PVC, gloves/apron/ boots and protective clothing to prevent prolonged or repeated skin contact with liquid.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 100 ppm; STEL (15-min): 150 ppm
- AFOSH PEL (8-hr TWA): 100 ppm; STEL (15-min): 150 ppm

Criteria
- NIOSH IDLH (30-min): 1000 ppm
- NIOSH REL (10-hr TWA): 100 ppm; ceiling (10-min): 200 ppm
- ACGIH TLV® (8-hr TWA): 100 ppm
- ACGIH STEL (15-min): 150 ppm

WATER EXPOSURE LIMITS:

Drinking Water Standards (3742)
MCLG: 10,000 μg/L (proposed)
MCL : 10,000 μg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 40 mg/L
- 10-day (child): 40 mg/L
- longer-term (child): 40 mg/L
- longer-term (adult): 10 mg/L
- lifetime (adult): 10 mg/L

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  No criterion established; xylene is not a priority pollutant.

- Aquatic Life (355)
  No criterion established; xylene is not a priority pollutant.

REFERENCE DOSES:

ORAL: 2.000E+03 μg/kg/day (3744)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Dimethylphenol (Xylenol) is designated a hazardous substance under the CWA. It has a reportable quantity (RQ) of 454 kg (347, 3764) 2,4-Dimethylphenol is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

In states with an approved Underground Injection Control program, a permit is required for the injection of 2,4-dimethylphenol-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

2,4-Dimethylphenol is identified as a toxic hazardous waste (U101) and listed as a hazardous waste constituent (3783, 3784). Waste streams from the following industries contain 2,4-dimethylphenol and are listed as specific sources of hazardous waste: wood preservation (creosote and/or penta- chlorophenol preserving processes), coking operations, and petroleum refining (3774, 3765). 2,4-Dimethylphenol is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective November 8, 1988, the land disposal of certain untreated 2,4-dimethylphenol-containing hazardous wastes is prohibited. These wastes must be treated according to Best Demonstrated Available Technology (BDAT) treatment standards before being disposed. Certain variances exist until May, 1990 for other hazardous wastes for which BDAT treatment standards have not been promulgated by EPA (3786). 2,4-Dimethyl-phenol is on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
2,4-Dimethylphenol is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing 2,4-dimethylphenol but these depend upon the concentration of the chemicals present in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of 2,4-dimethylphenol must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Food, Drug and Cosmetic Act (FDCA)
The level for phenols in bottled drinking water is 0.001 mg/L (365).

Occupational Safety and Health Act (OSHA)
Employee exposure to xylene in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 100 ppm in any 8-hour work-day or a short-term-exposure limit of 150 ppm for 15 minutes (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 2,4-dimethylphenol as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria.

ARIZONA
Arizona has a water quality criterion of 5 μg/L for phenolics in all public waters (3827).

DISTRICT OF COLUMBIA
The District of Columbia has a human health criterion of 400 μg/L for public water supply (class D) surface waters and 200 μg/L for class C surface waters (3828, 3827).

FLORIDA
Florida has water quality criterion for phenolic compounds of 1 μg/L for general use surface waters, and 0.2 mg/L for Class V (navigation, industrial use) surface waters (3220).

ILLINOIS
Illinois has a water quality standard for phenols of 100 μg/L for general use waters, 1 μg/L for public and food processing water supplies, and 300 μg/L for aquatic life waters (3371, 3827).

INDIANA
Indiana has set the following surface water quality criteria for phenols and phenolic compounds: 10 μg/L for the Ohio River and Wabash River, 300 μg/L (daily maximum) for Lake Michigan and contiguous harbor areas, and 10 μg/L for the Grand Calumet River and Indiana Harbor (3827).

IOWA
Iowa has a surface water quality standard of 50 μg/L for phenolic compounds in Class B and C surface waters (3327).

KANSAS
Kansas has an action level for 2,4-dimethylphenol of 400 μg/L for ground-water (3213).

KENTUCKY
Kentucky has a surface water quality criterion of 5 μg/L for phenolic compounds in warm and coldwater aquatic habitats (3827).

LOUISIANA
Louisiana has water quality criteria for phenols of 5 μg/L for drinking water supply waters, 440 μg/L for marine surface waters, and 50 μg/L for fresh surface waters (3406).

MINNESOTA
Minnesota has surface water quality criterion of 10 μg/L for phenols in Fisheries and Recreation waters (3827).

MISSISSIPPI
Mississippi requires that the level of phenolic compounds in the public water supply not exceed 1 μg/L (3684). Mississippi also has a surface water quality standard of 50 μg/L for phenolic compounds for fish and wildlife protection (3684).

NEVADA
Nevada has a water quality criterion for phenolics of 1 μg/L for all surface waters (3827).

NEW HAMPSHIRE
New Hampshire has a drinking water standard of 1 μg/L for phenols (3710). New Hampshire also has a surface water quality standard of 1 μg/L for Class A and B waters and 2 μg/L for Class C waters (3684).

NEW JERSEY
New Jersey sets the maximum concentration levels for phenols in the Delaware River and Bay at the following levels: 5 μg/L for Zones 1, 2 and 3, 20 μg/L for Zone 4, and 10 μg/L for Zones 5 and 6. These are maximum levels that apply unless exceeded due to natural conditions (3498).

NEW YORK
New York has an ambient water quality standard for aquatic life of 5 μg/L for total unchlorinated phenols for all freshwater classes of surface waters (3500). New York has also set an MCL of 5 μg/L for 2,4-dimethylphenol in drinking water and a water quality standard of 1 μg/L for phenol and phenolic compounds in ground-water and surface water classed for drinking water supply (3501).

NORTH CAROLINA
North Carolina has a water quality standard of 1 μg/L for phenolic compounds in Class WS-I, WS-II, and WS-III surface waters (3681).

OHIO
Ohio has a surface water quality standard for phenolic compounds of 1 μg/L for Lake Erie use waters, public water supply waters, aquatic life habitat coldwaters and exceptional warmwaters, and 10 μg/L for aquatic life habitat warmwaters (3827).

OKLAHOMA
Oklahoma has set an unenforceable Toxic Substance Goal of 55.5 μg/L for public and private water supply surface waters (3534).

OREGON
Oregon has a surface water quality criterion of 1 μg/L for phenols in all surface waters (3827).

PENNSYLVANIA
Pennsylvania has a human health criterion for total phenolics of 5 μg/L measured in surface waters at the point of water supply intake (3561). Pennsylvania also has a human health criterion of 400 μg/L for 2,4-dimethylphenol in surface water (3561).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 106 μg/L and a chronic guideline of 2.4 μg/L for surface waters for the protection of aquatic life. These guidelines are enforceable under Rhode Island state law (3590).

TENNESSEE
Tennessee sets an effluent limitation of 1.0 mg/L for phenols in effluent from industrial wastewater treatment plants (3827).

VIRGINIA
Virginia has a water quality criterion for phenols of 1 μg/L for groundwater and public water supply surface waters, and a chronic criterion for the protection of aquatic life of 1 μg/L for phenol in surface water (3135, 3827).

WEST VIRGINIA
West Virginia sets 0.001 mg/L as the maximum concentration secondary contaminant level for phenols in drinking water in the community public water systems (3576).

WISCONSIN
Wisconsin has a taste and odor criterion threshold concentration of 400 μg/L for 2,4-dimethylphenol in surface waters (3841).

Proposed Regulations

- Federal Programs
  No proposed federal regulations are pending.

- State Water Programs
  MOST STATES
  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

  IOWA
  Iowa has proposed acute criteria for phenols of 50 μg/L for Class C surface waters, 1000 μg/L for Class B cold surface waters, and 2500 μg/L for Class B warm surface waters, and a chronic criterion of 50 μg/L for all Class B surface waters. These criteria are for the protection of aquatic life (3326).

  MINNESOTA
  Minnesota has proposed a Sensitive Acute Limit (SAL) of 530 μg/L and a chronic criterion of 12 μg/L for 2,4-dimethylphenol in designated surface waters for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Xylene is listed as a Class II/c harmful substance and is subject to packaging and labeling regulations.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert poly-meric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Xylene is classified as a harmful substance and is subject to packaging and labeling regulations. Xylene may contain a stablizer. If the stablizer changes the dangerous properties, this substance should be labeled in accordance with rules in Annex I and EEC/88/490, 22 July 1988.

EEC Directive-Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
Xylene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

21.1 MAJOR USES

Commercial xylene is a mixture of the ortho, meta and para isomers, with the meta form usually the principal component (60-70%). Xylene may also contain 6 to 10% impurities such as benzene, ethyl benzene, trimethylbenzene, toluene, phenol, thiophene, pyridene and nonaromatic hydrocarbons. The xylenes are widely used as fuel components and as solvents for inks, rubbers, gums, resins, adhesives, lacquers, paints and insecticides. Xylenes are commonly used in the chemical industry as intermediates. Specifically, o-xylene is used in the manufacture of phthalic anhydride which is a basic building block for plasticizers. Meta-xylene is an intermediate in the preparation of isophthalic acid which is the base of unsaturated polyester resins. Commercially, para-xylene is the most important isomer. Almost all is converted to terephthalic acid or dimethylterephthalate and used to make fibers, films and resins (2, 12, 21).

21.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

21.2.1 Transport in Soil/Ground-water Systems

21.2.1.1 Overview

Xylene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by using an equilibrium partitioning model as shown in Table 21-1. These calculations predict the partitioning of xylene among soil particles, soil water and soil air. The portions of xylene associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that nearly all of the xylene (98.8%) is expected to be sorbed to the soil. A much smaller amount (0.7%) is expected to be present in the soil-water phase and thus available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the portion of xylene in the gaseous phase of the soil (0.5%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, will be a significant loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the xylene (26%) is likely to be present in the soil-water phase (Table 21-1) and transported with flowing ground water.

TABLE 21-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR XYLENE
IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	98.8	0.7	0.5
Saturated deep soil[d]	74.4	25.6	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 691 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 0.007 atm • m^3/mol at 25°C.
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

Laboratory batch and column experiments by Schwarzenbach and Westall (228) showed that p-xylene could be fairly mobile in soil/ground-water systems. The relative velocity (velocity of xylene/velocity of water) was 0.05 in a river sediment and 0.45 in aquifer material. Demirjian et al. (522) found that xylene applied (at 0.13 μg/ha) in a sludge land-treatment study was not detectable in the soil at the end of the study period. Volatilization losses may have been an important transport pathway.

In a field study on the removal of organics in water by dune-infiltration (using water from the Rhine River), Piet et al. (226) actually found increases in the concentration of o-xylene after infiltration. While the reason for this increase is not known, and may have been due to some artifact of the study, the results do indicate that xylene is easily transported by infiltrating water.

21.2.1.2 Sorption on Soils

The mobility of xylene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 1450 (average for the 3 isomers), the soil sorption coefficient (K_{oc}) is estimated to be 691. This number is indicative of moderate sorption potential.

21.2.1.3 Volatilization from Soils

Transport of xylene vapors through the air-filled pores of unsaturated soils is an important transport mechanism for near-surface soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

21.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of xylene in soil/ground-water systems has not been studied. In most cases, it should be assumed that the chemical will persist for months to years (or more).

Xylene under normal environmental conditions is not expected to undergo hydrolysis since it contains no hydrolyzable functional groups (529).

No information on the biodegradability of xylene in the soil/ground-water environment is available. However, based upon data for other structurally-similar chemicals (e.g., toluene, ethyl benzene), it is expected that xylene would be biodegradable. The importance of biodegradation as a fate pathway would, of course, depend upon the type and concentration of microorganisms present as well as many other environmental factors.

21.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that the xylene isomers are highly volatile from aqueous solutions, moderately adsorbed by soil and have a moderate potential for bioaccumulation. The xylene isomers may volatilize from soil surfaces. The portion not removed by volatilization may eventually migrate to ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of xylenes from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. In addition, there is a potential for ground water contamination, particularly in sandy soil. Mitre (83) reported that xylene has been found at 40 of the 546 National Priority List (NPL) sites. It was detected at 30 sites in ground water, 8 sites in surface water and 8 sites in air.

This compound was reported in the USEPA (531) Ground Water Supply Survey (GWSS). This survey examined 945 finished water supplies that use ground-water sources. The results for the xylene isomers are summarized Table 21-2.

The random results are intended to statistically represent the U.S. ground-water drinking water supplies. The non-random samples were chosen by the states as being potentially contaminated. Xylenes have also been detected in the National Organic Monitoring Survey (NOMS) (90).

The properties and the survey results described above indicate that xylenes have the potential for movement in soil/ground-water systems. These compounds may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure.
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures.
- Recreational use of these waters may result in dermal exposures.
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower then exposure from drinking contaminated ground water for two reasons. First, the Henry's law constants for xylenes suggest that volatilization will occur upon reaching surface waters. Secondly, the BCF for xylene is not high enough to suggest consumption of aquatic organisms or domestic animals as a significant source of exposure compared to drinking water.

TABLE 21-2
XYLENE ISOMERS IN GROUND-WATER

Sample Type	No.	%	Median of Positives (μg/L)	Maximum (μg/L)
m-Xylene				
Random				
Supplies serving <10,000 people (280 samples)	6	2.1	0.32	1.5
Supplies serving >10,000 people (186 samples)	2	1.1	0.59	0.91
Non-Random				
Supplies serving <10,000 people (321 samples)	8	2.5	0.38	0.83
Supplies serving >10,000 people (158 samples)	0	0	-	-
o- and p-Xylene				
Random				
Supplies serving <10,000 people (280 samples)	6	2.1	0.34	0.59
Supplies serving >10,000 people (186 samples)	2	1.1	0.59	0.91
Non-Random				
Supplies serving <10,000 people (321 samples)	10	3.1	0.44	2.5
Supplies serving >10,000 people (158 samples)	0	0	-	-

*Samples having levels over quantification limit of 0.2 μg/L.

21.2.4 Other Sources of Exposure

The volatility of xylenes suggest that they may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric data for a number of volatile organics. For xylenes, they had data for o-xylene and m/p-xylene. For o-xylene, they had data for 2182 locations. For rural and remote areas, the median concentration of o-xylene was 0.4 $\mu g/m^3$. In urban and suburban areas, the median was 5.2 $\mu g/m^3$, and in

source-dominated areas, the median was 3.5 $\mu g/m^3$. For m/p-xylene, the median concentration for rural and remote areas was 0.38 $\mu g/m^3$. In urban and suburban areas, the median was 12 $\mu g/m^3$, and in source-dominated areas, the median was 7.4 $\mu g/m^3$. These results suggest inhalation exposures even in rural and remote areas.

Xylene is found in drinking water obtained from ground water. There is a lack of data on the occurrence of xylenes in finished surface water supplies. Discharge of effluents contaminated with xylenes near water intakes in surface water could potentially result in ingestion exposures from drinking water. The use of this compound as a solvent in a variety of consumer products suggest that direct dermal and inhalation exposures may occur during consumer use.

21.3 HUMAN HEALTH CONSIDERATIONS

21.3.1 Animal Studies

21.3.1.1 Carcinogenicity

Xylene (commercial mixture), administered to rats and mice by gavage, was tested for carcinogenicity by NTP (3484). No evidence of 500 carcinogenicity was seen for male or female F344/N rats given 250 or 500 mg/kg or for male or female $B6C3F_1$ mice given 500 or 1,000 mg/kg by gavage for 2 years.

21.3.1.2 Genotoxicity

Xylenes have been tested for mutagenicity in both bacterial and mammalian systems and have shown fairly conclusive evidence for the absence of mutagenic activity. Xylene failed to induce sister chromatid exchange in cultured human lymphocytes (798) and produced no evidence of bone marrow chromosome damage in rats exposed to technical-grade xylene (which contains 18.3% v/v ethyl benzene) by inhalation at 300 ppm, 6 hours per day, 5 days per week for up to 18 weeks (799). The ortho-, meta- and para-isomers of xylene gave negative results with and without metabolic activation in the Salmonella microsome assay (795, 3276) as did technical-grade xylene (3859). Only the para-isomer was tested by Shimizu et al. (3645) in the five standard strains of Salmonella and in Escherichia coli, and it was found negative at all concentrations tested. It was toxic at 500 and 1000 μg/plate. Technical-grade xylene was also inactive in DNA repair assays with E. coli and B. subtilis (796, 797). Technical-grade xylene did induce a low frequency of recessive lethals in Drosophila; the ortho- and meta-isomers of xylene alone, as well as ethyl benzene alone, were negative in this assay (799). All three isomers of xylene were tested by intraperitoneal injection in male mice and their bone marrow cells examined for the presence of micronuclei; all were negative (3462, 3463).

21.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

A study assessing the teratogenicity of the xylene isomers was conducted by Ungvary et al. (212). Rats were exposed by inhalation to 35, 350 or 700 ppm of ortho-, meta-, or para-xylene continuously on days 7 through 14 of gestation. The incidence of visceral, skeletal and external abnormalities was not affected by any of the isomers, leading the authors to conclude that xylene was not a teratogen. Decreased fetal development was observed at the highest exposure level for all 3 isomers. This was attributed to the decrease in maternal food intake at that level. Additional groups of rats were exposed to the same vapor concentrations but only to o-xylene for 2 hours on the 18th day of gestation. The o-xylene was found to cross the placenta and was present in the fetal blood and amniotic fluid. The same research group (Ungvary and Tatrai, 3753) later exposed rats, mice, and rabbits to xylene mixtures by inhalation (3753). Skeletal and weight retardation of fetuses was significant in mice at 1000 mg/m^3. The same level was toxic to pregnant rabbits, causing death, abortion, or total resorption. In rats, significant skeletal retardation was found at 250 mg/m^3, while 3400 mg/m^3 greatly increased weight retardation, skeletal retardation, minor anomalies, and dead or resorbed embryos. Ortho-xylene, meta-xylene, and para-xylene used individually with mice resulted in weight and skeletal retardation at the 500 mg/m^3 level in all three groups. Mirkova et al. (3453) exposed pregnant rats to xylene concentrations of approximately 0, 14, 53, or 468 mg/m^3 for 6 hr/da, 5 da/wk from gestation days 1-21. Their results differed from those in previous studies, as they reported a significant increase in postimplantation loss and delayed ossification along with inhibition of fetal weight gain at the relatively low dose of 53 mg/m^3. Hood and Ottley (3296), in an extensive review, expressed reservations about the health of the test rats and about other aspects of this study. When male rats were exposed to mixed xylenes at 2,175 mg/m^3 for at least 131 days premating, no adverse effects were noted in their offspring (3808, as reported in 3296).

A commercial mixture of the xylene isomers was administered by gavage to mice at dosages of 0, 520, 1030, 2060, 2580, 3100 or 4130 mg/kg/day on days 6-15 of gestation (794). No effects were observed in either the dams or fetuses exposed to a level of 1030 mg/kg/day or less. At exposures of 2060 mg/kg/day and higher, doses approaching lethal levels in the dams, fetal weight was significantly decreased and the average percentage of malformed fetuses was increased; cleft palate was the major malformation noted (794). In a study by Nawrot and Staples (3488), CD-1 mice were adminisered by gavage meta-, ortho-, or para-xylene at doses of 0.3, 0.75, or 1.00 mg/kg three times a day for days 6-15 of gestation. Meta-xylene caused overt maternal toxicity and a significantly increased number of resorptions, but only at the high dose. These effects and an increased incidence of cleft palate in the offspring were noted at the middle and high doses of ortho- and para-xylene. In this same paper the authors report of subsequent studies in which CD-1 mice were given by gavage 0.75 or 1.00 mg/kg meta-xylene three times a day for days 6-15 of gestation.

No overt maternal toxicity was observed and a low (4.4% vs. 0.0% in vehicle controls) but statistically significant increase in cleft palates was seen in the high dose group. The authors state that this is an indication of a weak teratogenic response.

21.3.1.4 Other Toxicologic Effects

Early animal experiments indicated xylene induced changes in the blood and bone marrow. These older findings have little significance, and have not been reported here, because the xylene used at that time was contaminated with benzene and other hydrocarbons. Recent studies strongly support the conclusion that uncontaminated xylene does not have myelotoxic effects (599).

21.3.1.4.1 Short-term Toxicity

Acute exposure to xylene primarily affects the central nervous system. No signs of CNS impairment were observed in rats and mice after a 4-hour exposure to vapor concentrations ranging from 510 to 800 ppm. Animals exposed to 1350 ppm for 2 hours exhibited poor coordination which disappeared shortly after exposure ceased. Higher concentrations of xylene (7000 ppm), cause initial symptoms of excitement which are followed by depression and death due to respiratory paralysis (70). An LC_{50} value of 500 ppm • 4 hr and an oral LD_{50} value of 4300 mg/kg have been reported for rats (47).

Acute liver injury was found in guinea pigs who were administered 1 to 2 g xylene/kg body weight intraperitoneally while rats exposed to vapor concentrations ranging from 1000 to 2000 ppm for 4 hours exhibited hepatotoxic effects which were inferred from increased serum enzyme activities (70).

Corneal vacuoles were observed in cats exposed for several hours to xylene vapor concentrations that were just sublethal. The vacuoles disappeared when xylene exposure was discontinued (599, 19). Two drops of xylene instilled into rabbits' eyes produced slight conjunctival irritation with very slight but transient, corneal injury (19, 599).

Repeated application of undiluted xylene to rabbit skin produced moderate irritation and necrosis (12).

21.3.1.4.2 Chronic Toxicity

Studies in animals indicate that xylene has a relatively low toxicity over the long-term. No changes were found in rats, guinea pigs, dogs and monkeys continuously exposed to 80 ppm for 127 days, nor in rats exposed to 700 ppm for 130 days (70). Another investigator reported behavioral changes in rats exposed by inhalation to 300 ppm, 6 hours a day for 5 to 18 weeks (70). Slight inflammation, congestion and necrosis of the kidney tubules were found in rabbits exposed by

inhalation to 700 ppm, 8 hours daily, 6 days per week for 130 days (70). Repeated exposure of rabbits to 1150 ppm for 40 to 55 days caused a reversible decrease in red and white blood cell count and an increase in platelets (70).

21.3.2 Human and Epidemiologic Studies

21.3.2.1 Short-term Toxicologic Effects

Xylene has narcotic effects on the central nervous system, variable effects on the liver and kidneys and irritant effects on the gastrointestinal tract (599).

NIOSH reports one incident of an accidental ingestion of a "small amount" of paint thinner composed of xylene (90%) and toluene. Several acetate impurities were also present. There was serological evidence of toxic hepatitis but the victim recovered within 20 days (599).

One fatality has been attributed to the inhalation of xylene vapors. Morley et al. (617) described an incident in which 3 painters were overcome by xylene vapors; the concentration was estimated to be 10,000 ppm. It is not known how long it took the men to lose consciousness because they were not found until 18.5 hours later. An autopsy conducted on one worker who was found dead revealed pulmonary edema, liver congestion and brain hemorrhages. The two surviving workers suffered from amnesia and hepatic impairment; one had evidence of temporary renal impairment. Both recovered within 2 days.

Exposure of human subjects to 90 ppm of m-xylene produced impairment of reaction time, manual coordination and body balance. Although tolerance to these effects developed over one work-week, it was largely lost over a weekend (17).

Brief exposure to 200 ppm causes irritation of the eyes, nose and throat (38). Workers exposed to concentrations above 200 ppm complained of nausea, vomiting, abdominal pain and loss of appetite (9). A recent report noted that artists as well as others who employ felt-tip-marker pens for extended periods of time in enclosed rooms may develop symptoms of nausea, dizziness and headache which can be attributed to xylene exposure; xylene is used as an ink solvent in these products (618).

Xylenes have been reported to cross the human placenta (43). Incomplete brain development has been reported in children whose mothers had been exposed to xylene, toluene and white spirit (59).

Xylene is a skin irritant and causes redness, dryness and defatting. Prolonged skin contact may cause the formation of vesicles (46). Absorption of liquid xylene through intact skin occurs readily and has been estimated to occur at a rate of 4.5-9.6 mg/sq.cm^2/hr (599).

An accidental splash of xylene into the eye causes only transient superficial damage with rapid recovery (19). Corneal vacuoles were reported in workers exposed to "practically pure" xylene vapors (concentration unspecified) for 2-3 days. Recovery occurred 8 to 11 days after exposure ceased. Is not known whether this effect is totally reversible on intermittent exposure or whether it may lead to permanent damage (19, 599).

21.3.2.2 Chronic Toxicologic Effects

The effects of long-term xylene exposure resemble those from acute exposure, but are more severe. Headache, irritability, fatigue, digestive disorders and sleep disorders have been reported (70). Inhalation of high concentrations of xylene vapors may produce CNS excitation, followed by depression and characterized by paresthesia, tremors, apprehension, impaired memory, weakness, vertigo, headache and anorexia (12). No bone marrow aplasia, but hyperplasia, moderate liver enlargement, necrosis and nephrosis may occur (12).

21.3.3 Levels of Concern

EPA Health Advisories have been proposed for xylene and are as follows: child, 1 day, 10 day, and longer term, all 40 mg/L; adult, longer-term and lifetime, 10 mg/L (3805). An Oral Reference Dose of 2000 μg/kg/day has also been proposed by the EPA (3277, 3879).

Both OSHA (3539) and the ACGIH (3005) have set an occupational exposure 8 hr - TWA of 100 ppm (435 mg/m^3) for xylene.

21.3.4 Hazard Assessment

Data on the effects of long-term human exposure to xylene are primarily high-level occupational inhalation exposures which have resulted in CNS effects, incoordination, nausea, vomiting and abdominal pain. Short-term inhalation exposures are associated with narcotic effects on the central nervous sytem. Ingestion data are almost completely lacking.

Studies in laboratory animals suggest xylene has a relatively low chronic toxicity. Some data suggest possible kidney and liver impairment with high level (>1000 ppm) inhalation exposures. An NTP bioassay for xylene using rats and mice showed no evidence of carcinogenicity. Available evidence indicates an absence of mutagenic activity for xylene. Teratogenicity and fetotoxicity have been observed in laboratory animals, frequently these effects were accompanied by maternal toxicity.

Although human experience with xylene in the industrial sector provides no indications of major health concerns associated with xylene exposure, the reported developmental toxicity seen in animals and the knowledge that xylenes can cross the

human placenta is sufficient reason for concern for pregnant women who are exposed to xylenes.

21.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of the concentrations of xylenes in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of xylenes, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight containers with no headspace; analysis should be completed within 14 days of sampling. However, recent studies (3430) show large losses of volatiles from soil handling. At the present, the best procedure is to collect the needed sample in an EPA VOA vial, seal with a foil-lined septum cap, and analyze the entire contents in the vial using a modified purge and trap apparatus. In addition to the targeted samples, quality assurance samples such as field blanks, duplicates, and spiked matrices should be included in the analytical program.

Xylenes are not included among the EPA-designated priority pollutants. However, EPA Methods 602, 624, 1624 (65), 8020 and 8240 (63) would be appropriate methods of choice for the analysis of xylenes in aqueous samples. An inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the xylenes from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the xylenes and transfer them onto a gas chromatographic (GC) column. The GC column is programmed to separate the volatile organics; xylenes are then detected with a photo-ionization detector (Method 602 and 8020) or a mass spectrometer (Methods 624, 1624, and 8240). Direct injection may also be used for samples containing elevated concentrations.

The EPA procedures recommended for xylene analysis in soil and waste samples, Methods 8020 and 8240 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The recommended method for low level soils (<1 mg/kg) involves dispersing the soil or waste sample in water and purging in a heated purge and trap device. Other sample introduction techniques include direct injection and a headspace method.

Xylene detection limits for most methods were not determined but would be in the range of 1-10 μg/L for aqueous samples and 1-10 μg/kg for non-aqueous samples.

Aqueous Detection Limits	Non-Aqueous Detection Limits
5 μg/L (Method 8240) Total Xylene	5 μg/kg (Method 8240) Total Xylene

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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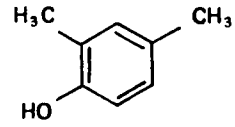
COMMON SYNONYMS:	CAS REG.NO.: 105-67-9 FORMULA: $C_8H_{10}O$ NIOSH N0: ZE5600000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C 4.98 mg/m³ ≈ 1 ppm; 0.201 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 122.16
1-Hydroxy-2, 4-dimethylbenzene 2,4-Dimethylphenol 2,4-Xylenol 4,6-Dimethylphenol M-Xylenol		

REACTIVITY	Reactions of phenols with organic peroxides or hydroperoxide stypically generate heat. Those with alkali or alkaline earth metals or nitrides may produce heat and flammable gases while reactions with azoor diazo compounds, or hydrazines may evolve heat and other gases. Reactions with oxidizing mineral acids or other strong oxidizers may result in heat generation and fire, while those with isocyanates, epoxides, or polymerizable compounds may result in evolution of heatand violent polymerization reactions. Contact with explosive materials may cause an explosion (511).

PHYSICO-CHEMICAL DATA	• Physical State: Solid, crystalline (at 20°C)	(23)
	• Color: White	(23)
	• Odor: No Data	
	• Odor Threshold: 0.400 mg/L	(67)
	• Density: 0.9650 g/mL (at 20°)	(68)
	• Freeze/Melt Point: 27.00°C	(68)
	• Boiling Point: 210.00°C	(68)
	• Flash Point: No Data	
	• Flammable Limits: No Data	
	• Autoignition Temp.: No Data	
	• Vapor Pressure: 6.70E-02 mm Hg (at 20°C)	(1219)
	• Satd. Conc. in Air: 4.5000E+02 mg/m³ (at 20°C)	(1219)
	• Solubility in Water: 1.48E+03 mg/L (at 20°C)	(1219)
	• Viscosity: No Data	
	• Surface Tension: No Data	
	• Log (Octanol-Water Partition Coeff.): 2.30	(29)
	• Soil Adsorp. Coeff.: 9.60E+01	(652)
	• Henry's Law Const.: 6.70E-06 atm · m³/mol (at 20°C)	(1219)
	• Bioconc. Factor: 9.5 (estim), 150 (bluegill)	(659,214)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Fairly mobile in soil-water systems, especially in aqueous phase. Volatilization through air-filled pores is not significant. Chemical is resistant to hydrolysis; it may be easily biodegraded in wastewater treatment plants, but biodegradation in natural environments may be insignificant. Chemical may thus persist for months to years.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of 2,4-dimethylphenol to groundwater drinking water supplies. Inhalation is not expected to be a pathway of concern for this compound.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (45) No reports of human exposure and associated effects were found. Acute Toxicity Studies: (3504) ORAL: LD_{50} 3200 mg/kg Rat LD_{50} 809 mg/kg Mouse SKIN: LD_{50} 1040 mg/kg Rat Long-Term Effects: No data Pregnancy/Neonate Data: No mammalian data Genotoxicity Data: Limited data are negative Carcinogenicity Classification: IARC - No data NTP - No data EPA - No data

HANDLING PRECAUTIONS (507)	Handle chemical only with adequate ventilation • There are no formal guidelines available for this chemical with respect to respirator use. If necessary, wear appropriate NIOSH/MSHA-approved respirator • Chemical goggles if there is a probability of eye contact • Appropriate clothing and chemical resistant gloves to prevent repeated or prolonged skin contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): none established
- AFOSH PEL (8-hr TWA): none established

Criteria
- NIOSH IDLH (30-min): none established
- ACGIH TLV® (8-hr TWA): none established
- ACGIH STEL (15 min): none established

WATER EXPOSURE LIMITS:

Drinking Water Standards
None Established

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
None established

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, no criterion established due to insufficient data. Based on ingestion of contaminated aquatic organisms only, no criterion established due to insufficient data. Based on organoleptic data only, 400 μg/L.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 2120 μg/L.

    chronic toxicity:
    no criterion established due to insufficient data.

  - Saltwater species
    acute toxicity:
    no criterion established due to insufficient data.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:
No reference dose available

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Dimethylphenol (Xylenol) is designated a hazardous substance under the CWA. It has a reportable quantity (RQ) of 454 kg (347, 3764) 2,4-Dimethylphenol is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

In states with an approved Underground Injection Control program, a permit is required for the injection of 2,4-dimethylphenol-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

2,4-Dimethylphenol is identified as a toxic hazardous waste (U101) and listed as a hazardous waste constituent (3783, 3784). Waste streams from the following industries contain 2,4-dimethylphenol and are listed as specific sources of hazardous waste: wood preservation (creosote and/or pentachlorophenol preserving processes), coking operations, and petroleum refining (3774, 3765). 2,4-Dimethylphenol is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective November 8, 1988, the land disposal of certain untreated 2,4-dimethylphenol-containing hazardous wastes is prohibited. These wastes must be treated according to Best Demonstrated Available Technology (BDAT) treatment standards before being disposed. Certain variances exist until May, 1990 for other hazardous wastes for which BDAT treatment standards have not been promulgated by EPA (3786). 2,4-Dimethylphenol is on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
2,4-Dimethylphenol is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing 2,4-dimethylphenol but these depend upon the concentration of the chemicals present in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of 2,4-dimethyl- phenol must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Food, Drug and Cosmetic Act (FDCA)
The level for phenols in bottled drinking water is 0.001 mg/L (365).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 2,4-dimethylphenol as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria.

ARIZONA
Arizona has a water quality criterion of 5 μg/L for phenolics in all public waters (3827).

DISTRICT OF COLUMBIA
The District of Columbia has a human health criterion of 400 μg/L for public water supply (class D) surface waters and 200 μg/L for class C surface waters (3828, 3827).

FLORIDA
Florida has water quality criterion for phenolic compounds of 1 μg/L for general use surface waters, and 0.2 mg/L for Class V (navigation, industrial use) surface waters (3220).

ILLINOIS
Illinois has a water quality standard for phenols of 100 μg/L for general use waters, 1 μg/L for public and food processing water supplies, and 300 μg/L for aquatic life waters (3371, 3827).

INDIANA
Indiana has set the following surface water quality criteria for phenols and phenolic compounds: 10 μg/L for the Ohio River and Wabash River, 300 μg/L (daily maximum) for Lake Michigan and contiguous harbor areas, and 10 μg/L for the Grand Calumet River and Indiana Harbor (3827).

IOWA
Iowa has a surface water quality standard of 50 μg/L for phenolic compounds in Class B and C surface waters (3327).

KANSAS
Kansas has an action level for 2,4-dimethylphenol of 400 μg/L for ground-water (3213).

KENTUCKY
Kentucky has a surface water quality criterion of 5 μg/L for phenolic compounds in warm and coldwater aquatic habitats (3827).

LOUISIANA
Louisiana has water quality criteria for phenols of 5 μg/L for drinking water supply waters, 440 μg/L for marine surface waters, and 50 μg/L for fresh surface waters (3406).

MINNESOTA
Minnesota has surface water quality criterion of 10 μg/L for phenols in Fisheries and Recreation waters (3827).

MISSISSIPPI
Mississippi requires that the level of phenolic compounds in the public water supply not exceed 1 μg/L (3684). Mississippi also has a surface water quality standard of 50 μg/L for phenolic compounds for fish and wildlife protection (3684).

NEVADA
Nevada has a water quality criterion for phenolics of 1 μg/L for all surface waters (3827).

NEW HAMPSHIRE
New Hampshire has a drinking water standard of 1 μg/L for phenols (3710). New Hampshire also has a surface water quality standard of 1 μg/L for Class A and B waters and 2 μg/L for Class C waters (3684).

NEW JERSEY
New Jersey sets the maximum concentration levels for phenols in the Delaware River and Bay at the following levels: 5 μg/L for Zones 1, 2 and 3, 20 μg/L for Zone 4, and 10 μg/L for Zones 5 and 6. These are maximum levels that apply unless exceeded due to natural conditions (3498).

NEW YORK
New York has an ambient water quality standard for aquatic life of 5 μg/L for total unchlorinated phenols for all freshwater classes of surface waters (3500). New York has also set an MCL of 5 μg/L for 2,4-dimethylphenol in drinking water and a water quality standard of 1 μg/L for phenol and phenolic compounds in ground-water and surface water classed for drinking water supply (3501).

NORTH CAROLINA
North Carolina has a water quality standard of 1 μg/L for phenolic compounds in Class WS-I, WS-II, and WS-III surface waters (3681).

OHIO
Ohio has a surface water quality standard for phenolic compounds of 1 μg/L for Lake Erie Use waters, public water supply waters, aquatic life habitat coldwaters and exceptional warmwaters, and 10 μg/L for aquatic life habitat warmwaters (3827).

OKLAHOMA
Oklahoma has set an unenforceable Toxic Substance Goal of 55.5 μg/L for public and private water supply surface waters (3534).

OREGON
Oregon has a surface water quality criterion of 1 μg/L for phenols in all surface waters (3827).

PENNSYLVANIA
Pennsylvania has a human health criterion for total phenolics of 5 μg/L measured in surface waters at the point of water supply intake (3561). Pennsylvania also has a human health criterion of 400 μg/L for 2,4-dimethylphenol in surface water (3561).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 106 μg/L and a chronic guideline of 2.4 μg/L for surface waters for the protection of aquatic life. These guidelines are enforceable under Rhode Island state law (3590).

TENNESSEE
Tennessee sets an effluent limitation of 1.0 mg/L for phenols in effluent from industrial wastewater treatment plants (3827).

VIRGINIA
Virginia has a water quality criterion for phenols of 1 μg/L for ground-water and Public Water Supply surface waters, and a chronic criterion for the protection of aquatic life of 1 μg/L for phenol in surface water (3135, 3827).

WEST VIRGINIA
West Virginia sets 0.001 mg/L as the maximum concentration secondary contaminant level for phenols in drinking water in the community public water systems (3576).

WISCONSIN
Wisconsin has a taste and odor criterion threshold concentration of 400 μg/L for 2,4-dimethylphenol in surface waters (3841).

Proposed Regulations

- Federal Programs

  No proposed federal regulations are pending.

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

  IOWA
  Iowa has proposed acute criteria for phenols of 50 μg/L for Class C surface waters, 1000 μg/L for Class B cold surface waters, and 2500 μg/L for Class B warm surface waters, and a chronic criterion of 50 μg/L for all Class B surface waters. These criteria are for the protection of aquatic life (3326).

  MINNESOTA
  Minnesota has proposed a Sensitive Acute Limit (SAL) of 530 μg/L and a chronic criterion of 12 μg/L for 2,4-dimethylphenol in designated surface waters for the protection of human health (3452).

EEC Directives

Directive on Drinking Water (533)
The mandatory values for phenols in surface water treatment categories A1, A2 and A3 used or intended for abstraction of drinking water are 0.001, and 0.005, and 0.1 mg/L, respectively. Guideline values for phenols under treatment categories A2 and A3 are 0.001 and 0.01 mg/L, respectively. No guideline value is given for treatment category A1.

Directive Relating to the Quality of Water Intended for Human Consumption (540)
The maximum admissible concentration for phenols (phenol index) is 0.5 μg/L. Excluded from this category are natural phenols which do not react to chlorine. No guideline levels for phenols are given.

Directive on Ground-Water (538)
Direct and indirect discharge into ground-water of substances which have a deleterious effect on the taste and/or odor of ground-water, and com-pounds liable to cause the formation of such substances in ground-water and to render it unfit for human consumption shall be subject to prior review so as to limit such discharges.

Directive on Bathing Water Quality (534)
Mandatory values for phenols (phenol indices) in bathing water are: (1) no specific odor and (2) concentrations ≤0.05 mg/L. Guideline values for phenols suggest concentrations ≤0.005 mg/L.

Directive on Fishing Water Quality (536)
Phenolic compounds in both salmonid and cyprinid waters must not be present in such concentrations that they adversely affect fish flavor.

Directive on the Quality Required of Shellfish Waters (537)
The mandatory specifications for substances affecting the taste of shellfish require that their concentrations be lower than that liable to impair the taste of the shellfish.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert poly-meric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto- pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
2,4-Dimethylphenol is classified as a toxic substance and is subject to packaging and labeling regulations.

22.1 MAJOR USES

The compound, 2,4-dimethylphenol, is a naturally-occurring, substituted phenol derived from the cresol fraction of petroleum or coal tars. It is one of 5 isomers of dimethylphenol. No direct commercial applications presently exist for 2,4-dimethylphenol, but it is used commercially in the manufacture of a wide range of products for industry and agriculture. These include phenolic antioxidants, disinfectants, solvents, pharmaceuticals, insecticides, plasticizers, rubber chemicals, polyphenylene oxide, wetting agents and dyestuffs (214).

22.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

22.2.1 Transport in Soil/Ground-water Systems

22.2.1.1 Overview

The 2,4-isomer of dimethylphenol may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by estimating equilibrium partitioning as shown in Table 22-1. These calculations predict partitioning of 2,4-dimethylphenol among soil particles, soil water and soil air. The 2,4-dimethylphenol associated with the water and air phases of the soil is more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that nearly all of the chemical (95%) would be associated with the soil particles. Most of the remainder (5%) is predicted to be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of 2,4-dimethylphenol in the gaseous phase of the soil (0.0004%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, will be possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the 2,4-dimethylphenol (71%) is likely to be present in the soil-water phase (Table 22-1) and transported with flowing ground water.

The 2,4-isomer of dimethylphenol is a weak acid (pK_a = 10.6) which will dissociate slightly in natural waters with elevated pHs (e.g., 7-9). Under most conditions, however, the chemical will be in its neutral, non-ionized form. The phenolic group can form complexes with dissolved metal cations, and this may influence environmental fate and transport in ways not applicable to other non-reacting organic compounds.

TABLE 22-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR 2,4-DIMETHYLPHENOL IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 20°C	94.8	5.1	0.0004
Saturated deep soil[d]	28.7	71.3	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 96. (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 6.7E-06 atm · m^3/mol at 20°C. (Estimated by Arthur D. Little, Inc.)
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

22.2.1.2 Sorption on Soils

The mobility of 2,4-dimethylphenol in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 200, the soil sorption coefficient (K_{oc}) is estimated to be 96. This is a relatively low number indicative of weak sorption to soils. However, this conclusion is based upon the assumption that

the chemical acts as a neutral species. As mentioned above, the phenolic group can complex with other cations and any such complexation could significantly alter the sorption properties of the chemical in unpredictable ways.

22.2.1.3 Volatilization from Soils

Transport of 2,4-dimethylphenol vapors through the air-filled pores of unsaturated soils is not expected to be an important transport mechanism because of the chemical's low vapor pressure and relatively high water solubility (which allows it to be carried down with infiltrating water).

22.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of 2,4-dimethylphenol in soil/ground-water systems has not been studied. In most cases, it should be assumed that the chemical will persist for months to years.

2,4-Dimethylphenol under normal environmental conditions is not expected to undergo hydrolysis (10,33). The possibility of aqueous phase oxidation, catalyzed by certain dissolved metals such as copper or iron, has been raised, but there is no evidence that such reactions occur under normal environmental conditions (10).

2,4-Dimethylphenol is likely to be easily biodegraded in biological wastewater treatment plants based on data reported by Callahan et al. (10) and Takak et al. (55). However, other data indicate that biodegradation in natural environments (e.g., rivers, soil/ground-water systems) may not occur at environmentally-significant rates (10). In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as 2,4-dimethylphenol is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in landfills with active microbiological populations.

22.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that the volatility of 2,4-dimethylphenol from aqueous solutions is low, it is weakly adsorbed by soil and has a low potential for bioaccumulation. The portion of the compound not adsorbed will be mobile in ground water.

The potential for ground water contamination is high, particularly in sandy soil. Mitre (83) reported that 2,4-dimethylphenol was found at 3 of the 546 National Priority List (NPL) sites. It was detected at one site in ground water and 3 sites in surface water. There was no available monitoring data for 2,4-dimethylphenol in drinking water supplies. There is, however, a potential for exposure through drinking water ingestion from ground water if supplies are contaminated.

Because 2,4-dimethylphenol has the potential for movement in soil/ground-water systems, this compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures through bioaccumulation;
- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposure from drinking contaminated ground water for two reasons. First, surface waters can provide a greater dilution volume. Secondly, the bioconcentration factor for this compound is expected to be low, suggesting limited bioaccumulation in aquatic organisms or domestic animals.

22.2.4 Other Sources of Exposure

There is a lack of data on the occurrence of 2,4-dimethylphenol in finished water supplies or in ambient air. 2,4-Dimethylphenol has been detected in industrial effluents (587). Discharge of contaminated effluents near drinking water intakes in surface water could potentially result in ingestion exposure.

22.3 HUMAN HEALTH CONSIDERATIONS

22.3.1 Animal Studies

22.3.1.1 Carcinogenicity

Boutwell and Bosch (588) reported that 2,4-dimethylphenol produced papillomas and carcinomas on the skin of tumor-susceptible female Sutter mice. It should be noted, however, that the 2,4-dimethylphenol was applied as a 10% solution in benzene and that the mice were housed in cages treated with creosote, both known carcinogens. These investigators (588) also evaluated the ability of 2,4-dimethylphenol to promote the appearance of tumors after a single application of the carcinogen, dimethylbenzanthracene. Five milligrams of 2,4-dimethylphenol in benzene applied twice a week elicited a carcinogenic response in 18% of the mice at 23 weeks. Again, the use of benzene as the solvent confounds interpretation of this study.

22.3.1.2 Genotoxicity

2,4-Dimethylphenol was observed to have no effect in the Salmonella/microsome assay (3469, 3569) and did not induce sister chromatid exchanges above control levels in human lymphocytes treated in vitro (3336).

22.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

The only study relating to the teratogenicity of the agent is provided by Holcombe et al. (3295) in an investigation on the effects of 2,4-dichlorophenol on embryonic, larval, and early juvenile fathead minnows. Embryos less than 24 hours old were exposed to 900, 1,360, 1,970, 3,110, or 5,130 μg/L of this chemical with exposure continuing through the 4th week after hatching. Survival was significantly reduced by exposure to 5,130 μg/L, but growth, a more sensitive indicator of effect, was significantly reduced at both 3,110 and 5,130 μg/L.

22.3.1.4 Other Toxicologic Effects

22.3.1.4.1 Short-term Toxicity

The effects of acute administration of 2,4-dimethylphenol have been examined in mice, rats and rabbits. Ten percent solutions in oil (unspecified) were administered by intubation to rats and mice. In general, dimethylphenols were less toxic than phenol and methylphenols in mice; 2,4-dimethylphenol was less toxic to rats. The oral LD_{50} values for 2,4-dimethylphenol were 809 mg/kg in mice and 3200 mg/kg in rats (214). No appreciable toxic effects were seen in rabbits following doses of 273-425 mg/kg; the route of administration was not specified (213). Topical administration has been shown to be lethal to mice at 5600 mg/kg; an LD_{50} value of 1040 mg/kg was recorded for rats (47, 213). Tested by application of a drop into rabbit eyes, the 3,5-isomer caused severe and presumably permanent injury (19). Bruze (3088) demonstrated that 2,4-dimethylphenol, when used as a rechallenge agent in the guinea pig maximization test, was able to elicit a response in animals sensitized to 2-methylol phenol, thus showing cross-reactivity. No inhalation studies of 2,4-dimethylphenol have been conducted. Other dimethylphenol isomers produce difficult respiration, disturbance of motor coordination and development of spasms with acute inhalation exposures (214).

22.3.1.4.2 Chronic Toxicity

No long-term toxicity studies of 2,4-dimethylphenol have been conducted. However, the 2,6- and 3,4-isomers of dimethylphenol were evaluated in a 10-week study with male rats given oral doses of 29.5 mg/kg 2,6-dimethyphenol or 72.5 mg/kg of 3,4-dimethylphenol. The dosing regimen was not indicated. Animals treated with the 2,6-isomer exhibited a depressed body weight gain and increased organ to body weight ratios for the liver and spleen. Rats treated with the 3,4-isomer exhibited the

same effects plus an increase in the organ to body weight ratios for the heart and lungs. Cellular changes in the liver were observed in both groups. No hematological changes were observed (589).

22.3.2 Human and Epidemiologic Studies

No reports of human toxicity were found in the literature. It is unlikely that any segment of the population is exposed to this compound alone. Many workers are exposed by inhalation to commercial degreasing agents which contain methylphenols and dimethylphenols; however, no adverse effects have been reported. Since 2,4-dimethylphenol has been identified in cigarette and marijuana smoke, smokers and those exposed to smoke may be at risk (214).

22.3.3.3 Levels of Concern

The USEPA (355) has not established an ambient water quality criterion for the protection of human health for 2,4-dimethylphenol due to the insufficiency of available data; a criterion of 400 μg/L is suggested by the USEPA on an organoleptic basis (355).

22.3.3.4 Hazard Assessment

Nominally, 2,4-dimethylphenol is a cocarcinogen. Assessment of positive findings in skin-painting and tumor-promotion studies conducted with 2,4-dimethylphenol, however, are confounded by the use of benzene as the vehicle for compound administration and concomitant exposure to creosote. The impact, if any, that these two carcinogens exerted on the test results for 2,4-dimethylphenol is uncertain. The lack of sufficient genotoxic, reproductive and long-term exposure data for this compound further complicates an assessment of the human health hazards associated with exposure to 2,4-dimethylphenol. In view of the paucity of available health effects data, an assessment of hazard associated with exposure to 2,4-dimethylphenol cannot be made with any degree of confidence at this time.

22.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of 2,4-dimethylphenol concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sample and analysis completed within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of 2,4-dimethylphenol, one of the EPA priority pollutants, in aqueous samples include EPA Methods 604, 625, and 1625

(65), 8040 and 8250 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. Methods 604 and 8040 also describe perfluorobenzylbromide (PFB) derivatization of the sample extract and additional clean-up procedures if interferences are present in the sample matrix. An aliquot of the concentrated sample extract or derivative is then injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; 2,4-dimethylphenol is then detected with a flame ionization detector (Methods 604 and 8040 without derivatization), as its PFB derivative with an electron capture detector (Methods 604 and 8040 with derivatization) or a mass spectrometer (Methods 625 and 1625).

The EPA procedures recommended for 2,4-dimethylphenol analysis in soil and waste samples, Methods 8040 and 8250 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical 2,4-dimethylphenol detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.32 μg/L (Method 604)	1 μg/g (Method 8250)
2.7 μg/L (Method 625)	0.2 μg/g (Method 8040 without derivatization)
10 μg/L (Method 1625)	0.4 μg/g (Method 8040 with derivatization)
3.2 μg/L (Method 8040 without derivatization)	1.8 μg/g (Method 8250)
6.3 μg/L (Method 8040 with derivatization)	
27 μg/L (Method 8250)	

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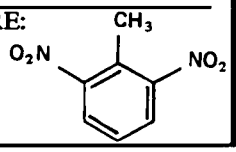
COMMON SYNONYMS:	CAS REG.NO: 606-20-2 FORMULA: $C_7H_6N_2O_4$ NIOSH N0: XT1925000	AIR W/V CONVERSION FACTOR at 25 ° C (12)
2,6-Dinitrotoluene 2,6-DNT 2-Methyl-1,3-dinitro-benzene	STRUCTURE: 	7.43 mg/m^3 ≈ 1 ppm; 0.1346 ppm ≈ 1 mg/m^3 MOLECULAR WEIGHT: 182.15

REACTIVITY	Reactions of phenols with organic peroxides or hydroperoxide stypically generate heat. Those with alkali or alkaline earth metals or nitrides may produce heat and flammable gases while reactions with azoor diazo compounds, or hydrazines may evolve heat and other gases. Reactions with oxidizing mineral acids or other strong oxidizers may result in heat generation and fire, while those with isocyanates, epoxides, or polymerizable compounds may result in evolution of heatand violent polymerization reactions. Contact with explosive materials may cause an explosion (511).

PHYSICO-CHEMICAL DATA	• Physical State: Solid, crystalline (at 20°C)	(25)
	• Color: Yellow	(3)
	• Odor: Slight	(3429)
	• Odor Threshold: No data	
	• Density: 1.2833 g/mL (at 111°C)	(59)
	• Freeze/Melt Point: 66.00°C	(222)
	• Boiling Point: 285.00°C; Decomposes at 260°C	(222,790)
	• Flash Point: 207.00°C (closed cup)	(3429)
	• Flammable Limits: No data	

PHYSICO-CHEMICAL DATA (Cont.)	• Autoignition Temp.: No data • Vapor Pressure: 1.80E-02 mm Hg (at 20°C)	(33)
	• Satd. Conc. in Air: 1.8000E+02 mg/m^3 (at 20°C)	(1219)
	• Solubility in Water: 2.12E+03 mg/L (at 25°C)	(1219)
	• Viscosity: No Data • Surface Tension: No data • Log (Octanol-Water Partition Coeff.): 1.98	(29)
	• Soil Adsorp. Coeff.: 4.60E+01	(652)
	• Henry's Law Const.: 7.90E-06 atm · m^3/mol	(33)
	• Bioconc. Factor: 4.60 (estim)	(659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	2,6-Dinitrotoluene is expected to be mobile in the soil/ground-water system. Volatilization is not expected to be a significant removal mechanism. Transformation processes such as hydrolysis and biodegradation are also not expected to be significant in natural soils. Photolysis faster in natural waters at higher pH.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of 2,6-dinitrotoluene to groundwater drinking water supplies. There is some evidence that such migration has occurred in the past.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (38, 54, 59) Dinitrotoluene affects the ability of blood to carry oxygen; a bluish discoloration of the skin may occur. Inhalation can result in symptoms resembling ethanol intoxication including headache, irritability, dizziness, weakness, nausea, vomiting, shortness of breath, drowsiness and unconsciousness. The onset of symptoms may be delayed. Death may occur if treatment is not given promptly. Alcohol ingestion may cause increased suscepibility to the toxic effects of dinitrotoluene. There may be a correlation between dinitrotoluene exposure and ischemic heart disease. Acute Toxicity Studies: (3504) ORAL: LD_{50} 177 mg/kg Rat LD_{50} 621 mg/kg Mouse Long-Term Effects: Anemia, methemoglobinemia Pregnancy/Neonate Data: No terata (technical); testicular damage (2,6-isomer) Genotoxicity Data: Limited evidence of genotoxic potential Carcinogenicity Classification: IARC - None assigned NTP - No evidence in female rats EPA - Group B2 (probable human carcinogen; sufficient evidence in animals and insufficient evidence in humans)
HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation • Vapor concentrations of 1.5-15 mg/m^3 2,4-dinitrotoluene: any supplied-air respirator or self-contained breathing apparatus • 15-75 mg/m^3: any supplied-air respirator or self-contained breathing apparatus with full facepiece • 75-200 mg/m^3: Type C supplied-air respirator with full facepiece operated in positive-pressure mode • Chemical goggles if there is probability of eye contact • Impervious clothing and gloves should be used to prevent repeated or prolonged skin contact with liquid.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 1.5 mg/m^3 (skin) for commercial-grade dinitrotoluene
- AFOSH PEL (8-hr TWA): 1.5 mg/m^3 (skin) for commercial-grade dinitrotoluene;
  STEL (15-min): 4.5 mg/m^3

Criteria
- NIOSH IDLH (30-min): NIOSH has recommended that commercial-grade dinitrotoluene be treated as a potential human carcinogen
- ACGIH REL (8-hr TWA): 1.5 mg/m^3 (skin) for commercial-grade dinitrotoluene

WATER EXPOSURE LIMITS:

Drinking Water Standards
None Established

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
None established

EPA Ambient Water Quality Criteria
- Human Health (355)
  - No criteria have been set for the 2,6-isomer.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity: no criterion.
    chronic toxicity: no criterion

  - Saltwater species
    acute toxicity: no criterion established due to insufficient data.
    chronic toxicity: no criterion.

REFERENCE DOSES:
No reference dose available

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

2,6-Dinitrotoluene is designated a hazardous substance under the CWA. It has a reportable quantity (RQ) limit of 454 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment standards for new and existing sources, and effluent guidelines and standards.(351, 3763). Effluent limitations exist for 2,6-dinitrotoluene effluent in the electroplating, the steam electric power generating, and the metal finishing point source categories (3767, 3802, 3768). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

The isomer 2,4-dinitrotoluene is included on the first drinking water priority list for which NPDWRs and MCLGs will be developed by January, 1991 (3781). The 2,6-isomer of dinitrotoluene is not regulated at this time under the Safe Drinking Water Act. In states with an approved Underground Injection Control program, a permit is required for the injection of 2,6-dinitrotoluene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

2,6-Dinitrotoluene is identified as a toxic hazardous waste (U106) and listed as a hazardous waste constituent (3783, 3784). 2,6-Dinitrotoluene is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). 2,6-Dinitrotoluene is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage,and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)

Under TSCA Section 4, EPA recommends that manufacturers and processors of 2,6-dinitrotoluene perform human health effects studies and chemical fate testing in support of the RCRA program (3792).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

2,6-Dinitrotoluene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 454 kg (3766). Reportable quantities have also been issued for RCRA hazardous waste streams containing dinitrotoluene, but these depend upon the concentrations of the chemical in the waste stream (3766). Under SARA Title III, manufacturers, processors, importers, and users of 2,6-dinitrotoluene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Occupational Safety and Health Act (OSHA)
Employee exposure to dinitrotoluene in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 1.5 mg/m^3. Employee skin exposure shall be prevented/reduced through the use of protective clothing and practices (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 2,6-dinitrotoluene as a hazardous material with a reportable quantity limit of 454 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

NEW YORK
New York has set an MCL of 5 μg/L for 2,6-dinitrotoluene in drinking water, and a nonenforceable guideline value of 0.07 μg/L for 2,6-dinitrotoluene in ground and surface waters (3501, 3500).

KANSAS
Kansas has an action level of 0.04 μg/L for 2,6-dinitrotoluene in ground-water (3213).

Proposed Regulations

- Federal Programs

No proposed federal regulations are pending.

- State Water Programs

MOST STATES
Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officers is advised. Changes are projected for 1989-90 (3683).

MINNESOTA
Minnesota has proposed a Sensitive Acute Limit (SAL) of 7750 μg/L for dinitrotoluene (isomer not indicated) in designated surface waters, and chronic criteria of 1 μg/L for designated surface waters and 1.1 μg/L for designated ground-waters for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on Toxic and Dangerous Wastes (542)

Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic an dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert poly-meric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto- pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)

2,6-Dinitrotoluene is classified as a toxic substance and is subject to packaging and labeling regulations.

Directive on the Approximation of the Laws, Regulations and Administrative Provisions Relating to the Classification, Packaging and Labeling of Dangerous Preparations (3980)

The labels on packages containing preparations classified as very toxic, toxic or corrosive must bear the safety advice S1/S2 and S46 in addition to the specific safety advice. It is physically impossible to give such information, the package must be accompanied by precise and easily understood instructions.

23.1 MAJOR USES

Six isomers of dinitrotoluene exist; the commercial-grade is predominantly a mixture of the 2,4-, 2,6-, and 3,4-isomers (2). Dinitrotoluene compounds are intermediates in the production of toluene diisocyanate which is used in the manufacture of polyurethane foams, coatings, and elastomers. Dinitrotoluenes are also used to a limited extent as gelatinizing and waterproofing agents in military and commercial explosives (222, 59).

23.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

23.2.1 Transport in Soil/Ground-water Systems

23.2.1.1 Overview

The 2,6-isomer of dinitrotoluene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil). Because the pure compound is a solid at ambient temperatures (melting point = 66°C), spills of bulk quantities of the chemical are unlikely to result in any significant penetration of the pure chemical into the soil/ground-water system. In general, transport pathways for low concentrations can be assessed by using an equilibrium partitioning model as shown in Table 23-1. These calculations predict the partitioning of low soil concentrations of 2,6-dinitrotoluene among soil particles, soil water and soil air. The portions of 2,6-dinitrotoluene associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that most of the chemical (90%) will be sorbed to the soil; however, a significant fraction (10%) will be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion, and diffusion. For the portion of 2,6-dinitrotoluene in the gaseous phase of the soil (0.01%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, will be a loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the 2,6-dinitrotoluene (84%) is likely to be present in the soil-water phase (Table 23-1) and transported with flowing ground-water.

Piet et al. (226) found that dune-infiltration treatment of Rhine River water reduced aqueous concentrations of dinitrotoluene (isomer unspecified) by 95% from the original values in the river water. The study showed that the chemical is somewhat mobile in the soil/ground-water environment.

TABLE 23-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
2,6-DINITROTOLUENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 20°C	89.8	10.2	0.01
Saturated deep soil[d]	16.2	83.8	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 46 (Estimated by Arthur D. Little, Inc.).
c) Henry's law constant taken as 7.9E-06 atm · m^3/mol at 20°C (33).
d) Used sorption coefficient K_p calculated as a function of K_{oc} assuming 0.1% organic carbon: $K_p = 0.001 \times K_{oc}$.

23.2.1.2 Sorption on Soils

The mobility of 2,6-dinitrotoluene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol water partition coefficient of 95, the soil sorption coefficient (K_{oc}) is estimated to be 46. This is a relatively low number indicative of weak sorption to soils. However, this conclusion is based upon the assumption that the chemical acts as a neutral species in solution. Callahan et al. (10) point out that polynitroaromatic compounds are able to form very stable charge-transfer complexes with more highly electro-negative aromatic compounds. This implies that

2,6-dinitrotoluene should be strongly adsorbed by both humus and clay. In addition, Callahan et al. (10) point out that basic sites on clay surfaces may form addition-type complexes with the chemical.

23.2.1.3 Volatilization from Soils

Transport of 2,6-dinitrotoluene vapors through the air-filled pores of unsaturated soils is not expected to be an important transport mechanism because of the chemical's low vapor pressure and relatively high water solubility (which allows it to be carried down with infiltrating water).

23.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of 2,6-dinitrotoluene in soil/ground-water systems has not been studied. In most cases, it should be assumed that the chemical will persist for months to years (or more).

Degradation via hydrolysis is not expected to be environmentally significant (10, 33, 3874). Photolysis of 2,6-dinitrotoluene appears to be dependent on pH, with more rapid hydrolysis occurring at higher pH (3307). Photolysis rates of the 2,4-isomer were found to be faster in natural waters than in distilled water, with the photolysis half-life in natural water estimated to be 2.7 to 9.6 hr compared to 43 hr in distilled water (3874).

In a shake-flask test simulating wastewater treatment plant conditions, Tabak et al. (55) found that 2,6-dinitrotoluene underwent significant degradation with gradual adaptation followed by a deadaptive process (toxicity) in subsequent subcultures. Thus biodegradation in wastewater treatment plants appears likely. Additional studies described by Callahan et al. (10) indicate that 2,6-dinitrotoluene is resistant to biodegradation in the natural environment.

In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as 2,6-dinitrotoluene is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in landfills with active microbiological populations.

23.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that the volatility of 2,6-dinitrotoluene is low, that it is weakly adsorbed by soil and has no significant potential for bioaccumulation. The portion of the compound not adsorbed will be mobile in ground-water.

Based on its properties, the potential for ground-water contamination is high, particularly in sandy soil. Mitre (83) reported that 2,6-dinitrotoluene has been found at 2 of the 546 National Priority List (NPL) sites. It was detected at 1 site in

ground-water and 1 site in surface water. There were no available monitoring data for 2,6-dinitrotoluene in drinking water supplies.

Because 2,6-dinitrotoluene has the potential for movement in soil/ground-water systems, this compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures through bioaccumulation;
- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposure from drinking contaminated ground-water, partially due to the greater dilution volumes generally associated with surface water. In addition, the bioconcentration factor for this compound is very low, suggesting no significant bioaccumulation in aquatic organisms or domestic animals.

23.2.4 Other Sources of Exposure

There is a lack of data on the occurrence of 2,6-dinitrotoluene in finished surface water supplies or in ambient air. As discussed under fate pathways, this compound has a very low vapor pressure and low volatility from aqueous solutions. Potential exposure through inhalation is low. However, 2,6-dinitrotoluene has been detected in industrial effluents (587). Discharge of contaminated effluents near drinking water intakes in surface water could potentially result in ingestion exposures.

23.3 HUMAN HEALTH CONSIDERATIONS

23.3.1 Animal Studies

23.3.1.1 Carcinogenicity

There are indications that the 2,6-isomer may be the major tumor-initiating component of dinitrotoluene. In a two-year feeding study with CD rats administered a dinitrotoluene mixture (98% 2,4-dinitrotoluene and 2% 2,6-dinitrotoluene) in the diet, 21% of the male rats fed at a level of 34 mg/kg/day (0.7 mg/kg/day 2,6-dinitrotoluene) developed hepatocellular carcinomas after 24 months (592). In another study, F344 rats were administered technical-grade dinitrotoluene (76%

2,4-dinitrotoluene, 19% 2,6-dinitrotoluene and 5% other isomers) in the diet at dosages of 35 mg/kg bw/day (6.6 mg/kg/day 2,6-dinitrotoluene), 14 or 3.5 mg/kg bw/day. After 12 months, 100% of the males and 50% of the females in the 35 mg/kg group were found to have hepatocellular carcinomas. Bile duct (cholangio) carcinomas were also observed in 25% of the males but none of the females in this group. At the end of two years, both sexes of rats in the 14 mg/kg group had an increased incidence of hepatocellular carcinomas, cholangiocarcinomas, mammary fibroadenomas and subcutaneous fibrosarcomas. An increased incidence of hepatocellular carcinomas was also noted in males in the lowest treatment group (3.5 mg/kg/day) at 24 months (591). The difference in tumor incidences in these two studies may be attributable to the larger dose of 2,6-dinitrotoluene received by the high-dose animals in the latter study. The higher incidence of tumors in males is consistent with the finding that male rats also experience a higher rate of unscheduled hepatic DNA synthesis after 2,6-dinitrotoluene administration than do female rats (218).

A one-year ingestion study appears to confirm the hepatocarcinogenicity of 2,6-dinitrotoluene. Feeding of 99.9% pure 2,6-dinitrotoluene to groups of 28 male F344 rats for 1 year resulted in a 100% incidence of hepatocellular carcinomas when dosed at 14 mg/kg/day and an 85% incidence when dosed at 7 mg/kg/day (3876). No hepatocarcinomas were seen in rats fed 27 mg/kg/day pure 2,4-dinitrotoluene for 1 year, while hepatocarcinomas were exhibited in 47% of those rats fed 35 mg/kg/day technical grade dinitrotoluene (21% 2,4-dinitrotoluene and 19% 2,6-dinitrotoluene) for 1 year (3876).

A study with male mice fed dinitrotoluene (98% 2,4-dinitrotoluene and 2% 2,6-dinitrotoluene) at dosages of 96.9 or 13.3 mg/kg/day for two years revealed the development of papillary and cortical carcinomas of the kidney and nonmalignant kidney tumors (592).

Using in vivo hepatic tumor initiation-promotion studies, technical-grade dinitrotoluene and 2,6-dinitrotoluene were shown to be weak initiators whereas 2,4-dinitrotoluene had no initiating activity (3878). In an effort to further determine the relative hepatocyte foci promoting activity of technical-grade dinitrotoluene, 2,4-dinitrotoluene, and 2,6-dinitrotoluene, a later study established that technical-grade dinitrotoluene, 2,4-dinitrotoluene, and 2,6-dinitrotoluene have hepatocyte promoting activity, with the 2,6-isomer ten times more potent than the 2,4-isomer (3880). Based on these two studies, the authors concluded that 2,6-dinitrotoluene could be considered a complete carcinogen, and suggest that the initiating capacity of technical-grade dinitrotoluene was due to the presence of the 2,6-isomer (3878, 3880).

Negative results were obtained in the lung-tumor bioassay in Strain A and A/J mice after administration of 2,6-dinitrotoluene for 30 weeks. Total doses ranged from 1200 to 6000 mg/kg orally and 600 to 3000 mg/kg intraperitoneally (220, 221). These negative results are not surprising in light of the fact that many hepatocarcinogens are either inactive or weakly active for lung-tumor induction in strain A mice (221).

23.3.1.2 Genotoxicity

No increase in genotoxicity was observed for 2,6-dinitrotoluene in Chinese hamster ovary cells (217) or in P388 mouse lymphoma cells (3866) with or without metabolic activation. 2,6-Dinitrotoluene was weakly mutagenic in the Salmonella/ microsome test (216, 3653, 3884). It induced increased unscheduled DNA synthesis in rat hepatocytes after in vivo administration (3455). Female rats experienced a much lower level of unscheduled DNA synthesis than did males (218). Concentrations of 2,6-dinitrotoluene covalently bound to liver cells are much higher than after an equivalent dose of 2,4-dinitrotoluene, indicating the greater toxicity of the 2,6-isomer (219).

23.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

No embryotoxic or teratogenic effects were observed in the off-spring of pregnant rats given doses of 100 mg/kg of technical grade dinitrotoluene (a mixture of 76% 2,4-dinitrotoluene, 19% 2,6-dinitrotoluene) by gavage on days 7 through 20 of gestation (791).

In a series of studies, male rats, mice, and dogs fed or orally administered 2,6-dinitrotoluene (purity >99%) developed testicular atrophy, decreased spermatogenesis and aspermatogenesis (absence of development of sperm) (792). Rats were given 2,6-dinitrotoluene at a dose of 144.7 mg/kg/day for 4 or 13 weeks; mice were fed 2,6-dinitrotoluene at a level of 288.8 mg/kg/day for 4 weeks while dogs were orally administered 100 mg/kg/day for 8 weeks (792). Similar effects were observed in male rats and mice fed technical grade dinitrotoluene for 2 years at a dosage of 34.5 mg/kg/day (rats) and 96.9 mg/kg/day (mice) (592). Nonfunctioning ovaries were also noted in female mice fed 911 mg/kg/day technical grade dinitrotoluene for 2 years (592).

23.3.1.4 Other Toxicologic Effects

23.3.1.4.1 Short-term Toxicity

Toxicity data on 2,6-dinitrotoluene are limited. In general, the isomers of dinitrotoluene are more toxic to the rat than to the mouse. The oral LD_{50} value for the 2,6-isomer is 177 (47) to 795 mg/kg in the rat (3875) and between 621 mg/kg (47) and 1000 mg/kg in the mouse (59).

Early animal experiments conducted in cats found that oral administration of 24 mL of a 1% solution of the 2,4-isomer of dinitrotoluene in cod liver oil, given in 2 or 4 mL increments, produced no toxic effects. Similarly, no toxic effects were observed after cutaneous application of 0.3 g/kg (2).

Both the 2,4- and the 2,6-isomers were found to be nonirritating to the eyes and mildly irritating to the skin of rabbits (3875).

Since dinitrotoluene is a solid at room temperature, splashes in the eye will not occur unless the substance is hot and then severe burns can be expected (46). A severe burn of the skin, eyelids and cornea, with permanent scarring, has been attributed to hot fumes of dinitrotoluene (15). Exposure to dinitrotoluene may also result in temporary visual disturbances (222).

23.3.1.4.2 Chronic Toxicity

A 13-week toxicity study of 2,6-dinitrotoluene was carried out in dogs, rats and mice. Dogs were administered 4, 20 or 100 mg/kg/day orally. Rats and mice were dosed in their feed at rates of 0.01, 0.05 and 0.25% per day. Toxic effects in dogs and rats included inhibition of muscular coordination and muscular rigidity of the hind legs, decreased appetite and weight loss. Only the latter 2 effects were observed in mice. The highest doses were lethal to some animals in all species, while the lowest doses produced no toxic effects. All species exhibited anemia and methemoglobinemia, a loss of the oxygen-carrying capacity of the blood. Also seen were testicular atrophy with aspermatogenesis and demyelination in the brain (593).

23.3.2 Human and Epidemiologic Studies

23.3.2.1 Short-term Toxicologic Effects

The toxic effects of the dinitrotoluene isomers are similar to those of other aromatic nitrocompounds (2). The primary toxic sign is methemoglobinemia. This effect can be caused by inhalation, ingestion or dermal absorption of dinitrotoluene (222). The symptoms often develop gradually but may be delayed up to 4 hours. Headache is commonly the first symptom and its intensity may increase as the methemoglobinemia progresses. Fatigue, nausea, vomiting and chest pain have also been reported (46). Cyanosis develops early in the intoxication when the methemoglobin concentration is 15% or more. It is noted as a blueness in the lips, nose and earlobes. At this early stage, the individual may feel well and have no complaints. When the methemoglobin concentration reaches 40%, there is usually weakness and dizziness. At 70%, there may be incoordination, increased heart rate, drowsiness, joint pain and muscular tremors (45, 46, 222). If treatment is not given promptly, death may occur (54).

In a severe case of poisoning with the 2,4-isomer, the individual was reported to have suffered from severe cyanosis and later complained of headache, palpitations, tightness in the chest, insomnia and lack of appetite. Other medical findings included tremors and impaired reflexes. The dose and route of exposure were not indicated (595).

Data on human reproductive effects are equivocal. One study of 9 workers exposed to concentrations of technical grade dinitrotoluene ranging from nondetectable to a maximum of 0.42 mg/m^3 found decreased sperm counts and a reduction in the number of large morphologic sperm forms. A nonsignificant increase in spontaneous abortions was also reported for the wives of the exposed workers

(3521). In contrast, another study of males exposed to 0.026 to 0.89 mg/m^3 technical grade dinitrotoluene in the workplace found no statistically significant differences between exposed and unexposed workers in sperm counts, sperm morphology, fertility or the rate of spontaneous abortions in their wives (790). Negative results were also obtained in a sample of 84 exposed and 119 unexposed workers evaluated against the same reproductive parameters. The level of exposure in this study was not reported (790).

In a study of 154 workmen exposed to 2,4-dinitrotoluene, the chief symptoms were an unpleasant metallic taste, weakness, headache, loss of appetite and dizziness. Fifty percent developed cyanosis and anemia. Jaundice was observed in 2 individuals. No permanent physical impairment was found. Fifteen percent showed a reduced tolerance to alcohol while 20% stated that their symptoms had been aggravated by alcohol ingestion. Some workers reported the inability to consume alcoholic beverages within 2 to 3 hours of finishing a shift without experiencing symptoms of acute illness (596). The ingestion of alcohol normally causes increased susceptibility to cyanosis and will therefore aggravate the toxic effects of dinitrotoluene. Also, since the body eliminates dinitrotoluene slowly, abstention from alcoholic beverages should be practiced for several days after exposure. Alcohol in any form should never be administered to a victim of dinitrotoluene poisoning (222).

A study of cohorts of workers exposed to technical-grade dinitrotoluene (19% 2,6-dinitrotoluene) and 2,4-dinitrotoluene (1% 2,6-dinitrotoluene) in two munitions plants operating during the 1940s and 1950s indicated an increase in ischemic heart disease over that seen in white males in the United States and in persons living in the vicinity of the two plants. Median exposure times to technical-grade dinitrotoluene and the 2,4-isomer were for 0.4 yr and 1.2 yr, respectively. The data suggest a correlation between mortality and length and intensity of exposure to dinitrotoluene (3524).

23.3.2.2 Chronic Toxicologic Effects

There are no reports in the literature on long-term human exposure to dinitrotoluene isomers. Mackison (38) states that repeated or prolonged exposure may cause anemia or jaundice.

23.3.3 Levels of Concern

No standards or criteria have been set specifically for the 2,6-isomer of dinitrotoluene. OSHA (3539) has set a standard for exposure to 1.5 mg/m^3 of dinitrotoluene (commercial mixture of isomers) averaged over an 8-hour work-shift; the ACGIH (3005) has set a similar standard for the commercial grade dinitrotoluene. The TLV was set by analogy with chemically-similar substances.

The USEPA (355) has established a zero ambient water quality criterion for the protection of human health from ingestion of the 2,4-isomer of dinitrotoluene; concentrations in water of 1.1, 0.11 and 0.011 μg/L 2,4-dinitrotoluene were estimated

to result in incremental lifetime cancer risks of 1E-05, 1E-06, and 1E-07, respectively, for individuals who consumed 2 liters of drinking water and 6.5 g of contaminated fish daily for a lifetime at the criterion level.

IARC does not list 2,6-dinitrotoluene in its weight-of- evidence ranking of potential carcinogens. However, based on the recent studies of Leonard et al. (3876, 3880, 3878), evidence of carcinogenicity in animals is available, and 2,6-dinitrotoluene is classified as an EPA Class B2 carcinogen (3879). In addition, NIOSH has recommended that 2,6-dinitrotoluene be considered a potential carcinogen.

23.3.4 Hazard Assessment

The notable lack of quantitative data available for either humans or experimental animals makes estimates of dose-response relationships uncertain, particularly with regard to long-term, low-level oral exposure.

Oral administration of commercial mixtures of dinitrotoluene have induced liver carcinomas in rats (591, 592) and studies with the 2,6-isomer alone indicate it to be a liver carcinogen (3876). There is limited evidence of genotoxic activity. There were no indications of teratogenic effects in rats given a technical grade dinitrotoluene mixture containing 19% 2,6-dinitrotoluene (791). However, testicular atrophy, decreased spermatogenesis and aspermatogenesis have been reported in three species orally administered 2,6-dinitrotoluene for 4-13 weeks (792). Similar findings were reported in one group of occupationally exposed workers but not for another (790).

Data on other toxic effects associated with exposure to dinitrotoluene are sparse. Anoxia due to the formation of methemoglobin is the most common sign of exposure in humans, but may be delayed for up to 4 hours after exposure. Ingestion of alcohol is reported to aggravate the toxic effects of dinitrotoluenes. A study of cohorts of workers exposed to technical-grade dinitrotoluene and 2,4-dinitrotoluene indicate an association between exposure time and amount and an increased incidence of ischemic heart disease (3524).

23.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of 2,6-dinitrotoluene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of 2,6-dinitrotoluene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 609, 625, and 1625 (65). Prior to analysis, samples are extracted with methylene chloride as a solvent using a

separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; 2,6-dinitrotoluene is then detected with an electron capture, detector (Methods 609 and 8090) or a mass spectrometer (Methods 625, 1625, and 8250). Toluene as well as methylene chloride have been used as the extraction solvent (3057). A method which uses macroreticular resins to concentrate the sample rather than liquid-liquid extraction has also been described (3592).

The EPA procedures recommended for 2,6-dinitrotoluene analysis in soil and waste samples, Methods 8090 and 8250 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection. Determinations are made with the electron capture detector.

Typical 2,6-dinitrotoluene detection limits that can be obtained in wastewaters and nonaqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Nonaqueous Detection Limit
0.01 μg/L (Method 609)	6.7 μg/kg (Method 8090)
1.9 μg/L (Method 625)	1.2 μg/g (Method 8250)
10 μg/L (Method 1625)	
0.1 μg/L (3592)	
0.1 μg/L (Method 8090)	
19 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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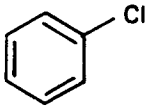
COMMON SYNONYMS:	CAS REG.NO.: 108-90-7 FORMULA: C_6H_5Cl NIOSH NO: CZ0175000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25 °C (12) 4.60 mg/m³ ≈ 1 ppm; 0.217 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 112.56
Monochlorobenzene Chlorobenzol Phenyl chloride MCB CP27		

REACTIVITY	Reactions of halogenated organic materials such as chlorobenzene with cyanides, mercaptans or other organic sulfides typically generate heat, while those with amines, azo compounds, hydrazines, caustics or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, zinc or magnesium, organic peroxides or hydroperoxides, strong oxidizing agents, or strong reducing agents typically result in heat generation and explosions and/or fires (511,505). Chlorobenzene is also known to form shock-sensitive solvated salts that are liable to explode when mixed with silver perchlorate, and to react violently with dimethyl sulfoxide (505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Clear	(23)
	• Odor: Almond-like	(23)
	• Odor Threshold: 0.21 ppm	(263)
	• Density: (g/mL at 20°C): 1.106	(14)
	• Freeze/Melt Point: -55/-45°C	(69)
	• Boiling Point: 132°C	(14)
	• Flash Point: 28° (closed cup)	(69)
	• Flammable Limits: 1.3-7.1% by volume	(60,513,504)
	• Autoignition Temp.: 593-640°C	(60,38,506)

PHYSICO-CHEMICAL DATA (Cont.)	• Vapor Pressure: 8.8 mm Hg (at 20°C) (38) • Satd. Conc. in Air: 54,000 mg/m^3 (at 20°C) (67) • Solubility in Water: 490 mg/L (at 25°C) (1219) • Viscosity: 0.765 cp (at 20°C) (21) • Surface Tension: 32.65 dyne/cm (at 20°C) (21) • Log (Octanol-Water Partition Coeff.): 2.84 (29) • Soil Adsorp. Coeff.: 333 (652) • Henry's Law Const.: 0.00346 atm · m^3/mol (at 25°C) (74) • BioconcentrationFactor: 10.3 (estim for edible aquatic organisms), 33 (estim) (262,659)
PERSISTENCE IN THE SOIL-WATER SYSTEM	Chlorobenzene is expected to be fairly mobile in soil/ground-water systems, particularly in deep soils of low organic content. In general, chlorobenzene will persist in the soil/ground-water environment. However, volatilization from surface soils may be important and biodegradation by acclimated microbial populations has been observed.
PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is probably the migration of chlorobenzene to groundwater drinking water supplies, although it is moderately adsorbed and may be biodegraded. Inhalation resulting from volatilization from surface soils may also be important under some conditions.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (38,45,51) The symptoms of inhalation and ingestion include dizziness, drowsiness, headache, nausea and vomiting. The urine may be colored burgundy-red. Chlorobenzene will cause irritation of the eyes, nose and skin. Acute Toxicity Studies: ORAL: LD_{50} 2910 mg/kg Rat (47) SKIN: No data INHALATION: LC_{Lo} 15,000 mg/m^3 Mouse (51) Long-term Effects: Liver and kidney damage Pregnacy/Neonate Data: Negative teratogen; near-lethal levels linked to decteased spermatogenesis in dogs Mutation Data: Limited evidence is negative Carcinogenicity Classification: IARC - No data NTP - Some evidence EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation • Vapor concentrations of 75-1000 ppm: chemical cartridge respirator with full facepiece and organic vapor cartridge • 1000- 2400 ppm: any supplied-air respirator or self-contained breathing apparatus with full facepiece, or gas mask with organic vapor canister • Chemical goggles if there is probability of eye contact • Protective clothing to prevent repeated or prolonged skin contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 75 ppm
- AFOSH PEL (8-hr TWA): 75 ppm; STEL (15-min): 112.5 ppm

Criteria
- NIOSH IDLH (30 min): 2400 ppm
- NIOSH REL: None established
- ACGIH TLV® (8-hr TWA): 75 ppm
- ACGIH STEL (15 min): None established

WATER EXPOSURE LIMITS:

Drinking Water Standards (3883)
MCLG: 100 μg/L (proposed)
MCL : 100 μg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 2000 μg/L
- 10-day (child): 2000 μg/L
- longer-term (child): 2000 μg/L
- longer-term (adult): 7000 μg/L
- lifetime (adult): 100 μg/L

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, 488 μg/L chlorobenzene. Adjusted for drinking water only, 488 μg/L. Based on adverse organoleptic effects, 20 μg/L chlorobenzene.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 250 μg/L of chlorinated benzenes.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

chronic toxicity:
no criterion established due to insufficient data, but toxicity occurs at concentrations as low as 50 μg/L for 7.5 days exposure.

- Saltwater species
  acute toxicity:
  no criterion, but lowest effect level occurs at 160 μg/L of chlorinated benzenes.

  chronic toxicity:
  no criterion, but lowest effect level occurs at 129 μg/L of chlorinated benzenes.

REFERENCE DOSES:
2.000E+01 μg/kg/day (3744)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

  Clean Water Act (CWA)
  Chlorobenzene is designated a hazardous substance under CWA. It has a reportable quantity (RQ) limit of 45.4 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), and metal molding and casting (892). Limitations vary depending on the type of industry and plant.

  Safe Drinking Water Act (SDWA)
  Chlorobenzene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 by January, 1991 (3781). EPA lists it as an unregulated contaminant requiring monitoring in all community water systems and non-community non-transient water systems (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of chlorobenzene-containing wastes designated as hazardous under RCRA (295).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of chlorobenzene must report production usage and disposal information to EPA. They, as well as others who possess health and safety studies on chlorobenzene, must submit them to EPA (334, 3789). EPA requires that manufacturers and importers of chemical substances made from chlorobenzene submit production, use, exposure, and disposal data in order to determine whether there is further need for dioxin and furan testing of the chemical products for which chlorobenzene is a precursor (3780). EPA requires that manufacturers, importers, and processors of chlorobenzene conduct reproductive and fertility effects testing (340).

Resource Conservation and Recovery Act (RCRA)
Chlorobenzene is identified as a toxic hazardous waste (U037) and listed as a hazardous waste constituent (3783, 3784). Non-specific sources of chlorobenzene-containing waste are solvent use (or recovery) activities, spent solvent mixtures containing 10% or more chlorobenzene, and chlorinated aliphatic hydrocarbon production (325). Waste streams from the organic chemicals industry (production of benzyl chloride, 1,2-dichloroethane, and chlorobenzene) contain chlorobenzene and are listed as specific sources of hazardous waste (3774, 3765). Chlorobenzene is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective July 8, 1987, the land disposal of untreated hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances exist until May, 1990 for some wastewaters and contaminated soils for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). Chlorobenzene is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated chlorobenzene as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Chlorobenzene is approved for use as an indirect food additive as a component of adhesives (3209).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Chlorobenzene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing chlorobenzene from non-specific but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of chlorobenzene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Federal Insectide, Fungicide and Rodentcide Act (FIFRA)
Chlorobenzene is exempt from a tolerance requirement when used as a solvent in pesticide formulations applied to growing crops. It must not contain more than 1% impurities, nor should it be used after the edible parts of the plant begin to form. Livestock should not be grazed in treated areas within 48 hours after application (315).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemicals constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to chlorobenzene in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 75 ppm (3539).

Clean Air Act (CAA)
After consideration of data regarding serious health effects from ambient air exposure to chlorobenzene, EPA has decided not to list this chemical as a hazardous air pollutant (3685).

- State Water Programs
  ALL STATES
  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

CALIFORNIA
California has set an MCL and an action level of 30 μg/L for chlorobenzene in drinking water (3096, 3098).

CONNECTICUT
Connecticut has a quantification limit of 2 μg/L for drinking water (3137).

DISTRICT OF COLUMBIA
The District of Columbia has a human health criterion of 20 μg/L for all chlorinated benzenes in public water supply waters (3828).

MISSOURI
Missouri has a water quality criterion of 20 μg/L for drinking water supply waters (3457).

NEW JERSEY
New Jersey has set an MCL of 4 μg/L for drinking water (3497).

NEW YORK
New York has set an MCL of 5 μg/L for drinking water, and has a nonenforceable water quality guideline of 20 μg/L for ground-water. New York has also set ambient water quality standards for surface waters: 20 μg/L for drinking water supplies, 5 μg/L for fresh water classed A, A-S, AA, AA-S, B, and C for fishing and fish propagation (3501, 3500).

OKLAHOMA
Oklahoma has a water quality standard of 0.7 μg/L for ground-water (3534).

PENNSYLVANIA
Pennsylvania has a human health criterion of 20 μg/L for surface waters (3561).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 795 μg/L and a chronic guideline of 18 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires chlorobenzene and monochlorobenzene to be nondetectable, using designated test methods, in ground-water (3671).

VERMONT
Vermont has a preventive action limit of 50 μg/L and an enforcement standard of 100 μg/L for ground-water (3682).

WISCONSIN
Wisconsin has a human threshold criterion of 0.94 mg/L for Public Water Supply surface waters (3842). Wisconsin has also set a taste and odor criterion threshold concentration of 20 μg/L for surface waters (3841).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)
  In November, 1985 EPA proposed an RMCL of 0.06 mg/L for chlorobenzene. In May, 1989, EPA will propose a maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) of 0.1 mg/L, with final action scheduled for May, 1990 (3759).

  Resource Conservation and Recovery Act (RCRA)
  EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 1.4 mg/L chlorobenzene. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565).

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

  KANSAS
  Kansas has proposed a water quality standard of 60 μg/L for ground-water (3213).

  MINNESOTA
  Minnesota has proposed a Recommended Allowable Limit (RAL) of 300 μg/L for drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 4884 μg/L for surface waters, and chronic criteria of 300 μg/L for ground-water and 109 μg/L for surface water. These criteria are for the protection of human health (3452).

  NEW JERSEY
  New Jersey has proposed a water quality standard of 4 μg/L for class FW2 surface waters (3496).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Quality Required of Shellfish Waters (537)
The mandatory specifications for organohalogenated substances specify that the concentration of each substance in the shellfish water or in shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The specifications for organohalogenated substances state that the concentration of each substance in shellfish flesh must be so limited that it contributes to the high quality of the shellfish product.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Chlorobenzene is listed as a Class II/a harmful substance and is subject to packaging and labeling regulations.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or under taking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert poly-meric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto- pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Chlorobenzene is classified as a harmful substance and is subject to packaging and labeling regulations.

EEC Directive-Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
Chlorobenzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

24.1 MAJOR USES

Chlorobenzene is used mainly as a solvent and degreasing agent. Chlorobenzene has been used as a feedstock in the production of phenol, nitrobenzenes, DDT and aniline, but its use in this area has declined due to restrictions on the use of DDT and replacement of chlorobenzene by cumene in the manufacture of phenol (38, 250).

24.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

24.2.1 Transport in Soil/Ground-water Systems

24.2.1.1 Overview

Chlorobenzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by estimating equilibrium partitioning as shown in Table 24-1.

These calculations predict the partitioning of chlorobenzene among soil particles, soil water and soil air. Portions of chlorobenzene associated with the water and air phases of the soil have higher mobility than the adsorbed portion.

Estimates for the unsaturated topsoil model indicate that almost 98% of the chlorobenzene is expected to be sorbed onto soil particles. Approximately 1.5% is expected to partition to the soil-water phase, and is thus available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of chlorobenzene in the gaseous phase of the soil (approximately 0.7%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, may be a significant loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the chlorobenzene (41.7%) is likely to be present in the soil-water phase (Table 24-1) and available for transport with flowing groundwater. Sorption onto deep soils is expected to be less than on to top soils, but may have some effect on mobility. Overall, groundwater underlying chlorobenzene-contaminated soils with low organic content is expected to be vulnerable to contamination.

TABLE 24-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR CHLOROBENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 25°C	97.8	1.5	0.7
Saturated deep soil[d]	58.3	41.7	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized soil sorption coefficient estimated with equations of Means et al. (611): K_{oc} = 333.
c) Henry's law constant taken as 3.46E-03 atm · m^3/mol at 25°C (74).
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: $K_p = 0.001 \times K_{oc}$.

24.2.1.2 Sorption on Soils

The mobility of chlorobenzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Wilson et al. (82) investigated the transport and fate of 1.04 mg/L and 0.18 mg/L chlorobenzene solutions applied to sandy soils. Chlorobenzene was found to be relatively mobile. In a soil column receiving 1.04 mg/L chlorobenzene, approximately 27% was volatilized, 23-33% percolated through the soil column with minimal retardation, and 40-50% was degraded or not accounted for; for the 0.18 mg/L solution, 54% was lost due to volatilization, 26-34% percolated through the soil column, and 12-20% was degraded or not accounted for.

Laboratory sorption studies (608) indicate that sorption of chlorobenzene (20 μg/L) by sediments and aquifer material is a reversible process. Retardation rates, which represent the interstitial water velocity/pollutant velocity in the soil, were reported by Wilson et al. (82) to be a function of K_{oc}, the ratio of soil density (a) to soil water content (b), and the organic content of the soil according to the following equation:

$$R_f = 1 + (a/b)K_{oc}(oc)$$

The following retardation factors have been calculated for chlorobenzene: 10 in river sediments (228), 1.7 in aquifer materials (228), and 1.9 in sandy soils (82). The data indicate some retardation (i.e., adsorption) in soils having 1-2% organic carbon and little or no retardation in deep soils having less than 0.1% organic carbon.

24.2.1.3 Volatilization from Soils

Transport of chlorobenzene vapors through the air-filled pores of unsaturated soils may occur in near-surface soils. However, only a small portion of the chlorobenzene loading is expected to be in the soil-air compartment. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phasediffusion coefficient (31).

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, is expected to increase significantly with increasing temperature. Moderate increases in H have also been observed with increasing salinity and the presence of other organic compounds (18). These results suggest that the presence of other materials may significantly affect the volatilization of chlorobenzene from surface soils.

No information was available for the two other physicochemical properties influencing chlorobenzene volatilization, i.e., the vapor-soil sorption coefficient and the vapor phase diffusion coefficient.

Half-lives for the volatilization of chlorobenzene from aerated and unaerated aqueous solutions in the laboratory were calculated to be about 0.5 hours and 9 hours, respectively (10). Compared to volatilization from well-stirred aqueous solutions, volatilization from surface soil was shown to be approximately one order of magnitude slower for some chlorinated organics (82).

Wakeham et al. (527) examined the fate and persistence of chlorobenzene in coastal seawater. Half-lives obtained for chlorobenzene in the water column were 21 days under spring conditions, 4.6 days under summer conditions, and 13 days under winter conditions. Volatilization was identified as the major removal process although biodegradation of chlorobenzene was also important in summer.

24.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of chlorobenzene in soil/ground-water systems is not well documented. In most cases, it should be assumed that chlorobenzene will persist for months to years (or more). Chlorobenzene that has been released from the soil into the air will eventually undergo photochemical oxidation; an atmospheric residence time of 13 days has been reported for chlorobenzene (601).

No information on the hydrolysis of chlorobenzene was available; under normal environmental conditions, hydrolysis is not expected to occur at a rate competitive with volatilization or biodegradation.

Several authors have reported the biodegradation of chlorobenzene particularly by acclimated microbial populations. Chlorobenzene has been reported to be metabolized by benzene-acclimated sludge (603) and by phenol-acclimated sludge (604). Gibson et al. (602) indicated that a soil microbe, Pseudomonas putida, could degrade chlorobenzene if initially grown on an aromatic hydrocarbon source such as toluene. Wilson et al. (82) reported that chlorobenzene applied to soil at 0.18 mg/L was not degraded while a major fraction of the chlorobenzene applied at 1.04 mg/L may have degraded.

The biodegradation of chlorobenzene in coastal waters has been reported (605, 527). Pfaender and Bartholomew (605) indicate that the rate of biodegradation in a marine water sample was significantly lower than that in estuarine or upstream samples. Lee and Ryan (606) examined chlorobenzene biodegradation in river water and sediments. The degradation in water was slow, and in the sediment samples chlorobenzene was found to have a half-life of 75 days.

Wilson et al. (236) studied chlorobenzene biodegradation in samples of two aquifer materials; chlorobenzene degraded slowly in material from one site, while no degradation was detected in material from the second site. No degradation of chlorobenzene was observed after injection into ground water (597).

In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as chlorobenzene is expected to be low and to drop off sharply with increasing depth. Thus, biodegradation in the deep soil/ground-water system should be assumed to be of minimal importance except, perhaps, near landfills with active microbiological populations.

24.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that chlorobenzene is highly volatile from aqueous solutions, moderately adsorbed by soil, and has a low potential for bioaccumulation. This compound may volatilize from soil surfaces. Through time, the portion not subject to volatilization is likely to be mobile in ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of chlorobenzene from a disposal site, particularly during drilling or restoration activities could result in inhalation exposures. There is a potential for ground water contamination, particularly in sandy soil. Mitre (83) reported that chlorobenzene has been found at 20 of the 546 National Priority List (NPL) sites. It was detected at 17 sites in groundwater and 7 sites in surface water.

This compound was reported in the Groundwater Supply Survey (GWSS) as shown below (531):

Sample Type		Occurrences* No.	%	Median of Positives (μg/L)	Maximum (μg/L)
Random					
Supplies serving	<10,000 people (280 samples)	0	0	-	-
Supplies serving	>10,000 people (186 samples)	0	0	-	-
Non-Random					
Supplies serving	<10,000 people (321 samples)	1	0.3	2.7	2.7
Supplies serving	>10,000 people (158 samples)	0	0	-	-

*Samples having levels over quantification limit of 0.5 μg/L.

The random results are intended to statistically represent the U.S. ground-water drinking water supplies. The non-random samples were chosen by the states as being potentially contaminated. Chlorobenzene has also been detected in the National Organic Monitoring Survey (NOMS) (90). Coniglio et al. (223) in a summary of data from SRI, NOMS and NORS, found that chlorobenzene was found at a frequency of 7.1% in finished ground water.

The properties of chlorobenzene and the survey results above indicate that this compound has a potential for movement in soil/groundwater systems close to the source (83). The lack of detection in the GWSS (531) suggests adsorption or biodegradation is ccurring as the compound moves from the source. If this compound reaches surface waters in ground water, several other exposure pathways are possible:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures;

- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposures from drinking contaminated ground water for several reasons. First, the Henry's law constant for chlorobenzene suggests that it will volatilize upon reaching surface waters. Secondly, because chlorobenzene is moderately adsorbed, the concentration reaching surface waters will be attenuated through adsorption to sediments. In addition, the BCF for this compound is low, suggesting that accumulation by aquatic organisms and domestic animals is not expected to be a primary exposure pathway.

24.2.4 Other Sources of Exposure

The volatility of chlorobenzene suggests that it may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric data for a number of volatile organics. For chlorobenzene they had data for 1192 locations. For urban and suburban areas, the median concentration was 1.5 $\mu g/m^3$. In source-dominated locations, the median concentration was 0.14 $\mu g/m^3$. The lower median concentration in source-dominated areas was not explained by the authors but is probably an artifact of the sampling locations included in each category. These results suggest the possibility of inhalation exposure to chlorobenzene.

The result of the GWSS study (531) reported above suggest that chlorobenzene is not commonly found in drinking water, particularly that obtained from ground water. There is a lack of data on the occurrence of chlorobenzene in finished surface water supplies. There has been concern regarding the inadvertent production of chlorobenzenes through chlorination of effluents containing benzene. The data that exist seem to indicate that chlorination is not a significant inadvertent source (265).

24.3 HUMAN HEALTH CONSIDERATIONS

24.3.1 Animal Studies

24.3.1.1 Carcinogenicity

A 103 week carcinogenicity study was carried out by the NTP in F344/N rats and B6C3F$_1$ mice (3922). Rats of both sexes and female mice were given doses of 60 or 120 mg/kg. Male mice received doses of 30 or 60 mg/kg. Chlorobenzene was administered in corn oil by gavage 5 days per week. Additional groups of animals served as vehicles or untreated controls. Carcinogenic effects were not observed in

either sex of mice or in female rats. However, the frequency of high-dose male rats with neoplastic nodules of the liver was slightly increased ($p<0.05$), providing some, but not definitive, evidence of carcinogenic activity.

24.3.1.2 Genotoxicity

In an in vivo micronucleus test, Mohtashamipur et al. (3464) injected 8-week old male NMRI mice intraperitoneally with 225, 450, 675, or 900 mg of chlorobenzene/kg body weight. Each dose was administered in two injections, 24 hours apart, and the animals were sacrificed 6 hours after the last injection. Statistically significant, dose-related increases in micronuclei were observed in the bone marrow cells (3464). In an in vitro human lymphoid cell culture study, no increase in sister chromatid exchanges or chromosome aberrations was observed when 4μg/mL chlorobenzene was added to the cultures (3667).

Although positive mutagenic findings were reported in tests with Streptomyces and Saccharomyces, several other bacterial and mammalian tissue culture systems were negative (597). Three publications reported negative effects in the Salmonella/ microsome assay (3646, 3276, 3508).

24.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

The teratogenicity of chlorobenzene was evaluated in rats and rabbits that were exposed to vapor concentrations of 75, 210 or 590 ppm (345, 966 or 2714 mg/m^3) 6 hours per day on gestational days 6 through 15 for rats and days 6 through 18 for rabbits (256). In rats, maternal liver weights were elevated and maternal bodyweights and feed consumption were decreased at the highest concentration, but in the offspring, there was no evidence of teratogenicity or embryotoxicity. In the rabbits, maternal liverweights were elevated at the highest concentration and the offspring exhibited a variety of malformations at all concentrations. However, these effects were not dose related and were present in the controls, as well. To ascertain whether the anomalies were a true effect of treatment, additional groups of rabbits were exposed to 10, 30, 75 or 590 ppm (46, 138, 345 or 2714 mg/m^3) within the same parameters. The incidences of malformations in these groups were not significant in comparison to the controls, leading the investigators to conclude that chlorobenzene was not embryotoxic or teratogenic in rabbits.

In a two-generation reproductive toxicity study, male and female rats were exposed by inhalation to vapors of chlorobenzene at concentrations of 50, 150, or 450 ppm (3478). No adverse effects on reproductive performance or fertility of the males or females were observed; however, the incidence of bilateral degeneration of the testicular germinal epithelium was increased among F_0 adults in the 450 ppm group and in the F_1 males of the 150 and 450 ppm groups. In addition, hepato- cellular hypertrophy and renal changes were observed in the F_0 and F_1 male rats exposed to 150 and 450 ppm of chlorobenzene.

Decreased spermatogenesis (sperm formation) and tubular atrophy were noted in three of four dogs given 272.5 mg/kg/day of chlorobenzene orally for 13 weeks;

however, this dose was sufficiently toxic that dogs died or were moribund (615). A subsequent inhalation study indicated bilateral atrophy of the epithelial tissue in the seminiferous tubules (major mass of the testis) in two of four dogs exposed to 2 mg/L chlorobenzene vapor (434 ppm) for 6 hours/day, 5 days a week for a total of 62 exposures. This effect was not seen in similarly exposed dogs at the concentration of 1.47 mg/L (319 ppm) (252).

24.3.1.4 Other Toxicologic Effects

24.3.1.4.1 Short-term Toxicity

The acute toxic effects of chlorobenzene are similar to those of the chlorinated hydrocarbons. In particular, the chemical is a CNS depressant (3906). Single oral doses of chlorobenzene were lethal at levels of 4000 mg/kg in male and female rats, 1000 mg/kg and greater in male mice, and 2000 mg/kg and greater in female mice (3922). Most deaths occurred within a few days of administration. In the rats, symptoms of toxicity that included transient ataxia, labored breathing, and prostration, were dose-related at 2000 and 4000mg/kg. Hyperpnea was frequently observed in all treated rats.

Cats exposed to a vapor concentration of 8000 ppm experienced severe narcosis after 30 minutes and died 2 hours after removal from exposure (3910). Levels of 660 ppm were tolerated for hours without significant effects (3918). No effects were observed in rats, rabbits and guinea pigs exposed to 200 ppm (vapor), 7 hours per day 5 days per week for a total of 32 exposures (3918). At 475 ppm, there was a slight increase in liver weight as well as minor pathological liver changes. At a concentration of 1000 ppm, there were lesions in the livers, kidneys and lungs of all species as well as a slight depression in growth. Guinea pigs showed a higher than average mortality; there was no mortality in rats or rabbits. Blood was normal in all animals.

To test the effects of inhaled chlorobenzene on the mouse lung host defenses, CD1 mice were exposed to 75 ppm [the threshold limit value (TLV)] of the chemical in a single 3-hour or five daily 3 ½ hour exposures, infected with Streptococcus zooepidemicus (Group C), and monitored for ensuing deaths from respiratory infection over 14 days (3893). Chlorobenzene, at the TLV in single or multiple exposures, did not produce significant changes in mortality, indicating that the chemical did not alter the susceptibility of the mouse to respiratory infection.

Eye contact with chlorobenzene may result in pain and transient conjunctival irritation (3917). No corneal injury has been observed (3918). Prolonged skin contact with chlorobenzene may also be painful (3917) and moderately irritating (3918).

24.3.1.4.2 Chronic Toxicity

Chronic administration of chlorobenzene produces pathological changes of the liver and kidneys. F-344/N rats and B6C3F$_1$ mice (10/sex/dose) received chlorobenzene doses of 0, 60, 125, 250, 500, or 750 mg/kg by gavage 5 d/wk for 13 wk (3922). The animals were closely observed throughout the treatment period for signs of toxicity, and at the end of treatment urine samples were obtained and subjected to various chemical analyses. Blood samples were assayed for various hematological and chemical constituents, and several tissues and all gross lesions were examined microscopically. Survival was reduced by doses of 500 mg/kg and higher in rats, and by doses of 250 mg/kg and higher in mice. Dose-dependent necrosis of the liver, degeneration or focal necrosis of the renal proximal tubules, and lymphoid depletion of the spleen, bone marrow, and thymus were produced by chlorobenzene doses of 250 mg/kg or greater in both sexes of rats and mice. However, the incidences of these lesions varied considerably according to sex and species. A mild porphyrinuria was detected at the higher doses, but there were no consistent changes in the elements of the circulating blood. Toxic effects were not observed at doses of 125 mg/kg or less.

Dogs administered chlorobenzene capsules in doses of 27.25 or 54.5 mg/kg/day, 5 days per week for 93 days exhibited no effect. At a dosage of 272.5 mg/kg/day, however, 50% of the animals died after 14 to 21 doses. Pathological changes in the liver, kidney and bone marrow were evident. This dosage also produced a reduction in blood sugar, an increase in immature white blood cells and elevated serum liver enzymes (253, 615).

A dosage of 376 mg/kg/day, 5 days per week for 192 days caused cirrhosis and decreased spleen weight in rats. Slight increases in liver and kidney weights were observed at 188 mg/kg/day, with the no-observed-adverse-effect-level being 18.8 mg/kg/day (254). Similar observations were noted in another study in which rats were administered 14.4, 144 or 288 mg/kg/day, orally, 5 days/week over a 192-day period (3906). No observable effects were noted for the 14.4 mg/kg treatment group. A slight decrease in growth was noted at the intermediate level, from which the rats recovered, while significant increases in liver and kidney weights and slight liver pathology were seen at the top treatment level. Blood and bone marrow were normal in all rats.

There is limited evidence to indicate that chlorobenzene may affect the hemopoietic system (3956). Male albino rats were treated with chlorobenzene doses of 0.001, 0.01, or 0.1 mg/kg by gavage for 9 months. Doses of 0.1 mg/kg produced inhibition of erythropoiesis (statistically significant),inhibition of mitotic activity in the marrow, thrombocytosis, and eosinophilia. Doses of 0.1 mg/kg also inhibited higher nervous activity. In addition, alkaline phosphatase and serum transaminase activities, and hepatic and renal acid phosphatase activities were increased, but whole blood SH groups and hepatic and renal alkalinephos phatase, DPN, TPN, succinic

dehydrogenase, glucose-6-phosphatase, and alphaglycerophosphate were reduced. Microscopic examination revealed no evidence of carcinogenic activity.

24.3.2 Human and Epidemiologic Studies

24.3.2.1 Short-term Toxicologic Effects

In humans, the most common symptoms of acute exposure to chlorobenzene are the same as those for the chlorinated hydrocarbons: mainly dizziness, drowsiness, nausea, vomiting, weakness and headache (2). Irritation of the eyes and mucous membranes of the respiratory tract occur after a few minutes exposure to 200 ppm of the vapor (38). Skin contact may result in minor irritation. Prolonged or repeated contact may result in skin burns (46).

In one case of accidental poisoning, a two-year-old child who swallowed 5 to 10 mL of a cleaning agent containing chlorobenzene lost consciousness within two hours. The child was cyanotic and had no detectable reflexes, displayed head and neck twitching and suffered heart failure. He recovered consciousness after approximately three hours and all signs had returned to normal by eight hours (260).

24.3.2.2 Chronic Toxicologic Effects

There are only a few reports of long-term human exposure to chlorobenzene. Severe anemia was reported in an elderly woman who had been chronically exposed to a glue containing 70% chlorobenzene. Early complaints included headache and irritation of the eyes and upper respiratory tract. Factory workers exposed to unknown vapor levels of chlorobenzene for 1 to 2 years suffered from headache, dizziness, drowsiness and digestive disorders. Eight of the 28 workers had tingling and numbness of the extremities and eight had hyperesthesia (abnormally increased sensitivity of the skin) of the hands (259, 261).

24.3.3 Levels of Concern

The U.S. Environmental Protection Agency (355) has established an ambient water quality criterion of 488 μg/L for the protection of human health from the toxic properties of chlorobenzene ingested through water and contaminated aquatic organisms. This criterion is based on the no-observed-effect level of 14.4 mg/kg/day reported for rats orally administered chlorobenzene over a period of 6 months (251). Applying an uncertainty factor of 1000, the acceptable daily intake of chloro-benzene for a 70-kg man was calculated to be 1.008 mg/day. A MCLG and MCL for chloro-benzene in drinking water of 100 μg/L has been proposed by the USEPA (3883).

Both OSHA (3539) and the ACGIH (3005) have set an occupational exposure 8-hr TWA of 75 ppm (350 mg/m^3) for chlorobenzene, based on preventing narcosis or chronic poisoning.

24.3.4 Hazard Assessment

The extent of available effects data for humans exposed to chlorobenzene is inadequate to determine with any confidence the potential health hazards associated with exposure to this compound. Rather meager data indicate that workers exposed intermittently to chlorobenzene vapors for up to two years exhibited signs of neurotoxicity (259, 261). Another report noted head and neck twitching in a child who accidentally ingested a small volume (5-10mL) of chlorobenzene (260). These reports are inadequate to establish whether these effects are reversible or if there are other toxic effects in humans exposed to chlorobenzene.

Animal studies indicate acute exposures to chlorobenzene can induce sensory irritation of the respiratory tract after a few minutes; longer exposures can result in narcosis and CNS depression.

Chlorobenzene administered to rats, rabbits and dogs at moderate to high doses by inhalation or oral routes caused hepatic and renal toxicity manifested by increased liver and kidney weights, pathological changes and elevated serum enzymes.

Carcinogenicity was not definitively demonstrated in an NTP study (255) conducted with rats and mice, but high-dose male rats (120 mg/kg/day orally) displayed a marked increase in neoplastic nodules of the liver. Limited mutagenic evidence is conflicting.

Repeated exposures to chlorobenzene at near-lethal levels of 272.5 mg/kg/day (oral) or 2 mg/L (~434 ppm vapor) induced atrophy of the epithelial tissue in the seminiferous tubules and decreased spermatogenesis in dogs (615, 252). No increase in malformations were noted in rats and rabbits exposed to 590 ppm chlorobenzene vapor during gestation (256).

24.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of chlorobenzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of chlorobenzene, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight containers with no headspace; analysis should be completed within 14 days of sampling. However, recent studies (3430) show large losses of volatiles from soil handling. At the present, the best procedure is to collect the needed sample in an EPA VOA vial, seal with a foil-lined septum cap, and analyze the entire contents in the vial using a modified purge and trap apparatus. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of chlorobenzene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 601, 602, 624, 1624 (65), and 8010, 8020, and 8240 (63). An inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the chlorobenzene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the chlorobenzene and transfer it onto a gas chromatographic (GC) column. The GC column is programmed to separate the volatile organics; chlorobenzene is then detected with a halide specific detector (Methods 601 and 8010), a photo-ionization detector (Methods 602 and 8020), or a mass spectrometer (Methods 624, 1624, and 8240).

The EPA procedures recommended for chlorobenzene analysis in soil and waste samples, Methods 8010, 8020 and 8240 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The recommended method involves dispersing the soil or waste sample in methanol to dissolve the chlorobenzene. Hexane has also been used to extract chlorobenzene (3169) for analysis by capillary GC. A portion of the solution is then combined with water and purged as described above. Other sample introduction techniques include direct injection and a headspace method where an aliquot of the vapor above the sample in a sealed vial is analyzed. Recoveries for the headspace technique may vary depending upon the concentration (3355).

Typical chlorobenzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.25 μg/L (Method 601)	2.5 μg/kg (Method 8010)
0.2 μg/L (Method 602)	2.0 μg/kg (Method 8020)
6.0 μg/L (Method 624)	5 μg/kg (Method 8240)
10 μg/L (Method 1624)	
2.0 μg/L (Method 8020)	
5 μg/L (Method 8240)	
2.5 μg/L (Method 8010)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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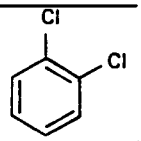
COMMON SYNONYMS:	CAS REG.NO.: 95-50-1 FORMULA: $C_6H_4Cl_2$ NIOSH NO: CZ4500000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25 ° C (12) 6.01 mg/m^3 ≈ 1 ppm; 0.1663 ppm ≈ 1 mg/m^3 MOLECULAR WEIGHT: 147.0
1,2-Dichlorobenzene DCB o-Dichlorobenzene o-Dichlorobenzol ODB		

REACTIVITY	Reactions of halogenated organic materials such as 1,2-dichlorobenzene with cyanides, mercaptans or other organic sulfides typically generate heat, while those with amines, azo compounds, hydrazines, caustics or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, zinc or magnesium, organic peroxides or hydroperoxides, strong oxidizing agents, or strong reducing agents typically result in heat generation and explosions and/or fires (511,505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23) (23)
	• Color: Colorless	(23)
	• Odor: Aromatic	(54)
	• Odor Threshold: 50 ppm	(10)
	• Density: 1.3060 g/mL (at 20°C)	(14)
	• Freeze/Melt Point: -17.00°C	(23)
	• Boiling Point: 180.40°C	(14)
	• Flash Point: 71.00°C closed cup	(21)
	• Flammable Limits: 2.20 to 9.20% by volume	(38,60,506)
	• Autoignition Temp.: 648.0°C	(38,60,506)
	• Vapor Pressure: 9.60E-01 mm Hg (at 20°C)	(1219)

PHYSICO-CHEMICAL DATA (Cont.)	• Satd. Conc. in Air: 8.0000E+03 mg/m^3 (at 20°C)	(67)
	• Solubility in Water: 1.00E+02 mg/L (at 20°C)	(67)
	• Viscosity: 1.302 cp (at 20°C)	(67)
	• Surface Tension: 3.6600E+01 dyne/cm (at 20°C)	(21)
	• Log (Octanol-Water Partition Coeff.): 3.38	(29)
	• Soil Adsorp. Coeff.: 1.16E+03	(652)
	• Henry's Law Const.: 1.88E-03 atm · m^3/mol (at 25°C)	(74)
	• Bioconc. Factor: 8.90E+01 (bluegills), 1.15E+02 (estim)	(278,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	1,2-Dichlorobenzene is expected to have limited mobility in soils, particularly soils with 1-2% organic carbon content; some migration with soil water may be observed in deep soils or sandy soils. Persistence of 1,2-dichlorobenzene is probably high. Only a small fraction is expected to be available to volatilize, and biodegradation is not expected to be significant.

PATHWAYS OF EXPOSURE	1,2-Dichlorobenzene is expected to have limited mobility in soils, particularly soils with 1-2% organic carbon content; some migration with soil water may be observed in deep soils or sandy soils. Persistence of 1,2-dichlorobenzene is probably high. Only a small fraction is expected to be available to volatilize, and biodegradation is not expected to be significant.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (38) 1,2-Dichlorobenzene vapor may cause irritation of the upper respiratory tract. Drowsiness, headache, nausea and dizziness may also result. Skin contact with the liquid causes burning and dermatitis. Both the vapor and the liquid are irritating to the eyes. Acute Toxicity Studies (3504) INHALATION: LC_{Lo} 4808 mg/m^3 · 24 hr — Guinea Pig LC_{Lo} 4934 mg/m^3 · 7hr — Rat ORAL: LD_{50} 500 mg/kg — Rat LD_{Lo} 2 g/kg — Guinea Pig LD_{50} 500 mg/kg — Rabbit Long-Term Effects: Liver and kidney injury Pregnancy/Neonate Data: Not teratogenic or embryotoxic in rats at doses causing slight maternal toxicity(400 ppm 6 hr/day(on days 6-15 of gestation). Genotoxicity Data: Suggestive evidence of genotoxicity Carcinogenicity Classification: IARC - Group 3 NTP - No evidence EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (38,54)	Handle chemical only with adequate ventilation • Vapor concentrations of 50-1000 ppm: chemical cartridge respirator with full facepiece and organic vapor cartridge • 1000-1700 ppm: gas mask with organic vapor canister, any supplied-air respirator or self-contained breathing apparatus with full facepiece • Chemical goggles if there is probability of eye contact • Protective clothing and rubber gloves and aprons are advisable to prevent repeated or prolonged contact with the liquid.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA Ceiling Limit: 50 ppm
- AFOSH Ceiling Limit: 50 ppm

Criteria
- NIOSH IDLH (30 min): 1700 ppm
- ACGIH CL: 50 ppm
- ACGIH STEL (15 min): None established

WATER EXPOSURE LIMITS:

Drinking Water Standards (3742)
MCLG: 600 μg/L (proposed)
MCL : 600 μg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)

The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 9000 μg/L
- 10-day (child): 9000 μg/L
- longer-term (child): 9000 μg/L
- longer-term (adult): 30000 μg/L
- lifetime (adult): 600 μg/L

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, 400 μg/L dichlorobenzenes (all isomers). Based on ingestion of contaminated aquatic organisms only, 2.6 mg/L dichlorobenzenes (all isomers). Adjusted for drinking water only, 470 μg/L.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 1120 μg/L dichlorobenzenes.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 763 μg/L dichlorobenzenes.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 1970 μg/L dichlorobenzenes.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:
8.900E+01 μg/kg/day (3742)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

  Clean Water Act (CWA)
  Dichlorobenzene is designated a hazardous substance under CWA. It has a reportable quantity (RQ) limit of 45.4 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), and metal finishing (3768). Limitations vary depending on the type of industry and plant.

Safe Drinking Water Act (SDWA)
Dichlorobenzene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 by January, 1991 (3781). EPA lists 1,2-dichlorobenzene as an unregulated contaminant requiring monitoring in all community water systems and non-transient non-community water systems (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of 1,2-dichlorobenzene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)
1,2-Dichlorobenzene is identified as a toxic hazardous waste (U070) and listed as a hazardous waste constituent (3783,3784). Non-specific sources of 1,2-dichlorobenzene- containing waste are solvent use (or recovery) activities, spent solvent mixtures containing 10% or more 1,2-dichlorobenzene, and chlorinated aliphatic hydrocarbon production (325). Waste streams from the following industries contain 1,2-dichlorobenzene and are listed as specific sources of hazardous waste: organic chemicals (production of chlorobenzene, and trichloroethylene/perchloroethylene), pesticides (2,4,5-T production), and ink formulation (3774, 3765). 1,2-Dichlorobenzene is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels (3785). Effective July 8, 1987, the land disposal of untreated hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances exist until May, 1990 for some wastewaters and nonwastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). 1,2-Dichlorobenzene is on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of 1,2-dichlorobenzene must report production, usage and disposal information to EPA. They, as well as others who possess health and safety studies on 1,2-dichlorobenzene, must submit them to EPA (334, 3789). EPA requires that manufacturers and processors of 1,2-dichlorobenzene conduct reproductive and fertility effects testing. Previous proposals for teratogenicity and subchronic toxicity testing have been withdrawn (340). Under TSCA Section 4, EPA requires that manufacturers and processors of 1,2-dichlorobenzene perform human health effects and

chemical fate testing in support of the RCRA program (3792). EPA requires that manufacturers and importers of chemical substances made from 1,2-dichlorobenzene submit production, use, exposure and disposal data in order to determine whether there is further need for dioxin and furan testing of the chemical products for which 1,2-dichlorobenzene is a precursor (3780).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
1,2-Dichlorobenzene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing 1,2-dichlorobenzene but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of 1,2-dichlorobenzene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Clean Air Act (CAA)
After consideration of the data regarding serious health effects from ambient air exposure to chlorinated benzenes, EPA has decided not to regulate them as hazardous air pollutants (3685).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to 1,2-dichlorobenzene shall at no time exceed the ceiling level of 50 ppm at any time during an 8-hour work-shift (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 1,2-dichlorobenzene as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs
  ALL STATES
  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

  CALIFORNIA
  California has an action level of 130 μg/L (ppb) for drinking water.

CONNECTICUT
Connecticut has a quantification limit of 2 μg/L for drinking water (3137).

DISTRICT OF COLUMBIA
The District of Columbia has a human health criterion of 20 μg/L for all chlorinated benzenes in public water supply waters (3828).

NEW JERSEY
New Jersey has set an MCL of 600 μg/L for drinking water (3497).

NEW YORK
New York has an MCL of 5 μg/L for total dichlorobenzenes in drinking water (3501). New York has a water quality standard of 4.7 μg/L for the sum of 1,2- and 1,4-isomers in ground-water classed for drinking water supply, and an ambient water quality standard for total dichlorobenzenes of 5 μg/L for Class A, A-S, AA, AA-S, B and C surface waters, and 50 μg/L for fresh surface water classed D (3500).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 79 μg/L and a chronic guideline of 1.8 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires o-dichlorobenzene to be nondetectable, using designated test methods, in ground-water (3671).

VERMONT
Vermont has a preventive action limit of 310 μg/L and an enforcement standard of 620 μg/L for ground-water (3682).

WISCONSIN
Wisconsin has a preventive action limit of 125 μg/L and an enforcement standard of 1250 μg/L for ground-water (3840). Wisconsin has also set a human threshold criterion of 1.4 mg/L for public water supply waters (3842).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)
  In November, 1985, EPA proposed a recommended maximum contaminant level (RMCL) of 0.62 mg/L for 1,2-dichlorobenzene. EPA will propose a maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) of 0.6 mg/L for 1,2-dichlorobenzene in May, 1989, with final action scheduled for May, 1990 (3759).

Resource Conservation and Recovery Act (RCRA)
EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 4.3 mg/L of 1,2-dichlorobenzene. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565).

- State Water Programs

MOST STATES
Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

KANSAS
Kansas has proposed a water quality standard of 620 μg/L for ground-water (3213).

MINNESOTA
Minnesota has proposed a Recommended Allowable Limit (RAL) of 620 μg/L for 1,2-dichlorobenzene in drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 632 μg/L for surface water, and chronic criteria of 14 μg/L for surface water and 620 μg/L for ground-water. These criteria are for the protection of human health (3452).

NEW JERSEY
New Jersey has proposed a water quality standard of 600 μg/L for class FW2 surface waters (3496).

EEC Directives

Directive on Ground Water (538)
Direct discharge into ground water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Quality Required of Shellfish Waters (537)
The mandatory specifications for organohalogenated substances specify that the concentration of each substance in the shellfish water or in shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The specifications for organohalogenated substances state that the concentration of each substance in shellfish flesh must be so limited that it contributes to the high quality of the shellfish product.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
1,2-Dichlorobenzene is listed as a Class II/a harmful substance and is subject to packaging and labeling regulations.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycylic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
1,2-Dichlorobenzene is classified as a harmful substance and is subject to packaging and labeling regulation.

EEC Directive-Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants
(545)
1,2-dichlorobenzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

25.1 MAJOR USES

The major use of 1,2-dichlorobenzene is in organic synthesis, primarily in the manufacture of 3,4-dichloroaniline (23). Approximately 15% is used as a process solvent in the manufacture of toluene diisocyanate. Miscellaneous solvent applications account for 8% of its use. These applications include cleaning and polishing formulations, motor oil additive formulations, paints, rust preventatives, degreasing of leather hides and woolen pelts and use as a carrier solvent for wood preservatives and repellents. Minor uses include the manufacture and application of dyes, odor control and pesticide manufacture (202, 265).

25.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

25.2.1 Transport in Soil/Ground-water Systems

25.2.1.1 Overview

The 1,2-isomer of dichlorobenzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by an equilibrium partitioning model, as shown in Table 25-1. Sorption onto deep soils (83%) is less than onto top soils, but may have some effect on mobility. Overall, ground water underlying 1,2-dichlorobenzene-contaminated soils with low organic content is expected to be vulnerable to contamination.

These calculations predict the partitioning of low soil concentrations of 1,2-dichlorobenzene among soil particles, soil water and soil air. The 1,2-dichlorobenzene associated with the water and air phases of the soil has higher mobility than the adsorbed portion.

Estimates for the unsaturated topsoil model indicate that 99.5% of the 1,2-dichlorobenzene is expected to be sorbed onto soil particles. Approximately 0.4% is expected to partition to the soil-water phase, and is thus available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of 1,2-dichlorobenzene in the gaseous phase of the soil (approximately 0.1%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, may be a significant loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a higher fraction of the 1,2-dichlorobenzene (17%) is predicted to be present in the soil-water phase (Table 25-1) and available for transport with flowing ground water.

TABLE 25-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
1,2-DICHLOROBENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 25°C	99.5	0.4	0.1
Saturated deep soil[d]	83.0	17.0	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized soil sorption coefficient estimated with equations of Means et al. (611): K_{oc} = 1160.
c) Henry's law constant taken as 1.88E-03 atm · m^3/mol at 25°C (74).
d) Used sorption coefficient K_p calculated as a function of K_{oc} assuming 0.1% organic carbon: $K_p = 0.001 \times K_{oc}$.

25.2.1.2 Sorption on Soils

The mobility of 1,2-dichlorobenzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Wilson et al. (82) investigated the transport and fate of the 1,4-dichlorobenzene isomer applied to sandy soils. Approximately 37-49% of the 1,4-dichlorobenzene percolated through the soil column with minimal retardation, and 51-63% was degraded or not accounted for; the loss due to volatilization was not determined. The 1,2-dichlorobenzene would be expected to exhibit similar transport properties.

Laboratory sorption studies (608) indicate that sorption of the chlorobenzenes by sediments and aquifer material is a reversible process. Retardation rates, which represent the interstitial water velocity/pollutant velocity in the soil, were reported by

Wilson et al. (82) to be a function of K_{oc}, the ratio of soil density (a) to soil water content (b), and the organic content (oc) of the soil according to the following equation:

$$R_f = 1 + (a/b)K_{oc}(oc)$$

Retardation factors reported for the 1,4-isomer range from 18-70 for river sediment to 1-2.7 for an aquifer far from the river bed (77). These data indicate some retardation (i.e., adsorption) in soils having 1-2% organic carbon and little or no retardation in deep soils having less than 0.1% organic carbon. Similar retardation factors would be expected for 1,2-dichlorobenzene.

25.2.1.3 Volatilization from Soils

Transport of 1,2-dichlorobenzene vapors through the air-filled pores of unsaturated soils may occur in near-surface soils. However, only a small portion of the 1,2-dichlorobenzene loading is expected to be present in soil-air. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, is expected to increase significantly with increasing temperature. The temperature dependence of H for 1,2-dichlorobenzene has been measured by Gossett and Lincoff (18) and is described by the following equation:

$$H(atm \cdot m^3/mol) = \exp[15.96\text{-}6665/T(°K)]$$

Gossett and Lincoff (18) have also examined the effect of other dissolved materials on volatilization. Moderate increases in H were observed with increasing salinity and the presence of other organic compounds. These results suggest that the presence of other materials may significantly affect the volatilization of 1,2-dichlorobenzene.

No information was available for the two other physicochemical properties influencing 1,2-dichlorobenzene volatilization, i.e., the vapor-soil sorption coefficient and the vapor phase diffusion coefficient.

Available data indicate that 1,2-dichlorobenzene probably volatilizes from the water column at a relatively rapid rate; the volatilization half-life from a 1 meter thick water column has been estimated to be approximately 8 or 9 hours (10). Garrison and Hill (600) reported almost complete volatilization (to less than 1 mg/L) of a 100 mg/L concentration of 1,2-dichlorobenzene in less than four hours from aerated distilled water and in less than three days from unaerated distilled water.

Wakeham et al. (527) examined the fate and persistence of the 1,4-isomer in coastal seawater; volatilization was identified as the major removal process. Half-lives obtained for spring, summer, and winter conditions were 18, 10, and 13 days, respectively; similar rates would be expected for 1,2-dichlorobenzene.

Actual volatilization rates will depend on factors such as depth, turbulence and other environmental conditions. Furthermore, compared to volatilization from well-stirred aqueous solutions, volatilization from surface soils has been shown to be slower by approximately one order of magnitude for some near-surface chlorinated organics (82).

In the atmosphere, 1,2-dichlorobenzene should exist mainly in the vapor phase and is expected to react with photochemically generated hydroxyl radicals (3949). Using a rate constant of 0.42E-12 cm^3/molecule-sec at 22°C and an ambient hydroxyl radical concentration of 8.0E+05 molecules/cm^3, the half-life for 1,2-dichlorobenzene in air of 24 days was estimated (3899). The detection of dichlorobenzene isomers in rain water (3930) suggests that atmospheric removal through washout is also possible (3949).

25.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of 1,2-dichlorobenzene in soil/ground-water systems is not well documented. In most cases, it should be assumed that 1,2-dichlorobenzene will persist for months to years (or more). The 1,2-dichlorobenzene that has been released from the soil into the air will eventually undergo photochemical oxidation; a half-life in air of approximately 3 days (609) and an atmospheric residence time of 38.6 days (601) have been reported for 1,2-dichlorobenzene.

No information on the hydrolysis of 1,2-dichlorobenzene in the soil/ground-water system was available; under normal environmental conditions, hydrolysis is not expected to occur at a rate competitive with volatilization or biodegradation.

The 1,2-isomer of dichlorobenzene is not expected to be rapidly biodegraded in the environment. The more halogenated a compound is, the more resistant it is to biodegradation, implying that 1,2-dichlorobenzene is more persistent than chlorobenzene, which is significantly degraded only by activated microbial populations. Furthermore, the presence of a chlorine atom on the benzene ring has been reported to retard the rate of biodegradation (10). Thom and Agg (80) have listed 1,2-dichlorobenzene as a synthetic material which is unlikely to be removed during biological sewage treatment.

However, several authors have reported the biodegradation of 1,2-dichlorobenzene by acclimated microbial populations. Davis et al. (612) reported comparatively rapid degradation of 1,2-dichlorobenzene using samples of microbial populations from industrial and municipal wastewater treatment plants; 1,2-dichlorobenzene

at 50 ng/L was degraded by both systems within 7 days. Kincannon et al. (613) reported biodegradation of 83 mg/L 1,2-dichlorobenzene by activated sludge populations.

Dichlorobenzenes were only slowly degraded by soil microbes in cultures (610), and no degradation was noted in studies on the transport and degradation of dichlorobenzenes injected into ground water (597). In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as 1,2-dichlorobenzene is expected to be low, and to drop off sharply with increasing depth. Thus, biodegradation in the deep soil/ground-water system should be assumed to be of minimal importance except, perhaps, near landfills with active microbiological populations.

25.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that 1,2-dichlorobenzene is highly volatile from aqueous solutions, moderately to strongly adsorbed by soil, and has a moderate potential for bioaccumulation. This compound may volatilize from soil surfaces. Through time, the portion not removed by volatilization is likely to be mobile in ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of 1,2-dichlorobenzene from a disposal site, particularly during drilling or restoration activities could result in inhalation exposures. In addition, there is a potential for ground water contamination, particularly in sandy soil. 1,2-Dichlorobenzene has been found in ground water at 3 of the 546 National Priority List (NPL) sites (83).

This compound was reported in the Ground Water Supply Survey (GWSS) conducted by USEPA (531) This survey examined 945 finished water supplies that utilize ground-water sources. The results for 1,2-dichlorobenzene are summarized below in the following table.

The random samples taken as part of the GWSS are intended to statistically represent the U.S. ground-water drinking water supplies. The non-random sample locations were chosen by the states as being potentially contaminated. 1,2-Dichlorobenzene has also been detected in the National Organic Monitor Survey (NOMS) (90). In this survey, 1,2-dichlorobenzene was detected in 4 out of 110 samples with a mean concentration of the positives of 2.5 μg/L.

Sample Type	Occurrences* No.	%	Median of Positives (μg/L)	Maximum (μg/L)
Random				
Supplies serving <10,000 people (280 samples)	0	0	-	-
Supplies serving >10,000 people (186 samples)	0	0	-	-
Non-Random				
Supplies serving <10,000 people (321 samples)	1	0.3	2.2	2.2
Supplies serving >10,000 people (158 samples)	1	0.6	2.7	2.7

*Samples having levels over quantification limit of 0.5 μg/L.

The properties of 1,2-dichlorobenzene and the survey results described above indicate that this compound has a limited potential for movement in soil/ground-water systems. If, however, this compound reaches surface waters, several other exposure pathways are possible:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;
- Aquatic organisms residing in these waters and bioaccumulating this chemical may be consumed, also resulting in ingestion exposures;
- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with contaminated surface water can be expected to be lower than exposures from drinking contaminated ground water for two reasons. First, the Henry's law constant for 1,2-dichlorobenzene suggests that it will volatilize upon reaching surface waters. Secondly, because 1,2-dichlorobenzene is moderately to strongly adsorbed, the concentration reaching surface waters will be attenuated through adsorption to soil and sediments. Although the availability of 1,2-dichlorobenzene in surface waters is expected to be limited, the bioconcentration factor for 1,2-dichlorobenzene suggests some potential for bioaccumulation.

25.2.4 Other Sources of Exposure

The volatility of 1,2-dichlorobenzene suggests that it may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric data for a number of volatile organics. For 1,2-dichlorobenzene, they had data for 909 locations. This compound was not found in rural and remote locations. In urban and suburban areas, the median 3 concentration was 0.066 $\mu g/m^3$. In source-dominated locations,

the 3 median concentration was 0.35 $\mu g/m^3$ These results suggest that inhalation is a source of exposure to persons in these areas, particularly in source-dominated areas.

Based on the survey data above, 1,2-dichlorobenzene does not appear to be a common contaminant in drinking water. However, discharge of industrial effluents contaminated with 1,2-dichlorobenzene near drinking water intakes in surface water could potentially result in ingestion via drinking water. There has been concern regarding the inadvertent production of chlorobenzenes through chlorination of sources or effluents containing benzene. The data that exist seem to indicate that chlorination is not a significant inadvertent source (265).

25.3 HUMAN HEALTH CONSIDERATIONS

25.3.1 Animal Studies

25.3.1.1 Carcinogenicity

The carcinogencity of 1,2-dichlorobenzene was recently evaluated in a 103-week study conducted by the National Toxicology Program (3514). Groups of F344/N rats and $B6C3F_1$ mice were administered 1,2-dichlorobenzene in corn oil by gavage, 5 times per week in doses of 60 or 120 mg/kg body weight. Malignant histiocytic lymphomas were observed in male and female mice at both dose levels (males: control, 0%; low dose, 2%; high dose, 8%, $p<0.05$) (females: control, 0%; low dose, 0%; high dose, 6%, $p<0.05$), but the incidences of all types of lymphomas in male or female mice were not increased. Therefore, the increase in histiocytic lymphomas was discounted. The investigators concluded that, under the conditions of the two-year gavage studies, there was no evidence of carcinogenicity of 1,2-dichlorobenzene in male or female rats or mice (3514). However, it should be noted that there is some doubt that the maximum tolerated dose was achieved as no significant compound-related effects were seen (3949).

25.3.1.2 Genotoxicity

In an in vivo micronucleus assay, 8-week-old NMRI male mice were injected intraperitoneally with 187, 375, 562, or 750 mg of 1,2-dichlorobenzene/kg body weight. Each dose was administered in two injections, 24 hours apart, and the animals were sacrificed 6 hours after the last injection. Statistically significant, dose-related increases in micronuclei were observed in the bone marrow cells (3464).

The 1,2-isomer of dichlorobenzene was found to be non-genotoxic in three studies involving 8 strains of histidine-requiring mutants of Salmonella typhimurium tested with and without metabolic activation (3646, 3508).

25.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

No teratogenic effects were observed in the offspring of Sprague-Dawley rats that were administered 50, 100 or 200 mg/kg 1,2-dichlorobenzene by gavage on days 6 through 15 of gestation (269).

In inhalation studies, Hayes et al. (3278) observed neither teratogenic nor fetotoxic effects in the offspring of rats or rabbits exposed to 1,2-dichlorobenzene vapors. Groups of bred female rats were exposed to 100, 200, or 400 ppm of 1,2-dichlorobenzene for 6 hours per day on days 6 through 15 of gestation. The dams exhibited reduced weight gain at each dose level and increased liver weights at 400 ppm, indicating maternal toxicity. Groups of inseminated rabbits were exposed to 100, 200, or 400 ppm of the agent on days 6 through 18 of gestation. Pregnant rabbits at all concentrations showed a significant weight loss during the first 3 days of exposure. No embryotoxic or teratogenic effects were observed in these studies for rats or rabbits exposed to 1,2-dichlorobenzene, even at concentrations that produced maternal toxicity.

25.3.1.4 Other Toxicologic Effects

25.3.1.4.1 Short-term Toxicity

The major targets for 1,2-dichlorobenzene are the liver, kidneys and central nervous system. Rats exposed to vapor concentrations of 977 ppm (5862 mg/m^3) survived a two-hour exposure period but succumbed after a seven-hour exposure period. A single seven-hour exposure to 539 ppm (3234 mg/m^3) was survived. These animals experienced drowsiness, unsteadiness and eye irritation. Kidney and liver injury were also observed (266). Liver dysfunction was noted in rats that were administered 455 to 1000 mg/kg 1,2-dichlorobenzene by stomach tube for 5 to 15 days (267).

Undiluted 1,2-dichlorobenzene instilled into the eyes of rabbits caused moderate pain and conjunctival irritation which cleared in a few days (19).

In vivo studies with Fischer rats, in which the hepatotoxic effects of three dichlorobenzenes were compared, indicated that the isomers tested can be ranked as follows: 1,2-dichlorobenzene >1,3-dichlorobenzene >1,4-dichlorobenzene (1,4-dichlorobenzene was not hepatotoxic in this study) (3940). The toxicity rankings were based on plasma glutamic pyruvate transaminase activities 24 hours after the rats were injected i.p. with doses of the isomers ranging from 0.9 to 4.5 mmol/kg; the rankings were supported by the results of in vitro studies.

25.3.1.4.2 Chronic Toxicity

NTP conducted a 13-week toxicity/range-finding study in F344/N rats and B6C3F$_1$ mice (3514). Groups of 10 rats and 10 mice of each sex were administered

1,2-dichlorobenzene by gavage, 5 days/week at doses of 0, 30, 60, 125, 250, or 500 mg/kg/day and were observed for signs of toxicity. At the end of the treatment period, hematological and clinical chemistry assays and necropsy and microscopic examination were performed. At 500 mg/kg/day, in both sexes of rats and mice, 1,2-dichlorobenzene produced centrolobular necrosis of the liver, hepatocellular degeneration, and depletion of lymphocytes in the thymus and spleen. In addition, renal tubular degeneration was observed in male rats and multifocal mineralization of the myocardial fibers of the heart and skeletal muscle were seen in mice. At 250 mg/kg/day, necrosis of individual hepatocytes was observed in male and female rats and male mice. At 125 mg/kg/day, minimal hepatocellular necrosis was observed in a few rats, but hepatic alterations were not observed in mice. The results of this study determined the doses selected for the NTP two-year carcinogenicity/toxicity bioassay.

Rats given 1,2-dichlorobenzene by gavage, 5 days per week for 28 weeks, exhibited minimal liver and kidney damage at 188 and 376 mg/kg body weight, but no adverse effects at 18.8 mg/kg (271). Therefore, the no effect level in this study was determined to lie between 18.8 and 188 mg/kg body weight.

In the two-year NTP study, 50 F344/N rats and 50 B6C3F$_1$ mice of each sex were given 1,2-dichlorobenzene in corn oil by gavage at doses of 0, 60, and 120 mg/kg/day (3514). The only nonneoplastic effect noted in the study was an increase in tubular regeneration of the kidney in the high-dose male mice (control, 17%; low dose, 24%; high dose, 35%).

No adverse effects were observed in mice, guinea pigs, rabbits and monkeys after 6 to 7 months of exposure to 93 ppm (558 mg/m^3) 1,2-dichlorobenzene, 7 hours per day, 5 days a week; however, rats exposed to 93 ppm had reduced body weights ($p<0.05$) (271).

25.3.2 Human and Epidemiologic Studies

25.3.2.1 Short-term Toxicologic Effects

The 1,2-isomer of dichlorobenzene appears to have a low toxicity to humans. Short-term inhalation exposure results in irritation of the eyes and throat. Eye irritation becomes noticeable at vapor concentrations of 25 to 30 ppm (150-180 mg/m^3). It may become painful at 60 to 100 ppm if the exposures are for more than a few minutes duration (46).

Chromosomal alterations consisting of single and double breaks were observed in a group of 26 clinical laboratory workers accidentally exposed to 1,2-dichlorobenzene vapors, 8 hours per day for 4 days. No determination of the exposure level was made; exposure levels were estimated to be above 100 ppm based on observed symptoms. The chromosomal aberrations seemed to be reversible after several months (273). It should be noted that these individuals worked in or around a clinical pathology laboratory and may have been exposed to other chemicals.

Application of 1,2-dichlorobenzene to the skin of human subjects for 15 minutes produced a burning sensation. This response intensified with continued exposure up to 1 hour and abated upon removal. Redness and blisters then developed followed by a brown pigmentation which persisted for 3 months (275).

Occupational exposure to average air concentrations of 15 ppm (90 mg/m^3) caused no organic injury or adverse hematologic effect; the length of exposure was not reported (271).

25.3.2.2 Chronic Toxicologic Effects

Most cases of human poisoning from 1,2-dichlorobenzene have resulted from chronic inhalation of vapors. Six months of industrial exposure to a product containing a mixture of 1,2-dichlorobenzene (95%) and the 1,4-isomer (5%) resulted in pallor, exhaustion, vomiting, intense abdominal pain, headache and hemolytic anemia in one worker. Complete recovery followed the cessation of exposure. Thirteen similarly exposed coworkers were unaffected (272).

Three cases of leukemia have been reported which involve chronic exposure to dichlorobenzene mixtures. A 15-year-old girl developed a fatal acute myeloblastic leukemia after using a product containing 37% 1,2-dichlorobenzene for an unspecified time period. A 40-year-old workman developed chronic lymphatic leukemia after 10 years of occupational exposure to a solvent containing 80% 1,2-, 15% 1,4-, and 2% 1,3-dichlorobenzene. A 55-year-old woman exposed to the same mixture for an unspecified period of time developed acute myeloblastic leukemia (272, 277). No conclusions can be drawn as to the causes of these leukemias; no evidence of benzene exposure was found in any of these cases (202).

Chronic skin contact with a 1,2-dichlorobenzene solution has been reported to cause eczematoid dermatitis (274).

25.3.3 Levels of Concern

The U.S. Environmental Protection Agency (355) has established an ambient water quality criterion of 400 μg/L for the protection of human health from the toxic properties of dichlorobenzenes ingested through water and contaminated aquatic organisms. This criterion is based on the calculated maximum chronic no-observed-effect-level of 13.42 mg/kg/day for rats orally administered 1,2-dichlorobenzene over a period of 5 to 7 months (254, 271). Applying an uncertainty factor of 1000, the acceptable daily intake of 1,2-dichlorobenzene for a 70-kg man was calculated to be 0.94 mg/day.

The USEPA (3949) also derived a reportable quantity (RQ) of 1000 for 1,2-dichlorobenzene, based on a LOAEL of 188 mg/kg/day for increased kidney and liver weights in female rats from the study of Hollingsworth et al. (271).

OSHA (3539) has established a ceiling limit of 50 ppm (300 mg/m^3) set to prevent serious irritation but not all eye and nasal irritation. This standard is identical to that recommended by the ACGIH (3005).

In the absence of chronic inhalation data for 1,2-dichlorobenzene, the USEPA (3949) estimated inhalation RfDs based on the NOAEL in rats of 44.2 mg/kg/day associated with 49 ppm (290 mg/m^3) 7 hours/day, 5 days/week, for 7 months (271). The subchronic RfD_i was estimated to be 31 mg/day, and from this the provisional chronic RfD_i of 3.1 mg/day was derived (3949). The oral RfD is 89 μg/kg/day (3742).

25.3.4 Hazard Assessment

A lifetime feeding study conducted with both rats and mice orally administered up to 120 mg/kg/bw of 1,2-dichlorobenzene gave no evidence of carcinogenicity (3514). The compound was not teratogenic in rats by oral administration (269, 3278). Possible evidence of mutagenic activity was reported for a group of workers accidentally exposed to 1,2-dichlorobenzene (concentration was not determined) for four work days (273). This study needs to be substantiated, particularly in light of the fact that these individuals worked in a clinical pathology laboratory and may thus have been occupationally exposed to a variety of chemicals.

Little specific information is available on human toxicity associated with 1,2-dichlorobenzene exposure. Anecdotal reports have linked chronic inhalation exposure to various forms of leukemia (272, 277) but no quantitative intake data are available. Additional toxicological studies are needed to clarify the mutagenic capability of 1,2-dichlorobenzene before a reliable estimate of risk can be made for humans chronically exposed to 1,2-dichlorobenzene in their drinking water.

25.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of 1,2-dichlorobenzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of 1,2-dichlorobenzene, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight glass containers preferably with no headspace; analysis should be completed within 14 days of sampling. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of 1,2-dichlorobenzene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 601, 602, 612, 624, 625, and 1625 (65) or Methods 8010, 8020, 8120, and 8250 (63). In Methods 601, 602, 624, 8010, and 8020 an inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the 1,2-dichlorobenzene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the 1,2-dichlorobenzene and transfer it onto a gas

chromatographic (GC) column. Methanol extracts of the sample may also be subjected to this purge and trap procedure (Methods 8010 and 8020). For Methods 612, 625, 1625, 8120, and 8250, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto the GC column using a solvent flush technique (Methods 625 and 1625) or the extract is concentrated, dried, and solvent exchanged to hexane prior to analysis (Methods 612, 8120, and 8250). The GC column is programmed to separate the organics; 1,2-dichlorobenzene is then detected with a halide specific detector (Methods 601 and 8010), a photo-ionization detector (Methods 602 and 8020), an electron-capture detector (Methods 612 and 8120), or a mass spectrometer (Methods 625, 1625, and 8250).

The EPA procedures recommended for 1,2-dichlorobenzene analysis in soil and waste samples, Methods 8010, 8020, 8120, and 8250 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The sample preparation in Methods 8010 and 8020, involves dispersing the soil or waste sample in water prior to "purge and trap." Alternatively, methanol extracts of the sediment/soil may be subjected to the purge procedure described above. Hexane has also been used to extract 1,2-dichlorobenzene from sludge samples (3169). The extract is "cleaned-up" on an alumina column, concentrated, and then analyzed by capillary GC. Other sample introduction techniques include direction injection and a headspace method where an aliquot of the vapor above the sample in a sealed vial is analyzed. Recoveries for the headspace technique may vary depending upon the concentration (3355). In Methods 8120 and 8250, solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical 1,2-dichlorobenzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The 1,2-dichlorobenzene detection limit for Method 624 was not determined. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.15 μg/L (Method 601)	1.5 μg/kg (Method 8010)
0.4 μg/L (Method 602)	4.0 μg/kg (Method 8020)
1.14 μg/L (Method 612)	0.8 μg/g (Method 8120)
1.9 μg/L (Method 625)	1.3 μg/g (Method 8250)
10 μg/L (Method 1625)	
1.5 μg/L (Method 8010)	
4.0 μg/L (Method 8020)	
11.4 μg/L (Method 8120)	
19 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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3948. U.S. Environmental Protection Agency (USEPA). 1988. Integrated Risk Information System (IRIS), 1,2,4-trichlorobenzene, March 1, 1988.

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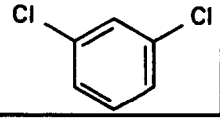
COMMON SYNONYMS:	CAS REG.NO.: 541-73-1 FORMULA: $C_6H_4Cl_2$ NIOSH NO: CZ4499000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C (12) 6.01 mg/m^3≈ 1 ppm; 0.1663 ppm≈ 1mg/m^3 MOLECULAR WEIGHT: 147.0
1,3-Dichlorobenzene m-Dichlorobenzene m-Dichlorobenzol m-Phenylene-dichloride		

REACTIVITY	Reactions of halogenated organic materials such as 1,3-dichlorobemzene with cyanides, mercaptans or other organic sulfides typically generate heat, while those with amines, azo compounds, hydrazines, caustics, or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases, and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, calcium, zinc or magnesium, organic peroxides or hydroroxides, strong oxidizing agents, or strong reducing agents typically result in heat generation and explosions and/or fires (511, 505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: No data	(23)
	• Odor Threshold: No data	
	• Density: 1.2880 g/mL (at 20°C)	(14)
	• Freeze/Melt Point: -24.80°C	(14)
	• Boiling Point: 172.00°C	(14)
	• Flash Point: No data	
	• Flammable Limits: No data	
	• Autoignition Temp.: No data	
	• Vapor Pressure: 1.60 mm Hg (at 20°C)	(1219)

PHYSICO-CHEMICAL DATA (Cont.)	• Satd. Conc. in Air: 1.2900E+04 mg/m^3 (at 20°C) (265) • Solubility in Water: 1.23E+02 mg/L (at 25°C) (21) • Viscosity: 1.025 cp (at 20°C) • Surface Tension: 3.6200E+01 dyn/cm (at 20°C) • Log (Octanol-Water Partition Coeff.): 3.60 (29) • Soil Adsorp. Coeff.: 1.92E+03 (652) • Henry's Law Const.: 3.55E-03 atm · m^3/mol (at 20°C) (74) • Bioconc. Factor: 6.60E+01 (bluegills), 1.90E+02 (estim) (278,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	1,3-Dichlorobenzene is expected to have limited mobility in soils, particularly in soils with 1-2% organic content; some migration in deep or sandy soils may occur. Persistence in soils is probably high. Volatilization from aqueous solutions is expected to occur, but volatilization from soils is less significant. Biodegradation in soil environments is not expected to be important.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is probably the migration of 1,3-dichlorobenzene to groundwater drinking water supplies. However, it is moderately to strongly sorbed, and extensive migration under most conditions is not expected. Inhalation could also be an important route of exposure under certain conditions.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (12) No reports on the effects of human exposure to 1,3-dichlorobenzene were located. Effects are probably analogous to those noted with the 1,2- and 1,4-isomers (see Chapters 25 and 27). Acute Toxicity Studies: No data Long-Term Effects: No data Pregnancy/Neonate Data: Not teratogenic in rats (200 mg/kg/day, on gestation days 6-15). Genotoxicity Data: Conflicting data Carcinogenicity Classification: IARC - No data NTP - No data EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (45,54)	Handle chemical only with adequate ventilation • There are no formal guidelines available for this chemical with respect to respirator use. Use a self-contained breathing apparatus with a full facepiece (or the equivalent) where there is any doubt as to the efficacy of gas masks or cartridge-type respirators • Chemical goggles if there is probability of eye contact • Appropriate clothing to prevent repeated or prolonged skin contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA (8-hr TWA): None established
- AFOSH PEL (8-hr TWA): None established

Criteria
- NIOSH IDLH (30-min): None established
- NIOSH REL: None established
- ACGIH STEL (15-min): None established

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (3883)
MCLG: 600 μg/L (proposed)
MCL: 600 μg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (3977)
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 9000 μg/L
- 10-day (child): 9000 μg/L
- longer-term (child): 9000 μg/L
- longer-term (adult): 30,000 μg/L
- lifetime (adult): 600 μg/L

WHO Drinking Water Guideline
No information available

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, 400μg/L dichlorobenzenes (all isomers).
  - Based on ingestion of all contaminted aquatic organisms only, 2.6 mg/L dichlorobenzenes (all isomers). Adjusted for drinking water only, 470 μg/L.

- Aquatic Life (355)
  - Fresh water species
    acute toxicity:
    no criterion, but lowest effect level occurs at 1120 μg/L dichlorobenzenes.

    chronic toxicity:
    no criterion but lowest effect level occurs at 763 μg/L dichlorobenzenes.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 1970 μg/L dichlorobenzenes.

    chronic toxicity:
    No criterion established due to insufficient data

REFERENCE DOSES: (3742)
ORAL: 8.900E+01 μg/kg/day

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Dichlorobenzenes are designated hazardous substances under CWA. They have a reportable quantity limit of 45.4 kg (347, 3764). 1,3-Dichlorobenzene is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), and metal finishing (3768). Limitations vary depending on the type of industry and plant.

Safe Drinking Water Act (SDWA)

Dichlorobenzene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 by January, 1991. EPA lists it as an unregulated contaminant requiring monitoring in all community water systems, and non-community non-transient water systems (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of 1,3-dichlorobenzene containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

1,3-Dichlorobenzene is identified as a toxic hazardous waste (U071) and listed as a hazardous waste constituent (3783, 3784). A non-specific source of 1,3-dichlorobenzene-containing waste is chlorinated aliphatic hydrocarbon production (325). Waste streams from the organic chemicals industry (chlorobenzene production) contain 1,3-dichlorobenzene and are listed as specific sources of hazardous waste (3774, 3765). 1,3-Dichlorobenzene is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels (3785). Effective July 8, 1987, the land disposal of untreated hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances exist until May, 1990 for some wastewaters and nonwastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). 1,3-Dichlorobenzene is on EPA's groundwater monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their groundwater for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of 1,3-dichlorobenzene must report production, usage and disposal information to EPA. They, as well as others who possess health and safety studies on 1,3-dichlorobenzene, must submit them to EPA (334, 3789). Under TSCA Section 4, EPA requires that manufacturers and processors of 1,3-dichlorobenzene perform human health effects studies and chemical fate testing in support of the RCRA program (3792).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
1,3-Dichlorobenzene is designated as a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing 1,3-dichlorobenzene but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of 1,3-dichlorobenzene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Clean Air Act (CAA)
After consideration of the data regarding serious health effects from ambient air exposure to chlorinated benzenes, EPA has decided not to regulate them as hazardous air pollutants (3685).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
None established (3539)

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 1,3-dichlorobenzene as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling, and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

CALIFORNIA
California has an action level of 130 μg/L (ppb) for drinking water. This level applies to either the single 1,3-isomer or the sum of 1,2-and 1,3-isomers (3098).

KANSAS
Kansas has an action level of 620 μg/L for groundwater (3213).

NEW JERSEY
New Jersey has set an MCL of 600 μg/L for drinking water (3497).

NEW YORK
New York has an MCL of 5 μg/L for total dichlorobenzenes in drinking water (3501). New York has also set ambient water quality standards for total dichlorobenzenes in surface waters: 20 μg/L for drinking water supply waters, 5 μg/L for Class A, A-S, AA, AA-S, B and C waters, and 50 μg/L for fresh surface waters class D (3500).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 390 μg/L and a chronic gudieline of 8.7 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires m-dichlorobenzene to be nondetectable, using designated test methods, in groundwater (3671).

VERMONT
Vermont has a preventive action limit of 310 μg/L and an enforcement standard of 620 μg/L for groundwater (3682).

WISCONSIN
Wisconsin has a preventive action limit of 125 μg/L and an enforcement standard of 1250 μg/L for groundwater (3840). Wisconsin also has a human threshold criterion of 1.5 mg/L for Public Water Supply surface waters (3842).

Proposed Regulations

- Federal Programs
  No proposed programs are pending.

- State Water Programs
  MOST STATES
  Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683)

  MINNESOTA
  Minnesota has proposed a Recommended Allowable Limit (RAL) of 620 μg/L for drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 1255 μg/L for surface water, and chronic criteria of 620 μg/L for groundwater and 28 μg/L for surface water for the protection of human health (3452).

  NEW JERSEY
  New Jersey has proposed a water quality standard of 600 μg/L for class FW2 surface waters (3496).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground-or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Quality Required of Shellfish Waters (537)
The mandatory specifications for organohalogenated substances specify that the concentration of each substance in the shellfish water or in shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The specifications for organohalogenated substances state that the concentration of each substance in shellfish flesh must be so limited that it contributes to the high quality of the shellfish product.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

EEC Directive - Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
1,3-dichlorobenzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

26.1 MAJOR USES

Commercial production of 1,3-dichlorobenzene is negligible although it has a number of potential uses as a pesticide (21) or fumigant (23). It may occur as a contaminant of 1,2- or 1,4-dichlorobenzene formulations.

26.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

26.2.1 Transport in Soil/Ground-water Systems

26.2.1.1 Overview

The 1,3-isomer of dichlorobenzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by estimating equilibrium partitioning, as shown in Table 26-1.

These calculations estimate the partitioning of 1,3-dichlorobenzene among soil particles, soil water and soil air. Portions of 1,3-dichlorobenzene associated with the water and air phases of the soil have higher mobility than the adsorbed portion.

Estimates for the unsaturated topsoil model indicate that 99.6% of the 1,3-dichlorobenzene is expected to be sorbed onto soil particles. Approximately 0.3% is expected to partition to the soil-water phase, and is thus available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of 1,3-dichlorobenzene in the gaseous phase of the soil (approximately 0.1%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, may be a significant loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a higher fraction of the 1,3-dichlorobenzene (11%) is predicted to be present in the soil-water phase (Table 26-1) and available for transport with flowing ground water. Sorption onto deep soils (89%) is less than onto top soils, but may have some effect on mobility. Overall, ground water underlying 1,3-dichlorobenzene-contaminated soils with low organic content is expected to be vulnerable to contamination.

26.2.1.2 Sorption on Soils

The mobility of 1,3-dichlorobenzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

TABLE 26-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
1,3-DICHLOROBENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 25°C	99.6	0.3	0.1
Saturated deep soil[d]	89.0	11.0	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized soil sorption coefficient estimated with equations of Means et al. (611): K_{oc} = 1920.
c) Henry's law constant taken as 3.55E-03 atm · m^3/mol at 25°C (74)
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

There are no studies specifically addressing the transport of 1,3-dichlorobenzene. However, the results reported for other chlorobenzenes applied to sandy soils (82) indicate that 25-50% of the applied material percolates through soil columns of low organic content and that 50-75% of the material may be volatilized, degraded or otherwise unaccounted for. The behavior of 1,3-dichlorobenzene is expected to be similar.

Other laboratory sorption studies (608) indicate that sorption of the chlorobenzenes by sediments and aquifer material is a reversible process. Retardation rates, which represent the interstitial water velocity/pollutant velocity in the soil, were predicted by Wilson et al. (82) to range from 1.9 to 7.0 for chlorobenzenes in sandy soils. Retardation factors reported by Schwarzenbach et al. (77) for 1,4-dichlorobenzene range from 18-70 for river sediment to 1-2.7 for an aquifer far from the

river bed (77). These data indicate some retardation (i.e., adsorption) in soils having 1-2% organic carbon and little or no retardation in deep soils having less than 0.1% organic carbon; infiltration of dichlorobenzene in river water to the ground water was observed.

26.2.1.3 Volatilization from Soils

Transport of 1,3-dichlorobenzene vapors through the air-filled pores of unsaturated soils may occur in near-surface soils. However, modeling results suggest only a small fraction of the dichlorobenzene loading is expected to be in the soil-air compartment. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, is expected to increase significantly with increasing temperature. Moderate increases in H were also observed with increasing salinity and the presence of other organic compounds (81). These results suggest that the presence of other materials may significantly affect the volatilization of 1,3-dichlorobenzene.

No information was available for the two other physicochemical properties influencing 1,3-dichlorobenzene volatilization, i.e., the vapor-soil sorption coefficient and the vapor phase diffusion coefficient.

Available data for other dichlorobenzenes indicate that volatilization from the water column occurs at a relatively rapid rate. Garrison and Hill (600) reported almost complete volatilization (to less than 1 mg/L) of 100 mg/L and 300 mg/L concentrations of dichlorobenzenes in less than four hours from aerated distilled water and in less than three days from unaerated distilled water. Volatilization was also identified as the major removal process for the 1,4-dichlorobenzene isomer from seawater (527). Half-lives obtained for spring, summer, and winter conditions were 18, 10 and 13 days, respectively; similar rates would be expected for 1,3-dichlorobenzene.

Actual volatilization rates from water will depend on factors such as depth, turbulence, and other environmental conditions. Furthermore, compared to volatilization from well-stirred aqueous solutions, volatilization of some near-surface chlorinated organics from soil was inhibited by approximately one order of magnitude (82).

In the atmosphere, 1,3-dichlorobenzene should exist mainly in the vapor phase and is expected to react with photochemically generated hydroxyl radicals (3949). Using a rate constant of 0.72E-12 cm^3/molecule-sec at 22°C and an ambient hydroxyl radical concentration of 8E+05 molecules/cm^3, the half-life for 1,3-dichlorobenzene in air of was estimated to be 14 days (3894). The detection of dichlorobenzene isomers

in rain water (3930) suggests that atmospheric removal through washout is also possible (3949).

26.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of 1,3-dichlorobenzene in soil/ground-water systems is not well documented. In most cases, it should be assumed that 1,3-dichlorobenzene will persist for months to years (or more). Based on information for the other dichlorobenzenes, 1,3-dichlorobenzene that has been released from the soil into the air is expected to undergo photochemical oxidation with a half-life in air of approximately 3 days (609) and an atmospheric residence time of approximately 38.6 days (601).

No information on the hydrolysis of 1,3-dichlorobenzene in the soil/ground-water system was available; under normal environmental conditions, hydrolysis is not expected to occur at a rate competitive with volatilization or biodegradation.

The 1,3-isomer of dichlorobenzene is not expected to be rapidly biodegraded in the environment. The more halogenated a compound is, the more resistant it becomes to biodegradation, implying that 1,3-dichlorobenzene is more persistent than chlorobenzene, which is significantly degraded only by activated microbial populations. Furthermore, the presence of a chlorine atom on the benzene ring has been reported to retard the rate of biodegradation (10). Thom and Agg (80) have listed 1,3-dichlorobenzene as a synthetic material which is unlikely to be removed during biological sewage treatment.

However, several authors have reported the biodegradation of other dichlorobenzene isomers, particularly by acclimated microbial populations. Kincannon et al. (613) report biodegradation of 83 mg/L 1,2-dichlorobenzene by activated-sludge populations.

Dichlorobenzenes were only slowly degraded by soil microbes in culture (610), and no degradation was noted in studies on the transport and degradation of dichlorobenzenes injected into ground water (597). Schwartzenbach et al. (77) report biotransformation of the 1,4-dichlorobenzene isomer during infiltration of contaminated river water to ground water. However, anaerobic conditions in the aquifer were reported to have hindered the process.

In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as 1,3-dichlorobenzene is expected to be low, and to drop off sharply with increasing depth. Thus, biodegradation in the deep soil/ground-water system should be assumed to be of minimal importance except, perhaps, near landfills with active microbiological populations.

26.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that 1,3-dichlorobenzene is highly volatile from aqueous solutions, moderately to strongly adsorbed by soil, and has a

moderate potential for bioaccumulation. This compound may volatilize from soil surfaces. Through time, the portion not removed by volatilization may be somewhat mobile in ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of 1,3-dichlorobenzene from a disposal site, particularly during drilling or restoration activities could result in inhalation exposures. There is a potential for ground-water contamination, particularly in sandy soil. This compound was not reported by Mitre Corp. (83) in their summary of the chemicals found in air, surface water and ground-water associated with the 546 National Priority List sites. It was monitored in the Ground-water Supply Survey (GWSS) but it was not found in any of the samples (531). This survey examined 945 ground-water supplies in the U.S. The 1,3-isomer of dichlorobenzene was detected in the National Organic Monitoring Survey (NOMS) (90). In this survey of both surface and ground-water supplies, 1,3-dichlorobenzene was detected in 2 out of 110 samples with a mean concentration (of the positives) of 0.10 μg/L.

The properties of 1,3-dichlorobenzene and the survey results above indicate that this compound has a limited potential for movement in soil/ground-water systems. If however, this compound reaches surface waters from ground water, several other exposure pathways are possible:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures through bioaccumulation;
- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposures from drinking contaminated ground water for two reasons. First, the Henry's law constant for 1,3-dichlorobenzene suggests that it will volatilize upon reaching surface waters. Secondly, because 1,3-dichlorobenzene is moderately to strongly adsorbed, the concentration reaching surface waters will be attenuated through adsorption to sediments. As a result, this compound is not likely to be available to aquatic species, although the bioaccumulation potential is moderate.

26.2.4 Other Sources of Exposure

The volatility of 1,3-dichlorobenzene suggests that it may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric data for a number of volatile organics. For 1,3-dichlorobenzene, they had data for 792 locations. This

compound was not found in rural and remote locations. In urban and suburban areas, the median concentration was 0.036 $\mu g/m^3$. In source-dominated locations, the median concentration was 0.56 $\mu g/m^3$. These results suggest the possibility of inhalation exposure, particularly to persons in source-dominated areas.

There is a lack of data on the occurrence of 1,3-dichlorobenzene in finished surface water supplies. Discharge of industrial effluents contaminated with 1,3-dichlorobenzene near drinking water intakes in surface water could potentially result in ingestion exposures. There has been concern regarding the inadvertent production of chlorobenzenes through chlorination of sources or effluents containing benzene. The data that exist seem to indicate that chlorination is not a significant inadvertent source (265).

Because bioaccumulation of 1,3-dichlorobenzene is expected to be moderate, there is a potential for ingestion exposure from the consumption of aquatic organisms residing in contaminated waters, and contaminated meats and poultry from domestic animals that have been exposed to 1,3-dichlorobenzene.

26.3 HUMAN HEALTH CONSIDERATIONS

26.3.1 Animal Studies

26.3.1.1 Carcinogenicity

No data are available.

26.3.1.2 Genotoxicity

Genotoxicity data for 1,3-dichlorobenzene are conflicting. In an in vivo micronucleus assay, 8-week-old NMRI male mice were injected intraperitoneally with 175, 350, 525, or 700 mg of 1,3-dichlorobenzene/kg body weight. Each dose was administered in two injections, 24 hours apart, and the animals were sacrificed 6 hours after the last injection. Statistically significant, dose-related increases in micronuclei were observed in the bone marrow cells (3464).

No reversions significantly above control values have been observed in the Salmonella/microsome assay (3464, 3646, 3276), in an E. coli reversion test, or in a Bacillus subtilis DNA-deficient repair test (3465).

26.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

No teratogenic effects were observed in Sprague-Dawley rats administered 50, 100 or 200 mg/kg 1,3-dichlorobenzene by gavage on days 6 through 15 of gestation (269).

26.3.1.4 Other Toxicologic Effects

26.3.1.4.1 Short-term Toxicity

Little toxicity data are available on 1,3-dichlorobenzene. Liver dysfunction was observed in rats that were administered 1,3-dichlorobenzene by gastric intubation at a dose of 900 to 1000 mg/kg/day for 9 days (279). Intraperitoneal injection of male rats with 192 mg/kg produced minimal liver necrosis and some glycogen loss (280).

In vivo studies with Fischer rats, in which the hepatotoxic effects of three dichlorobenzenes were compared, indicated that the isomers tested can be ranked as follows: 1,2-dichlorobenzene >1,3-dichlorobenzene >1,4-dichlorobenzene (1,4-dichlorobenzene was not hepatotoxic in this study) (3940). The toxicity rankings were based on plasma glutamic pyruvate transaminase activities 24 hours after the rats were injected i.p. with doses of the isomers ranging from 0.9 to 4.5 mmol/kg; the rankings were supported by the results of in vitro studies.

26.3.1.4.2 Chronic Toxicity

No data are available regarding the long-term toxic effects of 1,3-dichlorobenzene in animals.

26.3.2 Human and Epidemiologic Studies

A 40-year-old workman developed chronic lymphatic leukemia after 10 years of occupational exposure to a solvent containing 80% 1,2-, 15% 1,4-, and 2% 1,3-dichlorobenzene. A 55-year-old woman exposed to the same mixture for an unspecified period of time developed acute myeloblastic leukemia (272,277). No conclusions can be drawn as to the causes of these leukemias; no evidence of benzene exposure was found in any of these cases (202).

26.3.3 Levels of Concern

The U.S. Environmental Protection Agency (355) has established an ambient water quality criterion of 400 μg/L for the protection of human health from the toxic properties of dichlorobenzenes ingested through water and contaminated aquatic organisms. This criterion is based on the maximum chronic no-observed-effect level of 13.42 mg/kg/day reported for rats orally administered either 1,2- or 1,4-dichlorobenzene over a period of 5 to 7 months (254, 271). Applying an uncertainty factor of 1000, the acceptable daily intake of 1,2- or 1,4-dichlorobenzene for a 70-kg man was calculated to be 0.94 mg/day. An oral Reference Dose of 89 μg/kg/day has been proposed by the U.S. EPA (3742). The similar toxicities among the dichlorobenzene isomers support the applicability of this value to 1,3-dichlorobenzene as well. The USEPA has proposed a value of 600 μg/L as both the MCLG and MCL for drinking water (3883).

26.3.4 Hazard Assessment

Based on the paucity of available data on potential carcinogenic, mutagenic, short-term and chronic toxic effects associated with exposure to 1,3-dichlorobenzene, an assessment of hazard for humans exposed to 1,3-dichlorobenzene cannot be made with any confidence. The health effects data base for the other dichlorobenzene isomers (see Chapters 25 and 27), although limited, does not suggest any major health hazard associated with exposure to these compounds. Until additional toxicological studies become available, no reliable estimate of hazard can be established for humans exposed to 1,3-dichlorobenzene.

26.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of 1,3-dichlorobenzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of 1,3-dichlorobenzene, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight glass containers preferably with no headspace; analysis should be completed within 14 days of sampling. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of 1,3-dichlorobenzene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 601, 602, 612, 624, 625, and 1625 (65) or Methods 8010, 8020, 8120, and 8250 (63). In Methods 601, 602, 624, 8010, and 8020 an inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the 1,3-dichlorobenzene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the 1,3-dichlorobenzene and transfer it onto a gas chromatographic (GC) column. Methanol extracts of the sample may also be subjected to this purge and trap procedure (Methods 8010 and 8020). For Methods 612, 625, 1625, 8120, and 8250, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto the GC column using a solvent flush technique (Methods 625 and 1625) or the extract is concentrated, dried, and solvent exchanged to hexane prior to analysis (Methods 612, 8120, and 8250). The GC column is programmed to separate the organics; 1,3-dichlorobenzene is then detected with a halide specific detector (Methods 601 and 8010), a photo-ionization detector (Methods 602 and 8020), an electron-capture detector (Methods 612 and 8120), or a mass spectrometer (Methods 625, 1625, and 8250).

The EPA procedures recommended for 1,3-dichlorobenzene analysis in soil and waste samples, Methods 8010, 8020, 8120, and 8250 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The sample preparation in Methods 8010 and 8020, involves dispersing the soil or waste sample in water prior to "purge and trap." Alternatively, methanol extracts of

the sediment/soil may be subjected to the purge procedure described above. Other sample introduction techniques include direction injection and a headspace method where an aliquot the vapor above the sample in a sealed vial is analyzed. Recoveries for the headspace technique may vary depending upon the concentration (3355). In Methods 8120 and 8250, solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical 1,3-dichlorobenzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The 1,3-dichlorobenzene detection limit for Method 624 was not determined. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.32 µg/L (Method 601)	3.2 µg/kg (Method 8010)
0.4 µg/L (Method 602)	4.0 µg/kg (Method 8020)
1.19 µg/L (Method 612)	0.8 µg/g (Method 8120)
1.9 µg/L (Method 625)	1.3 µg/g (Method 8250)
10 µg/L (Method 1625)	
3.2 µg/L (Method 8010)	
4.0 µg/L (Method 8020)	
11.9 µg/L (Method 8120)	
19 µg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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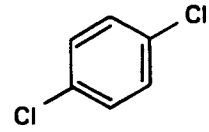
COMMON SYNONYMS:	CAS REG.NO.: 106-46-7 FORMULA: $C_6H_4Cl_2$ NIOSH NO: CZ4550000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25 °C (12) 6.01 mg/m³ ≈ 1 ppm; 0.1663 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 147.0
1,4-Dichlorobenzene P-Chlorophenyl-chloride P-Dichlorobenzene P-Dichlorobenzol Paradichlorobenzene PDB		

REACTIVITY	Reactions of halogenated organic materials such as 1,4-dichlorobenzene with cyanides, mercaptans or other organic sulfides typically generate heat, while those with amines, azo compounds, hydrazines, caustics or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, zinc or magnesium, organic peroxides or hydroperoxides, strong oxidizing agents, or strong reducing agents typically result in heat generation and explosions and/or fires (511, 505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid and crystals, (sublimes readily) (at 20°C)	(23,45)
	• Color: Colorless to white	(23)
	• Odor: Aromatic	(12)
	• Odor Threshold: 15.000 to 30.000 ppm	(12)
	• Density: 1.2475 g/mL (at 20°C)	(68)
	• Freeze/Melt Point: 53.10°C	(14)
	• Boiling Point: 174.40°C	(14)
	• Flash Point: 65.50°C closed cup	(23)
	• Flammable Limits: 2.50 to ?% by volume;	(38)
	• Autoignition Temp.: No data	
	• Vapor Pressure: 6.00E-01 mm Hg (at 20°C)	(67)

PHYSICO-CHEMICAL DATA (Cont.)	• Satd. Conc. in Air: 4.8000E+03 mg/m^3 (at 20°C)	(67)
	• Solubility in Water: 8.00E+01 mg/L (at 20°C)	(38)
	• Viscosity: 1.258 cp (at 20°C)	(48)
	• Surface Tension: 3.1400E+01 dyne/cm (at 20°C)	(21)
	• Log (Octanol-Water Partition Coeff.): 3.39	(29)
	• Soil Adsorp. Coeff.: 1.18E+03	(652)
	• Henry's Law Const.: 1.58E-03 atm · m^3/mol	(74)
	• Bioconc. Factor: 6.00E+01 (bluegills), 1.17E+02 (estim)	(278,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	1,4-Dichlorobenzene is expected to have limited mobility in soils with 1-2% organic content although some migration is expected in sandy soils or other low organic content soils. This compound will persist in the soil/ground-water system. Volatilization from aqueous solutions is rapid but volatilization from soils is expected to be much less significant; biodegradation in soils is not expected to be important.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of 1,4-dichlorobenzene to groundwater drinking water supplies, although there is no extensive evidence that such migration has occurred in the past. Inhalation resulting from volatilization from surface soils may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (38, 54) Vapors are irritating to the eyes, nose and throat. Exposure may cause headache, rhinitis, loss of appetite, nausea and vomiting. Particles of solid 1,4-dichlorobenzene in contact with the eye may cause pain; held in contact with the skin, it also produces a burning sensation, with a slight irritation. Acute Toxicity Studies: (3504) ORAL: LD_{50} 500 mg/kg — Rat TD_{Lo} 300 mg/kg — Human LD_{50} 2830 mg/kg — Rabbit LD_{Lo} 2800 mg/kg — Guinea pig LD_{50} 2950 mg/kg — Mouse LD_{Lo} 857 mg/kg — Human Long-Term Effects: Liver and kidney toxicity Pregnancy/Neonate Data: Negative Genotoxicity Data: Negative Carcinogenicity Classification: IARC - Group 2B (possibly carcinogenic to humans) NTP - "Clear evidence" of carcinogenicity in male F344/N rats and male and female B6C3F$_1$ mice EPA - Group C (possible human carcinogen)

HANDLING PRECAUTIONS (38,54,59)	Handle chemical only with adequate ventilation • Vapor concentration of 75-1000 ppm: any supplied-air respirator or selfcontained breathing apparatus with a full facepiece; chemical cartridge respirator with full facepiece, organic vapor cartridge and dust filter • Above 1000 ppm: self-contained breathing apparatus with full facepiece operated in a positive pressure mode • Chemical goggles if there is probability of eye contact • Protective clothing and rubber gloves and aprons are advisable to prevent prolonged or repeated contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA (8-hr TWA): 75 ppm; STEL (15 min): 110 ppm
- AFOSH PEL (8-hr TWA): 75 ppm; STEL (15-min): 110 ppm

Criteria
- NIOSH IDLH (30 min): 1000 ppm
- ACGIH TLV® (8-hr TWA): 75 ppm
- ACGIH STEL (15-min): 110 ppm

WATER EXPOSURE LIMITS:

Drinking Water Standards (3883)
MCGL: 75 μ/L
MCL: 75 μg/L

EPA Health Advisories and Cancer Risk Levels
The EPA has developed the following Health Advisories which provide specific advice on the levels of contaminants in drinking water at which adverse health effects would not be anticipated.

- 1-day (child): 10,000 μg/L
- 10-day (child): 10,000 μg/L
- longer-term (child): 10,000 μg/L
- longer-term (adult): 40,000 μg/L
- lifetime (adult): 75 μg/L

WHO Drinking Water Guideline
No Information available.

EPA Ambient Water Quality Criteria
Human Health (355)
- Based on ingestion of contaminated water and aquatic organisms, 400 μg/L dichlorobenzenes (all isomers).
- Based on ingestion of contaminated aquatic organisms only, 2.6 mg/L dichlorobenzenes (all isomers). Adjusted for drinking water only, 470 μg/L.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 1120 μg/L dichlorobenzenes.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 763 μg/L dichlorobenzenes.
  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 1970 μg/L dichlorobenzenes.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES: (3742)
1.000E+02 μg/kg/day

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations
- Federal Programs

Clean Water Act (CWA)
Dichlorobenzene is designated a hazardous substance under CWA. It has a reportable quantity (RQ) limit of 45.4 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), and metal finishing (3768). Limitations vary depending on the type of industry and plant.

Safe Drinking Water Act (SDWA)
Dichlorobenzene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 by January, 1991 (3781). The Maximum Contaminant Level (MCL) and Maximum Contaminant Level Goal (MCLG) for 1,4-dichlorobenzene in drinking water has been set at 0.075 mg/L (3773, 3772). In states with an approved Underground Injection Control program, a permit is required for the injection of 1,4-dichlorobenzene containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)
1,4-Dichlorobenzene is identified as a toxic hazardous waste (U072) and listed as a hazardous waste constituent (3783, 3784). A non-specific source of 1,4-dichlorobenzene-containing waste is the production of chlorinated aliphatic hydrocarbons (325). Waste streams from the organic chemicals industry (production of chlorobenzene, 1,2-dichloroethane, and trichloroethylene/ perchloroethylene) contain 1,4-dichlorobenzene and are listed as specific sources of hazardous wastes (3774, 3765). 1,4-Dichlorobenzene is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels (3785). Effective July 8, 1987, the land disposal of untreated hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances exist until May, 1990 for some wastewaters and nonwastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). 1,4-Dichlorobenzene is on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of 1,4-dichlorobenzene must report production, usage and disposal information to EPA. They, as well as others who possess health and safety studies on 1,4-dichlorobenzene, must submit them to EPA (334, 3789). EPA requires that manufacturers and processors of 1,4-dichlorobenzene conduct reproductive and fertility effects testing. Previous proposals for teratogenicity and subchronic toxicity testing have been withdrawn (340). Under TSCA Section 4, EPA requires that manufacturers and processors of 1,4-dichlorobenzene perform human health effects studies and chemical fate testing in support of the RCRA program (3792). EPA requires that manufacturers and importers of chemical substances made from 1,4-dichlorobenzene submit production, use, exposure and disposal date in order to determine whether there is further need for dioxin and furan testing of the chemical products for which 1,4-dichlorobenzene is a precursor (3780).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
1,4-Dichlorobenzene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing 1,4-dichlorobenzene but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of 1,4-dichlorobenzene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to 1,4-dichlorobenzene in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 75 ppm. An employee's 15-minute short-term exposure limit (STEL) of 110 ppm shall not be exceeded at any time during the work day (3539).

Clean Air Act (CAA)
After consideration of the data regarding serious health effects from ambient air exposure to chlorinated benzenes, EPA has decided not to regulate them as hazardous air pollutants (3685).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 1,4-dichlorobenzene as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs

ALL STATES

All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

ALABAMA

Alabama requires that the annual average maximum contaminant level not exceed 0.075 mg/L for 1,4-dichlorobenzene in drinking water. This applies to all community water systems and non-community non-transient water systems (3015).

CALIFORNIA

California has a quantification limit of 0.5 μg/L for drinking water (3098).

CONNECTICUT

Connecticut has a quantification limit of 2 μg/L for drinking water (3137).

NEW YORK

New York has an MCL of 5 μg/L for total dichlorobenzenes in drinking water (3501). New York has also set ambient water quality standards for total dichlorobenzenes in surface waters: 20 μg/L for drinking water supply waters, 5 μg/L for Class A, A-S, AA, AA-S, B and C waters, and 50 μg/L for fresh surface waters Class D (3500).

RHODE ISLAND

Rhode Island has an acute freshwater quality guideline of 56 μg/L and a chronic guideline of 1.2 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

VERMONT

Vermont has a preventive action limit of 7.5 μg/L and an enforcement standard of 75 μg/L for ground-water (3682).

WISCONSIN

Wisconsin has a preventive action limit of 150 μg/L and an enforcement standard of 750 μg/L for ground-water (3840).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)

  EPA will propose a maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) of 0.6 mg/L for 1,4-dichlorobenzene in May, 1989, with final action scheduled for May, 1990 (3759).

  Resource Conservation and Recovery Act (RCRA)

  EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 10.8 mg/L of 1,4-dichlorobenzene. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565).

- State Water Programs

  MOST STATES

  Most states are in the process of revising their water programs and proposing changes to their regulations which will EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

  IOWA

  Iowa has proposed an acute criterion of 7.5 μg/L for Class C surface waters (raw source of drinking water) (3326).

  MINNESOTA

  Minnesota has proposed a Sensitive Acute Limit (SAL) of 448 μg/L for surface water, and chronic criteria of 75 μg/L for ground-water and 10 μg/L for surface water for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Quality Required of Shellfish Waters (537)
The mandatory specifications for organohalogenated substances and metals specify that the concentration of each substance in the shellfish water or in shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The specifications for organohalogenated substances state that the concentration of each substance in shellfish flesh must be so limited that it contributes to the high quality of the shellfish product.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
1,4-Dichlorobenzene is classified as a harmful substance and is subject to packaging and labeling regulations.

EEC Directives - Proposed
Resolution on a Revised List of Second-Category Pollutants (545)
1,4-Dichlorobenzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

27.1 MAJOR USES

Most of the 1,4-dichlorobenzene produced in the United States is used as an air deodorant and moth repellant. Air deodorizing accounts for 55% of the 1,4-dichlorobenzene market. These products are usually sold as blocks or cakes, with or without perfumes. Approximately 35% of 1,4-dichlorobenzene is used as moth repellant for textiles. Mothballs which are available to consumers contain upwards of 99% 1,4-dichlorobenzene. The remaining 10% is used in agricultural chemicals, abrasives manufacture, floor waxes and dye and chemical synthesis (265).

27.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

27.2.1 Transport in Soil/Ground-water Systems

27.2.1.1 Overview

The 1,4-isomer of dichlorobenzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways can be assessed by using an equilibrium partitioning model, as shown in Table 27-1.

These calculations predict the partitioning of low soil concentrations of 1,4-dichlorobenzene among soil particles, soil water and soil air. Portions of 1,4-dichlorobenzene associated with the water and air phases of the soil have higher mobility than the adsorbed portion.

Estimates for the unsaturated topsoil model indicate that 99.5% of the 1,4-dichlorobenzene is expected to be sorbed onto soil particles. Approximately 0.4% is expected to partition to the soil-water phase, and is thus available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of 1,4-dichlorobenzene in the gaseous phase of the soil (less than 0.1%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, may be a significant loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the 1,4-dichlorobenzene (27.8%) is predicted to be present in the soil-water phase (Table 27-1) and available for transport with flowing ground-water. Sorption onto deep soils (83%) is less than onto surface soils, but may have some effect on mobility. Overall, ground-water underlying 1,4-dichlorobenzene-contaminated soils with low organic content is expected to be vulnerable to contamination.

TABLE 27-1

EQUILIBRIUM PARTITIONING CALCULATIONS FOR
1,4-DICHLOROBENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 25°C	99.5	0.4	0.1
Saturated deep soil[d]	83.2	16.8	-

a) Calculations based on Mackay's equilibrium partitioning model (34,35,36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized soil sorption coefficient estimated with equations of Means et al. (611): K_{oc} = 1180.
c) Henry's law constant taken as 1.58E-03 atm · m^3/mol at 25°C (74).
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

27.2.1.2 Sorption on Soils

The mobility of 1,4-dichlorobenzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Wilson et al. (82) investigated the transport and fate of 1,4-dichlorobenzene in 0.8 mg/L and 0.13 mg/L solutions applied to sandy soils. The 1,4-dichlorobenzene was found to be relatively mobile. In a soil column receiving 0.8 mg/L of 1,4-dichlorobenzene, approximately 37% percolated through the soil column with minimal retardation and 63% was degraded or not accounted for; for the 0.13 mg/L solution,

49% percolated through the soil column and 51% was degraded or not accounted for. The loss due to volatilization was not determined.

Laboratory sorption studies (608) indicate that sorption of 1,4-dichlorobenzene (20 μg/L) by sediments and aquifer material is a reversible process. Retardation factors, which represent the interstitial water velocity/pollutant velocity in the soil, were reported by Wilson et al. (82) to be a function of K_{oc}, the ratio of soil density (a) to soil water content (b), and the organic content (oc) of the soil according to the following equation:

$$R_f = 1 + (a/b)K_{oc}(oc)$$

The retardation factors calculated for 1,4-dichlorobenzene have been summarized in Table 27-2. The data indicate some retardation (i.e., adsorption) in soils having 1-2% organic carbon and little or no retardation in deep soils having less than 0.1% organic carbon.

27.2.1.3 Volatilization from Soils

Transport of 1,4-dichlorobenzene vapors through the air-filled pores of unsaturated soils may occur in near-surface soils. However, modeling results suggest that a relatively small fraction of the 1,4-dichlorobenzene loading will be present in the soil-air phase. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, is expected to increase significantly with increasing temperature. Moderate increases in H have also been observed with increasing salinity and the presence of other organic compounds (18). These results suggest that the presence of other materials may significantly affect the volatilization of 1,4-dichlorobenzene particularly from surface soils.

No information was available for the two other physicochemical properties influencing 1,4-dichlorobenzene volatilization, i.e., the vapor-soil sorption coefficient and the vapor phase diffusion coefficient.

The 1,4-isomer of dichlorobenzene has been reported to volatilize from aqueous solutions at a relatively rapid rate; the volatilization half-life from a water column 1 meter thick has been calculated to be 11 hours (10). Garrison and Hill (600) reported almost complete volatilization (1 mg/L) of a 300 mg/L concentration of 1,4-dichlorobenzene in less than four hours from aerated distilled water, and in less than three days from unaerated distilled water. Wakeham et al. (527) examined the fate and persistence of 1,4-dichlorobenzene in coastal seawater. Half-lives calculated for 1,4-dichlorobenzene in the marine water column were 18 days in the spring, 10 days in summer, and 13 days in winter. Volatilization was identified as the major removal process. Another field study of 1,4-dichlorobenzene transport in Lake

TABLE 27-2

RETARDATION FACTORS FOR 1,4-DICHLOROBENZENE IN RIVER SEDIMENTS AND AQUIFER MATERIALS

Retardation Factor	Matrix
18 - 70[a]	River Sediment (1-2% organic carbon)
2.7 - 35[a]	Aquifer Close to River Bed (0.1-1% organic carbon)
1 - 2.7[a]	Aquifer Far from River Bed (less than 0.1% organic carbon)
4.0[b]	Sandy Soil

[a]Reference 77
[b]Reference 82

Zurich (607) indicated a half-life of approximately 100 days. Of the 90 kg/yr entering the lake, 67% was removed by volatilization, 2% was removed to the sediment and 31% was present in the lake's outflow of 1,4-dichlorobenzene, particularly from surface soils.

Actual volatilization rates will depend on factors such as depth, turbulence and other environmental conditions. Compared to volatilization from well-stirred aqueous solutions, volatilization of some chlorinated organics from surface soils was inhibited by approximately one order of magnitude (82).

In the atmosphere, 1,4-dichlorobenzene should exist mainly in the vapor phase and is expected to react with photochemically generated hydroxyl radicals (3949). Using a rate constant of 0.32E-12 cu.cm/molecule-sec at 22°C and an ambient hydroxyl radical concentration of 8.0E+5 molecules/cu.cm., the half-life for 1,4-dichlorobenzene in air of 31 days was estimated (3894). The detection of dichlorobenzene isomers in rain water (3930) suggests that atmospheric removal through washout is also possible (3949).

27.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of 1,4-dichlorobenzene in soil/ground-water systems is not well documented. In most cases, it should be assumed that 1,4-dichlorobenzene will persist for months to years (or more). The 1,4-dichlorobenzene that has been released from the soil into the air will eventually undergo photochemical oxidation; a half-life in air of three days (609) and an atmospheric residence time of 38.6 days (601) have been reported for 1,4-dichlorobenzene.

No information on the hydrolysis of 1,4-dichlorobenzene was available; under normal environmental conditions, hydrolysis is not expected to occur at a rate competitive with volatilization or biodegradation.

The 1,4-isomer of dichlorobenzene is not expected to be rapidly biodegraded in the environment. The more halogenated a compound is, the more resistant it becomes to biodegradation, implying that 1,4-dichlorobenzene is more persistent than chlorobenzene which is significantly degraded only by acclimated microbial populations. Furthermore, the presence of a chlorine atom on the benzene ring has been reported to retard the rate of biodegradation (10). Thom and Agg (80) have listed 1,4-dichlorobenzene as a synthetic organic chemical which is unlikely to be removed during biological sewage treatment.

Dichlorobenzenes were only slowly degraded by soil microbes in culture (610) and no degradation of 1,4-dichlorobenzene injected into ground-water was observed (597). Schwartzenbach et al. (77) report that 1,4-dichlorobenzene was biodegraded during infiltration of contaminated river water to ground-water. However, they also indicate that anaerobic conditions in the aquifer hindered the process. Wakeham et al. (527) report that biodegradation is not an important fate process for 1,4-dichlorobenzene in seawater.

In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as 1,4-dichlorobenzene is expected to be low and to drop off sharply with increasing depth. Thus, biodegradation in the deep soil/ground-water system should be assumed to be of minimal importance except, perhaps, near landfills with active microbiological populations.

27.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The physicochemical properties of 1,4-dichlorobenzene and the above discussion of fate pathways suggest that 1,4-dichlorobenzene is highly volatile from aqueous solutions, moderately to strongly adsorbed by soil and has a moderate potential for bioaccumulation. This compound may volatilize from soil surfaces. Over time, the portion not subject to volatilization may eventually migrate to ground-water. These fate characteristics suggest several potential pathways.

Volatilization of 1,4-dichlorobenzene from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. In addition, there is a potential for ground-water contamination, particularly in sandy soil. However, Mitre (83) did not find 1,4-dichlorobenzene in ground-water, surface water or air at any of the 546 National Priority List (NPL) sites.

This compound was reported in the Ground-water Supply Survey (GWSS) conducted by the USEPA (531). This survey examined 945 finished water supplies that use ground-water sources. The results for 1,4-dichlorobenzene are summarized below:

Sample Type	Occurrences* No.	%	Median of Positives (μg/L)	Maximum (μg/L)
Random				
Supplies serving < 10,000 people (280 samples)	2	0.7	0.60	0.68
Supplies serving > 10,000 people (186 samples)	3	1.6	0.66	1.3
Non-Random				
Supplies serving < 10,000 people (321 samples)	4	1.2	0.74	0.9
Supplies serving > 10,000 people (158 samples)	0	0	-	-

*Samples having levels over quantification limit of 0.5 μg/L.

The random samples taken as part of the GWSS are intended to statistically represent the U.S. ground-water drinking water supplies. The non-random supplies were chosen by the states as being potentially contaminated. 1,4-Dichlorobenzene has also been detected in the National Organic Monitoring Survey (NOMS) (90). In this survey, 1,4-dichlorobenzene was detected in 20 out of 113 samples with a mean concentration of the positives of 0.14 μg/L. Coniglio et al. (223) in a summary of data from SRI, NOMS and NORS, found that 1,4-dichlorobenzene was found at a frequency of 12.9% in finished ground-water.

The properties of 1,4-dichlorobenzene and the survey results described above suggest that this compound has some potential for movement in soil/ground-water systems. The movement of 1,4-dichlorobenzene in ground-water may eventually contaminate surface waters, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;

- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures through bioaccumulation;

- Recreational use of these waters may result in dermal exposures;

- Domestic animals may consume or be dermally exposed to contaminated ground- or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposures from drinking contaminated ground-water for two reasons. First, the Henry's law constant for 1,4-dichlorobenzene suggests that it will volatilize upon reaching surface waters. Secondly, because 1,4-dichlorobenzene is moderately to strongly adsorbed, the concentration reaching surface waters will be attenuated through adsorption to sediments. Thus, the availability of 1,4-dichlorobenzene may be limited. It does, however, have a moderate potential for bioaccumulation.

27.2.4 Other Sources of Exposure

The data reported in the previous section show that 1,4-dichlorobenzene has been reported in ground-water supplies. In addition, Coniglio et al. (223) in a summary of data from SRI, NOMS and NORS, noted that 1,4-dichlorobenzene was found at a frequency of 12.5% in finished surface water. This suggests that exposure through ingestion of such drinking-water supplies would be important.

The volatility of 1,4-dichlorobenzene suggests that it may be found in air as well. Brodzinsky and Singh (84) compiled all available atmospheric data for a number of volatile organics. For 1,4-dichlorobenzene, they had data for 430 locations. This compound was not found in rural and remote locations. In urban and suburban areas, the median concentration was 0.28 $\mu g/m^3$. In source-dominated locations, the median concentration was zero $\mu g/m^3$. There was no explanation for the lower value found in source-dominated areas. These results suggest the possibility of inhalation exposure to persons, particularly those in urban and suburban areas.

This compound has been widely used for a number of years as a moth repellant. Inhalation, and perhaps dermal exposures, are possible to consumers during use. One report cited 1,4-dichlorobenzene concentrations of 1700 $\mu g/m^3$ in a wardrobe where mothballs were used, 315 $\mu g/m^3$ within the closet and 105 $\mu g/m^3$ in the bedroom adjacent to the wardrobe (733). Although data are limited, the use of 1,4-dichlorobenzene as a moth repellant could be a significant source of exposure.

27.3 HUMAN HEALTH CONSIDERATIONS

27.3.1 Animal Studies

27.3.1.1 Carcinogenicity

An NTP carcinogenicity bioassay of 1,4-dichlorobenzene was conducted, in which male F344/N rats were given 0, 150, or 300 mg/kg of the chemical and female rats and B6C3F$_1$ mice were given 0, 300, or 600 mg/kg/day by gavage 5 days/week for 2 years (3523). 1,4-Dichlorobenzene produced an increased incidence in tubular cell adenocarcinomas of the kidney in male rats (control, 2%; low dose, 6%; high dose, 14%, p=0.030 by Fisher exact test) and a marginal increase in the incidence of mononuclear cell leukemia in males over that of the controls (10%; 14%; 22%, p=0.086). Treated mice exhibited increased incidences of hepatocellular carcinomas (males: 28%; 22%; 64%, p<0.001) (females: 10%; 10%; 38%, p<0.001); hepatocellular adenomas (males: 10%; 27%, p=0.030; 32%, p=0.006) (females: 20%; 13%; 42%, p=0.015), and pheochromocytomas of the adrenal gland (males only: 0%; 4%; 6%, p=0.129). The investigators concluded that under the conditions of the study 1,4-dichlorobenzene produced clear evidence of carcinogenicity for male rats, and male and female mice, and no evidence of carcinogenicity for female rats.

Long-term inhalation studies in rats and mice gave no indication of a carcinogenic response. Wistar rats (both sexes) were exposed to vapor concentrations of 0, 75 or 500 ppm, 5 hours per day, 5 days a week for 76 weeks and were killed at 102 weeks. No signs of treatment-related toxicity were observed at 75 ppm; liver and kidney weights were increased at 500 ppm but no indications of pathological changes were found (257). A second study was conducted with female Swiss mice. These animals received the same doses for 57 weeks and were held through weeks 75-76. This limited mouse study was also negative for neoplastic effects (257).

27.3.1.2 Genotoxicity

1,4-Dichlorobenzene did not induce genotoxic activity in the Salmonella Ames test with or without metabolic activation (202, 3646, 3276). Negative results were also obtained in a dominant lethal assay in which male CD-1 mice were exposed to vapor levels of 75, 225 or 450 ppm, 6 hours per day for 5 days (257); no increase in the number of observable chromosome abnormalities in bone-marrow cells could be detected in rats exposed to levels as high as 682 ppm (single two hour exposure) or as high as 500 ppm (5 hours/day, 5 days a week for 3 months) (257); and there was no evidence of chromosomal aberrations or sister chromatid exchanges above control values when Chinese hamster ovary cells were treated in culture with this isomer (3235). Conversely, micronuclei were induced at statistically significant levels in bone marrow cells of male mice injected intraperitoneally with 1,4-dichlorobenzene at 6 and 30 hours before sacrifice (3464).

27.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

There was no evidence of teratogenicity or fetotoxicity in rats exposed to vapor concentrations up to 500 ppm six hours per day or oral doses up to 200 mg/kg/day administered on days 6 through 15 of gestation (257, 269).

In other inhalation studies, Hayes et al. (3278) observed no teratogenic or fetotoxic effects in rabbits exposed to 1,4-dichlorobenzene vapors. Inseminated rabbits were exposed to 100, 300, or 800 ppm of 1,4-dichlorobenzene for 6 hours per day on days 6 through 18 of gestation. Pregnant rabbits exposed to 800 ppm of the chemical gained significantly less weight than the controls during days 6 through 8 of gestation, indicating slight maternal toxicity. A statistically identified increase in fetal resorptions was observed in the 300 ppm group when compared to current controls. However, the increase was not observed in the 800 ppm group and was within the range of values for historical controls. It was concluded that inhalation of 1,4-dichlorobenzene vapor was not embryotoxic or teratogenic at any exposure level tested.

27.3.1.4 Other Toxicologic Effects

27.3.1.4.1 Short-term Toxicity

The toxic effects of 1,4-dichlorobenzene are primarily on the liver and central nervous system. Signs of hepatic porphyria were noted in rats after daily administration of 770 mg/kg by stomach tube for 5 days (202). In another study, rats succumbed to an oral dose of 4 g/kg administered as a 20% solution in olive oil. A dose of 1 g/kg was survived (254).

The 1,4-isomer appears to be less toxic than the 1,2-isomer of dichlorobenzene. This may be due to the fact that its binding to liver proteins is not as pronounced (202). In vivo studies with Fischer rats, in which the hepatotoxic effects of three dichlorobenzenes were compared, indicated that the isomers tested can be ranked as follows: 1,2-dichlorobenzene > 1,3-dichlorobenzene > 1,4-dichlorobenzene (1,4-dichlorobenzene was not hepatotoxic in this study) (3940). The toxicity rankings were based on plasma glutamic pyruvate transaminase activities 24 hours after the rats were injected i.p. with doses of the isomers ranging from 0.9 to 4.5 mmol/kg; the rankings were supported by the results of in vitro studies.

27.3.1.4.2 Chronic Toxicity

The NTP conducted 13-week oral studies with 1,4-dichlorobenzene in F344/N rats and B6C3F$_1$ mice (3523) to characterize its toxicity and set doses for 2-year studies. Two studies were performed in rats. In the first, in which rats were given 300-1500 mg/kg/day, histologic changes were noted in the kidneys at all doses tested; therefore, the second study was performed with lower doses of 38-600 mg/kg/day. Doses of 1500 ppm decreased survival (females). Doses of 1,200 or more produced

decreased weight gain (females), degeneration and necrosis of hepatocytes, hypoplasia of the bone marrow, lymphoid depletion of the spleen and thymus, epithelial necrosis of the nasal turbinates, and increased urinary (but not liver) porphyrins (males and females). Doses of 600 and 900 mg/kg and more produced changes in clinical chemistry parameters (males and females, respectively). Doses of 300 mg/kg or more produced decreased weight gain (males), renal tubular cell degeneration in the first study (males; the effect was also observed in the second study, but was slight), and slight hematological changes (males).

In two studies, mice were given doses of dichlorobenzene ranging either from 600 to 1,800 mg/kg/day or from 85 to 900 mg/kg/day for 13 weeks (3523). In the first study, survival was decreased in male and female mice receiving doses of 1,500 mg/kg or more and body weights were decreased at all doses. Hepatocellular degeneration was observed in both sexes at all doses, and liver weight to brain weight ratios were increased at doses of 900 mg/kg or more. Modest clinical chemistry changes (900 mg/kg) and significantly reduced white blood cell counts (600 mg/kg) were also seen. In the second study, hepatocellular cytomegaly was observed in male and female mice at doses of 675 mg/kg or more, but not at 338 mg/kg. Neither renal damage nor hepatic porphyria was observed in either mouse study.

Hepatic cirrhosis, focal necrosis and increased liver and kidney weights were noted in rats given a daily oral dose of 376 mg/kg, 5 days/week for 7 months. At 188 mg/kg, a slight increase in liver and kidney weights was observed. No adverse effects were observed at 18.8 mg/kg or 13.42 mg/kg/day (18.8 x 5/7) (254).

In the two-year NTP study, male rats were given 150 and 300 mg/kg/day and female rats and male and female mice were given 300 and 600 mg/kg/day (3523). For the rats, survival of the males was significantly lower than that of vehicle controls; survival and body weights were not significantly affected in other groups. The main nonneoplastic effects involved the kidneys of males and females. Increased incidences of the following lesions were observed in males: epithelial hyperplasia of the renal pelvis (control, 2%; high dose 60%; low dose 62%); mineralization of the collecting tubules in the renal medulla (8%; 92%; 94%); and focal hyperplasia of the renal epithelium (0%; 2%; 18%). In females, the incidences of nephropathy were also increased (43%; 64%; 84%).

In male mice, 1,4-dichlorobenzene increased the incidences of thyroid gland follicular cell hyperplasia (control, 2%; low dose, 8%; high dose, 21%) and adrenal gland medullary hyperplasia (0%; 8%; 8%), as well as that of focal hyperplasia of the adrenal gland capsule (23%; 44%; 57%). In male and female mice, the incidences of nonneoplastic liver lesions including alterations in cell size, hepatocellular degeneration, and individual cell necrosis, were increased. There were also increased incidences of nephropathy in male mice and renal tubular regeneration in female mice.

Hepatic and renal effects have also been observed in Alderly Park Wistar rats exposed to 1,4-dichlorobenzene via inhalation. The animals were exposed to 0, 75, or 500 ppm, 5 hours/day, 5 days/week for 76 weeks (3934). At 500 ppm, organ weights, including liver and kidneys, were increased and there were slight increases in urinary protein and coproporphyrin output in the males. The no-observed-adverse-effect level was identified as 75 ppm.

Rats, rabbits and guinea pigs exposed to vapor concentrations of 798 ppm (4788 mg/m^3) according to a schedule of 7 hours/day, 5 days/week showed definite toxic reactions. The actual number of exposure periods ranged from a few to as many as 69. Symptoms included weakness, weight loss, tremors, eye irritation and liver damage. Rats, mice, guinea pigs, rabbits and monkeys exposed to 93 ppm (558 mg/m^3) over the same schedule for 7 months experienced no adverse effects (251, 254).

Rabbits repeatedly exposed to an average of 825 ppm (4950 mg/m^3) 8 hours/day developed edema of the cornea and optic nerve which cleared within 17 days of discontinuance. Oral doses of 0.5 to 1.0 g/kg/day produced the same reversible effects (19).

27.3.2 Human and Epidemiologic Studies

27.3.2.1 Short-term Toxicologic Effects

In five cases of household inhalation intoxication from 1,4-dichlorobenzene used as a mothproofing agent, one person with moderate exposure suffered from severe headache, swelling around the eyes and profuse rhinitis, all of which subsided within 24 hours. The remaining four individuals, all of whom had prolonged exposure to 1,4-dichlorobenzene, developed nausea, vomiting, weight loss and hepatic necrosis with jaundice. Two died and another developed cirrhosis (258). A 3-year-old male developed jaundice and hemolytic anemia after acute poisoning by ingestion; the amount was not indicated (281). Ingestion of 20 g has been reported to be well tolerated in man (284).

The vapor has been noted to be painful and irritating to the eyes and nose at concentrations between 50 and 160 ppm. Solid particles cause pain when in contact with the eye, but no serious injury (19).

The solid material produces a burning sensation when held in contact with the skin but the resulting irritation is slight. Warm fumes or strong solutions may irritate the skin on prolonged or repeated contact (38). The 1,4-isomer of dichlorobenzene is not absorbed through intact skin in acutely hazardous amounts (12).

27.3.2.2 Chronic Toxicologic Effects

Two cases of chronic ingestion of 1,4-dichlorobenzene have been reported. In one case, a woman who ingested 1 to 2 air freshener blocks per week throughout her pregnancy developed hemolytic anemia. She recovered completely after withdrawal of the chemical. Examination of the child revealed no abnormalities (282). In the other case, a woman who ingested 4 to 5 moth pellets daily for 2.5 years developed areas of increased skin pigmentation which diminished upon withdrawal of the chemical (283).

In workmen exposed to airborne concentrations of 45 ppm (270 mg/m^3) over an average of 4-8, years there was no evidence of organic injury, blood disorders or eye changes (254).

A woman who worked for 18 months with a mixture of hexachloroethane (10%) and 1,4-dichlorobenzene (90%) experienced tingling of the extremities, weight loss, dizziness and anemia. She recovered after cessation of exposure (276).

Girard and coworkers (259) reported five cases of blood disorders in individuals exposed by chronic inhalation and/or dermal contact to dichlorobenzenes, including 1,4-dichlorobenzene. However, no cause and effect relationship can be reliably inferred from these anecdotal reports.

27.3.3 Levels of Concern

The U.S. Environmental Protection Agency (355) has established an ambient water quality criterion of 400 $\mu g/L$ for the protection of human health from the toxic properties of dichlorobenzenes ingested through water and contaminated aquatic organisms. This criterion is based on the maximum chronic no-observed-effect level of 13.42 mg/kg/day reported for rats orally administered 1,4-dichlorobenzene over a period of 5 to 7 months (254, 271). Applying an uncertainty factor of 1000, the acceptable daily intake of 1,4-dichlorobenzene for a 70-kg man was calculated to be 0.94 mg/day. A reference dose (RfD) of 0.1 mg/kg/day for 1,4-dichlorobenzene has been calculated by the USEPA (3951).

Both OSHA (3539) and the ACGIH (3005) have set an occupational exposure limit of 75 ppm (450 mg/m^3) for 1,4-dichlorobenzene with a short-term exposure limit (15 minutes) value of 110 ppm. These values are believed to be sufficient to prevent acute and chronic poisoning (38).

27.3.4 Hazard Assessment

Available health effects data for 1,4-dichlorobenzene suggest no major health hazard associated with exposure to the compound; however, the potential effects of chronic, low-level exposure to 1,4-dichlorobenzene have yet to be established.

Little specific information is available on the toxicity of 1,4-dichlorobenzene to humans. One report of five cases has suggested an association between human leukemia and exposure to dichlorobenzenes, including 1,4-dichlorobenzene (259). A cause and effect relationship, however, cannot be reliably inferred from these anecdotal reports (202).

When administered by gavage to rats and mice for two years, 1,4-dichlorobenzene doses of 150 or 300 mg/kg in male rats and doses of 300 or 600 in female rats and B6C3F$_1$ mice produced clear evidence of carcinogenicity for male rats, and male and female mice, but no evidence of carcinogenicity for female rats (3523). Non-oncogenic effects in these studies included renal lesions in rats and mice and thyroid, adrenal, and liver lesions in mice.

Long-term inhalation studies in rats and female mice failed to demonstrate either a carcinogenic or hematological response, even at a high-level (500 ppm) exposure. Elevated kidney and liver weights were noted at this exposure level, suggesting some functional response of these organs to 1,4-dichlorobenzene exposure. No histological changes were detected (257).

A set of in vivo mutagenicity tests using the dominant lethal assay in mice and a cytogenic assay on bone marrow of rats demonstrated no effects suggestive of mutagenic activity for 1,4-dichlorobenzene (257), but a micronucleus test indicated evidence for clastogenicity in bone marrow cells of male mice injected with this isomer (3464). No evidence for any effect on reproductive function was indicated in the dominant lethal assay (257) or a set of embryotoxicity studies (257, 267).

Long-term oral administration of 1,4-dichlorobenzene to rats indicated exposure to 13.42 mg/kg/day produced no observed adverse effects (254). The USEPA calculated an acceptable daily intake for 1,4-dichlorobenzene based on this report (355).

27.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of 1,4-dichlorobenzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Due to the volatility of 1,4-dichlorobenzene, care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in airtight glass containers preferably with no headspace; analysis should be completed within 14 days of sampling. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of 1,4-dichlorobenzene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 601, 602, 612, 624, 625, and 1625 (65) or Methods 8010, 8020, 8120, and 8250 (63). In Methods 601,

602, 624, 8010, and 8020 an inert gas is bubbled through the aqueous sample in a purging chamber at ambient temperature, transferring the 1,4-dichlorobenzene from the aqueous phase to the vapor phase and onto a sorbent trap. The trap is then heated and backflushed to desorb the 1,4-dichlorobenzene and transfer it onto a gas chromatographic (GC) column. Methanol extracts of the sample may also be subjected to this purge and trap procedure (Methods 8010 and 8020). For Methods 612, 625, 1625, 8120, and 8250, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto the GC column using a solvent flush technique (Methods 625 and 1625) or the extract is concentrated, dried, and solvent exchanged to hexane prior to analysis (Methods 612, 8120, and 8250). The GC column is programmed to separate the organics; 1,4-dichlorobenzene is then detected with a halide specific detector (Methods 601 and 8010), a photo-ionization detector (Methods 602 and 8020), an electron-capture detector (Methods 612 and 8120), or a mass spectrometer (Methods 625, 1625, and 8250).

The EPA procedures recommended for 1,4-dichlorobenzene analysis in soil and waste samples, Methods 8010, 8020, 8120, and 8250 (63), differ from the aqueous procedures primarily in the method by which the analyte is introduced into the GC. The sample preparation in Methods 8010 and 8020, involves dispersing the soil or waste sample in water prior to "purge and trap." Alternatively, methanol extracts of the sediment/soil may be subjected to the purge procedure described above. Hexane has also been used to extract 1,4-dichlorobenzene from sludge samples (3169). The extract is "cleaned-up" on an alumina column, concentrated, and then analyzed by capillary GC. Other sample introduction techniques include direction injection and a headspace method where an aliquot the vapor above the sample in a sealed vial is analyzed. Recoveries for the headspace technique may vary depending upon the concentration (3355). In Methods 8120 and 8250, solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical 1,4-dichlorobenzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The 1,4-dichlorobenzene detection limit for Method 624 was not determined. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.4 µg/L (Method 601)	2.4 µg/kg (Method 8010)
0.3 µg/L (Method 602)	3.0 µg/kg (Method 8020)
1.34 µg/L (Method 612)	0.9 µg/g (Method 8120)
4.4 µg/L (Method 625)	2.9 µg/g (Method 8250)
10 µg/L (method 1625)	
2.4 µg/L (Method 8010)	
3.0 µg/L (Method 8020)	
13.4 µg/L (Method 8120)	
44 µg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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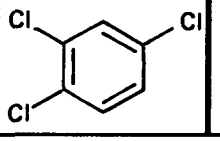
COMMON SYNONYMS:	CAS REG.NO.: 120-82-1 FORMULA: $C_6H_3Cl_3$ NIOSH NO: DC2100000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C 7.41 mg/m³ ≈ 1 ppm; 0.1348 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 181.45
1,2,4-Trichloro-benzene 1,2,4-Trichlorobenzol TCB Unsym-trichloro-benzene		

REACTIVITY	Reactions of halogenated organic materials such as 1,2,4-trichlorobenzene with cyanides, mercaptans or other organic sulfides typically generate heat, while those with amines, azo compounds, hydrazines, caustics or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, zinc or magnesium, organic peroxides or hydroperoxides, strong oxidizing agents, or strong reducing agents typically result in heat generation and explosions and/or fires (511, 505).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23) (23)
	• Color: Colorless	(23)
	• Odor: Aromatic	(23)
	• Odor Threshold: 3.000 ppm (approximate data)	(2)
	• Density: 1.4540 g/mL (at 20°C)	(68)
	• Freeze/Melt Point: 17.00°C	(14)
	• Boiling Point: 213.50°C	(68)
	• Flash Point: 99.00°C closed cup	(21)
	• Flammable Limits: 1.30 to 7.10% by volume	(514)
	• Autoignition Temp.: 571.0 to 638.0°C	(514)
	• Vapor Pressure: 2.70E-01 mm Hg (at 20°C)	(1219)

PHYSICO-CHEMICAL DATA (Cont.)	• Satd. Conc. in Air: 2.7000E+03 mg/m^3 (at 20°C) (1219) • Solubility in Water: 3.00E+01 mg/L (at 25°C) (286) • Viscosity: 1.448 cp (at 20°C) (21) • Surface Tension: 3.8540E+01 dyne/cm (at 20°C) (21) • Log (Octanol-Water Partition Coeff.): 4.12 (29) • Soil Adsorp. Coeff.: 6.35E+03 (652) • Henry's Law Const.: 4.33E-03 $atm \cdot m^3/mol$ (74) • Bioconc. Factor: 1.82E+02 (bluegill), 6.30E+02 (estim) (262,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	1,2,4-Trichlorobenzene is expected to be strongly sorbed onto soils with 1-2% organic carbon. However, migration through surface soils and to a much greater extent through deep soils has been reported. This compound is expected to be persistent. Volatilization from aqueous solutions has been observed although volatilization from soils is expected to be much slower. Biodegradation in natural soil systems is slow and not expected to be significant except in acclimated microbial populations.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of 1,2,4-trichlorobenzene to groundwater drinking water supplies. This pathway will be less important in soils of high organic content, and there is limited evidence that such migration has occurred in the past. Inhalation resulting from volatilization from surface soils may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (19, 54) Acute exposure may cause drowsiness, incoordination and unconsciousness. Vapors are irritating to the eyes, skin and respiratory tract. Prolonged or repeated contact with liquid may cause skin burns. Acute Toxicity Studies: ORAL: LD_{50} 756 mg/kg Rat (47) LD_{50} 300 mg/kg Mouse (3504) SKIN: LD_{50} 6139 mg/kg Rat (2) Long-Term Effects: Liver and kidney damage Pregnancy/Neonate Data: Not teratogenic in animals. Embryotoxic in rats only at maternally lethal doses (360 mg/kg/day, on gestation days 9-13) Genotoxicity Data: Limited evidence is negative Carcinogenicity Classification: IARC - No data NTP - No data EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS	Handle chemical only with adequate ventilation • There are no formal guidelines available for this chemical with respect to respirator use. Use a self-contained breathing apparatus with a full facepiece (or the equivalent) where there is any doubt as to the efficacy of gas masks or cartridge-type respirators • Chemical goggles if there is a probability of eye contact • Appropriate clothing to prevent repeated or prolonged skin contact. Wear impervious gloves.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA Ceiling Limit: 5 ppm
- AFOSH Ceiling Limit: 5 ppm

Criteria
- NIOSH IDLH (30 min): None established
- NIOSH REL: None established
- ACGIH CL: 5 ppm
- ACGIH STEL (15-min): None established

WATER EXPOSURE LIMITS:

Drinking Water Standards (3504)
MCLG: 9 μg/L (tentative)

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - No criterion established due to insufficient data.

- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 250 μg of chlorinated benzenes/L.

    chronic toxicity:
    no criterion but lowest effect level occurs at 50 μg of chlorinated benzenes/L for species exposed for 7.5 days.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 160 μg of chlorinated benzenes/L.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 129 μg of chlorinated benzenes/L.

REFERENCE DOSES: (3744)
2.00E-02 mg/kg/day

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

1,2,4-Trichlorobenzene is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources and to effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768). Limitations vary depending on the type of industry and plant.

Safe Drinking Water Act (SDWA)

Trichlorobenzene is on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 by January 1991 (3781). EPA lists it as an unregulated contaminant with no EPA monitoring requirements. The individual states decide which systems require analysis for this contaminant (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of 1,2,4-trichlorobenzene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

1,2,4-Trichlorobenzene is listed as a hazardous waste constituent (3783). A non-specific source of 1,2,4-trichlorobenzene-containing waste is the production of chlorinated aliphatic hydrocarbons (325). Waste streams from the organic chemicals industry (production of chlorobenzene, 1,2-dichloroethane, and trichloroethylene/perchloroethylene) contain 1,2,4-trichlorobenzene and are listed as specific sources of hazardous waste (3774, 3765). 1,2,4-Trichlorobenzene is subject to land disposal restrictions when its concentration as a hazardous waste constituent exceeds designated levels (3785). Effective July 8, 1987, the land disposal of untreated hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances exist until May, 1990 for some wastewaters and nonwastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786). 1,2,4-Trichlorobenzene is included on EPA's groundwater monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their groundwater for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of 1,2,4-trichlorobenzene must report production, usage and disposal information to EPA. They, as well as others who possess health and safety studies on 1,2,4-trichlorobenzene, must submit them to EPA (334, 3789). EPA requires that manufacturers and importers of chemical substances made from 1,2,4-trichlorobenzene submit production, use, exposure and disposal data in order to determine whether there is further need for dioxin and furan testing of the chemical products for which 1,2,4-trichlorobenzene is a precursor (3780). EPA requires that manufacturers and processors of 1,2,4-trichlorobenzene conduct oncogenicity, environmental effects, and chronic toxicity testing. Previous proposals for teratogenicity and subchronic toxicity testing have been withdrawn (340).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
1,2,4-Trichlorobenzene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing 1,2,4-trichlorobenzene but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of 1,2,4-trichlorobenzene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
A ceiling level of 5 ppm of 1,2,4-trichlorobenzene shall not be exceeded at any time during an 8-hour work-shift (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated 1,2,4-trichlorobenzene as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs

ALL STATES

All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

CONNECTICUT

Connecticut has a quantification limit of 2 μg/L for drinking water (3137).

DISTRICT OF COLUMBIA

The District of Columbia has a human health criterion of 20 μg/L for all chlorinated benzenes in surface waters (3828).

NEW JERSEY

New Jersey has set an MCL of 8 μg/L for drinking water (3497).

KANSAS

Kansas has an action level of 13 μg/L for groundwater (3213).

NEW YORK

New York has an MCL of 5 μg/L for the sum of all trichlorobenzenes in drinking water and a nonenforceable water quality guideline of 10 μg/L for groundwater (3501). New York has also set ambient water quality standards for the sum of all isomers of trichlorobenzenes in surface waters: 10 μg/L for drinking water supply waters, 50 μg/L for Class D and SD waters, and 5 μg/L for Classes A, A-S, AA, AA-S, B, C, SA, SB and SC waters (3500).

PENNSYLVANIA

Pennsylvania has a human health criterion of 700 μg/L for surface water (3561).

RHODE ISLAND

Rhode Island has an acute freshwater quality guideline of 75 μg/L and a chronic guideline of 1.7 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA

South Dakota requires trichlorobenzene to be nondetectable, using designated test methods, in groundwater (3671).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)

  EPA plans to propose MCLs, MCLGs, and monitoring requirements for 1,2,4-trichlorobenzene in March, 1990, with final action scheduled for March, 1991 (3751).

- State Water Programs

  MOST STATES

  Most states are in the process of revising their water programs and proposing changes to their regulations which will EPA's changes when they become final. Contact with state officers is advised. Changes are projected for 1989-90 (3683).

  NEW JERSEY

  New Jersey has proposed a water quality standard of 8 μg/L for Class FW2 surface waters (3496).

EEC Directives

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Quality Required of Shellfish Waters (537)

The mandatory specifications for organohalogenated substances specify that the concentration of each substance in the shellfish water or in shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The specifications for organohalogenated substances state that the concentration of each substance in shellfish flesh must be so limited that it contributes to the high quality of the shellfish product.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into groundwater.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

EEC Directives - Proposed
Resolution Second-Category Pollutants (545)
1,2,4-trichlorobenzene is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

28.1 MAJOR USES

The major user of 1,2,4-trichlorobenzene is the textile industry where it is utilized as a dye carrier. The pesticide industry consumes 28% which is used during the production of dicamba, stirofos and trichlorodinitrobenzene. Eighteen percent is used in functional fluids such as dielectric liquids and transformer oils. Miscellaneous uses account for the remainder. These uses include degreasing agents, septic tank and drain cleaner formulations, wood preservatives and abrasive formulations used in the manufacture of grinding wheels (262).

28.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

28.2.1 Transport in Soil/Ground-water Systems

28.2.1.1 Overview

The 1,2,4-isomer of trichlorobenzene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways can be assessed by using an equilibrium partitioning model, as shown in Table 28-1. These calculations predict the partitioning of low soil concentrations of 1,2,4-trichlorobenzene among soil particles, soil water and soil air. Portions of 1,2,4-trichlorobenzene associated with the water and air phases of the soil have higher mobility than the adsorbed portion.

Estimates for the unsaturated topsoil model indicate that 99.9% of the 1,2,4-trichlorobenzene is expected to be sorbed onto soil particles. Approximately 0.08% is expected to partition to the soil-water phase, and is thus available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of 1,2,4-trichlorobenzene in the gaseous phase of the soil (less than 0.04%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, may be a significant loss pathway.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a slightly higher fraction of the 1,2,4-trichlorobenzene (3.6%) is likely to be present in the soil-water phase (Table 28-1) and available for transport with flowing ground water. The percentage sorbed onto deep soils (96.4%) is less than for surface soils. Due to the potential mobility of the non-absorbed 1,2,4-trichlorobenzene, ground water underlying contaminated soils may be vulnerable to contamination. In laboratory studies, Schwarzenbach and Westall (228) predicted that trichlorobenzene will be somewhat mobile through river sediment and highly mobile through aquifer materials.

TABLE 28-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
1,2,4-TRICHLOROBENZENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil[b,c] at 25°C	99.9	0.08	0.04
Saturated deep soil[d]	96.4	3.6	-

a) Calculations based on Mackay's equilibrium partitioning model (34,35,36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized soil sorption coefficient estimated with equations of Means et al. (611): K_{oc} = 6350
c) Henry's law constant taken as 4.33E-03 atm · m^3/mol at 25°C (74).
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: $K_p = 0.001 \times K_{oc}$.

28.2.1.2 Sorption on Soils

The mobility of 1,2,4-trichlorobenzene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Laboratory sorption studies (608) indicate that sorption of 1,2,4-trichlorobenzene (40 μg/L) by sediments and aquifer material is a reversible process. Retardation rates, which represent the interstitial water velocity/pollutant velocity in the soil, were reported by Wilson et al. (82) to be a function of K_{oc}, the ratio of soil density (a) to soil water content (b), and the organic content (oc) of the soil according to the following equation:

$$R_f = 1 + (a/b)K_{oc}(oc)$$

The retardation factors (R_f) calculated for 1,2,4-trichlorobenzene in laboratory soil columns are: 7 in sandy soils (82), 6.7 in aquifer material (228), and 100 in river sediment (228). The data indicate some retardation (i.e., adsorption) in soils having high organic carbon content (approximately 1-2%) and little retardation in sandy soils and aquifer materials having less than 0.1% organic carbon.

Wilson et al. (82) investigated the transport and fate of 1,2,4-trichlorobenzene in 3.4 mg/L and 0.57 mg/L solutions applied to sandy soils. It was found to be relatively mobile. In a soil column receiving 3.4 mg/L of 1,2,4-trichlorobenzene, approximately 46% percolated through the soil column with minimal retardation and 54% was degraded or not accounted for; for the 0.57 mg/L solution, 39% percolated through the soil column and 61% was degraded or not accounted for. The loss due to volatilization was not determined.

Soil and ground-water monitoring data in the area of an accidental spill of 1500 gallons of transformer liquid containing 1,2,4-trichlorobenzene and other chlorinated organics revealed that 1,2,4-trichlorobenzene migrated quickly from the spill area, through the soil, and into the ground water. Ground water concentrations of 500 μg/L were observed after the spill and detectable levels remained up to two years later (614).

28.2.1.3 Volatilization from Soils

Transport of 1,2,4-trichlorobenzene vapors through the air-filled pores of unsaturated soils may occur in near-surface soils. However, a relatively small percentage of 1,2,4-trichlorobenzene is expected to be present in the soil-air phase. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, is expected to increase significantly with increasing temperature. Moderate increases in H have also been observed with increasing salinity and the presence of other organic compounds (18). These results suggest that the presence of other materials may significantly affect the volatilization of 1,2,4-trichlorobenzene particularly from surface soils.

No information was available for the two other physicochemical properties influencing 1,2,4-trichlorobenzene volatilization, i.e., the vapor-soil sorption coefficient and the vapor phase diffusion coefficient.

Volatilization of 1,2,4-trichlorobenzene from aqueous solutions has been reported to occur at a relatively rapid rate (10). Ware and West (609) reported an evaporation half-life of 45 minutes from 10 cm of water at standard temperature and pressure. More than 99% of a 100 mg/L solution of 1,2,4-trichlorobenzene was reported to volatilize from aerated distilled water in less than four hours and from unaerated distilled water in less than two days (600), corresponding to half-lives of 36 minutes from aerated water and 72 hours from unaerated water. The same authors demonstrated that the addition of mixed cultures of aerobic microorganisms increased the half-life of volatilization from aerated water to four or five hours; this effect is probably due to adsorption of 1,2,4-trichlorobenzene onto suspended biological material.

Wakeham et al. (527) examined the fate and persistence of 1,2,4-trichlorobenzene in coastal seawater. Half-lives calculated for 1,2,4-trichlorobenzene in the marine water column were 22 days in the spring, 11 days in summer, and 12 days in winter. Volatilization was identified as the major removal process. Actual volatilization rates will depend heavily on factors such as depth, turbulence and other environmental conditions. Compared to volatilization from well-stirred aqueous solutions, volatilization from surface soils has been shown to be slower by approximately one order of magnitude for some chlorinated organics (82).

28.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of 1,2,4-trichlorobenzene in soil/groundwater systems is not well documented. In most cases, it should be assumed that 1,2,4-trichlorobenzene will persist for months to years (or more). The portion of 1,2,4-trichlorobenzene that has been released from the soil into the air will eventually undergo photochemical oxidation; a half-life in air of several days (10) and an atmospheric residence time of 116 days (601) has been reported for 1,2,4-trichlorobenzene.

No information on the hydrolysis of 1,2,4-trichlorobenzene was available; under normal environmental conditions, hydrolysis is not expected to be a significant biodegradation pathway.

The 1,2,4-isomer of trichlorobenzene is not expected to be rapidly biodegraded in the environment. The more halogenated a compound is, the more resistant it becomes to biodegradation. Therefore, 1,2,4-trichlorobenzene is expected to be more persistent than chlorobenzene which is significantly degraded only by acclimated microbial populations (10).

Trichlorobenzenes were only slowly degraded by soil microbes in culture (610) and no degradation of 1,2,4-trichlorobenzene injected into ground water was observed (597). In addition, Wakeham et al. (527) report that biodegradation is not an important fate process for 1,2,4-trichlorobenzene in seawater.

Biodegradation of 1,2,4-trichlorobenzene by microbial populations in soil has been reported (616) to occur at very slow rates (1 nmol/day per 20 g of soil). Anaerobic conditions were shown to have a negative effect on biodegradation while increased temperature exhibited a positive effect (optimum temperature = 28°C); mineral fertilizers or cosubstrates failed to increase degradation rates. Biodegrading populations were unaffected by 1,2,4-trichlorobenzene toxicity in the range of 1 μg/g to 10 μg/g.

In most soil/groundwater systems, the concentration of microorganisms capable of biodegrading chemicals such as 1,2,4-trichlorobenzene is expected to be low and to drop off sharply with increasing depth. Furthermore, optimum temperatures and aerobic conditions for biodegradation are not expected to occur naturally. Thus, biodegradation in the deep soil/ground-water system should be assumed to be of minimal importance except, perhaps, near landfills with active microbiological populations.

28.2.3 Primary Routes of Exposure From Soil/Ground-water Systems

The above discussion of fate pathways suggests that 1,2,4-trichlorobenzene is highly volatile from aqueous solutions, moderately to strongly adsorbed by soil and has a moderate potential for bioaccumulation. This compound may volatilize from soil surfaces. The portion not removed by volatilization is likely to be mobile in ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of 1,2,4-trichlorobenzene from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. There is a potential for ground water contamination, particularly in sandy soil. Mitre (83) reported that 1,2,4-trichlorobenzene has been found at one of the 546 National Priority List (NPL) sites in both surface and ground water. It has also been detected in the National Organic Monitoring Survey (NOMS) (90). In this survey, 1,2,4-trichlorobenzene was detected in 2 out of 113 drinking water samples with a mean concentration (of the positives) of 0.29 μg/L.

The fate discussion above, and the survey results indicate that this compound has a limited potential for movement in soil/ground-water systems of higher organic content. In some soils this compound may eventually reach surface waters, suggesting several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures through bioaccumulation;
- Recreational use of these waters may result in dermal exposures;

- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposures from drinking contaminated ground water for two reasons. First, the Henry's law constant for 1,2,4-trichlorobenzene suggests that it will volatilize upon reaching surface waters. Secondly, because 1,2,4-trichlorobenzene is moderately to strongly adsorbed, the concentration reaching surface waters will be attenuated through adsorption to sediments. Thus, the availability of 1,2,4-trichlorobenzene to aquatic organisms may be limited, although they have a moderate potential to bioaccumulate this compound.

28.2.4 Other Sources of Exposure

The volatility of 1,2,4-trichlorobenzene suggests that it may be found in air. Brodzinsky and Singh (84) compiled all available atmospheric data for a number of volatile organics. For trichlorobenzene, they had data for 732 locations. They did not specify whether the trichlorobenzene monitored was the 1,2,4-isomer. Trichlorobenzene was not found in rural and remote locations. In urban and suburban areas, the median concentration was 0.062 $\mu g/m^3$. In source-dominated locations, the median concentration was 0.66 $\mu g/m^3$. These results suggest possible inhalation exposure, particularly to persons residing in source-dominated areas.

It was noted in Section 28.2.3 that 1,2,4-trichlorobenzene was infrequently detected in drinking water. However, effluents contaminated with 1,2,4-trichlorobenzene and discharged near drinking water intakes in surface water could potentially result in ingestion exposures. There has been concern regarding the inadvertent production of chlorobenzenes through chlorination of sources or effluents containing benzene. The data that exist seem to indicate that chlorination is not a significant inadvertent source (265).

28.3 HUMAN HEALTH CONSIDERATIONS

28.3.1 Animal Studies

28.3.1.1 Carcinogenicity

No adequate studies are available on the possible carcinogenic effects associated with 1,2,4-trichlorobenzene exposure. A 6-month study of ICR-JCL mice fed 1,2,4-trichlorobenzene at a level of 600 mg/kg diet (~72 mg/kg bw/day; see Appendix 3 for conversion assumptions) reported no increased incidence of hepatomas (tumors of the liver) (289).

A two-year skin-painting study was conducted in Slc:ddY mice. Solutions of 1,2,4-trichlorobenzene in acetone (60% and 30%) were applied in 0.3 mL increments twice per week. The local effects were thickening and keratinization of the epidermis followed by inflammation. Mean survival was significantly reduced in the 60% treatment group (both sexes) and in females in the 30% group. Tumors developed in both experimental groups at numerous sites but no single tumor type was significantly increased over the control incidence. The actual incidence in terms of tumor-bearing animals was not provided (translation of Japanese text) (290).

These two studies are clearly inadequate for drawing any conclusions about the potential carcinogenicity of 1,2,4-trichlorobenzene in humans.

28.3.1.2 Genotoxicity

Studies utilizing Salmonella typhimurium reported negative results in as many as seven strains with and without metabolic activation at concentrations up to 3 mg/plate (3626, 3276, 3508, 3406). This system is generally insensitive to chlorinated compounds. 1,2,4-Trichlorobenzene was positive in an in vivo assay for clastogenicity using 8-week old male NMRI mice. The mice were injected intraperitoneally with doses of 105, 210, 315, or 420 mg of 1,2,4-trichlorobenzene/kg body weight at 0 and 24 hrs and sacrificed at 30 hrs. The number of micronucleated cells in the bone marrow of the treated males shows a positive, statistically significant ($p<0.01$), dose-related response (3464).

28.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Teratogenic effects were not observed following treatment of rats and mice with 1,2,4-trichlorobenzene and embryotoxic effects of this chemical were seen only at concentrations which produced maternal toxicity.

The reproductive effects of 1,2,4-trichlorobenzene were assessed in rats orally administered doses of 0, 36, 120, 360 or 1200 mg/kg/day on days 9 through 13 of gestation. Maternal deaths were observed in the 360 and 1200 mg/kg groups (22% and 100%, respectively). Embryonic development was significantly retarded at 360 mg/kg/day (maternal body weight gain was significantly reduced in this group) but no increases in teratogenicity or embryolethality were reported. Marked maternal liver enzyme induction was observed at both the 120 mg/kg and 360 mg/kg treatment levels. No observed effects were noted for the lowest dosage level (288). Also, no evidence of teratogenic effect was noted in another study conducted with rats given oral doses up to 300 mg/kg/day of 1,2,4-trichlorobenzene on days 6-15 of pregnancy (269).

Gray and Kavlock (3251) observed no changes in viability, birth weight, or weight gain in mice exposed orally to 130 mg/kg/day of 1,2,4-trichlorobenzene on days 8 through 12 of gestation. In another study, pregnant mice were exposed by gavage to 130 mg/kg/day of 1,2,4-trichlorobenzene on days 8 through 12 of pregnancy.

Locomotor activity levels in the offspring, measured in a figure eight maze on postnatal days 22, 58, or 200, were not significantly different from controls.

Robinson and coworkers (586) conducted a multigeneration study with rats exposed to 1,2,4-trichlorobenzene in their drinking water at levels of 0, 25, 100 or 400 ppm. These exposure levels were calculated to amount to 3.7, 14.8 and 53.6 mg/kg, respectively, for females at 83 days of age and 2.5, 8.9 and 33.0 mg/kg, respectively, for male rats. No treatment-related effects with respect to fertility, viability or growth were seen in any generation.

28.3.1.4 Other Toxicologic Effects

28.3.1.4.1 Short-term Toxicity

The toxic effects of trichlorobenzenes are reportedly not as severe as those of the dichlorobenzenes (54). Acute oral LD_{50} values of 756 mg/kg and 766 mg/kg have been reported for rats and mice, respectively (51).

Reversible hepatic porphyria was induced in rats fed 730 mg/kg/day for 15 days (267) and rats exposed to vapor levels of 30-100 ppm 7 hours/day, 5 days/week for 30 days had elevated urinary levels of uroporphyrin and coproporphyrin. Both dogs and rats exhibited increased liver weights at the 100 ppm level. The no adverse effect level in rats was 24 mg/m^3. There were no significant effects on body weight, hematology or pathology in any of the animals at any dose level (585).

28.3.1.4.2 Chronic Toxicity

Few long-term studies of 1,2,4-trichlorobenzene have been conducted. The available data indicate slight changes in the liver, kidney and adrenal glands.

No adverse effects were noted in monkeys given oral doses of 1 to 25 mg/kg/day for 120 days. Dosages of 90 mg/kg or above were toxic. At doses of 125 mg/kg, there was temporary weight loss and evidence of hepatic enzyme induction but no evidence of jaundice. Doses of 174 mg/kg were lethal within 20 to 30 days (287).

An oral study, described as "subchronic" in the IRIS database, was the basis for the derivation of a chronic reference dose (RfD) by the USEPA (Carlson and Tardiff [3899]). Male CD rats (6/group) were given 1,2,4-trichlorobenzene in corn oil at doses of 0, 10, 20, or 40 mg/kg/day, and hematological parameters and induction of various enzymes were evaluated. The lowest dose tested, 10 mg/kg, induced some of the enzymes assayed, but did not affect liver-to-body weight ratio, blood hemoglobin level or hematocrit. Enzyme induction was more pronounced at 20 mg/kg, but did not affect other parameters. The highest dose tested, 40 mg/kg, induced enzymes and also increased liver-to body weight ratio, effects which unlike those that occurred at lower doses, persisted throughout a 30-day "recovery period". The 20 mg/kg dose was considered the NOAEL (no-observed-adverse-effect level).

No exposure-related changes in body weight, hematology or serum biochemistry were reported in rats, rabbits or monkeys exposed to 25, 50 or 100 ppm 7 hours per day, 5 days a week for periods of 4, 13 and 26 weeks. In addition, no liver, kidney or ophthalmic changes were observed in monkeys or rabbits. Liver and kidney effects were noted in rats at 4 and 13 weeks but had disappeared by the 26th week (285).

Robinson et al. noted adrenal gland enlargement at 95 days of age in both male and female rats of two generations continuously exposed to 1,2,4-trichlorobenzene in drinking water at a level of 400 ppm but not at 100 ppm (586).

Subchronic studies have assessed the dermal toxicity of 1,2,4-trichlorobenzene. Powers et al. (584) applied technical-grade 1,2,4-trichlorobenzene at concentrations of 5 or 25% (in petroleum ether) or undiluted trichlorobenzene topically in 0.2 mL increments to the ears of rabbits, 3 times weekly for 13 weeks. No overt signs of systemic toxicity were noted. Dermal responses ranged from redness and scaling at the 5% level to severe scaling, encrustation and desquamation at the two upper levels. No signs of systemic toxicity were observed. These findings are in contrast to those of Brown et al. (598) who reported that topical application of 0.5 mL/day of 1,2,4-trichlorobenzene 5 days/week for 3 weeks was lethal to some guinea pigs. Death followed extensor convulsions. Livers of these animals showed necrotic foci. The different results in the studies may be attributed to different sites of application, the volume applied, dosage frequency and species used.

Rao et al. (3932) observed slight systemic toxicity in rabbits following dermal application of a mixture of technical grade trichlorobenzene (70% 1,2,4-trichlorobenzene and 30% 1,2,3-trichlorobenzene). Doses of 30, 150 or 450 mg/kg trichlorobenzene were applied to the backs of the animals once each day, 5 days/week for 22 (males) or 23 (females) applications over 30-31 days. In addition to dermal irritation, systemic effects were observed that included a slight but statistically significant increase in the urinary coproporphyrin excretion in males and slight pallor of the liver at gross necropsy in both sexes.

28.3.2 Human and Epidemiologic Studies

In humans, eye and respiratory tract irritation have been reported following exposure to 3 ppm (22 mg/m^3) while a level of 2.4 ppm (17.8 mg/m^3) produced no effects (291). The only other additional data on human exposure that could be found are two individual case reports of aplastic anemia in a 68-year-old woman who often soaked her husband's work-clothes in trichlorobenzene (isomer unspecified) and anemia in a 60-year-old man who had been occupationally exposed to various chlorinated benzenes over a 30-year period (597). The oral lethal dose has been estimated to be between 50 and 500 mg/kg (~2.5-25 mL) for a 70-kg person (17).

28.3.3 Levels of Concern

The levels of concern associated with human exposure to 1,2,4-trichlorobenzene cannot be reliably established at this time due to the general lack of health effects data. The USEPA (355) has not set a water quality criterion for the protection of human health from the toxic effects of 1,2,4-trichlorobenzene ingested through water and contaminated aquatic organisms due to the scant information available. However, the USEPA has derived an oral RfD of 2E-02 mg/kg/day for 1,2,4-trichlorobenzene, based on the study of Carlson and Tardiff (3899), as reported in the IRIS Database (3949).

The ACGIH (3005) and OSHA (3539) recommend a 5 ppm (40 mg/m^3) ceiling limit, based on the irritating properties of 1,2,4-trichlorobenzene.

28.3.4 Hazard Assessment

The hazard to human health associated with long-term, low-level exposure to 1,2,4-trichlorobenzene such as the ingestion of contaminated drinking water is uncertain. Available human data for 1,2,4-trichlorobenzene are limited to reported eye and respiratory tract irritation resulting from acute exposure to 22 mg/m^3 in air (but not to a level of 17.8 mg/m^3) (291).

Animal data suggest few adverse effects are likely at low levels of exposure but the data are insufficient to estimate dose-response relationships for humans with any reliability. No adverse effects were reported for monkeys orally administered 25 mg/kg/day of 1,2,4-trichlorobenzene for 120 days; dosages of 90 mg/kg/day and above were toxic to the liver (287). Similar results were observed in rats, rabbits and dogs inhaling 1,2,4-trichlorobenzene in concentrations up to 800 mg/m^3, 7 hours/day, 5 days/week for up to 26 weeks (285). Enlargement of the adrenal glands was observed in both sexes of parent and offspring rats at 95 days of age subsequent to exposure to 400 ppm 1,2,4-trichlorobenzene in their drinking water in a multigenerational study (586). Dermal toxicity studies with 1,2,4-trichlorobenzene suggest that skin absorption of the compound may occur with subsequent systemic effects (598, 3932).

Carcinogenicity data are inadequate for drawing conclusions about the potential carcinogenicity of 1,2,4-trichlorobenzene in humans. Limited genotoxic data are negative in the Salmonella/microsome assay but positive in an in vivo micronucleus test in mice (3464).

A multigenerational study conducted with rats indicated no adverse reproductive effects (586) resulting from ingesting 400 ppm 1,2,4-trichlorobenzene in drinking water. Two studies indicated no teratogenic findings in rats ingesting 300 mg/kg/day (269) but reduced embryonic development at 360 mg/kg/day, a dose which was toxic to maternal animals (288).

28.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of 1,2,4-trichlorobenzene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of 1,2,4-trichlorobenzene, one of the EPA priority pollutants, in aqueous samples include EPA methods 612, 625, 1625 (65), 8120 and 8250 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extracted is injected onto a gas chromatographic (GC) column using a solvent flush technique (Methods 625 and 1625) or the extract is solvent exchanged to hexane prior to analysis (Methods 612, 8120, and 8250). The GC column is programmed to separate the semi-volatile organics; 1,2,4-trichlorobenzene is then detected with an electron capture detector (Methods 612 and 8020) or a mass spectrometer (Methods 625, 1625, and 8250).

The EPA procedures recommended for 1,2,4-trichlorobenzene analysis in soil and waste samples, Methods 8120 and 8250 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical 1,2,4-trichlorobenzene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.05 μg/L (Method 612)	0.03 μg/g (Method 8120)
1.9 μg/L (Method 625)	1.3 μg/g (Method 8250)
10 μg/L (Method 1625)	
0.5 μg/L (Method 8120)	
19 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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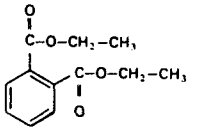
COMMON SYNONYMS:	CAS REG.NO.: 84-66-2 FORMULA: $C_{12}H_{14}O_4$ NIOSH NO: TI1050000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25 °C (12) 9.07 mg/m³ ≈ 1 ppm; 0.11 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 222.24
1,2-Benzenedicarboxylic acid, diethyl ester DEP Diethyl phthalate Diethyl-o-phthalate Ethyl phthalate Phthalic acid diethylester		

REACTIVITY	Reactions of esters such as diethyl phthalate with strong acids, strong alkali, strong oxidizers, strong reducing agents, or explosive materials typically result in the generation of heat and occasional fires and/or explosions (38,511,505). Reactions with hydrazines, alkali or alkaline earth metals, or nitrides generally produce heat and flammable or otherwise potentially hazardous gases (511).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(2)
	• Odor: Odorless	(23)
	• Odor Threshold: None	
	• Density: 1.1175 g/mL (at 20°C)	(12)
	• Freeze/Melt Point: -40.50°C	(23)
	• Boiling Point: 298.00°C	(23)
	• Flash Point: 162.70°C open cup	(23)
	• Flammable Limits: 0.70 to ? % by volume	(60,504)
	• Autoignition Temp.: 457.0°C	(60,504)
	• Vapor Pressure: 3.50E-03 mm Hg (at 25°C)	(33)
	• Satd. Conc. in Air: 4.3000E+01 mg/m³ (at 20°C)	(1219)
	• Solubility in Water: 1.04E+03 mg/L (at 25°C)	(656)
	• Viscosity: 31.300 cp (at 0°C)	(23)

PHYSICO-CHEMICAL DATA (Cont.)	• Surface Tension: 3.75E+01 dyne/cm (at 20°C) (23) • Log (Octanol-Water Partition Coeff.): 2.47 (29) • Soil Adsorp. Coeff.: 1.42E+02 (652) • Henry's Law Const.: 9.80E-07 atm · m^3/mol (at 25°C) (1219) • Bioconc. Factor: 1.40E+01 (estim), 1.17E+02 (bluegills) (659,399)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Fairly mobile in wet or saturated soils as chemical is easily transported in solution. Fairly immobile in dry soils; vapor-phase transport through air-filled pores of soil is probably not significant. Chemical is resistant to hydrolysis and photolysis but is readily biodegraded.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of diethyl phthalate to groundwater drinking water supplies, although it has not been detected in ground water from NPL sites. Inhalation resulting from volatilization from surface soils is not likely to be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (54) Diethyl phthalate appears to have a low order of acute toxicity. Heated vapors may irritate the nose and throat. Acute Toxicity Studies: INHALATION: LC_{50} 7510 mg/m^3 Rat (47) ORAL: LD_{50} 8600 mg/kg Rat (47) LD_{50} 6172 mg/kg Mouse (3504) SKIN: LD_{50} 3000 mg/kg Guinea Pig (403)

HEALTH HAZARD DATA	Long-Term Effects: No significant toxicity Pregnancy/Neonate Data: Negative in mice; suggestive evidence in rats Genotoxicity Data: Primarily negative Carcinogenicity Classification: IARC - No data NTP - Study in progress EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (54,59)	Handle chemical only with adequate ventilation • There are no formal guidelines available for this chemical with respect to respirator use. Use a self-contained breathing apparatus with a full facepiece (or the equivalent) where there is any doubt as to the efficacy of a NIOSH approved respirator or cartridge-type respirators • Chemical goggles if there is probability of eye contact with liquid • There may also be need for skin protection.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 5 mg/m^3
- AFOSH PEL (8-hr TWA): 5 mg/m^3; STEL (15 min): 15 mg/m^3

Criteria
- NIOSH IDLH (30-min): None established
- NIOSH REL: None established
- ACGIH TLV® (8-hr TWA): 5 mg/m^3

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (3742)
MCLG: 0 (tentative)

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (355)
  - Based on ingestion of contaminated water and aquatic organisms, 350 mg/L phthalate esters.
  - Based on ingestion of contaminated aquatic organisms only, 1.8 g/L phthalate esters.
  - Based on ingestion of contaminated water only, 434 mg/L.
- Aquatic Life (355)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 940 µg/L phthalate esters.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 3 µg/L phthalate esters.
  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 2944 µg/L phthalate esters.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:
ORAL: 8.000E+02 µg/kg/day (3744)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Diethyl phthalate is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Phthalates are on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 (3781). In states with an approved Underground Injection Control program, a permit is required for the injection of diethyl phthalate-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Diethyl phthalate is identified as a toxic hazardous waste (U088) and listed as a hazardous waste constituent (3783, 3784). Wastestreams from the production of phthallic anhydride from naphthalene are listed as specific sources of phthallic acid-containing toxic hazardous waste (3774, 3765). Diethyl phthalate is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective August 8, 1988, the land disposal of certain "first third" untreated diethyl phthalate-containing hazardous wastes is prohibited. These wastes must first be treated according to the Best Demonstrated Available Technology (BDAT) treatment standards promulgated by EPA (3786). Diethyl phthalate is included on EPA's groundwater monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their groundwater for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)

Manufacturers, processors or distributors of diethyl phthalate must report production, usage and disposal information to EPA. They, as well as others who possess health and safety studies on diethyl phthalate, must submit them to EPA (334, 3789).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
Diethyl phthalate is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 454 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing phthallic acid, but these depend upon the concentration of the chemical in the wastestream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of diethyl phthalate must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
Diethyl phthalate is exempt from a tolerance requirement when used as a solvent in pesticide formulations applied to animals (315).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to diethyl phthalate in any 8-hour work day shall not exceed an 8-hour time-weighted average (TWA) of 5 mg/m^3 (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated diethyl phthalate as a hazardous substance, with a reportable quantity of 454 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Diethyl phthalate is approved for use as an indirect food additive as a component of adhesives (3209).

- State Water Programs

  ALL STATES
  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria.

KANSAS
Kansas has an action level of 350 mg/L for groundwater (3213).

NEW YORK
New York has an MCL of 50 μg/L for drinking water, and a nonenforceable water quality guideline of 50 μg/L for surface and groundwaters (3501).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 2605 μg/L and a chronic guideline of 58 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires phthalates to be nondetectable, using designated test methods, in groundwater (3671).

WISCONSIN
Wisconsin has set a human threshold criterion of 170 mg/L for public water supply cold surface waters, and 270 mg/L for warm sport fishing waters (3842).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)
  EPA will propose MCLs, MCLGs, and monitoring requirements for phthalates in March, 1990, with final promulgation scheduled for March 1991 (3751).

  Resource Conservation and Recovery Act (RCRA)
  EPA has proposed that effective June 8, 1989, the land disposal of certain "second third" untreated diethyl phthalate-containing hazardous wastes be prohibited. These wastes would have to be treated according to Best Demonstrated Available Technology (BDAT) treatment standards before being disposed. Certain variances would exist until May, 1990 for some wastewaters for which BDAT treatment standards had not been promulgated by EPA (3795).

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with the state officer is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA
  Minnesota has proposed a Sensitive Acute Limit (SAL) of 13,025 μg/L, and a chronic criterion of 290 μg/L for surface waters for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on Toxic and Dangerous Wastes (542)

Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

EEC Directive - Proposed

Resolution on a Revised List of Second Category Pollutants (545)

Diethyl phtlate is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

29.1 MAJOR USES

Diethyl phthalate (DEP) was originally used as a replacement for camphor in the manufacture of cellulose nitrate. Its major use is as a plasticizer for cellulosic plastics. This accounts for 95% of DEP produced. Miscellaneous uses include: a fixative for perfumes; a solvent for cellulose acetate in varnishes; and use as an alcohol denaturant (403).

29.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

29.2.1 Transport in Soil/Ground-water Systems

29.2.1.1 Overview

Diethyl phthalate may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways can be assessed with the use of an equilibrium partitioning model as shown in Table 29-1. These calculations predict the partitioning of low soil concentrations of diethyl phthalate among soil particles, soil water and soil air. The portions of diethyl phthalate associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that most of the chemical (96%) will be sorbed on the soil; a small amount (3.5%) of the chemical will be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of diethyl phthalate in the gaseous phase of the soil (0.0004%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind is possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the diethyl phthalate (63%) is likely to be present in the soil-water phase (Table 29-1) and transported with flowing ground water. Ground water underlying DEP-contaminated soils with low organic content is thus vulnerable to pollution by the chemical.

There are no data from laboratory or field studies that focus on the fate of diethyl phthalate in soil-water systems. However, Lewis et al. (703) studied the transport and fate of DEP in simulated (laboratory) aquatic ecosystems and much of their work, which focused on elucidation of key environmental processes, is pertinent to soil-water systems. Their results showed that sorption, photolysis and chemical hydrolysis were insignificant processes in the fate of DEP in water, sediments and microbiota; the fate was almost solely determined by bacterial transformation.

TABLE 29-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR DIETHYL PHTHALATE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	96.5	3.5	0.0004
Saturated deep soil[d]	37.4	62.6	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated top-soil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 142 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken 9.8E-07 atm · m^3/mol at 25°C (Estimated by Arthur D. Little, Inc.)
d) Used sorption coefficient calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

Additional information on DEP is also available in the thorough review of phthalic acid esters by Giam et al. (768).

29.2.1.2 Sorption on Soils

The mobility of diethyl phthalate in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperatures;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 295, the soil sorption coefficient (K_{oc}) is estimated to be 142. This is a relatively low number indicative of weak sorption to soils. The laboratory aquatic ecosystem studies of Lewis et al. (703) also demonstrate the weak sorption behavior of DEP. They found no loss of DEP resulting from sorption in flasks containing up to several grams of biomass

(autoclaved aquatic microbial growth), no sorption of DEP on 36 sediment samples, and less than 1% of DEP loss due to sorption on the channel surfaces (of the laboratory test apparatus).

According to reports by Autian (765), Ogner and Schnitzer (766) and Matsuda and Schnitzer (767), phthalate esters readily complex with natural organic substances (e.g., fulvic acid) to form complexes which are very soluble in water. Thus, sorption to soils may be significantly weaker than might be expected based upon the information given above.

29.2.1.3 Volatilization from Soils

Transport of DEP vapors through the air-filled pores of unsaturated soils is not expected to be an important transport mechanism except for near-surface dry soils. The extremely low value of Henry's law constant for DEP (9.8E-07 atm · m^3/mol at 25°C) implies that, when water is present, nearly all the DEP will be in the water or soil compartments (see Table 29-1).

29.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of diethyl phthalate in soil/ground-water systems is not well documented. In most cases, it should be assumed that DEP will persist for months to years (or more). DEP that has been released into the air, or that enters surface waters with significant sunlight exposure, is not expected to be degraded by direct photolysis. Resistance to photolytic degradation was demonstrated in the laboratory model ecosystem tests of Lewis et al. (703) which used fluorescent lighting. Resistance to direct photolysis would also be expected based upon DEP's ultraviolet absorption spectrum which shows no absorbance above 300 nm (657).

DEP under normal environmental conditions is not expected to undergo rapid hydrolysis. This general conclusion was reached by Lewis et al. (703) based upon their laboratory model ecosystem tests which used fresh water at 20°C, a DEP concentration of 191 μg/L, and a pH of 10. Loss of DEP from water as a result of chemical hydrolysis was barely measurable within the 12-hr retention period (in the model reactor), amounting to approximately 10 μg/L of the 191 μg/L concentration.

Wolfe et al. (705) measured the second-order, alkaline, hydrolysis rate constant (kOH) for several phthalates, including DEP, at 30°C. Phthalate concentrations were always less than E-05 M. The reported kOH value for DEP was (2.5+0.2)E-02/M/sec. A first-order hydrolysis rate constant (k) can be calculated from this, at any pH, from the following equation:

$$k(sec^{-1}) = 2.5E\text{-}02\ [OH]$$

where [OH] is the molar concentration of the OH^- ion. At pH = 7, [OH] = 1E-07 and k = 2.5E-09/sec. Under these conditions (e.g., 30°C, pH = 7) the hydrolysis half-life is 8.8 years. A 20°C drop in temperature (to a more typical ground-water

temperature of 10°C) would increase the hydrolysis half-life by about a factor of 5, i.e., to 44 years.

DEP has been shown to be fairly easily biodegradable in several studies. Rapid degradation was seen in laboratory aquatic ecosystem tests reported by Lewis et al. (703, 764); however, DEP was transformed in only two out of ten tests using field-collected microbiota (763). Rapid (primary) biodegradation has also been shown in activated sludge tests (55, 704, 763), in acclimated shake-flask CO_2 evolution tests (678), and in river die-away tests (763). A number of bacterial strains have been shown capable of having their growth supported by DEP cultures. In the activated sludge, shake-flask type of tests, 90-100% degradation was usually obtained within 1 to 28 days. First- and/or second-order biodegradation rate constants are given by several of these studies (678, 703, 704, 764). The applicability of these laboratory-derived rate constants to real environments would involve significant uncertainty. Additional information on the biodegradability of phthalic acid esters is given by Giam et al. (768).

There are no data available on the possibility of anaerobic biodegradation. In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as DEP is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in near-surface soils and in landfills with active microbiological populations.

29.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The above discussion of fate pathways suggests that diethyl phthalate has a very low volatility, is moderately adsorbed to soil and has a low potential for bioaccumulation. Therefore, the volatilization of this compound from surface soils is not likely to be a primary route of exposure. Its moderate adsorption to soil suggests that it may be somewhat mobile in ground water, particularly in sandy soils.

Mitre (83) reported that diethyl phthalate has been found at only one of the 546 National Priority List (NPL) sites in surface water. It was not detected in ground water at any of the sites. The fact that DEP has not been found at these sites may be attributed to its low production volume and its limited mobility in soil/ground-water systems. In addition, this compound is not as commonly analyzed for as are volatiles.

Even though this compound has a limited potential for movement in soil/ground-water systems, it may reach surface waters via ground water under certain conditions. Releases of this nature to surface water suggest several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;

- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures;
- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

Of these, the ingestion of surface water probably represents the most significant exposure pathway. DEP reaching surface water will not be readily volatilized or absorbed, and hence may be persistent in the water column relative to other compounds. The indirect ingestion pathways (aquatic organisms and domestic animals) are not likely to be important due to the low bioconcentration factor for DEP.

29.2.4 Other Sources of Exposure

There are little data regarding other sources of exposure to DEP. It was detected in six out of ten city water supplies tested at levels of 0.01 to 1 μg/L (691). In addition, it is used in the formulation of some products that consumers may come in contact with; dermal or inhalation exposures may result from these uses.

29.3 HUMAN HEALTH CONSIDERATIONS

29.3.1 Animal Studies

29.3.1.1 Carcinogenicity

There are no carcinogenicity data available for DEP; it is presently being tested by the National Toxicology Program.

29.3.1.2 Genotoxicity

Diethyl phthalate (DEP) has given negative results in almost all short-term tests in which it has been studied. It was negative in the Salmonella/microsome test (3070, 3861) with or without metabolic activation. There are two reports in which strains TA98 and/or TA100 are positive without metabolic activation but negative with activation (400, 3009, and one report that claims that strain TA100 is positive with or without activation for 8-azaguanine resistance (3633)). DEP was reported negative in the Bacillus subtilis rec assay (3612) and it did not induce chromosomal aberrations in Chinese hamster lung cells treated in culture (3330), nor did it induce chromosomal aberrations or chromatid gaps in human leukocytes treated in vitro for 8 hrs (3729).

29.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Diethyl phthalate has been observed to be non-teratogenic in mice in teratogenic and reproductive studies utilizing several routes of administration of the chemical. Lamb et al. (3387) exposed both male and female mice to 0.25%, 1.25%, or 2.5% of DEP in their diet for 7 days prior to and during a 98 day cohabitation period. No reduction was observed, at any dose level, on the number of litters produced, number of pups per litter, birth weights, or survival of pups. However, when the F_1 offspring of the 2.5% group were mated, litter size was reduced significantly (9.95 vs 11.53 in controls). CD-1 mice exposed by gavage to 4,500 mg/kg/day of DEP on gestational days 6-13 displayed no changes in number of viable litters, litter size, percentage survival, or birth weight. In this study by Hardin et al. (3271), a nonsignificant increase in maternal mortality but not in average maternal weight change was observed.

Tanaka et al. (3699) exposed mice percutaneously on gestational days 0-17 to 50, 1650, or 5600 mg/kg/day of DEP. No external, visceral, or skeletal anomalies in the fetuses were attributable to DEP exposure when they were examined on gestational day 18. However, fetal body weight was reduced and a higher incidence of cervical and lumbar ribs was observed at the high dose. Maternal toxicity was indicated by reduced thymus and spleen weight at all doses and at the high dose by increased adrenal weights. These studies indicate that in mice DEP is not teratogenic, but can be embryotoxic at doses resulting in maternal toxicity.

Skeletal abnormalities were observed in 30 to 50% of rat fetuses from dams injected intraperitoneally with 0.5-1.7 mL/kg DEP on days 5, 10 and 15 of gestation. Incomplete or missing skull bones were the most prominent skeletal abnormality. No fetal deaths were seen (401).

No changes were noted in the testicular tissue of young male rats given 1600 mg/kg/day by gavage for 4 days (402).

29.3.1.4 Other Toxicologic Effects

29.3.1.4.1 Short-term Toxicity

The acute toxicity for laboratory animals by most routes is relatively low (2).

A total of 650 mg/kg in a 3% acacia solution was administered intravenously to rabbits without significant effect. Each 50 mg/kg dose produced a transient decrease in blood pressure (292). Intradermal injection of 0.2 mL of a 100 mg/mL emulsion of DEP in 3% acacia into rabbits produced a marked inflammatory response (292). However, undiluted DEP applied to rabbits' eyes produced no obvious irritation (404).

29.3.1.4.2 Chronic Toxicity

The no-effect levels determined from long-term feeding studies of 6 or more weeks duration were 2.5 g/kg/day for the rat and 1.25/kg/day for the dog with no specific lesion attributable to DEP and no unusual incidence of tumors (2). In addition, mice showed no signs of toxicity during a six-week study consisting of daily intraperitoneal injections with 125 mg/kg DEP. Autopsy revealed some degree of peritonitis in all animals (292). Brown and coworkers (769) administered DEP to male and female rats in the diet at concentrations of 0.2, 1 or 5% for 16 weeks. These dietary concentrations correspond to approximately 150, 770 and 3160 mg/kg/day in males and 150, 750 and 3710 mg/kg/day in females. Several organs were enlarged at study termination but pathological changes were observed only in the liver (fatty degeneration) and kidney (occasional pyelonephritis and lymphocytic infiltration) and were not dose-related.

In a 2-year feeding study Food Research Laboratories, Inc. (3221) administered 0, 0.5, 2.5, or 5.0% DEP to groups (15/sex) of albino rats. Growth of animals in the 5% group was retarded throughout the study, with no depression of food intake. No other treatment-related effects were noted.

29.3.2 Human and Epidemiologic Studies

29.3.2.1 Short-term Toxicologic Effects

The lowest published toxic concentration for humans is 110 ppm (1000 mg/m^3) (47). No other short-term human inhalation or ingestion data are available.

Diethyl phthalate does not act as a primary irritant when applied to the skin nor has it induced allergic reactions in humans who have contact with it. Heated vapors may produce transient irritation of the nose and throat (399).

29.3.2.2 Chronic Toxicologic Effects

There is little information available on chronic human exposure. In one study, symptoms of hepatitis were observed in 3 individuals who underwent up to 33 hemodialysis treatments with PVC dialysis tubing. DEP was found to be present in the aqueous perfusates from the tubing at a level of 10-50 mg/L. The symptoms disappeared shortly after the tubing was changed (405).

29.3.3 Levels of Concern

An Oral Reference Dose of 800 μg/kg/day has been proposed by the USEPA (3744). The USEPA (355) has established an ambient water quality criterion of 350 mg/L for the protection of human health from the toxic properties of DEP ingested through water and contaminated aquatic organisms. The criterion is based on the

assumption that a 70-kg adult ingests two liters of drinking water and 6.5 g of contaminated fish daily.

The OSHA 8-hr TWA for DEP is 5 mg/m^3 (3539). The ACGIH (3005) has adopted a threshold limit value of 5 mg/m^3 (8-hr TWA) for DEP based on its essential nontoxicity.

29.3.4 Hazard Assessment

The acute toxicity of DEP by most routes of administration is very low and it seems to be devoid of major toxic effects with long-term exposure. The no-effect levels from subchronic feeding studies were 2.5 g/kg/day for the rat and 1.25 g/kg/day for the dog (2). Human data are few but suggest no adverse effects associated with DEP exposure. Short-term tests for genotoxicity have proved to be negative. Teratogenic effects were reported following intraperitoneal administration of DEP to rats. There are no data available regarding possible carcinogenic activity of DEP, but a study is presently being conducted by the National Toxicology Program.

Based on the inadequacy of available data on potential carcinogenic, mutagenic, short-term and chronic toxic effects associated with exposure to DEP, no reliable assessment of hazard can be established for humans exposed to DEP.

29.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of diethyl phthalate concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 40 days. In addition to the trapped targeted samples, quality control samples such as field blanks, duplicates and spiked matrices may be specified in the recommended methods. Since phthalate esters are commonly found in many materials in the laboratory, method blanks must also be analyzed to demonstrate that the sample or extract has not been contaminated.

EPA-approved procedures for the analysis of diethyl phthalate, one of the EPA priority pollutants, in aqueous samples include EPA Methods 606, 625 and 1625 (65), 8060 and 8250 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; diethyl phthalate is then detected with a flame ionization detector (Method 8060), a mass spectrometer (Methods 625, 1625, and 8250) or an electron capture detector (Method 606 and 8060).

The EPA procedures recommended for diethyl phthalate analysis in soil and waste samples, Methods 8060 and 8250 (63), differ from the aqueous procedures

either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical diethyl phthalate detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.49 μg/L (Method 606)	1 μg/g (Method 8060)
1.9 μg/L (Method 625)	1 μg/g (Method 8250)
10 μg/L (Method 1625)	21 μg/g (Method 8060/FID)
0.31 μg/mL (Method 8060/FID)	0.3 μg/g (Method 8060/ECD)
4.9 μg/L (Method 8060/ECD)	1.3 μg/g (Method 8250)
19 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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3774. U.S. Environmental Protection Agency 1987. Identification and listing of hazardous wastes: hazardous wastes from specific sources. Fed. Regist. 52:28698. 40 CFR261.32.

3775. U.S. Environmental Protection Agency 1987. List of hazardous constituents for ground-water monitoring. Fed. Regist. 52:25942. 40 CFR264 and 270 Appendix IX.

3777. U.S. Environmental Protection Agency 1987. Organic chemicals, plastics, and synthetic fibers category: Effluent limitations guidelines, pretreatment standards, and new source performance standards. Fed. Regist. 52:42522. 40 CFR414.

3781. U.S. Environmental Protection Agency 1988. Notice of substituted contaminants and first drinking water priority list. Fed. Regist. 53:1892-1902. 40 CFR141 (SARA Section 110).

3783. U.S. Environmental Protection Agency 1988. Identification and listing of hazardous wastes: Hazardous constituents. Fed. Regist. 53:13388. 40 CFR261 Appendix VIII.

3784. U.S. Environmental Protection Agency 1988. Identification and listing of hazardous wastes: discarded commercial chemical products and their hazardous waste numbers. Fed. Regist. 53:13384. 40 CFR261.33.

3785. U.S. Environmental Protection Agency 1988. Standards for the management of specific hazardous wastes and management facilities: Land disposal restrictions. Fed. Regist. 53:31138. 40 CFR268.

3786. U.S. Environmental Protection Agency 1988. Land disposal restrictions for first third scheduled wastes: Waste specific prohibitions-California list wastes. Fed. Regist. 53:31138-31222. 40 CFR268.32.

3787. U.S. Environmental Protection Agency 1988. Toxic chemical release reporting: Community right-to-know. Fed. Regist. 53:4500 and revised 1988, 53:23108. 40 CFR372 (SARA Title III Section 313).

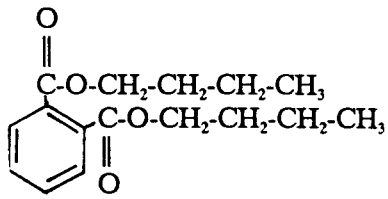
3789. U.S. Environmental Protection Agency 1988. 40 CFR716. Health and safety data reporting. Fed. Regist. 53:38642.

3795. U.S. Environmental Protection Agency 1989. Land disposal restrictions for second third scheduled wastes. Proposed rule. Fed. Regist. 54:1056. 40 CFR268.

3802. U.S. Environmental Protection Agency 1982. Steam and electric power generating point source category: Pretreatment standards for new sources (PSNS), Table - 126 Priority Pollutants. 40 CFR423.17 Appendix A.

3842. Wisconsin Water Quality Criteria 1989. Wisconsin Chapter NR105, Surface Water Quality Criteria for Toxic Substances, 2/89. Wisconsin, Chapter NR105

3861. Zeiger, E.; Haworth, S.; Mortelmans, K.; Speck, W. 1985. Mutagenicity testing of di(2-ethylhexyl)phthalate and related chemicals in Salmonella. Environ. Mutagen. 7:213-232.

COMMON SYNONYMS:	CAS REG.NO.: FORMULA:	AIR W/V CONVERSION FACTOR at 25°C (12)
1,2-Benzenedicarboxylic acid, dibutyl ester Butyl phthalate DBP Di-n-butyl phthalate Dibutyl 1,2-benzenedicarboxylate Phthalic acid, dibutyl ester	84-74-2 $C_{16}H_{22}O_4$ NIOSH NO: TI0875000 STRUCTURE: 	11.36 mg/m³ ≈ 1 ppm; 0.088 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 278.35

REACTIVITY	Reactions of esters such as di-n-butyl phthalate with strong acids, strong alkalies, strong oxidizers, strong reducing agents, or explosive materials typically result in the generation of heat and occasional fires and/or explosions (38,511, 505). Reactions with hydrazines, alkali or alkaline earth metals, or nitrides generally produce heat and flammable or otherwise potentially hazardous gases (511).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Odorless	(23)
	• Odor Threshold: Not pertinent	
	• Density: 1.0480 g/mL (at 20°C)	(23)
	• Freeze/Melt Point: -35.00°C	(23)
	• Boiling Point: 340.00°C	(14)
	• Flash Point: 157.20°C closed cup	(12)
	• Flammable Limits: 0.50 to 2.50% by volume; (calc)	(60,504)
	• Autoignition Temp.: 403.0°C	(51,60,504)
	• Vapor Pressure: 1.60E-04 mm Hg (at 25°C)	(33)
	• Satd. Conc. in Air: 2.5000E+00 mg/m³ (at 20°C)	(1219)
	• Solubility in Water: 4.50E+03 mg/L (at 20°C)	(38)
	• Viscosity: 20.300 cp (at 20°C)	(23)

PHYSICO-CHEMICAL DATA (Cont.)	• Surface Tension: 3.4000E+01 dyne/cm (at 20°C) (59) • Log (Octanol-Water Partition Coeff.): 4.57 (29) • Soil Adsorp. Coeff.: 1.79E+04 (652) • Henry's Law Const.: 4.50E-06 atm · m^3/mol (at 25°C) (1219) • Bioconc. Factor: 8.90E+01 (estim), 1.80E+03 (estim) (399,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Somewhat mobile in wet or saturated soils as chemical is easily transported in solution at low concentrations. Fairly immobile in dry soils; vapor-phase transport through air-filled pores of soil is probably not significant. Chemical is resistant to hydrolysis and direct photolysis, but is fairly easily biodegraded.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of di-n-butyl phthalate to groundwater drinking water supplies, although this compound is strongly sorbed to soil and such migration has not been observed in the past. Inhalation resulting from volatilization from surface soils is not expected to be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (38) Ingestion of di-n-butyl phthalate may cause nausea, dizziness, light sensitivity and watering and redness of the eyes. Heated vapors may irritate the eyes, nose and throat. Acute Toxicity Studies: (3504) INHALATION: LC_{50} 7.9 mg/m^3 Rat ORAL: LD_{50} 8000 mg/kg Rat SKIN: LD_{50} >20,900 mg/kg Rabbit

HEALTH HAZARD DATA	Long-Term Effects: Database too incomplete for assessment Pregnancy/Neonate Data: Teratogen/testicular atrophy Genotoxicity Data: Limited evidence is negative Carcinogenicity Classification: IARC - No data NTP - Study in progress EPA - Group D (not classifiable as to human carcinogenicity)

HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation • Vapor concentrations of 5-250 mg/m^3: any supplied-air respirator or selfcontained breathing apparatus with full facepiece • 250-9300 mg/m^3: a type C supplied-air respirator with a full facepiece operated in positive-pressure mode • Chemical goggles if there is probability of eye contact with liquid • There may also be a need for skin protection.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 5 mg/m^3
- AFOSH PEL (8-hr TWA): 5 mg/m^3; STEL (15-min): 15 mg/m^3

Criteria
- NIOSH IDLH (30-min): 9300 mg/m^3
- ACGIH TLV® (8-hr TWA): 5 mg/m^3

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (3742)
MCLG: 0 (tentative)

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (3770)
  - Based on ingestion of contaminated water and aquatic organisms, 34 mg/L.
  - Based on ingestion of contaminated aquatic organisms only, 154 mg/L.
  - Based on ingestion of contaminated water only, 44 mg/L.

- Aquatic Life (3770)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 940 µg/L phthalate esters.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 3 µg/L phthalate esters.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 2944 µg/L phthalate esters.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES: (3744)
ORAL: 1.000E+02 µg/kg/day

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Di-n-butyl phthalate is designated a hazardous substance. It has a reportable quantity (RQ) limit of 4.54 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), metal finishing (3768), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Phthalates are on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 (3781). In states with an approved Underground Injection Control program, a permit is required for the injection of di-n-butyl phthalate-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Di-n-butyl phthalate is identified as a toxic hazardous waste (U069) and listed as a hazardous waste constituent (3783, 3784). Wastestreams from the production of phthallic anhydride from naphthalene, and the petroleum refining industry are listed as specific sources of phthallic acid-containing hazardous waste (3774, 3765). Di-n-butyl phthalate is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective November 8, 1988, the land disposal of certain untreated di-n-butyl phthalate-containing untreated hazardous wastes is prohibited. These wastes must be treated according to Best Demonstrated Available Technology (BDAT) treatment standards before being disposed. Certain variances exist until May, 1990 for other wastes for which BDAT treatment standards have not been promulgated by EPA (3786). Di-n-butyl phthalate is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of di-n-butyl phthalate must report production, usage and disposal information to EPA. They, as well as others who possess health and safety studies on di-n-butyl phthalate, must submit them to EPA (334,3789). Under TSCA Section 4, EPA is requiring certain selected manufacturers and processors of di-n-butyl phthalate to perform environmental effects and chemical fate tests on their products (3201).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
Di-n-butyl phthalate is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 4.54 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing di-n-butyl phthalate, but these depend upon the concentrations of the chemical in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of di-n-butyl phthalate must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to di-n-butyl phthalate in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 5 mg/m^3 (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated di-n-butyl phthalate as a hazardous material with a reportable quantity of 4.54 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Di-n-butyl phthalate is approved for use as an indirect food additive as a component of adhesives (3209).

- State Water Programs

  ALL STATES

  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

  KANSAS

  Kansas has an action level of 770 μg/L for ground-water (3213).

  NEW YORK

  New York has an MCL of 50 μg/L for di-n-butyl phthalate in drinking water, a water quality standard of 770 μg/L for ground-water, and a nonenforceable ambient water quality guideline of 50 μg/L for surface water (3501).

  SOUTH DAKOTA

  South Dakota requires phthalates to be nondetectable, using designated test methods, in ground-water (3671).

  WISCONSIN

  Wisconsin has set a human threshold criterion of 13 mg/L for public water supply cold surface waters and 23 mg/L for warm sport fishing surface waters (3842).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)

  EPA will propose MCLs, MCLGs, and monitoring requirements for phthalates in March, 1990, with final promulgation scheduled for March, 1991 (3751).

- State Water Programs

  ALL STATES

  No proposed regulations are pending.

  MOST STATES

  Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with the state officers is advised. Changes are projected for 1989-90 (3683).

EEC Directives

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on Toxic and Dangerous Wastes (542)

Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

EEC Directives - Proposed

Resolution on a Revised List of Second-Category Pollutants (545)

Di-n-butyl phthalate is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

30.1 MAJOR USES

Di-n-butyl phthalate (DBP) is primarily used as a plasticizer for epoxy resins and polyvinyl chloride (PVC). Its use in PVC applications is limited, however, due to its high volatility at typical processing temperatures. It has been used in plastisol formulations for carpet-back coating and other specialized vinyl compounds. Other applications of DBP include use as an adjusting agent for lead chromate pigments; use as a concrete additive; use in polyvinyl acetate emulsions, use as an insect repellent (403), and use in cosmetics (3032).

30.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

30.2.1 Transport in Soil/Ground-water Systems

30.2.1.1 Overview

Di-n-butyl phthalate may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways can be assessed with the use of an equilibrium partitioning model as shown in Table 30-1. These calculations predict the partitioning of low soil concentrations of DBP among soil particles, soil water and soil air. The portions of DBP associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that essentially all of the chemical (99.97%) would be sorbed on the soil; a relatively small amount (0.03%) of the chemical will be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the very small portion of DBP in the gaseous phase of the soil (2E-05 %), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, is possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a higher fraction of the DBP (1.3%) is likely to be present in the soil-water phase (Table 30-1) and transported with flowing ground water. Ground water underlying DBP-contaminated soils with low organic content is thus vulnerable to contamination by the chemical.

Additional information on DBP is available in the thorough review by Giam et al. (768).

TABLE 30-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR DI-N-BUTYL PHTHALATE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	99.97	0.03	0.00002
Saturated deep soil[d]	98.7	1.3	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 17,900 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 4.5E-06 atm · m^3/mol at 25°C (Estimated by Arthur D. Little, Inc.)
d) Used sorption coefficient calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

30.2.1.2 Sorption on Soils

The mobility of DBP in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content (except that complexation with humic or fulvic acids may decrease the extent of sorption);
- increase slightly with decreasing temperatures;
- increase moderately with increasing salinity of the soil water (701); and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 37,200, the soil sorption coefficient (K_{oc}) is estimated to be 17,900. This is a relatively high number indicative of strong sorption to soils. Sullivan et al. (701) studied the sorption of DBP from seawater onto montmorillonite and sediments from the Gulf of Mexico. Sorption constants [K, (ng DBP sorbed/mg sorbent) - (ng DBP in solution/mL water)] for the

adsorption process ranged from K=0.004 to 0.044 for the mineral sorbents and was 0.149 for the sediment. Some hysteresis was apparent in the desorption process.

According to reports by Autian (765), Ogner and Schnitzer (766) and Matsuda and Schnitzer (767), phthalate esters readily complex with natural organic substances (e.g., fulvic acid) to form complexes which are very soluble in water. Thus, sorption to soils may be significantly weaker than might be expected based upon the information given above.

30.2.1.3 Volatilization from Soils

Transport of DBP vapors through the air-filled pores of unsaturated soils is not expected to be an important transport mechanism except for near-surface dry soils. The very low value of Henry's law constant for DBP (4.5E-06 atm · m^3/mol at 25°C) implies that, when water is present, nearly all the DBP will be in the water or soil compartments (see Table 30-1).

30.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of DBP in soil/ground-water systems is not well documented. In most cases, it should be assumed that DBP will persist for months to years (or more). DBP that has been released into the air, or that enters surface waters with significant sunlight exposure, is not expected to be degraded by direct photolysis. Resistance to direct photolysis would be expected based upon DBP's ultraviolet absorption spectrum which shows no absorbance above 300 nm (657).

DBP under normal environmental conditions is not expected to undergo rapid hydrolysis. Wolfe et al. (705) measured the second-order, alkaline, hydrolysis rate constant (k_{OH}) for several phthalates, including DBP, at 30°C. Phthalate concentrations were always less than E-05 M. The reported k_{OH} value for DBP was 1.0 (+ 0.05)E-02/M/sec. A first-order hydrolysis rate constant (k) can be calculated from this at any pH, from the following equation:

$$k(sec^{-1}) = 1E\text{-}02\ [OH]$$

where [OH] is the molar concentration of the OH^- ion. At pH = 7, [OH] = E-07 and k = E-09/sec. Under these conditions (i.e., 30°C, pH 7) the hydrolysis half-life is 22 years. A 20°C drop in temperature (to a more typical ground-water temperature of 10°C) would increase the hydrolysis half-life by about a factor of 5, i.e., to 110 years.

DBP has been shown to be fairly easily biodegradable in several studies. Many of these studies are summarized in the reviews given by Overcash et al. (524). The data show that there are a number of microorganisms capable of using DBP as the sole source of carbon, and that ultimate degradation is possible. The studies also document significant degradation in tests with DBP added to soils at fairly high concentrations (up to 1% by weight). More recent tests have also documented the

extent of DBP biodegradability. Shake-flask, activated-sludge type tests by Sugatt et al. (678), O'Grady et al. (763) and Tabak et al. (55) have shown that DBP would be easily degraded in active mixed cultures (and thus in sewage treatment plants). Tabak et al. (55) characterized DBP as undergoing "significant degradation [with] rapid adaptation."

Tests simulating more natural environments have been conducted by Walker et al. (674) and Inman et al. (706). The studies by Walker et al. (674) showed DBP disappearance was rapid in microbiologically active systems using water and sediment samples from six Gulf Coast sites. Lag times before adaptation were quite variable and site specific. The researchers also noticed some degree of sediment-enhanced abiotic degradation of DBP which may, they speculate, be related to the presence of active microbial enzymes that remain after the formalin-sterilization process used on the sediment samples. The tests by Inman et al. (706) investigated the effects of soil pH, temperature and other soil properties on the degradation of DBP in soils. They concluded that DBP should not persist in the majority of soils (studied) for more than 100 days.

The effects of temperature and other variables on DBP biodegradation in sediments has also been reported by Thomas et al. (416); in general, they found the chemical to be readily degraded (e.g., nearly 85% in 14 days at 22°C).

Wolfe et al. (705) report a second-order microbial degradation rate constant for DBP of about 4E-11 L/org/hr based on tests with natural water samples.

Anaerobic biodegradation of DBP appears possible based upon anaerobic metabolic studies conducted with Pseudomonas pseudocaligenes (768) and by the finding of significant DBP degradation in submerged (presumably anaerobic) soils by Inman et al. (706).

In most soil/ground-water systems, however, the concentration of microorganisms capable of biodegrading chemicals such as DBP may be low and would drop off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in near-surface soils and in landfills with active microbiological populations.

30.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The above discussion of fate pathways suggests that di-n-butyl phthalate has a very low volatility, is strongly adsorbed to soil and has a high potential for bioaccumulation. Therefore, the volatilization of this compound from surface soil is not likely to result in a primary route of exposure. In addition, its strong adsorption to soil suggests that it will not be particularly mobile in ground water. As partial evidence of this lack of mobility, it was not detected in ground water, surface water or air associated with the 546 National Priority Test (NPL) sites (83).

The strong adsorption of this compound to soil suggests that it may reach surface waters via runoff in some situations. The presence of this compound in surface waters suggests several other exposure pathways:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposures;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposures;
- Recreational use of these waters may result in dermal exposures;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

Of these, the indirect pathways (particularly aquatic organisms) are likely to be the most significant exposure pathways. DBP reaching surface waters is likely to be found in the sediment, rather than the water column. Therefore, direct ingestion of surface water may not result in as significant a source of exposure as ingestion of aquatic organisms, given the high BCF of this compound.

30.2.4 Other Sources of Exposure

There are little data regarding other sources of exposure to DBP. It was detected in 6 water supplies out of ten cities tested at levels of 0.01 to 5.0 μg/L. In addition, it is used in the formulation of some products that contact the consumer, and dermal or inhalation exposures may result from these uses.

30.3 HUMAN HEALTH CONSIDERATIONS

30.3.1 Animal Studies

30.3.1.1 Carcinogenicity

No carcinogenicity data are available for DBP.

30.3.1.2 Genotoxicity

Dibutyl phthalate has produced negative results in all Salmonella studies in which it has been tested. If it was positive without metabolic activation, it was rendered negative in the presence of an exogenous activation system (400, 407, 3861, 3009, 3508, 3642). Negative results were also observed in a yeast assay in which 3 different loci were not induced to revert (3636). A slight increase in chromosomal aberrations was noted in Chinese hamster cells exposed in culture to 0.03 mg/mL DBP for 24 hours (406), but the authors called this result "suspicious" (3330). Human leukocytes treated with 0.03 μg/mL for 8 hrs in culture showed no increase in chromosomal aberrations above controls.

There are conflicting reports on the effects of DBP and sister chromatid exchanges in Chinese hamster cells in culture. One report (3004) claims positive results with no dose response and the other (3351) claims negative results.

30.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

DBP causes increased embryo mortality, decreased birth weight, and teratogenic effects in rats and mice. In groups of pregnant Sprague-Dawley rats that were injected intraperitoneally with 0.305, 0.610 or 1.017 mL/kg on days 5, 10 and 15 of gestation, fetal weights were significantly reduced in all treatment groups. The number of resorptions was increased at all dosage levels but was particularly significant at the 1.017 mL/kg level. Skeletal abnormalities were observed in 30 to 50% of the fetuses and were dose-related. Elongated or fused ribs and incomplete or missing skull bones were the most prominent skeletal abnormalities (401). Holtzman rats were gavaged on days 1-8 of pregnancy with 500, 1000, or 2000 mg/kg/day of DBP in a study designed to investigate the effect of DBP on implantation and to differentiate between maternal toxicity and embryotoxicity (3146). On gestational day 9, no effects on the number of implantation sites or on pregnant uterine weights were observed.

When ICR mice were fed a diet containing 1% DBP (equivalent to 2100 mg/kg/day) throughout gestation, maternal weight gain was significantly suppressed (due to the increase in early resorptions) and 98.4% of the fetuses were either resorbed or were dead (3648). Of the three fetuses which survived to term, two were malformed showing exencephaly. Groups of mice in this study were also administered 0.05, 0.1, 0.2, and 0.4% DBP (equivalent to 80, 180, 370, and 660 mg/kg/day) without the occurrence of statistically significant effects. An increased incidence of extra lumbar ribs was observed at these doses. Hamano et al. (3262) found that a level of 0.5% in the diet during gestation resulted in teratogenic effects in JCL:ICR mice, predominantly spina bifida, encephalocoele, and open eye. The number of live offspring was also reduced (9.6/mouse) compared to controls (around 12/mouse). When Hardin et al. (3271) exposed CD-1 mice to 2,500 mg/kg/day of DBP by gavage on days 6-13 of gestation no viable litters were produced. Maternal mortality was 10% at this exposure level. Lamb et al. (3387) exposed both male and female mice to 0.03%, 0.3%, or 1.0% of DBP in their diet for 7 days prior to and during a 98 day cohabitation period. The high dose resulted in a reduction in the number of litters, live pups per litter, and the live pup weights. These fetotoxic effects were not observed at the lower dose levels. A crossover mating trial demonstrated that female mice, but not males, were affected by the 1% DBP diet. Oral administration of 2000 mg/kg/day of DBP in corn oil to young male rats for 4 days resulted in testicular injury and a 30-40% decrease in the weight of the testes. Urinary zinc excretion increased while testicular zinc levels were significantly decreased. The weights of the liver and kidneys were not affected (411).

Marked species differences in sensitivity to testicular toxicity of DBP was noted by Gray et al. (431). Oral administration of 2000 mg/kg bw DBP for 9 days to rats, mice and hamsters and for 7 days to guinea pigs produced uniformly severe

seminiferous tubular atrophy in rats and guinea pigs, only focal atrophy in mice and no testicular changes in hamsters (431).

30.3.1.4 Other Toxicologic Effects

30.3.1.4.1 Short-term Toxicity

Increased mortality and significant enlargement of the liver and spleen were reported in rats fed 1 or 5 mL/kg/day for 3 weeks (410). Murakami et al. (3475) administered DBP in the diets of male Wistar rats (five/group) at a level of 0.5 or 5% (~250 and 2500 mg/kg) for 34 to 36 days. A dose response was noted for the following: growth depression, liver enlargement, testicular atrophy, decreased activities of succinate and pyruvate dehydrogenases in liver mitochondria, and abnormal changes in biochemical tests of serum and in histological examinations of the liver and testicles. In a study in which ddY male and female mice (unspecified numbers) were fed diets containing 0.25 or 2.5% DBP (~325 and 3250 mg/kg) for 2 weeks, centrilobular necrosis and degeneration with distention of the capsule and proliferation of the bile ducts was seen in the liver (3543, 3542). The kidneys of high dose animals were increased in weight and had cysts which were present throughout the organ leading to atrophy of the tubules.

A single intradermal injection of 0.2 mL of a 100 mg/mL emulsion of DBP in 3% acacia produced a moderate inflammatory response in rabbits (292); injection of 0.2 mL undiluted DBP produced no inflammation. Installation of 0.1 mL into the rabbit eye did not produce any observable degree of irritation (404).

For further information the reader is referred to a comprehensive review of the toxicity of phthalate esters (3849).

30.3.1.4.2 Chronic Toxicity

No adverse effects were reported in rats administered 260 or 520 mg/kg DBP intravenously twice weekly for 52 weeks (412). Similarly, rats maintained for 3 generations on diets containing 300 or 500 mg/kg/day or for 5 generations on diets containing 100 mg/kg/day experienced no adverse effects (414). Smith (3663) found no effects in rats fed diets containing up to 0.25% DBP for 1 year, but when the dose was increased to 1.25%, 50% of the animals died during the first week of the study. Liver and kidney lesions were observed in mice receiving oral doses of 0.5 and 5.0 g/kg/day for 1 to 3 months (413).

30.3.2 Human and Epidemiologic Studies

30.3.2.1 Short-term Toxicologic Effects

Only 1 case of human exposure is reported in the literature. It involved the accidental ingestion of 10 g DBP (~140 mg/kg). Symptoms, delayed by several hours, included nausea, vomiting and dizziness, followed later by headache, pain and

irritation in the eyes, lacrimation, photophobia and conjunctivitis. There was also some renal involvement. Recovery was complete within 2 weeks. It was concluded that the symptoms most likely resulted from the hydrolysis products of DBP (415).

Skepticism, however, has been expressed whether one could actually drink DBP by mistake without immediate revulsion, because its taste is so strong and bitter (19).

Eye contact has caused immediate, severe, stinging pain but no appreciable damage (19). Heated vapors may be irritating to the eyes, nose and throat. It is relatively non-irritating to the skin (38).

30.3.2.2 Chronic Toxicologic Effects

No data are available regarding the effects of long-term exposure to DBP.

30.3.3 Levels of Concern

An Oral Reference Dose of 100 μg/kg/day has been proposed for DBP by the USEPA (3744). The ambient water quality criterion established for DBP by the USEPA for the maximum protection of human health is 34 mg/L (3770), and is based on the assumption that a 70-kg adult ingests two liters of drinking water and 6.5 g of contaminated fish daily.

Both OSHA (3539) and the ACGIH (3005) have set a TWA exposure limit of 5 mg/m^3 averaged over an 8-hour work-shift.

30.3.4 Hazard Assessment

DBP has a low order of acute toxicity in experimental animals. Human ingestion of 10 g of DBP was reported to have produced nausea, dizziness, lacrimation, light sensitivity and conjunctivitis; recovery was prompt and uneventful. No long-term human exposure data are available for DBP; however, it has been extensively used as an insect repellant with no apparent adverse effects. Rats were maintained for five generations on diets containing 100 mg/kg/day of DBP without effect.

No data are available on the carcinogenic effects of DBP although a study is in progress by the National Toxicology Program. Mutagenicity studies, although limited, are predominantly negative. Intraperitoneal injection of DBP induced increased embryo mortality, decreased birth weight and terata in rats. Dietary administration to mice resulted in fetotoxicity and teratogenicity. Oral intubation of 2 g DBP/kg/day for 7 to 10 days produced testicular atrophy of varying intensity in rats, mice and guinea pigs but not in hamsters. Additional data is required to determine the implications of these findings to humans in view of the marked species differences and the high dose levels administered.

30.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of di-n-butyl phthalate concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods. Since phthalate esters are commonly found in many materials in the laboratory, method blanks must also be analyzed to demonstrate that the sample or extract has not been contaminated.

EPA-approved procedures for the analysis of di-n-butyl phthalate, one of the EPA priority pollutants, in aqueous samples include EPA Methods 606, 625, 1625 (65), 8060 and 8250 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract (after solvent exchanging the methylene chloride for hexane in method 606 and 8060/ECD) is injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; di-n-butyl phthalate is then detected with a flame ionization detector (Method 8060), a mass spectrometer (Methods 625 1625, and 8250), or an electron capture detector (Method 606 and 8060).

The EPA procedures recommended for di-n-butyl phthalate analysis in soil and waste samples, Methods 8060 and 8250 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical di-n-butyl phthalate detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.36 μg/L (Method 606)	1 μg/g (Method 8060)
2.5 μg/L (Method 625)	1 μg/g (Method 8250)
10 μg/L (Method 1625)	9.4 μg/g (Method 8060/FID)
0.14 μg/mL (Method 8060/FID)	0.24 μg/g (Method 8060/ECD)
3.6 μg/L (Method 8060/ECD)	1.7 μg/g (Method 8250)
25 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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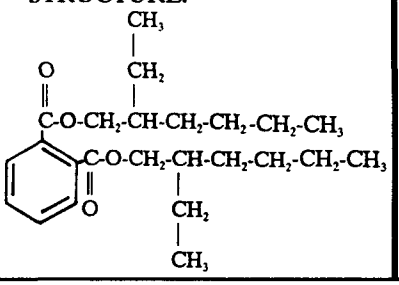
COMMON SYNONYMS:	CAS REG NO: 117-81-7 FORMULA: $C_{24}H_{38}O_4$ NIOSH NO: TI10350000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C (12) 15.94 mg/m^3 ≈ 1 ppm; 0.0627 ppm ≈ 1 mg/m^3 MOLECULAR WEIGHT: 390.54
1,2-Benzenedicarbonxylic acid, bis(2-ethylhexyl) ester 2-Ethylhexylphthalate DEHP Di(2-ethylhexyl) phthalate Di-sec-octylphthalate Phthalic acid, dioctyl ester		

REACTIVITY	Reactions of esters such as di(2-ethylhexyl)phthalate with strong alkalies, strong oxidizers, or explosive materials typically result in the generation of heat and occasional fires and/or explosions (38, 511, 505). Reactions with hydrazines, alkali or alkaline earth metals or nitrides generally produce heat and flammable or otherwise potentially hazardous gases (511).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Light-colored	(23)
	• Odor: Odorless	(23)
	• Odor Threshold: Not pertinent	
	• Density: 0.9861 g/mL (at 20°C)	(23)
	• Freeze/Melt Point: -50.00°C	(59)
	• Boiling Point: 230.00°C at 5 mm Hg	(12)
	• Flash Point: 215.00°C open cup	(59)
	• Flammable Limits: 0.30 % by volume	(504)
	• Autoignition Temp.: 390.0°C	(504)
	• Vapor Pressure: 2.00E-07 mm Hg (at 20°C)	(33)
	• Satd. Conc. in Air: 4.0000E-03 mg/m^3 (at 20°C)	(1219)

PHYSICO-CHEMICAL DATA (Cont.)	• Solubility in Water: 4.00E-01 mg/L (at 25°C) (658) • Viscosity: 81.400 cp (at 20°C) (59) • Surface Tension: 1.5000E+01 dyne/cm, estimation (at 20°C) (59) • Log (Octanol-Water Partition Coeff.): 3.98; 5.11 (29,653) • Soil Adsorp. Coeff.: 6.20E+04 (652) • Henry's Law Const.: 2.50E-07 $atm \cdot m^3/mol$ (at 20°C) (1219) • Bioconc. Factor: 3.30E+02 (fathead minnow), 6.20E+03 (estim) (399,659)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively immobile due to strong soil sorption, low water solubility and low vapor pressure. Chemical is resistant to hydrolysis and direct photolysis, but is subject to (slow) biodegradation under favorable conditions.

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of DEHP to groundwater drinking water supplies. This is not expected to be prevalent due to the adsorptive nature of DEHP. The high potential for DEHP to bioaccumulate suggests that pathways involving the contamination of aquatic organisms or domestic animals could also be of prime importance.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (54) DEHP will cause irritation of the eyes, nose, throat. Inhalation or ingestion will cause gastrointestinal effects.

HEALTH HAZARD DATA (Cont.)	Acute Toxicity Studies: INHALATION: LC_{50} 30000 mg/m^3 Unspecified Mammal (51) ORAL: LD_{50} 31000 mg/kg Rat (47) SKIN: LD_{50} 25000 mg/kg Rabbit (47) Long-Term Effects: Liver toxicity Pregnancy/Neonate Data: Teratogen; testicular damage Genotoxicity Data: Negative Carcinogenicity Classification: IARC - Group 2B (possibly carcinogenic to humans) NTP - Positive evidence EPA - Group B2 (probable human carcinogen; sufficient evidence in animals and inadequate evidence in humans)

HANDLING PRECAUTIONS (54,59)	Handle chemical only with adequate ventilation • Vapor concentrations of 50 mg/m^3: supplied-air respirator or self-contained breathing apparatus • 50-250 mg/m^3: supplied-air respirator or self-contained breathing apparatus with full facepiece • Chemical goggles if there is probability of eye contact • There may also be need for skin protection.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 5 mg/m^3; STEL (15 min): 10 mg/m^3
- AFOSH PEL (8-hr TWA): 5 mg/m^3; STEL (15-min): 10 mg/m^3

Criteria
- NIOSH IDLH (30-min): NIOSH has recommended that the substance be treated as a potential human carcinogen.
- NIOSH REL: Reduce exposure to lowest feasible limit
- ACGIH TLV® (8-hr TWA): 5 mg/m^3
- ACGIH STEL (15-min): 10 mg/m^3

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS: (3742)

Drinking Water Standards
MCLG: 0 (tenative)

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (3770)
  - Based on ingestion of contaminated water and aquatic organisms, 15 mg/L.
  - Based on ingestion of contaminated aquatic organisms only, 50 mg/L.
  - Based on ingestion of drinking water only, 21 mg/L.

- Aquatic Life (3770)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 940 µg/L phthalates.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 3 µg/L phthalates.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 2944 µg/L phthalates.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:
ORAL: 2.000E+01 µg/kg/day (3742)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Di(2-ethylhexyl)phthalate is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and to effluent standards and guidelines (351, 3763). Effluent limitations have been set for this chemical in the following point source categories: electroplating (3767), organic chemicals, plastics and synthetic fibers (3777), metal finishing (3768), metal molding and casting (892), and steam electric power generating (3802). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Phthalates are on the list of 83 contaminants required to be regulated under the SDWA of 1974 as amended in 1986 (3781). In states with an approved Underground Injection Control program, a permit is required for the injection of di(2-ethylhexyl)- phthalate-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Di(2-ethylhexyl)phthalate is identified as a toxic hazardous waste (U028) and listed as a hazardous waste constituent (3783, 3784). Specific sources of di(2-ethylhexyl)- phthalate-containing toxic hazardous waste are wastestreams from the petroleum refining and ink formulation industries (3774, 3765). Di(2-ethylhexyl)phthalate is included on EPA's groundwater monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their groundwater for chemicals on this list when suspected contamination is first detected and annually thereafter (3775). Di(2-ethylhexyl)phthalate is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective August 8, 1988, untreated di(2-ethylhexyl)phthalate-containing wastestreams from the ink formulation industry are prohibited from land disposal. Effective August 8, 1990, untreated di(2-ethyl- hexyl)phthalate-containing wastestreams from the petroleum refining industry are prohibited from land disposal. Between November 8, 1988 and August 8, 1990, these wastes may be disposed of in a landfill or surface impoundment only if such unit is in compliance with the requirements specified in 40CFR268.5(h)(2) (3785).

Toxic Substances Control Act (TSCA)
Manufacturers, processors or distributors of di(2-ethylhexyl)phthalate must report production usage, disposal, and exposure-related information to EPA (334). They, as well as others who possess health and safety studies on di(2-ethylhexyl)phthalate, must submit them to EPA (3789). Under TSCA Section 4, EPA is requiring certain selected manufacturers and processors of di(2-ethylhexyl)phthalate to perform environmental effects and chemical fate tests on their products (3201).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
Di(2-ethylhexyl)phthalate is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 0.454 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing di(2-ehtylhexyl)phthalate, but these depend upon the concentrations of the chemical in the waste stream (3766). Under SARA Title III, manufacturers, processors, importers, and users of di(2-ethylhexyl)phthalate must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Occupational Safety and Health Act (OSHA)
Employee exposure to di(2-ethylhexyl)phthalate in any 8-hour work shift of a 40-hour work week shall not exceed an 8-hour time-weighted average (TWA) of 5 mg/m^3. An employee's 15-minute short term exposure limit (STEL) of 10 mg/m^3 shall not be exceeded at any time during a work-day (3539).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated di(2-ethylhexyl)phthalate as a hazardous material with a reportable quantity of 0.454 kg, subject to requirements for packaging, labeling, and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Di(2-ethylhexyl)phthalate is approved for use as an indirect food additive as a component of adhesives (3209).

- State Water Programs

  ALL STATES

  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

  KANSAS

  Kansas has an action level of 4200 μg/L for groundwater (3213).

  NEW YORK

  New York has set an MCL of 50 μg/L for drinking water, a water quality standard of 4200 μg/L for public water supply groundwaters, and an ambient water quality standard of 0.6 μg/L for fresh surface waters for protection of fishing and fish propagation. New York also has a nonenforceable ambient water quality guideline for human health of 4 μg/L for surface waters (3501, 3500).

  RHODE ISLAND

  Rhode Island has an acute freshwater quality guideline of 555 μg/L and a chronic guideline of 12 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

  SOUTH DAKOTA

  South Dakota requires phthalates to be nondetectable, using designated test methods, in groundwater (3671).

  WISCONSIN

  Wisconsin has set a human threshold criterion of 5.8 mg/L for public water supply cold surface waters (3842).

Proposed Regulations

- Federal Programs

  Safe Drinking Water Act (SDWA)

  EPA will propose MCLs, MCLGs, and monitoring requirements for phthalates in March, 1990 with final promulgation scheduled for March, 1991 (3751).

  Resource Conservation and Recovery Act (RCRA)

  EPA has proposed listing wastestreams from the organic chemicals (phthallic anhydride production) industry as specific sources of di(2-ethylhexyl)phthalate-containing hazardous wastes (3795, 3774).

- State Water Programs

  MOST STATES

  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officer is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA

  Minnesota has proposed a Recommended Allowable Limit (RAL) of 40 μg/L for drinking water, a Sensitive Acute Limit (SAL) of 5550 μg/L for surface water, and a chronic criterion of 1 μg/L for surface water for the protection of human health (3451, 3452).

EEC Directives

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Discharge of Dangerous Substances (535)

Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)

Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list are covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

EEC Directives - Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
Di(2-ethylhexyl)phthalate is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

31.1 MAJOR USES

Di(2-ethylhexyl)phthalate (DEHP) is considered the standard polyvinyl chloride (PVC) plasticizer and is used primarily for this purpose. PVC plasticized with DEHP is one of the most economical plastics available. It can be easily processed and can be formulated to yield a broad range of physical properties. DEHP-plasticized materials are frequently used in medical devices such as syringes, catheters and blood storage bags. A relatively small amount of DEHP is used to plasticize a variety of other polymeric materials including natural and synthetic rubbers, nitrocellulose and cellulose acetate butyrate. The only significant non-plasticizer use for DEHP is as a replacement for polychlorinated biphenyls in dielectric fluids for electrical capacitors (403, 202, 416).

31.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

31.2.1 Transport in Soil/Ground-water Systems

31.2.1.1 Overview

Di(2-ethylhexyl)phthalate may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways can be assessed with the use of an equilibrium partitioning model as shown in Table 31-1. These calculations predict the partitioning of low soil concentrations of DEHP among soil particles, soil water and soil air. The portions of DEHP associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model indicate that essentially all of the chemical (99.99%) would be sorbed on the soil; a very small amount (0.008%) of the chemical will be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the very small portion of DEHP in the gaseous phase of the soil (3E-07 %), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind is possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a higher fraction of the DEHP (0.4%) is likely to be present in the soil-water phase (Table 31-1) and transported with flowing ground water. However, the extent of sorption is still very strong and ground waters underlying DEHP-contaminated sites may not be affected unless the DEHP is mobilized by complexation with other chemical species.

TABLE 31-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
DI(2-ETHYLHEXYL)PHTHALATE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	99.99	0.008	3E-07
Saturated deep soil[d]	99.6	0.4	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 62, 100 (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken 2.5E-07 atm · m^3/mol at 20°C (Estimated by Arthur D. Little, Inc.)
d) Used sorption coefficient calculated as a function of K_{oc} assuming 0.1% organic carbon: $k_p = 0.001 \times K_{oc}$.

In addition to the uncertainty (over environmental mobility) related to the possibility of complexation with mobilizing chemicals, e.g., fulvic acid, there remains significant uncertainties with regard to other basic properties of DEHP relating to mobility, including water solubility and vapor pressure. Additional information on DEHP is available in the thorough review of phthalic acid esters by Giam et al. (768).

31.2.1.2 Sorption on Soils

The mobility of DEHP in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content (except that complexation with humic or fulvic acids may decrease the extent of sorption);
- increase slightly with decreasing temperatures;
- increase moderately with increasing salinity of the soil water (701); and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 129,000, the soil sorption coefficient (K_{oc}) is estimated to be 62,100. This is a relatively high number indicative of strong sorption to soils. Sullivan et al. (701) studies the sorption of DEHP onto montmorillonite, kaolinite, calcite, calcium montmorillonite and sediments from the Gulf of Mexico. Sorption was relatively rapid (e.g., reaching 90% of equilibrium value in 12 hours) although hysteresis was evident in almost all tests. Sorption constants for DEHP were in the range of 1.3-13 [units are (ng DEHP/mg adsorbent) + (ng DEHP/mL water)]. The sediment sample did not adsorb appreciably more DEHP than the clay samples. Some increase in sorption was noted with an increase in the salinity of the solution.

According to reports by Autian (765), Ogner and Schnitzer (766) and Matsuda and Schnitzer (767), phthalate esters readily complex with natural organic substances (e.g., fulvic acid) to form complexes which are very soluble in water. Thus, sorption to soils may be significantly weaker than might be expected based upon the information given above.

31.2.1.3 Volatilization from Soils

Transport of DEHP vapors through the air-filled pores of unsaturated soils is not expected to be an important transport mechanism except for near-surface dry soils. The very low value of Henry's law constant for DEHP (2.5E-07 atm · m^3/mol at 20°C) implies that, when water is present, nearly all the DEHP will be in the water or soil compartments (see Table 31-1). Some experiments to measure the rate of volatilization of DEHP from water were carried out by Klopffer et al. (676); however, the results were inconclusive in part due to the fact that the DEHP concentrations used (0.35 mg/L) were above the water solubility limit.

31.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of DEHP in soil/ground-water systems is not well documented. In most cases, it should be assumed that DEHP will persist for months to years (or more). DEHP that has been released into the air, or that enters surface waters with significant sunlight exposure, is not expected to be degraded by direct photolysis. Resistance to photolytic degradation would be expected based upon DEHP's ultraviolet absorption spectrum which shows no absorbance above 300 nm (657).

Wolfe et al. (705) measured the second-order alkaline hydrolysis rate constant (k_{OH}) for several phthalates, including DEHP, at 30°C. Phthalate concentrations were always less than 1E-05 M. The reported k_{OH} value for DEHP was (2.5 ± 0.2)E-02/ M/sec. A first-order hydrolysis rate constant (k) can be calculated from this, at any pH, from the following equation:

$$k(/sec) = 1.1E\text{-}04\ [OH]$$

where [OH] is the molar concentration of the OH^- ion. At pH = 7, [OH] = 1E-07 and k = 1.1E-11/sec. Under these conditions (e.g., 30°C, pH = 7) the hydrolysis half-life is 2000 years. A 20°C drop in temperature (to a more typical ground-water temperature of 10°C) would increase the hydrolysis half-life by about a factor of 5, i.e., to 10,000 years.

DEHP has been found to be biodegradable in several studies. The ease of degradability is, however, less than that of most other phthalate esters (e.g., diethyl, di-n-butyl). Many of these studies are summarized in the reviews given by Overcash et al. (524), Callahan et al. (10) and Giam et al. (768).

Shake-flask activated-sludge tests have been carried out by Tabak et al. (55), Sugatt et al. (678), and O'Grady et al. (763). The percent primary degradation was typically in the range of 73-95% over the test periods (up to 28 days). Tabak et al. (55) characterized their results as involving "significant degradation (with) gradual adapation."

Johnson et al. (707) have studied the factors controlling degradation of DEHP in freshwater sediments. In one test conducted at 22°C, they observed 14% ultimate biodegradation in 28 days under aerobic conditions and 9.9% under anaerobic conditions. Effects of temperature, chemical concentration and acclimation were also observed.

Wolfe et al. (705) report a second-order microbial degradation rate constant for DEHP of 4.2E-05 L/org/h based on tests with natural water samples. The applicability of such laboratory-derived rate constants to real environments would involve significant uncertainty.

In most soil/ground-water systems, however, the concentration of microorganisms capable of biodegrading chemicals such as DEHP may be low and would drop off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in near-surface soils and in landfills with active microbiological populations.

31.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The properties of DEHP and the above discussion of fate pathways suggest that DEHP is nonvolatile, strongly adsorbed and has a high potential for bioaccumulation. This compound is not likely to volatilize from soil surfaces. In addition, in soil systems it should be strongly sorbed, although it may be mobile in sandy soils.

These fate characteristics suggest several potential exposure pathways. Drinking water may become contaminated in some situations. Mitre (83) reported that DEHP has been found in 6 of the 546 National Priority List (NPL) sites. It was detected at 4 sites in ground water and 3 sites in surface water. Although this is a relatively high frequency compared to some other chemicals, DEHP is a high-production organic chemical.

The potential for movement of DEHP in soil/ground-water systems is limited; however, it may move to surface water with soil particles. In such a situation, several other exposure pathways are possible:

- Surface waters may be used in drinking water supplies, resulting in direct ingestion exposures;
- Aquatic organisms residing in these water may be consumed, also resulting in direct ingestion exposure;
- Recreational use of these waters may result in dermal exposure;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

For DEHP, exposure pathways resulting from the contamination of aquatic organisms or domestic animals could be of concern due to the high potential of this compound to bioaccumulate.

31.2.4 Other Sources of Exposure

DEHP is commonly found in flexible plastics which are widely distributed in the United States. Thus, many direct exposure situations exist, aside from intake of food and drinking water. Examples include polyvinyl chloride respiratory tubing (3602) and polyvinyl chloride dialysis tubes and bags (3477).

DEHP is approved for a number of food-related uses. Based upon a survey of levels found in a variety of foods, an average intake of DEHP in the diet of 0.25 mg/day was estimated (403).

DEHP has not been monitored extensively in drinking water. In any case, the exposure from this source does not appear to be as significant as food exposure. In addition, DEHP has been reported in tobacco smoke and this may represent an exposure route for smokers and those exposed to cigarette smoke (403).

Direct contact of humans with PVC products could result in dermal or inhalation exposure due to leaching of DEHP from the product. This has been an exposure route for persons receiving blood stored in PVC blood bags or circulated through PVC tubing (403).

31.3 HUMAN HEALTH CONSIDERATIONS

31.3.1 Animal Studies

31.3.1.1 Carcinogenicity

Available evidence suggests that DEHP is a carcinogen in rats and mice. In a study conducted by the National Toxicology Program (NTP), DEHP was administered to groups of 50 Fischer 344 rats of each sex at 0, 6000 or 12,000 mg/kg diet and groups of 50 B6C3F_1 mice of each sex at 0, 3000 or 6000 mg/kg diet for 103 weeks. Liver cell tumors were observed in all treated animals with the tumor incidence in male and female mice and female rats being the most significant. In addition, the number of male rats with either liver cell tumors or neoplastic nodules was significantly elevated (417). Several aspects of the study have been scientifically challenged. These include the improper feeding and housing of the animals as well as the exceeding of the maximum tolerated dose. There is also the question of whether tumor incidence in the control group was unusually low (418). The positive carcinogenic results have been attributed to the metabolic response of rodents to DEHP. At the doses used in the NTP study, DEHP is known to cause a significant increase in the number of liver peroxisomes (subcellular particles involved in the oxidation of lipid) which in turn might induce the formation of liver tumors (419, 3105). These effects are similar to those of a class of hypolipidemic drugs which are also hepatocarcinogenic in rodents (420). In interpreting the relevance of this observation to man, it is interesting to note that there is no substantial evidence that these agents elicit the same liver peroxisome proliferation in humans that they do in rodents. Furthermore, epidemiological studies have not revealed an increase in hepatic neoplasia in humans receiving such medication (421). On the basis of the NTP findings of clear evidence of carcinogenic activity, IARC has determined that there is sufficient evidence for the carcinogenicity of DEHP in mice and rats and lists DEHP in category 2B (sufficient evidence of animal carcinogenicity) in its weight-of-evidence ranking of potential carcinogens (202).

31.3.1.2 Genotoxicity

DEHP has given negative results in numerous strains of Salmonella typhimurium with and without liver enzyme activation (419, 3358, 3508). Positive results were claimed by Tomita et al. (422) who found DEHP to be mutagenic in strain TA100 in the presence of activation. Zeiger et al. (3861) obtained a sample of DEHP from Tomita, and following his protocol, tested it in strain TA100 at 5 concentrations (ranging from 625 to 10,000 micrograms/plate), and it was negative. It did not induce chromosomal aberrations in Chinese hamster cells (406, 3566), human fetal lung cells or human leukocytes (423), nor did it induce mutations at the HPRT locus or sister chromatid exchanges in cultured Chinese hamster ovary cells (3566). DEHP also gave negative results in the sex-linked recessive lethal assay in Drosophila (3856) and in the mouse lymphoma assay (3358). Oral dominant lethal assays in ICR mice at doses ranging from 2.5 to 15 g/kg have given negative results (424, 425) while one

intraperitoneal dose of 12.8 mL/kg (3658) and subcutaneous administration of 9.9 grams/kg (3008) of DEHP resulted in a weakly positive dominant lethal test and in antifertility effects. The bone marrow cells of male mice gavaged with DEHP or its metabolites did not show an increase in chromosomal effects (3577).

Negative results have also been obtained in DNA binding assays conducted in vivo and in vitro (421, 426). The study by Butterworth et al. (426) is the most significant because it was conducted at the same dosage levels as the NTP carcinogenesis bioassay. The negative results in the DNA binding assays suggest the DEHP-induced liver tumors in rodents may be the result of a non-genotoxic mechanism (421).

31.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Several studies in rats have demonstrated testicular damage following administration of DEHP. The degree of damage appears to be directly proportional to the size of the dose and length of exposure: 20,000 mg/kg diet produced degeneration of the seminiferous tubules and testicular atrophy within 7 days, 12,000 mg/kg diet produced the same effects within 90 days and 6000 mg/kg diet within 2 years (427, 417). Mice fed 6000 mg/kg of diet for 2 years also exhibited tubular degeneration (417). In these cases, testicular atrophy has been associated with a reduced testicular zinc concentration. However, concurrent administration of zinc did not prevent testicular atrophy and despite increases in the zinc concentrations of the liver and serum, the zinc concentration in the testis was not increased. These results suggest that DEHP may promote the loss of testicular zinc and interfere with testicular zinc uptake (429). Also, DEHP-induced testicular atrophy does not appear to be morphologically reversible in rats to any significant extent (430).

DEHP was a reproductive toxicant in male and female CD-1 mice exposed to dietary levels of 0.01, 0.1, and 0.3% for 105 days. This was evidenced by a decrease in fertility index, number of litters and live births per litter. In addition, male mice at the 0.3% level experienced a decreased sperm concentration and a decreased percentage of motile sperm. The percentage of abnormal sperm was increased and seminiferous tubules were severely damaged. High dose females mated with control males were unable to produce offspring (432). Daily doses of 4000 or 10,000 mg/kg diet to ICR mice throughout pregnancy caused complete resorption (433). One thousand or 2000 mg/kg caused teratogenic effects of the CNS and increased embryolethality. No adverse effect was observed at 500 mg/kg diet.

Shiota and Mima (3647) reported that DEHP is highly embryotoxic and teratogenic in mice when given orally but not intraperitoneally. On days 7, 8, and 9 of gestation ICR mice were exposed by gavage to 250, 500, 100, or 2000 mg/kg of DEHP or intraperitoneally to 500, 1000, 2000, 4000, or 8000 mg/kg of DEHP. In the group given DEHP orally, resorption, fetal weight reduction, and malformed fetuses increased significantly at 100 mg/kg. The most common malformations were anencephaly and exencephaly. No teratogenic effects were observed with ip exposure to DEHP. When CD-1 mice were gavaged on gestational days 6-13 with 9,650

mg/kg/day of DEHP, Hardin et al. (3271) observed only 2 viable litters from 32 treated dams. The average litter size was reduced when compared to the control values (6.5 vs 9.5).

Embryotoxic and teratogenic effects were observed in Sprague-Dawley rats given intraperitoneal injections of 5 or 10 g/kg body weight on days 5, 10, and 15 of gestation. There was a dose-related increase in fetal resorptions and gross abnormalities were observed in the high-dose group only. These included the absence of eyes and tails (401). Ritter et al. (3597) exposed Wistar rats by gavage to 5 or 10 mL/kg of DEHP on gestational day 12. A dose response was seen with 5 mL/kg causing 4.5% of the survivors to be malformed, compared to 20.8% malformed with the 10 mL/kg exposure. Malformations in the high dose group included hydronephrosis, cardiovascular malformations, and tail and limb defects.

31.3.1.4 Other Toxicologic Effects

31.3.1.4.1 Short-term Toxicity

The oral toxicity of DEHP is relatively low with oral LD_{50} values of approximately 30 g/kg in rats and rabbits (47). Short-term repeated administration of 0.5 to 2 g/kg/day to rodents produced liver enlargement, liver peroxisome proliferation and induction of enzymes involved in fatty acid oxidation in the liver (421). In contrast, marmoset monkeys given oral doses of 2 g/kg/day or intraperitoneal doses of 1 g/kg/day for 14 days experienced no adverse effects (421).

Topically applied undiluted DEHP does not produce eye or skin irritation in rabbits. Although DEHP is absorbed through rabbit skin, the LD_{50} by this route is 25 g/kg (12, 47).

31.3.1.4.2 Chronic Toxicity

In mice, oral administration of 0.5 or 5.0 g/kg/day for 1 to 3 months resulted in liver and kidney degeneration (434). Daily intraperitoneal injections of 0.25 g/kg/day for 6 weeks caused liver enlargement, testicular atrophy, liver and testicular abscesses and severe peritonitis (292). Mitchell et al. (3458) administered DEHP in the diets of male and female Wistar albino rats for 9 months such that the rats received 0, 50, 200, or 1000 mg/kg/day. Groups of six control animals and four per treatment group were sacrificed 3, 7, 14, and 28 days and 9 months after commencement of feeding. Among the changes observed were hypertrophy of the hepatocytes, centrilobular loss of glycogen, and a fall in glucose-6-phosphatase activity which did not reach maximal levels until 28 days after treatment. These effects were clearly seen at 200 and 1000 mg/kg but only marginally evident at 50 mg/kg. Other changes such as midzonal to periportal accumulation of fat and induction of peroxisomal enzymes developed more quickly. Alterations in female rats were less pronounced than in males. Price et al. (3573) administered the same dietary doses of DEHP as in the Mitchell et al. study for at least 3 months and showed that male Wistar rats developed alterations of the

thyroid gland including increases in the number and size of lysosomes, hypertrophy of the Golgi apparatus, and dilation of the rough endoplasmic reticulum.

The leaching of DEHP into transfusion fluids has the potential to produce toxic reactions. Rhesus monkeys showed signs of abnormal liver pathology after receiving weekly or biweekly transfusions of plasma that had been stored in PVC bags for periods up to one year. The cumulative concentrations of DEHP received by the monkeys during a one-year period ranged from 6.6 to 33 mg/kg (435).

31.3.2 Human and Epidemiologic Studies

31.3.2.1 Short-term Toxicologic Effects

Little data are available detailing effects of human exposure to DEHP. Shaffer et al. (436) report that a single human subject who swallowed 10 g DEHP experienced gastritis and evacuation of the bowel, while a subject who swallowed 5 g did not. No reaction was noted when undiluted DEHP was applied to human skin for 7 days (436). A potential route of human exposure is through blood transfusions. The extraction of DEHP from PVC bags by human blood at 4°C has been found to occur at a rate of 0.25 mg/100 mL/day for 21 days. DEHP was found in both the lipid-containing and lipid-free portions of the plasma with the red cells containing only a small amount. From these findings, it can be calculated that a whole body exchange transfusion in a 70-kg man with 20-day-old blood could result in intravenous administration of 300 mg DEHP. This scenario, however, is unlikely since fresher blood would normally be used (416).

The results of a recent study indicate that hemodialysis patients are exposed to substantial amounts of DEHP, MEHP and phthalic acid. Time-averaged-circulating concentrations during dialysis were 1.91 - 2.11 μg/mL DEHP, 1.33 - 0.58 μg/mL MEHP and 5.22 - 3.49 μg/mL phthalic acid. The length of time that patients had been receiving dialysis treatment was correlated with the circulating concentration of phthalic acid but not with the concentrations of DEHP and MEHP (627).

31.3.2.2 Chronic Toxicologic Effects

In a small prospective cohort study, eight deaths were observed among 221 workers exposed to DEHP for periods of 3 months to 24 years. One carcinoma of the pancreas and one bladder papilloma were reported (437). In a study of the chromosomal effects of DEHP, occupational exposure to 0.01 - 0.16 mg/m^3 for 10 to 34 years was found not to increase the incidence of aberrations in blood leukocytes (438).

31.3.3 Levels of Concern

The USEPA (3770) has established an ambient water quality criterion of 15 mg/L for the protection of human health from the toxic properties of DEHP ingested through water and aquatic organisms that bioaccumulate DEHP; this criterion is

presently under review by USEPA and it is likely that a new criterion based on carcinogenicity will be proposed. An Oral Reference Dose of 20 μg/kg/day has been proposed by the USEPA (3742).

NTP (417) categorizes DEHP as presenting positive evidence of carcinogenic activity in rodents. IARC (3325) lists DEHP in category 2B (sufficient evidence of animal carcinogenicity) in its weight-of-evidence ranking of potential carcinogens.

Both OSHA (3539) and the ACGIH (3005) have set 8-hour TWA occupational exposure limits of 5 mg/m^3 for DEHP.

31.3.4 Hazard Assessment

High dietary concentrations of DEHP (3000-12,000 mg/kg diet) fed to rats and mice for two years induced liver tumors in both species (417). The relevance of these findings to humans has been questioned (418, 419) based on the response of the rodent liver to DEHP (proliferation of peroxisomes); there is no substantial evidence that this process occurs in humans exposed to agents that elicit this response in rodents, suggesting that the pathological changes seen in rodents administered high doses of DEHP may be species-specific. Standard in vitro genotoxic tests give negative responses for DEHP. A weakly positive response was recorded in a rodent dominant lethal assay following large intraperitoneal or subcutaneous doses of DEHP (3658, 3008) but approximately the same dose given orally in another dominant lethal study gave negative results (425), suggesting a nongenotoxic mechanism.

Several studies have demonstrated testicular damage in the rat, mouse and ferret induced by administration of high doses (>6000 mg/kg) of DEHP (427, 417, 428). The degree of testicular damage appears to be dose-related and proportional to the length of exposure. Embryolethal and teratogenic effects have also been demonstrated in mice and rats (432, 433, 401).

Little data are available on the effects of exposure to DEHP in humans. Ingestion of 5 g DEHP was reported to be without effect; ingestion of 10 g induced gastritis and bowel evacuation. Given the ubiquitous exposure to DEHP in our society, the lack of adverse effect reports attest to its generally low toxicity to humans. However, until such time as the difference in the metabolic fate of DEHP in rodents is clearly identified as a species-specific mechanism of liver tumor formation, the hazards associated with human exposure to DEHP will need to be re-examined periodically.

31.4 SAMPLING AND ANALYSIS CONSIDERATION

Determination of DEHP concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sampling

and analysis completed within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of di(2-ethylhexyl)phthalate, one of the EPA priority pollutants, in aqueous samples include EPA Methods 606, 625, 1625 (65), 8060 (63), and 8250 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; di(2-ethylhexyl)phthalate is then detected with a flame ionization detector (Method 606) electron capture detector (Method 8060), or a mass spectrometer (Methods 625, 1625, and 8250).

The EPA procedures recommended for di(2-ethylhexyl)phthalate analysis in soil and waste samples, Methods 8060, and 8250 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction (Method 3540) or sonication methods (Method 3550). Neat and diluted organic liquids may be analyzed by direct injection. Determinations are made with either the electron capture or flame ionization detector. A screening procedure using capillary GC with mass spectrometric detection has also been described (3356).

Typical di(2-ethylhexyl)phthalate detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
2.0 μg/L (Method 606)	13.4 μg/g (Method 8060/FID)
2.5 μg/L (Method 625)	1.3 μg/g (Method 8060/ECD)
10 μg/L (Method 1625)	1.7 μg/g (Method 8250)
0.2 μg/L (Method 8060/FID)	
0.02 μg/L (Method 8060/ECD)	
25 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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3770. U.S. Environmental Protection Agency 1986. Quality criteria for water. U.S. EPA 440/5-86-001, updated May 1, 1987.

3774. U.S. Environmental Protection Agency 1987. Identification and listing of hazardous wastes: hazardous wastes from specific sources. Fed. Regist. 52:28698. 40 CFR261.32.

3775. U.S. Environmental Protection Agency 1987. List of hazardous constituents for ground-water monitoring. Fed. Regist. 52:25942. 40 CFR264 and 270 Appendix IX.

3777. U.S. Environmental Protection Agency 1987. Organic chemicals, plastics, and synthetic fibers category: Effluent limitations guidelines, pretreatment standards, and new source performance standards. Fed. Regist. 52:42522. 40 CFR414.

3781. U.S. Environmental Protection Agency 1988. Notice of substituted contaminants and first drinking water priority list. Fed. Regist. 53:1892-1902. 40 CFR141 (SARA Section 110).

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3784. U.S. Environmental Protection Agency 1988. Identification and listing of hazardous wastes: discarded commercial chemical products and their hazardous waste numbers. Fed. Regist. 53:13384. 40 CFR261.33.

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3787. U.S. Environmental Protection Agency 1988. Toxic chemical release reporting: Community right-to-know. Fed. Regist. 53:4500 and revised 1988, 53:23108. 40 CFR372 (SARA Title III Section 313).

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3795. U.S. Environmental Protection Agency 1989. Land disposal restrictions for second third scheduled wastes. Proposed rule. Fed. Regist. 54:1056. 40 CFR268.

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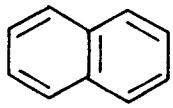
COMMON SYNONYMS:	CAS REG.NO.: 91-20-3 FORMULA: $C_{10}H_8$ NIOSH NO: QJ0525000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C (12) 5.24 mg/m³ ≈ 1 ppm; 0.191 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 128.16
Naphthalene Naphthene Tar camphor White tar		

REACTIVITY	Naphthalene may generate heat, react vigorously, and possibly ignite or explode in contact with oxidizing mineral acids or other strong oxidizing agents (511, 505).

PHYSICO-CHEMICAL DATA	• Physical State: Solid, volatile crystalline flakes (at 20°C)	(23)
	• Color: White	(23)
	• Odor: "Moth balls" or coal tar	(54,59)
	• Odor Threshold: 0.084 ppm	(384)
	• Density: 1.1450 g/mL (at 20°C)	(14)
	• Freeze/Melt Point: 80.20°C	(23)
	• Boiling Point: 218.00°C	(23)
	• Flash Point: 79.00°C closed cup	(21)
	• Flammable Limits: 0.90 to 5.90% by volume	(38,51,506)
	• Autoignition Temp.: 526.0 to 567.0°C	(38,51,506)
	• Vapor Pressure: 5.30E-02 mm Hg (at 20°C)	(30)
	• Satd. Conc. in Air: 3.7500E+02 mg/m³ (at 20°C)	(1219)
	• Solubility in Water: 3.17E+01 mg/L (at 20°C)	(440)
	• Viscosity: 0.754 cp (at 100°C)	(21)
	• Surface Tension: 3.1800E+01 dyne/cm (at 100°C)	(59)

PHYSICO-CHEMICAL DATA (Cont.)	• Log (Octanol-Water Partition Coeff.): 3.30 (29) • Soil Adsorp. Coeff.: 9.62E+02 (652) • Henry's Law Const.: 4.82E-04 atm · m^3/mol (74) • Bioconc. Factor: 4.40E+01 (blue mussel), 7.70E+01 (sand dab), 9.50E+01 (estim) (439,659)
PERSISTENCE IN THE SOIL-WATER SYSTEM	Naphthalene is expected to be fairly mobile in the soil/ground-water system. Transport with infiltrating water is expected to be important, particularly in sandy soils and soils of low organic content. Volatilization may be important at the surface. Biodegradation has been shown to occur with acclimated microbial populations and under aerobic conditions; biodegradation in natural soils and groundwater is not expected to be significant.
PATHWAYS OF EXPOSURE	The primary pathway of concern from the soil-water system is the migration of naphthalene to groundwater drinking water supplies. There is some evidence that migration from disposal sites to ground water and surface water has occurred in the past. Inhalation exposures resulting from volatilization from surface soils may also occur.
HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (54) Ingestion or inhalation of naphthalene causes eye irritation, headache, nausea, vomiting, sweating and abdominal pain. Skin contact may cause redness and dermatitis. Both the vapor and the solid are irritating to the eye. Acute Toxicity Studies: (3504) ORAL: LD_{50} 490 mg/kg Rat LD_{Lo} 100 mg/kg Child LD_{50} 533 mg/kg Mouse LD_{50} 1200 mg/kg Guinea pig

HEALTH HAZARD DATA	Long-Term Effects: Limited data suggest no significant changes. Pregnancy/Neonate Data: Negative Genotoxicity Data: Negative Carcinogenicity Classification: IARC - No data NTP - Under study (histopathology in progress) EPA - No data

HANDLING PRECAUTIONS (38)	Handle chemical only with adequate ventilation • Vapor concentrations of 10-500 ppm: any supplied-air respirator or selfcontained breathing apparatus with full facepiece; chemical cartridge respirator with full facepiece, organic vapor cartridge and dust filter • Above 500 ppm: self-contained breathing apparatus with full facepiece operated in positive-pressure mode • Chemical goggles if there is probability of eye contact • Protective clothing to prevent prolonged or repeated skin contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 10 ppm; STEL (15 min): 15 ppm
- AFOSH PEL (8-hr TWA): 10 ppm; STEL (15-min): 15 ppm

Criteria
- NIOSH IDLH (30-min): 500 ppm
- ACGIH TLV® (8-hr TWA): 10 ppm
- ACGIH STEL (15-min): 15 ppm

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards
None established

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (3770)
  - No criterion established due to insufficient data.

- Aquatic Life (3770)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 2300 μg/L.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 620 μg/L.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 2350 μg/L.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:
ORAL: 4.100E+02 μg/kg/day (3744)

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

Naphthalene is designated a hazardous substance under CWA. It has a reportable quantity (RQ) limit of 45.4 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources and effluent standards and guidelines (351, 3763). Effluent limitations have been set for napthalene effluents in the following point source categories: iron and steel manufacturing industry (354), electroplating (3767), organic chemicals, plastics, and synthetic fibers (3777), steam electric power generating (3802), and metal molding and casting (892). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Naphthalene is listed as an unregulated contaminant with no EPA monitoring requirements. The individual states decide which systems require analysis for this contaminant (3771). In states with an approved Underground Injection Control program, a permit is required for the injection of naphthalene-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)

Naphthalene is identified as a toxic hazardous waste (U165) and listed as a hazardous waste constituent (3783, 3784). A non-specific source of naphthalene-containing waste is the production of chlorinated aliphatic hydrocarbons (325). Waste streams from the following industries contain naphthalene and are listed as specific sources of hazardous wastes: wood preservation (creosote and/or pentachlorophenol preserving processes), pesticides (creosote production), coking (operational residues), organic chemicals (production of 1,2-dichloro- ethane), petroleum refining, and ink formulation (3774, 3765). Naphthalene is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective November 8, 1988, the land disposal of certain untreated naphthalene-containing hazardous wastes is prohibited. These wastes must be treated according to Best Demonstrated Available Technology (BDAT) treatment standards before being disposed. Certain variances exist until May, 1990 for other naphthalene-containing hazardous wastes for which BDAT treatment standards have not been promulgated by EPA (3786). Naphthalene is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors, and importers who possess health and safety studies on naphthalene must submit them to EPA (3789).

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
Naphthalene is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg. Reportable quantities have also been issued for RCRA hazardous waste streams containing naphthalene but these depend upon the concentration of the chemicals in the waste stream (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of naphthalene must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Occupational Safety and Health Act (OSHA)
Employee exposure to naphthalene in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 10 ppm, or a 15-minute short-term exposure limit (STEL) of 15 ppm for any 8-hour work-day (3539).

Clean Air Act (CAA)
EPA has concluded health and source screening assessments on naphthalene and has decided not to regulate it under the Clean Air Act (3685).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated naphthalene as a hazardous material with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling and transportation (3180).

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
Pesticide registration standards for naphthalene have been issued by EPA (3798).

- State Water Programs

  ALL STATES
  All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

  KANSAS
  Kansas has an action level of 143 μg/L for naphthalene in groundwater (3213).

NEW MEXICO
New Mexico has set a human health criterion of 0.03 mg/L for total naphthalene plus monomethylnaphthalenes in ground-water (3499).

NEW YORK
New York has set an MCL of 50 μg/L for drinking water, an ambient water quality standard of 10 μg/L for surface waters classed for drinking water supply, and a nonenforceable water quality guideline of 10 μg/L for ground-water (3501).

OKLAHOMA
Oklahoma has set a Toxic Substance Goal of 143 μg/L for surface waters used for public and private water supplies (3534).

PENNSYLVANIA
Pennsylvania has a human health criterion of 10 μg/L for surface waters (3561).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 115 μg/L and a chronic guideline of 2.6 μg/L for surface waters for the protection of aquatic life. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires naphthalene to be nondetectable, using designated test methods, in ground-water (3671).

Proposed Regulations

- Federal Programs

  Resource Conservation and Recovery Act (RCRA)
  EPA has proposed BDAT treatment standards for naphthalene-containing wastes from chlorinated aliphatic hydrocarbon production, and organic chemical (1,2-dichloroethane) production. Final promulgation is expected by June, 1989 (3795).

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes to their regulations which will follow EPA's changes when they become final. Contact with the state officer is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA
  Minnesota has proposed a Sensitive Acute Limit (SAL) of 920 μg/L for surface water, and a chronic criterion of 20.4 μg/L for designated surface waters for the protection of human health (3452).

EEC Directives

Directive on Drinking Water (533)
The mandatory values for polycyclic aromatic hydrocarbons in surface water treatment categories Al, A2 and A3 used or intended for the abstraction of drinking water are 0.0002 and 0.001 mg/L, respectively. No guideline values are given for any treatment category.

Directive Relating to the Quality of Water Intended for Human Consumption (540)
The maximum admissible concentration for polycyclic aromatic hydrocarbons is 0.2 μg/L.

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils an hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

32.1 MAJOR USES

The production of phthalic anhydride is the main use for naphthalene. It accounts for approximately 60% of U.S. consumption. Twenty percent is used in the production of carbaryl, an insecticide; the remainder is used in the manufacture of tanning agents, moth repellents, surfactants and chemicals such as beta-naphthol, alpha-naphthol and decahydronaphthalene (440).

32.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

32.2.1 Transport in Soil/Ground-water Systems

32.2.1.1 Overview

Naphthalene may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways of low soil concentrations can be assessed by equilibrium partitioning, as shown in Table 32-1. These calculations predict the partitioning of naphthalene among soils particles, soil water and soil air. The portions of naphthalene associated with the water and air phases of the soil are more mobile than the adsorbed portion. The estimates for the unsaturated topsoil model indicate that most of the naphthalene (99%) is expected to be sorbed to the soil. Only a small amount (0.5%) will be present in the soil water phase and available to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. Very little naphthalene will be in the gaseous phase of the soil (<0.1%).

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a higher fraction of the naphthalene (20%) is expected to be present in the soil-water phase (Table 32-1) and transported with flowing ground water.

32.2.1.2 Sorption on Soils

The mobility of naphthalene in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;

TABLE 32-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR NAPHTHALENE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	99.4	0.5	0.03
Saturated deep soil[d]	80.2	19.8	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 962. (Estimated by Arthur D. Little, Inc.)
c) Henry's law constant taken as 4.82E-04 atm · m^3/mol at 25°C (74).
d) Used sorption coefficient (K_p) calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

The available data (10, 759, 760) indicate that naphthalene sorption onto soils and sediments is a reversible process, and that the kinetics of desorption are slower than the kinetics of adsorption. These observations and the relatively high aqueous solubility of naphthalene suggest that migration with infiltrating water may be an important transport process for naphthalene.

- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

In a field study of the effects of dune soil on the removal and modification of river-borne organics during dune-infiltration (using water from the Rhine River), Piet et al. (226) found increases in the naphthalene concentration after infiltration. While the reason for the increase is not known, and may have been due to some artifact of the study, the results do indicate that naphthalene is easily transported by infiltrating water.

Retardation factors, which represent the ratio of the interstitial water velocity to the pollutant velocity in the soil, have been reported for naphthalene. Fu et al. (760) report a retardation coefficient of 23 for naphthalene in soil columns containing approximately 2% organic carbon. Schwarzenbach et al. (77) report the following retardation factors for naphthalene: 16-62 in river sediment (1-2% organic carbon); 2.5-31 in an aquifer close to the river bed (0.1-1% organic carbon); and 1-2.5 in an aquifer far from the river bed (<0.1% organic carbon). These data indicate some retardation (i.e., adsorption) in soils having 1-2% organic carbon, and little or no retardation in deep soils having less than 0.1% organic carbon.

32.2.1.3 Volatilization from Soils

Transport of naphthalene vapors through the air-filled pores of unsaturated soils is a potentially important transport mechanism for near-surface soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

Volatilization of naphthalene from aqueous solution has been reported to be a significant removal process with rates dependent on current and wind velocities (440). There are no data from laboratory or field tests showing actual soil volatilization rates for naphthalene; sorption of the naphthalene vapors on the soil may slow the vapor phase transport.

The Henry's law constant (H), which provides an indication of a chemical's tendency to volatilize from solution, increases significantly with increasing temperature (28). Moderate increases in H are also observed with increasing salinity due to a decrease in naphthalene's solubility (517).

32.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of naphthalene in soil/ground-water systems is not well documented. In most cases, it should be assumed that the chemical will persist for months to years (or more). Naphthalene that has been released into the air will eventually undergo photochemical oxidation (10).

Naphthalene under normal environmental conditions is not expected to undergo hydrolysis (10). Furthermore, naphthalene is not expected to be susceptible to oxidation or reduction reactions in the soil/ground-water environment. Photolysis of naphthalene in surface soils may occur due to the high absorptivities of the compound in the UV/VIS range; however, no specific data were available.

Naphthalene has been reported to be readily susceptible to aerobic biodegradation after an initial period of acclimation (10, 55, 519, 761). However, the rate and extent of degradation vary considerably depending on environmental

conditions. Certain pure and mixed cultures can apparently degrade naphthalene under environmental conditions. Biodegradation in acclimated wastewater treatment plants (e.g., activated sludge) would be expected to be relatively easy based upon the data of Tabak et al. (55). Lee (519) and Herbes (761) have demonstrated biodegradation in aqueous systems located near industrial sources of naphthalene; the highest degradation rates were reported in oil-polluted areas or areas receiving continuous input of naphthalene. Naphthalene does occur in most soils, and soil microbes have been shown to degrade (aerobic) some PAHs (10). Schwarzenbach et al. (77) report that biological processes were responsible for the "elimination" of naphthalene during infiltration of river water to ground water. However, in most soil/ground-water systems such aerobic degradation would be of minimal importance because of the low concentration of microorganisms (at depth) and the low dissolved oxygen (anaerobic) conditions. No data are available on the possibility of anaerobic biodegradation.

32.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The properties of naphthalene and the above discussion of fate pathways suggest that naphthalene is moderately volatile, moderately adsorbed by soil, and has a moderate potential for bioaccumulation. This compound may volatilize from soil surfaces. That portion not subject to volatilization may migrate to ground water particularly in sandy soils. These fate characteristics suggest several potential exposure pathways.

Inhalation exposures could result from volatilization of naphthalene during drilling or restoration activities. In addition, there is some potential for ground water contamination, particularly in sandy soils. Mitre (83) reported that naphthalene has been found in 12 of the 546 National Priority List (NPL) sites. It was detected at 9 sites in ground water and 4 sites in surface water. Naphthalene's properties, as well as its presence at NPL sites suggest that it has some potential for movement in soil/ground-water systems. This compound may eventually reach surface waters by this mechanism, suggesting several other exposure pathways:

- Surface water may be used as drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposure;
- Recreational use of these waters may result in dermal exposure;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposure.

In general, exposures associated with surface water contamination can be expected to be lower than drinking contaminated ground water, partially due to the

greater dilution volume for surface waters. In addition, the BCF for naphthalene is not high enough for bioaccumulation to represent a more significant source of exposure than drinking water.

32.2.4 Other Sources of Exposure

Naphthalene is commercially produced and used in part as a moth repellent. This use can result in direct consumer exposure. Estimates of bedroom air concentrations resulting from this use were about 7 $\mu g/m^3$. In addition, naphthalene has been reported in cigarette smoke. Estimated exposures range from 3-300 μg/day, depending on the number of cigarettes smoked (440).

Ambient levels of naphthalene in drinking water and air appear to be generally low or below detection limits, and exposures would not be significant as compared to that resulting from moth ball usage or smoking (440). Brodzinsky and Singh (84) compiled all available atmospheric monitoring data for a number of organics. For naphthalene, they had data for 106 locations. In urban and suburban locations, the median concentration was 0.94 $\mu g/m^3$. In source-dominated areas, the median concentration was 2.1 $\mu g/m^3$.

32.3 HUMAN HEALTH CONSIDERATIONS

32.3.1 Animal Studies

32.3.1.1 Carcinogenicity

Results of two studies on naphthalene carcinogenicity via oral or subcutaneous routes indicate a negative response. The studies however, are inadequate for assessment of carcinogenic risk. In one study, rats were given 10 g of naphthalene over "a period of time." The rats were followed for up to 1000 days; none developed tumors (442). The other study which provided no indications of carcinogenicity was conducted with rats given a subcutaneous injection of 820 mg of naphthalene/rat. None of the 10 rats developed tumors (442). Another experiment indicated a nonstatistically significant increase in lymphosarcoma in rats given 7 subcutaneous injections of 500 mg/kg. However, the naphthalene used contained 10% of an unknown impurity and carbolfuchsin, a known carcinogen, was applied to the injection site prior to administration. A skin-painting study in mice produced lymphocytic leukemia and lung adenoma, but these results are of little significance with respect to naphthalene since benzene, a known carcinogen, was utilized as the vehicle (441). Another negative response was reported when strain A/J mice were exposed by inhalation to 30 ppm naphthalene for 6 hours/day, 5 days/week for 6 months and then observed for the presence of lung adenomas (3007).

Neither IARC nor the NTP has categorized naphthalene with regard to its potential carcinogenicity, but NTP does have a bioassay underway which has progressed to analysis of the histopathology.

32.3.1.2 Genotoxicity

Naphthalene was found to be nonmutagenic in E. coli and various strains of Salmonella typhimurium (443, 444). In vitro cell transformation assays were also negative (445).

32.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Hardin et al. (208) reported no adverse fetal or maternal effects in rats administered 395 mg/kg naphthalene intraperitoneally on days 1-15 of gestation. However, Harris et al. (3273) found retarded cranial osssification and heart development ($P<0.001$) in Sprague Dawley rat pups when dams were administered 395 mg/kg body weight of naphthalene intraperitoneally in corn oil on gestation days 1-15. Plasterer et al. (3568) gavaged naphthalene to mice on days 7-14 of gestation with a dose (300 mg/kg) considered to be just below adult lethality. No gross congenital defects were detected in neonates. There was a significant reduction in number of neonate survivors. Hardin et al. (3271) gavage fed 50 pregnant mice with 300 mg/kg/day. Ten of the mice died, while the survivors had a significant decrease in weight gain. There was a significant decrease in number of liveborn pups per litter, but those born had normal birth weights and normal survival rates and weight gain to day 3.

32.3.1.4 Other Toxicologic Effects

32.3.1.4.1 Short-term Toxicity

Ocular toxicity is the most common effect resulting from short-term, high-level exposure to naphthalene in animals. Cataracts and retinopathy were produced in rabbits fed 1000 mg/kg daily for 46 days. Retinal changes were noted as early as day 3 (446). Weanling rats fed a diet of 2% naphthalene for 60 days also developed cataracts (447). Grant (19) reports that nearly all parts of the eye are affected in varying degrees, with the response differing from animal to animal. The mechanism by which cataracts are induced is thought to be due to the formation of reactive metabolites (1, 2-dihydroxynaphthalene and 1, 2-naphthoquinone) in the eye which combine irreversibly with thiol groups of lens protein (19).

Curiously, direct application of a 10% solution in oil to the eyes or intraperitoneal injection of 500 mg/day for 50 days failed to produce cataracts in rabbits (446).

The lung also appears to be a target for naphthalene-induced toxicity, with bronchiolar necrosis being observed in mice after single intraperitoneal doses of 128 mg/kg; the tissue had returned to normal within 7 days (449). O'Brien et al. (3529) found that there were species differences when naphthalene was administered intraperitoneally to mice and rats. An injection of 200 mg/kg to male Swiss T.O. mice resulted in severe lung damage compared with other organs, and at doses of 400

and 600 mg/kg, there was also damage to the cells in the proximal tubules of the kidney. In contrast, doses as high as 1600 mg/kg caused no detectable pulmonary or renal damage in male Wistar rats. Dogs experienced an 83% drop in hemoglobin levels after receiving an oral dose of 1800 mg/kg divided over 5 days (450).

32.3.1.4.2 Chronic Toxicologic Effects

A 90-day feeding study of CD-1 mice revealed no significant ocular or hematological changes. The only significant organ change was a reduction in the spleen weight of females but there was no evidence of immunotoxicity in any treatment group. The dosages ranged from 5.3 to 133 mg/kg/day (451).

32.3.2 Human and Epidemiologic Effects

32.3.2.1 Short-term Toxicologic Effects

Hemolytic anemia is the most severe effect associated with naphthalene exposure and individuals with a deficiency of glucose-6-phosphate dehydrogenase (G6PD) are more susceptible (54). G6PD catalyzes the production of NADPH, which maintains a proper reducing environment inside the erythrocytes (3814). Without it, structural and enzymatic proteins function improperly and cells hemoyze. G6PD-deficiency is most prevalent in blacks, Orientals and individuals of Jewish ancestry, making them more susceptible to these effects (54). Newborn infants are also susceptible to the possible hemolytic effects of naphthalene due to the reduced activity of enzyme systems normally found in all newborn infants.

The lethal ingested dose of naphthalene in non-sensitive adults ranges between 5 and 15 g (17). Ingestion of 6 g has been survived but 2 g ingested over a day killed a child (452, 453). Initial symptoms of ingestion include eye irritation, headache, abdominal pain and nausea which may progress to jaundice and renal tubular blockade. Hematologic features include dramatic decreases in hemoglobin, hematocrit and red cell count (46). Greater damage occurs when naphthalene is ingested in combination with fats which facilitate absorption and subsequent systemic effects of naphthalene.

Naphthalene is irritating to the skin upon direct contact and a small percentage of the population may be hypersensitive to it. In one case, an individual developed a case of exfoliative dermatitis. A patch test for naphthalene proved positive. When naphthalene exposure was discontinued, the skin condition cleared rapidly and did not recur in a 3-year follow-up period (454). Clothing impregnated with naphthalene has caused skin rashes and systemic poisoning in infants. Effects may have been enhanced by the application of baby oil to the infants' skin, thus increasing the absorption of the highly lipidsoluble naphthalene (455, 56).

Naphthalene vapor causes eye irritation at 15 ppm. Eye contact with the solid may result in conjunctivitis, corneal injury and diminished visual acuity (46).

There is one report of transplacental naphthalene poisoning but no details are available (456).

32.3.2.2 Chronic Toxicologic Effects

In the general population, 50 cases of severe chronic effects have been reported from repeated ingestion of a mixture of naphthalene and isopropyl alcohol. The symptoms resembled those of ethanol intoxication and included tremors, restlessness and hallucinations. The effects subsided in a few days (457).

Repeated inhalation of vapors may produce malaise, headache and vomiting (12). In a study of 21 workers exposed to high concentrations of vapors for 5 years, 8 developed peripheral lens opacities (446). In other studies, no eye abnormalities occurred in workers exposed to naphthalene for several years (46).

In a single case report, aplastic anemia was found in a 68-year-old black woman who had been exposed to moth-proofing compounds for a period of 39 years. It was estimated that she was exposed to 184 ppm of naphthalene and 1400 ppm of 1, 4-dichlorobenzene. No other cases of aplastic anemia have been attributed to either of these chemicals alone or in combination (458).

32.3.3 Levels of Concern

The USEPA has proposed an Oral Reference Dose for naphthalene of 410 μg/kg/day (3742).

Both OSHA (3539) and the ACGIH (3005) have set an 8-hr TWA occupational exposure limit of 10 ppm and a 15-min STEL of 15 ppm for naphthalene.

32.3.4 Hazard Assessment

Evaluation of the potential risks to humans from exposure to naphthalene is hampered by the scarcity of quantitative data on carcinogenic or long-term effects of naphthalene exposure.

The two major effects linked to naphthalene exposure include cataract formation and hemolytic anemia. Information on the production of cataracts is mainly anecdotal. Cataracts have been described in workers exposed to high levels of naphthalene vapor; other studies have noted negative findings. The dose-effect relationship between naphthalene and hemolytic anemia also is not clear. Individuals with relative deficiencies in the enzymes needed to maintain reduced glutathione levels, as well as the fetus and young infants (1-2 weeks old), appear at increased risk to develop hemolytic anemia, which can lead to renal damage.

The data that are available regarding the carcinogenicity of naphthalene suggest that the compound is not carcinogenic. A definitive answer should be possible once

the results of the NTP bioassy are available. Naphthalene does not appear to be genotoxic but tests in laboratory animals have shown developmental toxicity.

32.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of naphthalene concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in amber glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 14 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of naphthalene, one of the EPA priority pollutants, in aqueous samples include EPA Methods 610, 625, 1625 (65), 8100, 8250, and 8310 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. The semi-volatile constituents in the concentrated extract may be separated by either a high performance liquid chromatographic (HPLC) column (Methods 610 and 8310), or a gas chromatographic (GC) column (Methods 610, 625, 1625, 8250 and 8100); naphthalene is then detected with an ultraviolet detector (Methods 610/HPLC and 8310), flame ionization detector (Methods 610/GC and 8100) or a mass spectrometer (Methods 625, 1625, and 8250).

The EPA procedures recommended for naphthalene analysis in soil and waste samples, Methods 8100, 8250, and 8310 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical naphthalene detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The naphthalene detection limits for Methods 610/GC and 8100 were not determined. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
1.8 μg/L (Method 610/HPLC)	1 μg/g (Method 8250)
1.6 μg/L (Method 625)	1.2 μg/g (Method 8310)
10 μg/L (Method 1625)	
16 μg/L (Method 8250)	
18 μg/L (Method 8310)	

32.5 REFERENCES

Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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COMMON SYNONYMS:	CAS REG.NO.: 111-44-4 FORMULA: $C_4H_8Cl_2O$ NIOSH NO: KN0875000 STRUCTURE: Cl-CH_2-CH_2-O-CH_2-CH_2-Cl	AIR W/V CONVERSION FACTOR at 25°C 5.85 mg/m^3 ≈ 1 ppm; 0.171 ppm ≈ 1 mg/m^3 MOLECULAR WEIGHT: 143.02
1,1'-Oxybis (2-chloro)ethane 2-Chloroethyl ether Bis(2-chloroethyl) ether DCEE Dichloroether Dichloroethyl ether Sym-dichloroethyl ether		

REACTIVITY	Bis(2-chloroethyl)ether is considered an ether and a halogenated organic material for compatibility classification purposes. Reactions of such materials with cyanides, mercaptans or other organic sulfides typically generate heat, while those with mineral acids, amines, azo compounds, hydrazines, caustics, or nitrides commonly evolve heat and toxic or flammable gases. Reactions with oxidizing mineral acids may generate heat, toxic gases and fires. Those with alkali or alkaline earth metals, certain other chemically active elemental metals like aluminum, zinc or magnesium, organic peroxides or hydroperoxides, strong oxidizing agents or strong reducing agents typically result in heat generation and explosions and/or fires (511).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Colorless	(23)
	• Odor: Fruity, pungent; nauseating	(59,67)
	• Odor Threshold: 0.049 ppm	(384)
	• Density: 1.2220 g/mL (at 20°C)	(23)
	• Freeze/Melt Point: -51.80°C	(23)
	• Boiling Point: 178.50°C	(23)
	• Flash Point: 55.00°C (closed cup)	(23)
	• Flammable Limits: No data	
	• Autoignition Temp.: 369.0°C	(38,60)
	• Vapor Pressure: 7.10E-01 mm Hg (at 20°C)	(67)

PHYSICO-CHEMICAL DATA (Cont.)	• Satd. Conc. in Air: 5.6000E+03 mg/m^3 (at 20°C) (1219) • Solubility in Water: 1.02E+04 mg/L (at 20°C) (67) • Viscosity: 2.065 cp (at 25°C) (3217) • Surface Tension: 3.7900E+01 dyne/cm (at 19°C) (59) • Log (Octanol-Water Partition Coeff.): 1.29 (29) • Soil Adsorp. Coeff.: 1.09E+02 (654) • Henry's Law Const.: 1.30E-05 atm · m^3/mol at 20°C) (33) • Bioconc. Factor: 9.00E-01, 1.10E+01 (estim) (659,495)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems, primarily with infiltrating or flowing groundwater. Weak sorption on soils. Resistant to hydrolysis and biodegradation, although may be biodegraded after acclimation period in active, mixed-culture systems (e.g., sewage treatment plants).

PATHWAYS OF EXPOSURE	The primary pathway of concern from a soil-water system is the migration of bis(2-chloroethyl)ether to groundwater drinking water supplies; limited evidence exists that such migration has occurred in the past. Inhalation via volatilization from surface soils may also be important.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (54) Bis(2-chloroethyl)ether is irritating to the eyes and respiratory tract. Vapor exposure results in irritation, lacrimation, coughing and nausea. Acute Toxicity Studies: INHALATION: LC_{50} 330 ppm · 4 hours — Rat (3504) ORAL: LD_{50} 75 mg/kg — Rat (59) SKIN: LD_{50} 90 mg/kg — Rabbit (3504) Long-Term Effects: Liver cell tumors Pregnancy/Neonate Data: No data Genotoxicity Data: Conflicting data Carcinogenicity Classification: IARC - Group 3 (not classifiable as to its carcinogenicity to humans) NTP - No data EPA - Group B2 (probable human carcinogen; sufficient evidence in animals and inadequate evidence in humans)

HANDLING PRECAUTIONS (38,54,59)	Handle chemical only with adequate ventilation • Vapor concentrations of 15-150 ppm: any supplied-air respirator, self-contained breathing apparatus or chemical cartridge respirator with organic vapor cartridge. If eye irritation occurs, respiratory equipment with full face-pieces should be used • 150-250 ppm: any supplied-air respirator or self-contained breathing apparatus with full facepiece; gas mask with organic vapor canister; chemical cartridge respirator with full facepiece and organic vapor cartridge • Chemical goggles if there is probability of eye contact • Impervious clothing to prevent prolonged or repeated skin contact with liquids.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA (8-hr TWA): 5 ppm (skin); STEL (15 min): 10 ppm
- AFOSH PEL (8-hr TWA): 5 ppm (skin); STEL (15-min): 10 ppm

Criteria
- NIOSH IDLH (30 min): 250 ppm
- ACGIH TLV® (8-hr TWA): 5 ppm (skin)
- ACGIH STEL (15-min): 10 ppm (skin)

WATER EXPOSURE LIMITS:

Drinking Water Standards
None established

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (3770)
  - Based on ingestion of contaminated water and aquatic organisms (1E-05, 1E-06, 1E-07 cancer risk), 0.3 μg/L, 0.03 μg/L, 0.003 μg/L.
  - Based on ingestion of contaminated aquatic organisms only (1E-05, 1E-06, 1E-07 cancer risk), 13.6 μg/L, 1.36 μg/L, 0.136 μg/L.
  - Based on ingestion of drinking water only (1E-05, 1E-06, 1E-07 cancer risk), 0.3 μg/L, 0.03 μg/L, 0.003, μg/L.

- Aquatic Life (3770)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 238,000 μg/L chloroalkyl ethers.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

chronic toxicity:
no criterion established due to insufficient data.

- Saltwater species
  acute toxicity:
  no criterion established due to insufficient data.

  chronic toxicity:
  no criterion established due to insufficient data.

REFERENCE DOSES:
No reference dose available.

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

  Clean Water Act (CWA)
  Bis(2-chloroethyl)ether is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and to effluent standards and guidelines (351, 3763). Effluent limitations have been set for this chemical in the electroplating (3767), the steam electric power generating (3802), and the metal finishing point source categories (3768). Limitations vary depending on the type of plant and industry.

  Safe Drinking Water Act (SDWA)
  In states with an approved Underground Injection Control program, a permit is required for the injection of bis(2-chloroethyl)ether-containing wastes designated as hazardous under RCRA (295).

  Resource Conservation and Recovery Act (RCRA)
  Bis(2-chloroethyl)ether is identified as a toxic hazardous waste (U025) and listed as a hazardous waste constituent (3783, 3784). Waste streams from the organic chemicals industry (epichlorohydrin production) contain bis(2-chloroethyl)ether and are listed as specific sources of hazardous wastes (3774, 3765). Bis(2-chloroethyl)ether is

is included on EPA's ground-water monitoring list. EPA requires that hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775). Bis(2-chloroethyl)ether is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Effective July 8, 1987, the land disposal of hazardous wastes which contain halogenated organic compounds in total concentrations greater than or equal to 1000 mg/kg is prohibited. Effective August 8, 1988, the underground injection into deep wells of these wastes is prohibited. Certain variances until May, 1990 for land and injection well disposal of some wastewaters and nonwastewaters for which Best Demonstrated Available Technology (BDAT) treatment standards have not been promulgated by EPA (3786).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Bis(2-chloroethyl)ether is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 0.454 kg (3766). Reportable quantities have also been issued for RCRA hazardous waste streams containing bis(2-chloroethyl)ether but these depend upon the concentration of the chemicals in the waste stream (3766). Bis(2-chloroethyl)ether is designated an extremely hazardous substance under SARA Title III. Any facility at which this chemical is present in excess of its threshold planning quantity of 10,000 pounds must notify state and local emergency planning officials. If this chemical is released from the facility in excess of its reportable quantity (RQ), local emergency planning officials must be notified (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of bis(2-chloroethyl)ether must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to bis(2-chloroethyl)ether in any 8-hour work-shift of a 40-hour work-week shall not exceed an 8-hour time-weighted average (TWA) of 5 ppm. An employee's 15-minute short term exposure limit (STEL) of 10 ppm shall not be exceeded at any time during a work-day (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated bis(2-chloroethyl)ether as a hazardous material with a reportable quantity of 0.454 kg, subject to requirements for packaging, labeling and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

NEW YORK
New York has set an MCL of 5 μg/L for bis(2-chloroethyl) ether in drinking water, a water quality standard of 1.0 μg/L for ground-water used for the drinking water supply, and a nonenforceable guideline of 0.03 μg/L for surface waters (3501).

KANSAS
Kansas has an action level of 4.2 μg/L for ground-water (3213).

Proposed Regulations

- Federal Programs

Resource Conservation and Recovery Act (RCRA)
EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 0.05 mg/L bis(2-chloroethyl)ether. Final promulgation of this Toxicity Characteristic Rule is expected in June, 1989 (1565).

- State Water Programs

  MOST STATES

  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officer is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA

  Minnesota has proposed a Recommended Allowable Limit (RAL) of 0.3 μg/L for bis(2-chloroethyl)ether in drinking water (3451).

EEC Directives

Directive on the Discharge of Dangerous Substances (535)

Organohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Ground-Water (538)

Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on Toxic and Dangerous Wastes (542)

Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Bis(2-chloroethyl)ether is listed as a Class I/a toxic substance and is subject to packaging and labeling regulations.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Bis(2-chloroethyl)ether is classified as a toxic substance and is subject to packaging and labeling regulations.

EEC Directives - Proposed Resolution
Resolution on a Revised List of Second-Category Pollutants (545)
Bis(2-chloroethyl) ether is one of the second-category pollutants to be studied by the Commission in the programme of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risk to human health and the environment, limits of pollutant levels in the environment, and determination of quality standards to be applied will be assessed.

33.1 MAJOR USES

Bis(2-chloroethyl)ether is no longer produced for sale in the United States. The companies producing it utilize it within their own plants and subsidiaries in a variety of proprietary processes. Bis(2-chloroethyl)-ether has been used as a soil fumigant, a solvent, a scouring agent for textiles and as an intermediate in the synthesis of divinyl ether and morpholine compounds. It can also be used to scavenge lead deposits in gasoline but apparently has never found much commercial use in this way (496).

33.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

33.2.1 Transport in Soil/Ground-water Systems

33.2.1.1 Overview

Bis(2-chloroethyl)ether may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways for low soil concentrations can be assessed by equilibrium partitioning, as shown in Table 33-1. These calculations predict the partitioning of bis(2-chloroethyl)ether among soil particles, soil water, and soil air. The portions of bis(2-chloroethyl)ether associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model predict that most of the chemical (95%) will be sorbed on the soil; a small amount (5%) of the chemical is expected to be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion and diffusion. For the small portion of bis(2-chloroethyl)ether in the gaseous phase of the soil (0.007%), diffusion through the soil-air pores up to the ground surface, and subsequent removal by wind, is possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon) a much higher fraction of the bis(2-chloroethyl)ether (69%) is likely to be present in the soil-water phase (Table 33-1) and transported with flowing ground water. Ground water underlying bis(2-chloroethyl)ether contaminated soils with low organic content are thus vulnerable to pollution by the chemical.

TABLE 33-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
BIS(2-CHLOROETHYL)ETHER IN MODEL ENVIRONMENTS(a)

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 20°C[b,c]	95.4	4.6	0.007
Saturated deep soil[d]	31.4	68.6	-

a) Calculations based on Mackay's equilibrium partitioning mode (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Used estimated soil sorption coefficient estimated with equation of Kenaga and Goring (655): K_{oc} = 109.
c) Henry's law constant taken as 1.3E-05 atm · m^3/mol at 20°C (33).
d) Used sorption coefficient calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

33.2.1.2 Sorption on Soils

The mobility of bis(2-chloroethyl)ether in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 19.5, the soil sorption coefficient (K_{oc}) is estimated to be 109. This is a relatively low number indicative of weak sorption to soils. This conclusion is in agreement with the discussion given by Callahan et al. (10).

33.2.1.3 Volatilization from Soils

Transport of bis(2-chloroethyl)ether vapors through the air-filled pores of unsaturated soils is not expected to be an important transport mechanism for near-surface soils except for dry soils. There are no data from laboratory or field tests showing actual volatilization rates from soils; however, data from studies on the Ohio River indicate volatilization would be unimportant even for losses from surface waters (10).

33.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of bis(2-chloroethyl)ether in soil/ground-water systems has not been investigated. In most cases, it should be assumed that the chemical will persist for months to years (or more). Bis(2-chloroethyl)ether that has been released into the air will eventually undergo photochemical oxidation; a tropospheric lifetime on the order of 4 hours is projected based on smog chamber data (10).

Bis(2-chloroethyl)ether under normal environmental conditions is not expected to undergo rapid hydrolysis. Two rough estimates of the hydrolysis half-life of bis(2-chloroethyl)ether (at 25°C) are 2 years and 16 years (33). The first was derived from a hydrolysis rate constant for bis(2-chloroethyl)ether in aqueous dioxane at 100°C (1.5E-05/min); the second was derived by analogy from data on chemically similar compounds. A neutral hydrolysis rate constant of 4E-06/hr (equivalent to a half-life of 20 years) was recommended based upon these data (10). The hydrolysis of bis(2-chloroethyl)ether should be independent of pH by analogy to other aliphatic hydrocarbons (10).

Literature references to microbial degradation of compounds such as bis(2-chloroethyl)ether are few and partially conflicting. The general indications are, however, that bis(2-chloroethyl)ether is resistant to biodegradation. Two biodegradation studies were cited by Callahan (10). The first study showed significant degradation of bis(2-chloroethyl)ether, which had been added to Ohio River water supplemented with sewage sludge, after a 25-30 day period of acclimation. The second study showed no degradation of bis(2-chloroethyl)ether five days after it had been added to Ohio River water. Dojlido (675) also found bis(2-chloroethyl)ether to be a biologically inert substance under the conditions of three tests, namely: (1) respirometric measurements; (2) river water tests; and (3) laboratory activated sludge units. By contrast, Tabak et al. (55) reported that bis(2-chloroethyl)ether underwent significant degradation with rapid adaptation in a static screening flask test using BOD dilution water and settled domestic wastewater as the microbial inoculum. Thus, biodegradation in acclimated wastewater treatment plants is possible.

In most soil/ground-water systems, the concentration of micro-organisms capable of biodegrading chemicals such as bis(2-chloroethyl)ether is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system

should be assumed to be of minimal importance except, perhaps, in landfills with active microbiological populations.

No data are available on the possibility of anaerobic biodegradation of bis(2-chloroethyl)ether.

33.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The properties and the above discussion of fate pathways suggest that bis(2-chloroethyl)ether is moderately adsorbed, is moderately volatile and has no significant potential for bioaccumulation. This compound may volatilize from soil surfaces, but that portion not removed by volatilization is likely to be somewhat mobile in ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of bis(2-chloroethyl)ether from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposures. In addition, there is some potential for ground water contamination (and drinking water exposure), particularly in sandy soils. Mitre (83) reported that this compound has not been found at any of the 546 National Priority List (NPL) sites. The reason for this could be that it is not commonly disposed of, and/or it is not commonly analyzed for.

The properties of bis(2-chloroethyl)ether suggest that it has the potential for movement in soil/ground-water systems. If it reaches surface water from a disposal site, several other exposure pathways are possible:

- Surface waters may be used as drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposure;
- Recreational use of these waters may result in dermal exposure;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposures from drinking contaminated ground water, partially due to the greater dilution volume in surface water. In addition, the very low BCF for bis(2-chloroethyl)ether suggests no significant potential for bioaccumulation in aquatic organisms or domestic animals.

33.2.4 Other Sources of Exposure

There are currently no data available on other sources of exposure to bis(2-chloroethyl)ether (495).

33.3 HUMAN HEALTH CONSIDERATIONS

33.3.1 Animal Studies

33.3.1.1 Carcinogenicity

Oral doses of bis(2-chloroethyl)ether have been found to be carcinogenic to mice but not to rats. Innes et al. (462) conducted a study in which they administered 100 mg/kg bis(2-chloroethyl)ether to mice by gavage daily from the seventh to twenty-eighth day of age. The dose was subsequently increased to 300 mg/kg/day for 80 weeks. This resulted in a significant incidence of liver cell tumors in the males. Weisburger et al. (497) reported negative results in rats fed daily doses of 25 and 50 mg/kg for 78 weeks. Significant mortality was observed in high-dose females only. There is also a question of whether the levels for males were high enough. Norpoth et al. (3511) also reported no significant increase in malignant or benign tumors in male or female Sprague-Dawley rats following weekly s.c. injections of 4.36 μ mole (0.35 mg/kg/day) and 13.1 μ mole (1.06 mg/kg/day) of bis(2-chloroethyl)ether. The study lasted for two years. As in the above study, the treatment levels may not have been high enough to cause an effect. In addition, the authors comment that the study was somewhat limited as only the organs exhibiting macroscopic disorders were examined histologically. In Swiss mice, weekly subcutaneous injections of 1 mg bis(2-chloroethyl)ether in 0.05 mL purified paraffin oil for 22 months produced a low incidence of sarcomas at the injection site (498).

33.3.1.2 Genotoxicity

Conflicting data can be found in the Salmonella/microsome assay. Weak positive results were reported by Mortelmans et al. (3469) in strain TA100 only with activation. The other three strains tested were negative, with or without activation. Norpoth et al. (3511) also reported weak positive results in strain TA100 with metabolic activation in the presence or absence of an NADPH generating system. Simmon and Tardiff (3655) found bis(2-chloroethyl)ether to be a strong mutagen in strain TA100 without activation, and they observed a ten-fold increase in revertants when the bacteria were treated in a desiccator. No data with activation were presented. Shirasu et al. (555) claimed bis(2-chloroethyl)ether to be a direct-acting, base-change mutagen in various strains of E. coli, B. subtilis, and S. typhimurium. Other investigators have reported negative results. No heritable translocations above control values were found in the progeny of male mice given bis(2-chloroethyl)ether daily by gavage at 3 concentrations (25, 50, and 100 mg/kg/day) for 56 consecutive days (3345). In addition, bis(2-chloroethyl)ether was not mutagenic in host-mediated

assays when given as a single oral dose or when administered for 2 weeks prior to the injection of S. typhimurium into the peritoneal cavity (3654).

33.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

No teratogenicity data are available for bis(2-chloroethyl)ether.

33.3.1.4 Other Toxicologic Effects

33.3.1.4.1 Short-term Toxicity

Bis(2-chloroethyl)ether is a severe respiratory and eye irritant. Acute, high level exposures cause narcosis and death in animals. Acute response at various air concentrations has been studied in the guinea pig and rat. Exposure of guinea pigs to continuous concentrations of 500 and 1000 ppm resulted in immediate lacrimation and nasal irritation which were followed by unsteadiness and coma. Death occurred within 5 to 8 hours due to pulmonary edema and hemorrhage. A concentration of 105 ppm resulted in death after 10 hours of continuous exposure; however, if limited to one hour, no serious systemic effects resulted but eye and nose irritation were still noted (551). Four-hour inhalation exposure to 250 ppm was lethal for rats. Three rats exposed to 1000 ppm for 45 minutes died within 2 weeks (552).

One drop of bis(2-chloroethyl)ether applied to rabbit eyes caused mild transient injury (19). On the skin of rabbits, the pure liquid had no local effect, but a sufficient amount penetrated the skin to cause death within 24 hours (46).

33.3.1.4.2 Chronic Toxicity

Rats and guinea pigs were exposed to vapor levels of 69 ppm for 93 seven-hour exposures, 5 days per week for 130 days. Only mild physiologic stress was noted. Microscopic examination revealed no cellular lesions (553).

33.3.2 Human and Epidemiologic Studies

33.3.2.1 Short-term Toxicologic Effects

Bis(2-chloroethyl)ether is a severe respiratory and eye irritant. Brief human inhalation of 500 ppm caused intolerable irritation to the eyes and nose along with coughing, nausea and vomiting. At 100 ppm, there was some irritation while at 35 ppm there were no effects (551). Grant (19) reports one instance of a human corneal burn; no details were listed. Death of a wool industry-worker presumably due to inhalation of bis(2-chloroethyl)ether vapor has been reported by Elkins (554). A TLV® of 5 ppm is recommended to prevent eye and respiratory irritation as well as lung injury (2).

33.3.2.2 Chronic Toxicologic Effects

It is reported that repeated exposures to low concentrations may cause mild bronchitis (38). No other data are available.

33.3.3 Levels of Concern

Based on the evidence of liver tumors induced in mice administered bis(2-chloroethyl)ether, the USEPA has specified an ambient water quality criterion for this compound of zero. In that attainment of a zero concentration level may be infeasible in some cases, the concentrations of bis(2-chloroethyl)ether in water calculated to result in incremental lifetime cancer risks of 1E-05, 1E-06 and 1E-07 from ingestion of both water and contaminated aquatic organisms were estimated to be 0.3, 0.03 and 0.003 μg/L, respectively (3770). Risk estimates are expressed as a probability of cancer after a lifetime consumption of two liters of water per day and consumption of 6.5 g of contaminated fish per day. Thus a risk of 1E-05 implies that a lifetime daily consumption of two liters of drinking water and 6.5 g of contaminated fish at the criterion level of 0.3 μg/L bis(2-chloroethyl)ether would be expected to produce one excess case of cancer above the normal background incidence for every 100,000 people exposed. It should be emphasized that these extrapolations are based on a number of assumptions and should be taken as crude estimates of human risk at best.

IARC (3882) lists bis(2-chloroethyl)ether in category 3 (insufficient evidence of carcinogenicity) in its weight-of-evidence ranking for potential carcinogens. The USEPA (3879) lists bis(2-chloroethyl)ether as a Group B2 carcinogen (probable human carcinogen).

OSHA (3539) has established an 8-hr TWA of 5 ppm and a 15-min STEL of 10 ppm for bis(2-chloroethyl)ether. The ACGIH (3005) recommends a threshold limit value of 5 ppm, set to prevent eye and throat irritation, as well as lung injury.

33.3.4 Hazard Assessment

Oral administration of bis(2-chloroethyl)ether induced liver tumors in mice (462). No carcinogenic response was observed, however, in another oral study conducted with rats (497). Based on the data for mice, the USEPA (3749) calculated an upper-limit incremental cancer risk of 1.14 $(mg/kg/day)^{-1}$ for ingestion of bis(2-chloroethyl)ether.

A heritable translocation assay conducted with mice was negative (3345). Negative results were also reported in a host-mediated assay (3654). Genotoxic responses have been documented in various bacterial test systems (555, 3655, 3469, 3511). There are no data available regarding potential reproductive toxicity associated with bis(2-chloroethyl)ether exposure.

Bis(2-chloroethyl)ether is a severe respiratory and eye irritant. Brief human inhalation exposure to 500 ppm caused intolerable irritation to the eyes and respiratory tract; no effects occurred at a level of 35 ppm (551). Reference to possible effects of chronic exposure to bis(2-chloroethyl)ether is limited to an indication of mild bronchitis associated with repeated, low-level exposures (38). The scarcity of health effects data for either humans or experimental animals makes estimates of dose-response relationships uncertain, particularly with regard to long-term, low-level oral exposure.

33.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of bis(2-chloroethyl)ether concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of bis(2-chloroethyl)ether, one of the EPA priority pollutants, in aqueous samples include EPA Methods 611, 625, and 1625 (65). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extracted is injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; bis(2-chloroethyl)ether is then detected with a halide specific detector (Method 611) or a mass spectrometer (Method 625 and 1625).

The EPA procedure recommended for bis(2-chloroethyl)ether analysis in soil and waste samples, Method 8250 (63), differs from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection. Determinations are made by gas chromatography/mass spectrometry. A screening procedure using capillary GC has also been described (3356).

Typical bis(2-chloroethyl)ether detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Nonaqueous Detection Limit
0.3 μg/L (Method 611) 5.7 μg/L (Method 625) 10 μg/L (Method 1625)	3.8 μg/g (Method 8250)

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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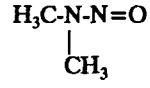
COMMON SYNONYMS:	CAS REG.NO.: 62-75-9 FORMULA: $C_2H_6N_2O$ NIOSH NO: IQ0525000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C (59) 3.03 mg/m³ ≈ 1 ppm; 0.33 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 74.1
DMN DMNA Dimethylnitrosamine N-Methyl-N-nitrosomethanamine N-Nitrosodimethylamine NDMA		

REACTIVITY	NDMA degrades under uv light (probably to diazomethane), can be oxidized by strong oxidizing agents to the nitramine (dimethylnitramine), and can be reduced to the corresponding hydrazine or amine (1,1-dimethylhydrazine, dimethylamine)(12). NDMA is relatively resistant to hydrolysis (3867). Toxic fumes of NO_x may be emitted if NDMA is heated to decomposition (3867).

PHYSICO-CHEMICAL DATA	• Physical State: Liquid (at 20°C)	(23)
	• Color: Yellow	(23)
	• Odor: Faint, characteristic odor	(59)
	• Odor Threshold: No data	
	• Density: 1.0060 g/mL (at 20°C)	(23)
	• Freeze/Melt Point: No data	
	• Boiling Point: 152.00°C	(23)
	• Flash Point: No data	
	• Flammable Limits: No data	
	• Autoignition Temp.: No data	
	• Vapor Pressure: 8.10 mm Hg (at 25°C)	(33)
	• Satd. Conc. in Air: 3.2900E+04 mg/m³ (at 20°C)	(1219)
	• Solubility in Water: Infinite (at 20°C)	(ADL estim)
	• Viscosity: No data	

PHYSICO-CHEMICAL DATA (Cont.)	• Surface Tension: No data • Log (Octanol-Water Partition Coeff.): -0.57 (29) • Soil Adsorp. Coeff.: 1.10E+01 (654) • Henry's Law Const.: 3.30E-05 atm · m^3/mol (at 25°C) (33) • Bioconc. Factor: 1.00E-02 (estim), 6.50E-02 (estim) (659)
PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems, primarily with infiltrating or flowing groundwater. Weak sorption to soils. Volatilization is important in near-surface, dry soils. Chemical is resistant to hydrolysis, but may undergo slow biodegradation.
PATHWAYS OF EXPOSURE	The primary pathway of concern from soil-water system is the migration of N-nitrosodimethylamine to groundwater drinking water supplies, although there is no evidence that such migration has occurred in the past. Inhalation resulting from volatilization from surface soils could occur in some situations. Human exposure may also occur from either food or tobacco smoke.
HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: (54,482) NDMA is highly toxic to the liver, inducing severe necrosis. Systemic effects are characterized by nausea, vomiting, abdominal cramps, headache and fever. Jaundice and internal hemorrhaging may also occur, and coma and death may follow. The liquid and vapor are not especially irritating to the eyes or skin, and warning properties are poor. Acute Toxicity Studies: INHALATION: LC_{50} 78 ppm · 4 hr Rat (59) ORAL: LD_{50} 58 mg/kg Rat (3504) LD_{50} 27 mg/kg Rat (3504) (Range of 27-41)

HEALTH HAZARD DATA	Long-Term Effects: Liver damage (necrosis), internal hemorrhages Pregnancy/Neonate Data: Not teratogenic in animals; embryotoxic at maternally toxic doses; not gonadotoxic Genotoxicity Data: Sufficient evidence of genotoxicity Carcinogenicity Classification: IARC - Group 2A (probably carcinogenic to humans) NTP - No data EPA - No data

HANDLING PRECAUTIONS (299)	Handling of NDMA is to be conducted as outlined in 29CFR 1910.1016. OSHA recommends a half-face, filter type respirator in accordance with 29CFR 1910.134. However, a respirator affording higher levels of protection may be substituted. Full-body protective clothing and gloves should be used.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA PEL (8-hr TWA): OSHA carcinogen - all contact should be avoided.
- AFOSH PEL (8-hr TWA): avoid all contact - carcinogen

Criteria
- NIOSH IDLH (30-min): NIOSH has recommended that the substance be treated as a potential human carcinogen
- ACGIH TLV (8-hr TWA): avoid exposure (A2, suspected human carcinogen) (skin)

WATER EXPOSURE LIMITS:

Drinking Water Standards
None established

EPA Health Advisories and Cancer Risk Levels
None established

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WHO Drinking Water Guideline

No information available.

EPA Ambient Water Quality Criteria

- Human Health (459)
  - Based on ingestion of contaminated water and aquatic organisms (1E-05, 1E-06, 1E-07 cancer risk), 14 ng/L, 1.4 ng/L, 0.14 ng/L.
  - Based on ingestion of contaminated aquatic organisms only (1E-05, 1E-06, 1E-07 cancer risk), 160 ug/L, 16 ug/L, 1.6 ug/L.

- Aquatic Life (459)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 5850 ug/L of nitrosamines.

    chronic toxicity:
    no criterion established due to insufficient data.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 3300 mg/L of nitrosamines.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:

No reference dose available.

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

N-nitrosodimethylamine is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), steam electric power generating (3802), and metal finishing (3768). Limitations vary depending on the type of plant and industry.

Resource Conservation and Recovery Act (RCRA)

N-nitrosodimethylamine is listed as an acute hazardous waste (P082) and a hazardous waste constituent (3783, 3784). This chemical is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). N-nitrosodimethylamine is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

N-nitrosodimethylamine is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 0.454 kg (3766). N-nitrosodimethylamine is designated an extremely hazardous substance under SARA Title III Section 302. Any facility at which this chemical is present in excess of its threshold planning quantity of 10 pounds must notify state and local emergency planning officials. If n-nitrosodimethylamine is released from a facility in excess of its reportable quantity (RQ), local emergency planning officials must be notified (3787).

Marine Protection Research and Sanctuaries Act (MPRSA)

Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to N-nitrosodimethylamine should be avoided. This chemical is designated an OSHA carcinogen. Detailed regulations exist in 29CFR1910.1016 for areas where N-nitrosodimethylamine is manufactured, processed, used, packaged, released, handled or stored. These include requirements for reporting maintenance and decontamination (299).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated this chemical as a hazardous substance with a reportable quantity of 0.454 kg, subject to requirements for packaging, labeling, and transportation (3180).

- State Water Programs
  All states have adopted EPA Ambient Water Quality Criteria and PDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

  KANSAS
  Kansas has an action level of 0.0014 μg/L for N-nitrosodimethylamine in ground-water (3213).

  NEW YORK
  New York has set an MCL of 50 μg/L in drinking water (3501).

  OKLAHOMA
  Oklahoma has set an enforceable Toxic Substance Goal of 0.8 ng/L or nitrosamines in surface waters classed for public and private water supplies (3534).

Proposed Regulations

- Federal Programs
  No proposed regulations are pending.

- State Water Programs
  MOST STATES
  Most states are in the process of revising their Water Programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officers is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA
  Minnesota has proposed a Recommended Allowable Limit (RAL) of 0.007 μg/L for drinking water (3451).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, carcinogen or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

34.1 MAJOR USES

Prior to April 1976, N-nitrosodimethylamine (NDMA) was used as an intermediate in the production of 1,1-dimethylhydrazine, a liquid rocket fuel believed to have contained up to 0.1% NDMA as an impurity (466). The chemical has also been used as an industrial solvent, as an antioxidant, in lubricants and condensers to increase the dielectric constant, as a nematocide, as a softener for copolymers, as an inhibiter of nitrification in soil, and in active metal anode-electrolyte systems (high energy batteries) (3867). No evidence was found that NDMA is used at present, except for research purposes (466).

34.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

34.2.1 Transport in Soil/Ground-water Systems

34.2.1.1 Overview

N-Nitrosodimethylamine may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways for low soil concentrations can be assessed by equilibrium partitioning, as shown in Table 34-1. These calculations predict the partitioning of NDMA among soil particles, soil water, and soil air. The portions of NDMA associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model predict that a major fraction (68%) of the chemical will be sorbed on the soil; however, a substantial amount (32%) of the chemical is expected to be present in the soil-water phase and can thus migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion, and diffusion. For the small portion of NDMA in the gaseous phase of the soil (0.1%), diffusion through the soil-air pores up to the ground surface and subsequent removal by wind will be possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the NDMA (96%) is likely to be present in the soil-water phase (Table 34-1) and transported with flowing ground water. Ground water underlying NDMA-contaminated soils with low organic content is thus vulnerable to pollution by the chemical.

TABLE 34-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
N-NITROSODIMETHYLAMINE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	67.8	32.1	0.1
Saturated deep soil[d]	4.4	95.6	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient based on equation given by Means et al. (611): K_{oc} = 10.6.
c) Henry's law constant taken as 3.3E-05 atm · m^3/mol at 25°C (33).
d) Used sorption coefficient calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

34.2.1.2 Sorption on Soils

The mobility of NDMA in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 0.27, the soil sorption coefficient (K_{oc}) is estimated to be 10.6. This is a very low number indicative of very weak soil sorption potential. In one laboratory test, the mobility of NDMA through a column of wet soil was found to be equivalent to that of sodium chloride, whose ions are only weakly sorbed on soils (10).

34.2.1.3 Volatilization from Soils

Transport of NDMA vapors through the air-filled pores of unsaturated soils can be an important transport mechanism for near-surface or dry soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents, and barometric pressure changes; important physicochemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31).

Laboratory experiments using glass chambers were performed by Oliver (671) to show that NDMA volatilizes so rapidly from warm (22°C) soils following surface applications that 30 to 80% of the application may be lost during the first few hours. Incorporation of NDMA into the soil reduces the rate of volatilization.

Because NDMA is infinitely soluble in water, its rate of volatilization will be greatly lowered if significant amounts of water are present. Data documenting the relatively slow rate of volatilization from surface waters are summarized by Callahan et al. (10).

34.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of NDMA in soil/ground-water systems is not well documented. In most cases, it should be assumed that NDMA will persist for months to years (or more). NDMA that has been released into the air will rapidly undergo photochemical oxidation; a tropospheric lifetime of less than one hour has been reported (10).

NDMA under normal environmental conditions is not expected to undergo rapid hydrolysis (10, 33). Only under conditions of high temperature and low pH is the chemical easily hydrolyzed (10).

Microbial degradation of NDMA in soils appears possible, but not at very fast rates. Oliver et al. (674) investigated the degradation of nitrosamines (including NDMA) in aerobic soils and found that they were degraded with a half-life of about three weeks; no degradation was seen in sterile soils. Mallik and Tesfai (673) also investigated the biodegradation of NDMA in a variety of soils. In unamended sandy loam, 17% of added NDMA was lost in 10 days of incubation; no further loss was noted during the next 30 days of incubation. Significant enhancement of the degradation was seen when tests were run with soil amended with wheat straw (i.e., having a higher content of organic matter).

Data cited by Callahan et al. (10) indicate that NDMA is not easily biodegraded in lake water; it appeared to be slowly degraded in sewage, but it was not affected by the anaerobic organisms of bog sediments.

In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as NDMA is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in landfills with active microbiological populations.

34.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The properties of NDMA and the above discussion of fate pathways suggest that N-nitrosodimethylamine is moderately volatile, very weakly adsorbed to soil, and has no significant potential for bioaccumulation. The compound may volatilize from soil surfaces, but that portion not removed by volatilization is likely to be mobile in ground water. These fate characteristics suggest several potential exposure pathways.

Volatilization of N-nitrosodimethylamine from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposure. In addition, the potential for ground water contamination is high, particularly in sandy soils. Mitre (83), however, reported that this compound was not found in either ground water or surface water at any of the 546 National Priority List (NPL) sites. The possible explanation is that NDMA is not commonly disposed of or not commonly analyzed for.

In any case, the properties of N-nitrosodimethylamine suggest that it has the potential for movement in ground water. If it reaches surface water, several other exposure pathways are possible:

- Surface water may be used as drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may be consumed, also resulting in ingestion exposure;
- Recreational use of these waters may result in dermal exposure;
- Domestic animals may consume or be dermally exposed to contaminated ground or surface waters; the consumption of meats and poultry could then result in ingestion exposure.

In general, exposures associated with surface water contamination can be expected to be lower than exposure from drinking contaminated ground water, partially due to the larger dilution volume common in surface water. In addition, the low BCF for this compound suggests no significant potential for bioaccumulation in aquatic organisms or domestic animals.

34.2.4 Other Sources of Human Exposure

Nitrosamines, including NDMA, are present in a wide variety of food as reported by Fine (757) and Scanlan (758). Nitrosamines are found most commonly in cured meats, particularly cooked bacon; beer; Scotch whiskey; some cheeses, especially Gouda and Edam types; nonfat dry milk and buttermilk; and sometimes fish. Levels of total volatile nitrosamines are generally less than 5 μg/kg in these foods (758). The average daily intake of volatile nitrosamines from food is estimated to be about 1 μg per person (758). NDMA is also found in rubber pacifiers and baby-bottle nipples and occasionally in cosmetics (757, 758). Smokers are exposed to an estimated 6.5 ng NDMA per cigarette from mainstream smoke (758); undiluted sidestream smoke may contain 20 to 100 times as much NDMA as does the mainstream smoke (3871).

NDMA does not appear to be common in either drinking water or ambient air (757). Brodzinsky and Singh (84) compiled all available atmospheric monitoring data for a number of organic compounds, including data on NDMA for 404 locations. In rural and remote areas, the median concentration of NDMA was 0.018 $\mu g/m^3$; the median concentration in urban and suburban areas was 0.028 $\mu g/m^3$, and in source-dominated areas, 0.042 $\mu g/m^3$. Indoor levels of NDMA measured in restaurants and public places have been between 0.01 and 0.24 $\mu g/m^3$ and are attributed primarily to tobacco smoke (3871).

34.3 HUMAN HEALTH CONSIDERATIONS

34.3.1 Animal Studies

34.3.1.1 Carcinogenicity

NDMA is carcinogenic in all animal species tested including mice, rats, hamsters, guinea pigs, rabbits, and fish. It is carcinogenic after single doses as well as after long-term administration by various routes, including ingestion and inhalation. NDMA produces tumors primarily in the liver, kidney, and respiratory tract. The most significant studies will be discussed below; more complete summaries can be found in the IARC monograph (466), Schut and Castonguay (3873), and Magee el al. (479).

In mice, a concentration of 50 mg/L NDMA in drinking water for one week was sufficient to induce lung and kidney tumors (484), and a dose equivalent to 0.4 mg/kg bw per day added to drinking water (total dose, 89 mg/kg bw) induced lung and liver tumors (485). A dose-response relationship was seen for lung tumors in mice following a single subcutaneous injection of NDMA; the responses ranged from an incidence of 29% with 1 mg/kg to 67% for a dose of 8 mg/kg (486). Single or

repeated injections (route not specified) of 12.5 to 75 mg/kg bw NDMA during the last days of pregnancy resulted in lung adenomas and hepatomas in the offspring (487).

In rats, single oral or intraperitoneal doses up to 30 mg/kg resulted in kidney tumors (488, 489). NDMA also induced a low frequency of kidney tumors in the offspring of rats given a total of 11 mg (route not specified) during pregnancy (490).

Rabbits and guinea pigs fed diets containing 25 mg/kg NDMA for 6 to 60 weeks developed liver carcinomas with lung metastases (491, 492).

In rats, long-term exposure to relatively low doses induced mainly liver tumors, whereas a single or a few high doses over a short period induced mainly kidney tumors (480). Kidney tumors have been induced in rats with low doses of NDMA combined with treatments that decreased the activity of NDMA-metabolizing enzymes in the liver. These treatments included the administration of carbon tetrachloride or the feeding of diets containing high carbohydrate and low protein levels (466). Partial removal of the liver also led to an increased tumor incidence in rats given intraperitoneal injections of 10 mg/kg NDMA. The incidence was greatest (43%) when NDMA was administered 24 hours after surgical removal of part of the liver, as opposed to 72 or 92 hours later, when the incidences were 28% and 12%, respectively (493).

IARC (3869) lists NDMA in Group 2A (probably carcinogenic to humans) in its weight-of-evidence ranking for potential carcinogens.

34.3.1.2 Genotoxicity

In the presence of metabolic activation, N-nitrosodimethylamine (NDMA) is genotoxic in bacteria and yeasts (467, 3276, 3870). There is a correlation between the ability to produce mutations in S. typhimurium G-46 and susceptibility for kidney tumors in different strains of mice (468). NDMA injected subcutaneously into mice at doses of 30 or 300 mg/kg bw was mutagenic in a blood-mediated assay in which E. coli K-12 cells were injected intravenously (469). Chromosome aberrations were found in Chinese hamster liver cells and rat lymphocytes after intraperitoneal injections of the animals with 5 g/kg and 30 mg/kg, respectively (470, 471), and mutations to ouabain resistance were increased in Chinese hamster V79 cells cultured in the presence of NDMA (3389). Cultured mouse lymphoma cells showed a dose-dependent mutagenic response at the thymidine kinase locus after treatment with this agent (3020). Hsu et al. (3868) demonstrated that human hepatocytes in vitro can activate NDMA and release mutagenic metabolites (as indicated by mutagenicity in Chinese hamster V79 cells) as effectively as mouse or rat hepatocytes.

A significant increase in sister chromatid exchanges was observed in femoral bone marrow cells of male mice injected with NDMA 24 hours prior to sacrifice (3550). Inoue et al. (3324) observed significant increases in sister chromatid exchanges in

human lymphocytes when whole blood was treated with NDMA for one hour; this increase was seen only in the presence of metabolic activation. Subcutaneous doses of 4.4 mg/kg NDMA in mice produced a significant increase in dominant lethal mutations, as determined by the number of dead implants (474).

Unscheduled DNA synthesis has been observed in cultured human fibroblasts and isolated rat hepatocytes following treatment with NDMA (472, 473) and in hepatocytes of rats administered NDMA by gavage two hours prior to sacrifice (3455). Small sections of human gingiva treated in organ culture with NDMA for 2 hours showed a dose-dependent increase in unscheduled DNA synthesis (3318). Significant amounts of 7-methylguanine and O(6)-methylguanine were observed in human liver samples from a case of probable NDMA poisoning, while no detectable methylated purines were found in control cases (deaths from Reye's syndrome or methyl bromide poisoning) (3287); these findings provide evidence that NDMA can cause alkylation of purines in vivo.

34.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

NDMA is embryotoxic but not teratogenic in rats. Single oral or intraperitoneal doses of 30 mg/kg or 20 mg/kg given intravenously to pregnant rats caused an increase in fetal mortality, particularly when given on days 3, 9, 10 or 12 of gestation (476). Intraplacental injections of 0.1 to 0.3 mg NDMA on gestational day 13 resulted in the death of all rat embryos (477).

In the Russian literature, Andropova et al. (3028) reported embryotoxicity in rats exposed to NDMA by single oral administration of 0.01 to 14 mg/kg or inhalation of 0.1 mg/m^3 for 4 months, in agreement with their available literature. Exposure to NDMA by inhalation of 0.014 mg/m^3 for 4 months had no effect on some generations of animals and was not gonadotoxic.

The acute toxic effect of NDMA has been found to be greater in pregnant than nonpregnant rats, and especially so near the end of pregnancy. Significant serological and histopathological changes were observed in pregnant Holzman rats given single oral doses of 15 or 20 mg/kg NDMA during days 7 through 18 of gestation. These changes included increased BUN, SGOT, triglyceride, and inorganic phosphorus levels, as well as increased liver weights. Decreases were observed in kidney, adrenal, and thyroid weights and also in the levels of serum cholesterol and glucose. None of these effects was observed in non-pregnant controls administered the same doses. The treatment was not lethal to nonpregnant rats or to pregnant rats up to day 16 of pregnancy. However, oral doses of 15 and 20 mg/kg on day 18 resulted in death rates of 9.4 and 35.3%, respectively (478).

In a sister-chromatid exchange (SCE) and cell replication kinetics study conducted by Sharma et al. (3637), NDMA induced significant increases ($p < 0.001$) in SCEs in both maternal and fetal cells following ip exposure to 20, 40, 60, or 100

mg/kg NDMA on gestational day 13. The maternal and fetal cells also showed a significant heterogeneity among doses with respect to the number of M1, M2, and M3 cells.

34.3.1.4 Other Toxicologic Effects

34.3.1.4.1 Short-term Toxicity

Dialkylnitrosamines such as NDMA are characteristically liver toxins. The relationship between structure and acute toxicity is not fully understood, but toxicity appears to decrease with chain length. Thus, NDMA is the most toxic of these compounds, having an oral LD_{50} between 27 and 58 mg/kg in rats (482, 3872). The major toxic effect in various species arises from severe centrilobular necrosis of the liver (479). Single doses of 20 to 40 mg/kg have produced severe liver damage in rats, dogs, rabbits, and guinea pigs. Mink appear to be especially sensitive to NDMA, experiencing wide-spread liver degeneration and necrosis of hepatocytes after being fed a diet containing 2.5 to 5 mg/kg NDMA for 7 to 11 days. Sheep and cattle have been found to be more sensitive than laboratory animals to the toxic effects of NDMA. Sheep given a single dose of 5 mg/kg or 12 doses of 0.5 mg/kg either died or were severely affected with respiratory difficulties. Cattle given daily doses of 0.1 mg/kg NDMA showed pronounced hepatotoxic effects in 1 to 6 months (480). Other organs in animals are much less severely affected by NDMA than is the liver. The main features of NDMA toxicity are peritoneal and pleural exudates, which may contain a high proportion of blood. There is also a tendency to hemorrhage into the lungs and other organs. In protein-deficient rats, there may be detectable necrosis of the testes or renal tubules (479).

Inhalation LC_{50} values of 57 ppm x 4 hr and 78 ppm x 4 hr have been reported for the mouse and rat, respectively (12, 3872).

34.3.1.4.2 Chronic Toxicity

When chronically exposed to nitrosamines, rats and other experimental animals exhibit various pathological changes of the liver, including biliary hyperplasia and fibrosis (479). Chronic administration of NDMA induces tumors in the liver and other organs (see 34.3.1.1, Carcinogenicity).

34.3.2 Human and Epidemiologic Studies

34.3.2.1 Short-term Toxicologic Effects

The effects of human exposure to NDMA were first reported by Freund in 1937 (481). He described illness in 2 workers who were engaged in NDMA-production. They developed headaches, drowsiness, backache, abdominal cramps, nausea, weakness, and giddiness. After repeated exposures, one of the workers developed ascites (accumulation of fluid in the abdominal cavity) and jaundice. He left his job,

but continued to be fatigued for many months. The other worker inhaled more NDMA fumes while cleaning up a spill. Six days after exposure, he developed abdominal cramps and distention and became jaundiced. He died 8 weeks after the onset of illness. Autopsy revealed extensive necrosis of the liver and hemorrhages throughout the small intestine, trachea, and bronchi.

In a case of NDMA poisoning, 5 family members became ill within a few hours of ingesting lemonade intentionally contaminated with NDMA. Symptoms of gastrointestinal illness persisted for several days. Three of the victims recovered within 16 days. The remaining two victims, males aged 11 months and 24 years, became comatose and died within 5 days. Autopsies revealed extensive hepatic necrosis and hemorrhages throughout the lungs, gastrointestinal tract, and brain. The lethal doses were estimated to be 1.3 g for the adult and 300-400 mg for the child (482).

It must be emphasized that NDMA is a highly toxic compound and that exposure to it by any route should be avoided. It has been suggested that vapor levels of 250 mg/m^3 (82 ppm) be considered clearly dangerous (12).

34.3.2.2 Chronic Toxicologic Effects

One case of long-term human ingestion of NDMA has been reported (483, 3865). The victim received repeated doses of 200-300 mg NDMA at 5 month intervals. The initial symptoms were gastrointestinal in nature. Within 2 years, she developed anemia, jaundice, and symptoms of progressive liver disease. Three years after the initial onset of symptoms, she died of pulmonary edema and cardiac fibrillation secondary to hyperkalemia (increased serum potassium) due to a hemolytic crisis. Autopsy revealed both cirrhosis and hemorrhages in the trachea and intestines. This case is notable because the cirrhosis seen was of the periportal-type as opposed to the centrilobular type usually seen after NDMA poisoning (483). The estimated total dose in this case was less than 1.5 g; the mean daily dose was probably less than 50 $\mu g/kg$ (3865).

34.3.3 Levels of Concern

Based on the evidence of liver tumors induced in rats administered NDMA, the USEPA has specified an ambient water quality criterion for this compound of zero. Because attainment of a zero concentration level may be infeasible in some cases, estimates were made of the concentrations of NDMA in water expected to result in incremental lifetime cancer risks of 1E-05, 1E-06, and 1E-07, from ingestion of both water and contaminated aquatic organisms. These values are 14, 1.4, and 0.14 ng/L, respectively (459). Risk estimates are expressed as the probability of cancer after a lifetime consumption of two liters of water per day and consumption of 6.5 g of contaminated fish per day. Thus a risk of 1E-05 implies that a lifetime daily consumption of two liters of drinking water and 6.5 g of contaminated fish at the criterion level of 14 ng/L NDMA would be expected to produce one excess case of

cancer above the normal background incidence for every 100,000 people exposed. It should be emphasized that these extrapolations are based on a number of assumptions and should be taken as crude estimates at best of the true risk to humans.

IARC (3869) lists NDMA in Group 2A (probably carcinogenic to humans) in its weight-of-evidence ranking for potential carcinogens.

OSHA (3539) and the ACGIH (3005) list NDMA as a suspect human carcinogen; all contact with NDMA should be avoided.

34.3.4 Hazard Assessment

NDMA is carcinogenic in all animal species tested and has induced tumors of the liver, kidney, and respiratory tract when administered by various routes. The compound has been shown to be carcinogenic after single doses to experimental animals, and animals have developed cancers following prenatal exposure to it. Although no data are available linking human exposure to NDMA with carcinogenic effects, for practical purposes NDMA should be regarded as a human carcinogen.

NDMA is mutagenic in bacteria, yeast and mammalian cells. Fetotoxic but not teratogenic effects have been noted in rats.

NDMA is highly toxic to the liver, inducing severe centrilobular necrosis along with internal bleeding, ascites, and jaundice in most tested species.

Systemic effects in humans are characterized by nausea, vomiting, abdominal cramps, and diarrhea; headache, fever, weakness, enlargement of the liver, and jaundice may also occur. There have been several cases in humans of severe liver injury following exposure to this compound.

34.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of N-nitrosodimethylamine concentrations in soil and water requires collection and laboratory analysis of representative field samples. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in amber glass containers; extraction of samples should be completed within 7 days of sampling and analysis within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of aqueous samples of N-nitrosodimethylamine, an EPA priority pollutant, include EPA Methods 607, 625, and 1625 (65). Prior to analysis, samples are extracted with methylene chloride using either a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto a gas chromatographic (GC) column using a

solvent flush technique. The GC column is programmed to separate the semi-volatile organic compounds; N-nitrosodimethylamine is then detected with a nitrogen-phosphorus detector (Method 607) or a mass spectrometer (Methods 625 and 1625). A method based on the conversion of the nitrosamine to NO2 with subsequent detection by chemiluminescence has also been described (3107).

The EPA procedure recommended for the analysis of N-nitrosodimethylamine in soil and waste samples, Method 8250 (63), differs from the procedures for aqueous samples primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection. Determinations are made by mass spectrometry. It has been noted that N-nitrosodimethylamine may be difficult to separate from the solvent using the prescribed column conditions described in Method 8250 (63).

Another method for the determination of this compound is based upon gas chromatography and fourier transform infrared spectrometry (GC-FTIR) (3257). Methylene chloride extracts of the waste sample are concentrated and analyzed by either packed or capillary GC. The extracts may also be cleaned up by gel permeation to reduce background and maintain high identification limits.

Typical N-nitrosodimethylamine detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The detection limit for N-nitrosodimethylamine with Method 625 was not determined. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.15 μg/L (Method 607) 50 μg/L (Method 1625)	1 μg/g (Method 8250)

34.5 REFERENCES

Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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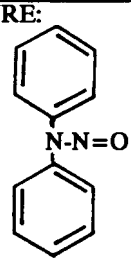
COMMON SYNONYMS:	CAS REG.NO: 86-30-6 FORMULA: $C_{12}H_{10}N_2O$ NIOSH NO: JJ9800000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C (12) 8.09 mg/m³ ≈ 1 ppm; 0.1236 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 198.24
Diphenyl-N-nitroso-amine Diphenylnitrosamine N-Nitroso-N-phenyl-benzamine N-Nitroso-N-phenyl-aniline N-Nitrosodiphenyl-amine NDPA NDPHA		

REACTIVITY	N-nitrosodiphenylamine may undergo trans-nitrosation reactions with secondary amines to convert them to N-nitrosamines. NDPA is probably degraded under uv light (photolysis). Technical grades of NDPA may decompose at temperature above 85°C to produce oxides of nitrogen.

PHYSICO-CHEMICAL DATA	• Physical State: Solid, crystalline (at 20°C)	(23)
	• Color: Yellow to green	(23,460)
	• Odor: No data	
	• Odor Threshold: No data	
	• Density: 1.2300 g/mL (at 20°C)	(59)
	• Freeze/Melt Point: 66.50°C	(59)
	• Boiling Point: No data	
	• Flash Point: No data	
	• Flammable Limits: No data	
	• Autoignition Temp.: No data	
	• Vapor Pressure: 6.30E-04 mm Hg (at 25°C)	(1219)
	• Satd. Conc. in Air: 7.0 mg/m³ (at 20°C)	(1219)
	• Solubility in Water: 1.13E+02 mg/L (at 25°C)	(1219)
	• Viscosity: No data	
	• Surface Tension: No data	
	• Log (Octanol-Water Partition Coeff.): 3.13	(29)

PHYSICO-CHEMICAL DATA (Cont.)	• Soil Adsorp. Coeff.: 6.50E+02 (652) • Henry's Law Const.: 1.40E-06 (1219) atm · m^3/mol (at 25°C) • Bioconc. Factor: 6.50E+01 (estim), (659,459) 2.17E+02 (bluegill)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems, primarily with infiltrating or flowing groundwater. Moderately strong sorption to soils. Chemical is resistant to hydrolysis but may undergo slow biodegradation.

PATHWAYS OF EXPOSURE	The primary pathway of concern from the soil-water system is the migration of NDPA to groundwater drinking water supplies, although there is no evidence that such migration has occurred in the past. Inhalation resulting from volatilization from surface soils could occur in some situations.

HEALTH HAZARD DATA	Signs and Symptoms of Short-term Human Exposure: No data are available regarding human exposure; animal data are also sparse. Acute Toxicity Studies: ORAL: LD_{50} 1650 mg/kg — Rat (47) LD_{50} 3850 mg/kg — Mouse (3504) LD_{50} 3000 mg/kg — Rat (3504) Long-Term Effects: Possible liver damage Pregnancy/Neonate Data: No data Genotoxicity Data: Predominantly negative Carcinogenicity Classification: IARC- Group 3 (not classifiable as to its carcinogenicity to humans) NTP - Positive evidence for rats, negative for mice EPA - No data

HANDLING PRECAUTIONS	Handle chemical only with adequate ventilation • There are no formal guidelines available for this chemical with respect to respirator use. Use a self-contained breathing apparatus with a full facepiece (or the equivalent) where there is any doubt as to the efficacy of gas masks or cartridge-type respirators • Chemical goggles if there is a probability of eye contact • Appropriate clothing to prevent repeated or prolonged skin contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): None established
- AFOSH PEL (8-hr TWA): None established

Criteria
- NIOSH IDLH (30-min): None established
- ACGIH TLV® (8-hr TWA): None established
- ACGIH STEL (15-min): None established

WATER EXPOSURE LIMITS:

Drinking Water Standards
None established

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Guideline
No information available.

EPA Ambient Water Quality Criteria
- Human Health (459)
  - Based on ingestion of contaminated water and aquatic organisms (1E-05, 1E-06, 1E-07 cancer risk), 49 μg/L, 4.9 μg/L, 0.49 μg/L.
  - Based on ingestion of contaminated aquatic organisms only (1E-05, 1E-06, 1E-07 cancer risk), 161 μg/L, 16.1 μg/L, 1.61 μg/L.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- Aquatic Life (459)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 5.85 mg/L nitrosamines.

    chronic toxicity:
    no criterion established due to insufficient data.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 3.3 g/L nitrosamines.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES:
No reference dose available

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs

  Clean Water Act (CWA)
  N-Nitrosodiphenylamine is listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent guidelines and standards (351, 3763). Effluent limitations specific to this chemical have been set in the following point source categories: electroplating (3767), steam electric power generating (3802), and metal finishing (3768). Limitations vary depending on the type of plant and industry.

  Resource Conservation and Recovery Act (RCRA)
  N-nitrosodiphenylamine is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
N-nitrosodiphenylamine is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 45.4 kg (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of n-nitrosodiphenylamine must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated this chemical as a hazardous substance with a reportable quantity of 45.4 kg, subject to requirements for packaging, labeling, and transportation (3180).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

KANSAS
Kansas has an action level of 71 μg/L for ground-water (3213).

NEW YORK
New York has an MCL of 50 μg/L for drinking water, and a nonenforceable water quality guideline of 50 μg/L for surface and ground-waters (3501).

OKLAHOMA
Oklahoma has set a nonenforceable Toxic Substance Goal of 0.8 ng/L for nitrosamines in surface waters classed for public and private water supply (3534).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 293 μg/L and a chronic guideline of 6.5 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

Proposed Regulations

- Federal Programs

  NONE
  No proposed regulations are pending.

- State Water Programs

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officers is advised. Changes are projected for 1989-90 (3683).

  MINNESOTA
  Minnesota has proposed a Recommended Allowable Limit (RAL) of 70 μg/L for drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 1462 μg/L for surface waters, and chronic criteria of 17 μg/L for designated surface waters and 70 μg/L for designated ground-waters. These criteria are for the protection of human health (3452).

EEC Directives

Directive on Ground-Water (538)
Direct discharge into ground-water (i.e., without percolation through the ground or subsoil) of organohalogen compounds and substances which may form such compounds in the aquatic environment, substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment, and mineral oils and hydrocarbons is prohibited. Appropriate measures deemed necessary to prevent indirect discharge into ground-water (i.e., via percolation through ground or subsoil) of these substances shall be taken by member countries.

Directive on the Discharge of Dangerous Substances (535)
Orgaohalogens, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero-emission applies to discharge of these substances into ground-water.

Directive on Toxic and Dangerous Wastes (542)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds, excluding inert polymeric materials and other substances referred to in this list or covered by other Directives concerning the disposal of toxic and dangerous waste; chlorinated solvents; organic solvents; biocides and phyto-pharmaceutical substances; ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

35.1 MAJOR USES

N-nitrosodiphenylamine (NDPA) is used almost exclusively as an intermediate in the manufacture of para-nitrosodiphenylamine and as a rubber-processing chemical. Its major use in the rubber industry is as an anti-scorching agent, or vulcanization retarder, during rubber compounding (459, 460, 757, 3677). It is also an effective radical scavenger and can be used to stabilize monomers, polymers, and petroleum products (460). NDPA has been reported to synergize the effects of halogen-containing flame retardants used in polymers, but no evidence was found that it is used commercially for that purpose (460). NDPA is also used in pesticide manufacture (459).

35.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

35.2.1 Transport in Soil/Ground-water Systems

35.2.1.1 Overview

N-Nitrosodiphenylamine may move through the soil/ground-water system when present at low concentrations (dissolved in water and sorbed on soil) or as a separate organic phase (resulting from a spill of significant quantities of the chemical). In general, transport pathways for low soil concentrations can be assessed by equilibrium partitioning, as shown in Table 35-1. These calculations predict the partitioning of NDPA among soil particles, soil water, and soil air. The portions of NDPA associated with the water and air phases of the soil are more mobile than the adsorbed portion.

The estimates for the unsaturated topsoil model predict that nearly all of the chemical (99%) will be sorbed on the soil; a small amount (1%) of the chemical is expected to be present in the soil-water phase and thus able to migrate by bulk transport (e.g., the downward movement of infiltrating water), dispersion, and diffusion. For the very small portion of chemical in the gaseous phase of the soil (0.0001%), diffusion through the soil-air pores up to the ground surface and subsequent removal of the chemical by wind will be possible.

In saturated, deep soils (containing no soil air and negligible soil organic carbon), a much higher fraction of the NDPA (27%) is expected to be present in the soil-water phase (Table 35-1) and transported with flowing ground-water. Ground-water underlying NDPA-contaminated soils with low organic content is thus vulnerable to contamination by the chemical.

TABLE 35-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR
N-NITROSODIPHENYLAMINE IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	99.2	0.8	0.0001
Saturated deep soil[d]	73.2	26.8	-

a) Calculations based on Mackay's equilibrium partitioning model (34, 35, 36); see Introduction for description of model and environmental conditions chosen to represent an unsaturated topsoil and a saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient based on equation given by Means et al. (611): K_{oc} = 650.
c) Henry's law constant taken as 1.4E-06 atm · m^3/mol at 25°C (estimated by Arthur D. Little, Inc.).
d) Used sorption coefficient calculated as a function of K_{oc} assuming 0.1% organic carbon: K_p = 0.001 x K_{oc}.

35.2.1.2 Sorption on Soils

The mobility of NDPA in the soil/ground-water system (and its eventual migration into aquifers) is strongly affected by the extent of its sorption on soil particles. In general, sorption on soils is expected to:

- increase with increasing soil organic matter content;
- increase slightly with decreasing temperature;
- increase moderately with increasing salinity of the soil water; and
- decrease moderately with increasing dissolved organic matter content of the soil water.

Based upon its octanol-water partition coefficient of 1350, the soil sorption coefficient (K_{oc}) is estimated to be 650. This is a moderately high number indicating the potential for significant sorption on soils.

35.2.1.3 Volatilization from Soils

Transport of NDPA vapors through the air-filled pores of unsaturated soils may be an important transport mechanism for near-surface soils. In general, important soil and environmental properties influencing the rate of volatilization include soil porosity, temperature, convection currents, and barometric pressure changes; important physico-chemical properties include the Henry's law constant, the vapor-soil sorption coefficient, and, to a lesser extent, the vapor phase diffusion coefficient (31). There are no data from laboratory or field tests showing actual volatilization rates.

35.2.2 Transformation Processes in Soil/Ground-water Systems

The persistence of NDPA in soil/ground-water systems is not well documented. In most cases, it should be assumed that NDPA will persist for months to years (or more). NDPA that has been released into the air will eventually undergo photochemical oxidation or direct photolysis (10).

NDPA under normal environmental conditions is not expected to undergo rapid hydrolysis (10, 33). Only under conditions of high temperature and low pH is the chemical easily hydrolyzed (10).

The extent to which NDPA may undergo microbial biodegradation in the environment is not clear. Mallik and Tesfai (673) looked at its degradation in a variety of soils and found significant degradation, e.g., 68% after 30 days in a sandy loam. In soil amended with wheat straw, disappearance of NDPA was accelerated substantially, and NDPA disappeared completely by day 10.

Data cited by Callahan et al. (10) indicate that the intestinal microflora of vertebrates are active in both the synthesis and degradation of NDPA. Tabak et al. (55) reported that NDPA at 5 or 10 mg/L underwent significant microbial degradation in a static shake-flask screening test using BOD dilution water and settled domestic wastewater as the microbial inoculum. The microbial population adapted rapidly to a concentration of 5 mg/L and more gradually to a concentration of 10 mg/L. Thus, degradation in acclimated wastewater treatment plants is likely. In most soil/ground-water systems, the concentration of microorganisms capable of biodegrading chemicals such as NDPA is very low and drops off sharply with increasing depth. Thus, biodegradation in the soil/ground-water system should be assumed to be of minimal importance except, perhaps, in landfills with active microbial populations.

No data are available on the possibility of anaerobic biodegradation of N-Nitrosodiphenylamine.

35.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The properties of NDPA and the above discussion of fate pathways suggest that NDPA has a low volatility in aqueous solutions, is moderately adsorbed to soil, and has a moderate potential for bioaccumulation. These fate characteristics suggest several potential exposure pathways.

Volatilization of NDPA from a disposal site, particularly during drilling or restoration activities, could result in inhalation exposure. In addition, the potential for ground-water contamination is moderate, particularly in sandy soils. Mitre (83) reported that this compound was found at 3 of 546 National Priority Lists (NPL) sites. It was found at 2 sites in ground-water and 2 sites in surface water.

The properties of NDPA suggest that it has the potential for movement in ground-water. If it reaches surface water, several other exposure pathways are possible:

- Surface waters may be used in drinking water supplies, resulting in direct ingestion exposure;
- Aquatic organisms residing in these waters may be consumed, also resulting in direct ingestion exposure;
- Recreational use of these waters may result in dermal exposure;
- Domestic animals may consume or be dermally exposed to contaminated ground- or surface waters; the consumption of meats and poultry could then result in ingestion exposures.

In general, exposures associated with surface water contamination can be expected to be lower than exposures from drinking contaminated ground-water, partially due to the larger dilution volume common in surface water. In addition, the low BCF for this compound suggests a moderate potential for bioaccumulation in aquatic organisms or domestic animals.

35.2.4 Other Sources of Exposure

Nitrosamines in general are present in a wide variety of foods, as reported by Fine (757) and Scanlan (758). They are found most commonly in cured meats (particularly cooked bacon), beer, Scotch whiskey, some cheeses, nonfat dry milk, and sometimes in fish. Levels of total volatile nitrosamines are generally less than 5 μg/kg in these foods (758). The average daily intake of volatile nitrosamines from food is estimated to be about 1 μg per person (758). Nitrosamines are also found in tobacco smoke (which may represent a significant source of exposure), cosmetics, and rubber baby-bottle nipples (757, 758). Specific information for NDPA is not available.

N-Nitrosodiphenylamine does not appear to be common in either drinking water or ambient air (757).

35.3 HUMAN HEALTH CONSIDERATIONS

35.3.1 Animal Studies

35.3.1.1 Carcinogenicity

Several studies have been conducted to evaluate the carcinogenicity of NDPA. However, most of them are inadequate in that they lacked appropriate controls or were conducted for too short a duration (460). The most significant study was carried out by the National Cancer Institute (461) in Fischer 344 rats and $B6C3F_1$ mice. Rats were administered 1000 or 4000 mg NDPA/kg diet for 100 weeks. Male mice were given 10,000 or 20,000 mg/kg diet for 101 weeks. Female mice received 5000 and 10,000 mg/kg diet for 38 weeks, none for 3 weeks, then 1000 and 4000 mg/kg diet for 60 weeks. The dosage change was necessitated by the excessive depression in mean body weight gain. In mice, the only changes related to NDPA administration were chronic inflammatory lesions in the urinary bladder. Also, mean body weights were lower than those of corresponding controls and were dose-related. In both male and female rats, transitional-cell carcinomas of the urinary bladder occurred at incidences of 36% and 81% in high-dose males and females, respectively. There was also a dose-related trend in fibromas of the subcutis and skin in male rats. The incidence was 20% in high-dose males versus 2% in low-dose males and 5% in controls. Since the historical incidence of this tumor in control male F-344 rats at the laboratory at which the test was conducted is 2%, the investigators concluded that the fibromas seen in the test animals were related to NDPA administration.

Other carcinogenicity studies are summarized in Table 35-2. IARC (3869) lists N-nitrosodiphenylamine in Group 3 (not classifiable as to their carcinogenicity to humans) in its weight-of-evidence ranking for potential carcinogens.

35.3.1.2 Genotoxicity

N-nitrosodiphenylamine has been extensively tested for mutagenic activity. It is not mutagenic in bacteria, nor does it induce unscheduled DNA synthesis or cause chromosomal damage under any test conditions employed (460). The test systems include various strains of Salmonella typhimurium (3188, 3860) V79 Chinese hamster cells tested for mutations at the HPRT locus or for ouabain resistance (3343), L5178Y mouse lymphoma cells tested for mutations at the thymidine kinase locus (3530), rat embryo cells, human foreskin fibroblasts, host-mediated assays in mice, and sex-linked recessive lethal studies in Drosophila melanogaster (460).

TABLE 35-2
CARCINOGENICITY DATA FOR N-NITROSODIPHENYLAMINE
IN EXPERIMENTAL ANIMALS

Species and Number	Dose, Route and Duration	Result	IARC Comment (460)	Ref.
18 (C57BL/6 x C3H/Anf)F_1 mice of each sex	100 mg/kg/bw in DMSO daily by gavage for 4 weeks, then 3769 mg/kg/ diet for 75 weeks	No increase in tumor incidence	Inadequate sample size	462
25 male Wistar rats	1070 μg in methylcellulose 5 days/week by gavage for 49 weeks weeks	No increase in tumor	Low dose and duration incidence	463
16 male and 24 female hairless hr/hr Oslo mice	20 weekly dermal applications of 0.1 mL of a 1% solution NDPA in acetone	3 lung adenomas in males	Lack of appropriate controls	464
24 male CB rats	Weekly ip injections of 25 mg/kg in polyethylene glycol 400 for 2 years	1 hepatoma and pituitary adenoma; 1 hepatoma in	Low dose; poor survival (21%) controls	465

Conflicting results were reported in a cell transformation assay using C3H/10T1/2 cells (3186). In this collaborative study with two laboratories using the same protocols and the same clone of cells, NDPA was positive in one laboratory and negative in the other. Bradley et al. (3080), using a filter elution method, found no double strand breaks in the DNA of Fischer rat hepatocytes treated with NDPA, but single-strand DNA breaks were significantly increased.

When Chinese hamster Don cells were treated in culture with increasing concentrations of NDPA, cell division was affected; a significant increase in sister chromatid exchanges was observed, but with no increase in chromosomal aberrations (3004). Chinese hamster lung cells treated in culture with NDPA showed chromosomal aberrations in one study, but the authors (3330) were reluctant to judge NDPA as positive, classifying it as "suspicious." No morphologically abnormal mature sperm were observed in male mice that had been injected previously with concentrations of NDPA as high as 1000 mg/kg/day for five days (3723).

In a metabolism study, Tatsumi et al. (3731) have shown that liver aldehyde oxidase supplemented with electron donors functions as an N-nitroreductase to catalyze the reduction of NDPA to 1,1-diphenylhydrazine.

35.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

In a study by Korhonen et al. (3374, 3373), three-day-old chicken embryos were exposed to N-nitrosodiphenylamine dissolved in acetone. Five μL of the solution were injected into the air space of the egg. The embryos were candled on day 5 and every second or third day thereafter. The incubation was terminated on day 14. NDPA was effective only at doses near saturation in acetone. The ED_{50} for NDPA was 7.0 μmol/egg, and the maximum percentage of malformed embryos was 13%. These results do not necessarily have implications for mammalian species, but do indicate a need for caution.

35.3.1.4 Other Toxicologic Effects

35.3.1.4.1 Short-term Toxicity

Acute oral LD_{50} values of 1650 and 3000 mg/kg have been recorded for the rat (459, 3604); no values for skin or inhalation exposures were found.

Dialkylnitrosamines, such as NDPA, are characteristically hepatotoxic, but no data are available specifically evaluating this effect for NDPA (459).

35.3.1.4.2 Chronic Toxicologic Effects

In subchronic feeding studies conducted by NCI (461), Fischer 344 rats and $B6C3F_1$ mice were fed diets containing up to 46,000 mg NDPA/kg diet for 8 to 11 weeks. Female rats did not survive doses greater than 16,000 mg/kg diet. Reductions in weight gain ranged from 14% in female mice fed 46,000 mg/kg diet to 37% in female rats fed 16,000 mg/kg diet. The only histopathologic lesions observed were trace amounts of pigmentation in liver cells.

35.3.2 Human and Epidemiologic Studies

No data on human exposure to NDPA are available.

35.3.3 Levels of Concern

Based on the evidence of transitional-cell carcinomas of the urinary bladder induced in female rats administered NDPA, the USEPA has specified an ambient water quality criterion of zero for this compound. In that attaining a zero concentration level may be infeasible in some cases, the concentrations of NDPA in water calculated to result in incremental lifetime cancer risks of 1E-05, 1E-06, and 1E-07 from ingestion of both water and contaminated aquatic organisms were

estimated to be 49, 4.9, and 0.49 μg/L, respectively (459). Risk estimates are expressed as a probability of cancer after a lifetime consumption of two liters of water per day and consumption of 6.5 g of fish per day containing a specified concentration of the contaminant. Thus, a risk of 1E-05 implies that a lifetime daily consumption of two liters of drinking water and 6.5 g of contaminated fish at the criterion level of 49 μg NDPA per liter would be expected to produce one excess case of cancer above the normal background incidence for every 100,000 people exposed. It should be emphasized that these extrapolations are based on a number of assumptions and should be taken as crude estimates at best of human risk.

IARC (3869) lists N-nitrosodiphenylamine in Group 3 (not classifiable as to carcinogenicity to humans) in its weight-of-evidence ranking for potential carcinogens.

35.3.4 Hazard Assessment

Dietary administration of NDPA induced transitional-cell carcinomas of the urinary bladder in rats; tests conducted with mice were negative (461). Based on the findings in rats, the USEPA (3755) calculated an upper-limit incremental unit cancer risk of 4.92E-03 $(mg/kg/day)^{-1}$ for NDPA.

Genotoxicity studies conducted with this compound have been predominantly negative. There are no data available in mammals regarding possible reproductive toxicity associated with this compound, although the compound is teratogenic at high doses in chickens.

The notable lack of quantitative data available for either humans or experimental animals regarding other toxic effects of NDPA makes estimates of other potential health hazards associated with human exposure to NDPA uncertain, particularly with regard to long-term, low-level oral exposure.

35.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of NDPA concentrations in soil and water requires collection and laboratory analysis of representative field samples. Care is required to prevent losses during sample collection and storage. Soil and water samples should be collected in amber glass containers; extraction of samples should be completed within 7 days of sampling and analysis within 40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of aqueous samples of NPDA, one of the EPA priority pollutants, include EPA Methods 607, 625, 1625 (65), and 8250 (63). Prior to analysis, samples are extracted with methylene chloride using either a separatory funnel or a continuous liquid-liquid extractor. An aliquot of the concentrated sample extract is injected onto a gas chromatographic (GC) column

using a solvent flush technique. The GC column is programmed to separate the semi-volatile organic compounds; NDPA is then detected with a nitrogen-phosphorus detector (Method 607) or a mass spectrometer (Methods 625, 1625, and 8250).

It should be noted that N-nitrosodiphenylamine decomposes in the gas chromatographic inlet and is determined as diphenylamine. Florisil and alumina column cleanup procedures separate any diphenylamine in the original sample from the nitrosamine and eliminate other possible interferences (Method 607). The Thermal Energy Analyzer (TEA) and the Hall detector may also be used in place of the nitrogen-phosphorus detector (Method 607). The TEA offers the greatest selectivity.

The EPA procedure recommended for the analysis of NDPA in soil and waste samples, Method 8250 (63), differs from the procedures for aqueous samples primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Typical NDPA detection limits that can be obtained in wastewaters and non-aqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Non-Aqueous Detection Limit
0.81 μg/L (Method 607)	1.3 μg/g (Method 8250)
1.9 μg/L (Method 625)	
20 μg/L (Method 1625)	
19 μg/L (Method 8250)	

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Note: The nonsequential numbers of the references reflect the order of references as they appear in the master bibliography.

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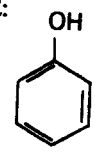
COMMON SYNONYMS:	CAS REG.NO.: 108-95-2 FORMULA: C_6H_6O NIOSH NO: SJ3325000 STRUCTURE: 	AIR W/V CONVERSION FACTOR at 25°C (12) 3.84 mg/m³ ≈ 1 ppm; 0.260 ppm ≈ 1 mg/m³ MOLECULAR WEIGHT: 94.11
Benzenol Carbolic acid Hydroxybenzene Phenic acid Phenol Phenyl hydroxide Phenylic acid		

REACTIVITY	Reactions of phenols or cresols with organic peroxides, organic hydroperoxides or non-oxidizing mineral acids typically generate heat, while those with oxidizing mineral acids or strong oxidizing agents generate heat and possibly fire. Reactions with elemental alkali or alkaline earth metals, nitrides or strong reducing agents evolve heat and flammable gases, while those with isocyanates, epoxides or polymerizable compounds may evolve heat and initiate violent polymerization reactions. Reactions with explosive compounds may cause explosions, while those with hydrazines or azo or diazo compounds may produce heat and generally innocuous gases. Reaction of phenol with calcium hypochlorite is exothermic and produces toxic fumes which may ignite. Addition of aluminum chloride to nitrobenzene containing 5% phenol may cause a violent explosion. Reaction of phenol with butadiene in a petroleum ether solution, catalyzed by boron trifluoride diethyletherate, may cause a closed container to pressurize and explode. Aluminum, magnesium, lead and zinc are attacked by hot phenol (505, 507, 511).

PHYSICO-CHEMICAL DATA	• Physical State: Solid, crystalline (at 20°C)	(23)
	• Color: White; pink to red with light exposure	(23)
	• Odor: Medicinal	(263)
	• Odor Threshold: 0.047 ppm	(263)
	• Density: 1.0576 g/mL (at 41°C)	(14)

PHYSICO-CHEMICAL DATA (Cont.)	• Freeze/Melt Point: 40.90°C	(14)
	• Boiling Point: 181.80°C	(14)
	• Flash Point: 79.00°C closed cup	(69)
	• Flammable Limits: 1.40 to 8.60% by volume	(60,506,507)
	• Autoignition Temp.: 715.0°C	(51,60,504)
	• Vapor Pressure: 5.29E-01 mm Hg (at 20°C)	(10)
	• Satd. Conc. in Air: 2.7300E+03 mg/m^3 (at 20°C)	(1219)
	• Solubility in Water: 8.40E+04 mg/L (at 20°C)	(38)
	• Viscosity: 3.020 cp (at 50°C)	(48)
	• Surface Tension: solid	(23)
	• Log (Octanol-Water Partition Coeff.): 1.46	(29)
	• Soil Adsorp. Coeff.: 1.40E+01, 1.35E+02	(652,654)
	• Henry's Law Const.: 7.00E-07 $atm \cdot m^3/mol$, (estim) (at 20°C)	(964)
	• Bioconc. Factor: 1.40E+00 (estim), 2.00E+00 (goldfish)	(659,940)

PERSISTENCE IN THE SOIL-WATER SYSTEM	Relatively mobile in soil-water systems. Volatilization also important for near-surface soils. Chemical is resistant to hydrolysis but is fairly susceptible to photo-oxidation, catalytic or free-radical oxidation (somewhat speculative), and to biodegradation.

PATHWAYS OF EXPOSURE	The primary pathway of concern from soil-water systems is the migration of phenol to groundwater supplies of drinking water. Data suggest that such migration has occurred in the past. The consumption of fish or other organisms is not expected to be a significant route of exposure.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure: (38, 54)

Phenol has a marked corrosive action on tissue. On contact with the eyes, it may cause severe damage and blindness. On skin, it induces anesthesia and blanching of the exposed area. If not removed promptly, it may cause a severe burn and systemic intoxication. Systemic effects, which can result from any route of exposure, include paleness, weakness, sweating, headache, ringing of the ears, cyanosis, shock, excitement, frothing of the nose and mouth and death.

Acute Toxicity Studies: (3504)

INHALATION:

LC_{50} 316 mg/m^3	Rat
LC_{50} 177 mg/m^3	Mouse

ORAL:

LD_{50} 317 mg/kg	Rat
LD_{Lo} 140 mg/kg	Human
LD_{Lo} 500 mg/kg	Dog
LD_{Lo} 420 mg/kg	Rabbit
LD_{Lo} 80 mg/kg	Cat
LD_{50} 270 mg/kg	Mouse
LD_{Lo} 14 g/kg	Human
LD_{Lo} 10 mg/kg	Infant

SKIN:

LD_{50} 669 mg/kg	Rat
LD_{50} 850 mg/kg	Rabbit

Long-Term Effects: Liver and kidney damage, skin discoloration

Pregnancy/Neonate Data: Teratogenic only at maternally lethal doses; fetotoxic at doses not toxic to the dams.

Genotoxicity Data: Conflicting evidence

Carcinogenicity Classification:
IARC - None assigned
NTP - None assigned
EPA - No data

HANDLING PRECAUTIONS (38,52,54)	Handle chemical only with adequate ventilation • Vapor concentrations of 5-50 ppm: any self-contained breathing apparatus or supplied-air respirator; any chemical cartridge respirator with an organic vapor cartridge and dust and mist filters • 50-100 ppm: any supplied-air respirator or selfcontained breathing apparatus with full facepiece; chemical cartridge respirator with full facepiece, organic vapor cartridge and dust and mist filter • Protective clothing, gloves, rubber boots and apron to prevent skin contact with solid or liquid phenol • Dust and splash-proof chemical goggles if there is probability of eye contact.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards
- OSHA TWA (8-hr): 5 ppm (skin)
- AFOSH PEL (8-hr TWA): 5 ppm (skin); STEL (15-min): 10 ppm

Criteria
- NIOSH IDLH (30-min): 250 ppm
- NIOSH REL (10-hr TWA): 5.2 ppm; 15-min ceiling, 15.6 ppm
- ACGIH TLV® (8-hr TWA): 5 ppm (skin)
- ACGIH STEL (15-min): STEL deleted (1987-88)

WATER EXPOSURE LIMITS:

Drinking Water Standards
None established

EPA Health Advisories and Cancer Risk Levels
None established

WHO Drinking Water Guideline
No information available.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- Human Health (3770)
  - Based on the intake of drinking water and aquatic organisms, the derived level is 3.5 mg/L. Adjusted for intake of drinking water alone, the level is 3.5 mg/L. Using available organoleptic data, for controlling undesirable taste and odor quality, the estimated level is 0.3 mg/L.

- Aquatic Life (3770)
  - Freshwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 10,200 μg/L.

    chronic toxicity:
    no criterion, but lowest effect level occurs at 2560 μg/L.

  - Saltwater species
    acute toxicity:
    no criterion, but lowest effect level occurs at 5800 μg/L.

    chronic toxicity:
    no criterion established due to insufficient data.

REFERENCE DOSES: (3744)
ORAL: 6.000E+02 μg/kg/day

REGULATORY STATUS (as of 01-MAR-89)

Promulgated Regulations

- Federal Programs
  Clean Water Act (CWA)
  Phenol is designated a hazardous substance. It has a reportable quantity (RQ) limit of 454 kg (347, 3764). It is also listed as a toxic pollutant, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (351, 3763). Effluent limitations have been set for phenol effluent in the following point source categories: glass manufacturing (897), textile mills (893), timber products processing (899), petroleum refining (896), metal molding and casting (892), iron and steel manufacturing (354), ferroalloys (895), organic chemicals, plastics and synthetic fibers (3777), electroplating (3767), steam electric power generating (3802), metal finishing (3768), and pulp paper and paperboard industries (898). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)
In states with an approved Underground Injection Control program, a permit is required for the injection of phenol-containing wastes designated as hazardous under RCRA (295).

Resource Conservation and Recovery Act (RCRA)
Phenol is identified as a toxic hazardous waste (U188) and listed as a hazardous waste constituent (3783, 3784). Waste streams from the following industries contain phenol and are listed as specific sources of hazardous wastes: wood preservation, organic chemicals (phenol/acetone production, aniline production), petroleum refining, and coking (operational residues) (3774, 3765). Phenol is subject to land disposal restrictions when its concentration as a hazardous constituent of certain wastewaters exceeds designated levels (3785). Phenol is included on EPA's ground-water monitoring list. EPA requires that all hazardous waste treatment, storage, and disposal facilities monitor their ground-water for chemicals on this list when suspected contamination is first detected and annually thereafter (3775).

Toxic Substances Control Act (TSCA)
Manufacturers, processors, or importers who possess health and safety studies on phenol must submit them to EPA (3789).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Phenol is designated a hazardous substance under CERCLA. It has a reportable quantity (RQ) limit of 454 kg (3766). Reportable quantities have also been issued for RCRA hazardous waste streams containing phenol but these depend upon the concentrations of the chemicals in the waste stream (3766). Phenol is designated an extremely hazardous substance under SARA Title III. Any facility at which phenol is present in excess of its threshold planning quantity of 500 pounds must notify state and local emergency planning officials. If phenol is released from the facility in excess of its reportable quantity (RQ), local emergency planning officials must be notified (3766). Under SARA Title III Section 313, manufacturers, processors, importers, and users of phenol must report annually to EPA and state officials their releases of this chemical to the environment (3787).

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
Phenol is exempt from a tolerance requirement when used as a solvent or cosolvent in pesticide formulations applied to animals and growing crops only (315).

Marine Protection Research and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of known or suspected carcinogens, mutagens or teratogens is prohibited except when they are present as trace contaminants. Permit applicants are exempt from these regulations if they can demonstrate that such chemical constituents are non-toxic and non-bioaccumulative in the marine environment or are rapidly rendered harmless by physical, chemical or biological processes in the sea (309).

Occupational Safety and Health Act (OSHA)
Employee exposure to phenol shall not exceed an 8-hour time-weighted average (TWA) of 5 ppm. Employee skin exposure to phenol should be prevented/reduced through the use of protective clothing and practices (3539).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated phenol as a hazardous material with a reportable quantity of 454 kg, subject to requirements for packaging, labeling and transportation (3180).

Food, Drug and Cosmetic Act (FDCA)
Phenol is approved for use as an indirect food additive as a component of adhesives when used as a preservative only (3209). The level for phenols in bottled drinking water is 0.001 mg/L (365).

- State Water Programs

ALL STATES
All states have adopted EPA Ambient Water Quality Criteria and NPDWRs (see Water Exposure Limits section) as their promulgated state regulations, either by narrative reference or by relisting the specific numeric criteria. These states have promulgated additional or more stringent criteria:

ARIZONA
Arizona has a water quality criterion of 5 μg/L for phenolics in all public waters (3827).

CALIFORNIA
California has set the following surface water quality standards for phenol: 120 μg/L -Ocean Plan waters, 40 μg/L -Region 8 waters, municipal and domestic use, 100 μg/L -Region 3 waters, protection of freshwater life, 1.0 μg/L -Regions 1 and 3 waters, municipal and domestic use (3097).

COLORADO
Colorado has a water quality criterion of 1 μg/L for monohydric phenol in drinking water supply waters and 500 μg/L for Aquatic Life Class I waters (3827).

DELAWARE
Delaware has a surface water quality criterion of 0.2 mg/L for fresh and saltwater streams (3827).

DISTRICT OF COLUMBIA
The District of Columbia has surface water quality criteria of 0.1 mg/L for phenol in Class C waters and 0.3 mg/L for Class D waters (3827).

FLORIDA
Florida has water quality criteria for phenolic compounds of 1 μg/L for general use surface waters, and 0.2 mg/L for Class V (navigation, industrial use) surface waters (3220).

GEORGIA
Georgia has changed the criterion for phenol from 5 μg/L to 300 μg/L for instream concentrations in all surface waters because the less stringent standard was considered more realistic (3240).

ILLINOIS
Illinois has a water quality standard for phenols of 100 μg/L for general use waters, 1 μg/L for Public and Food Processing Water Supplies, and 300 μg/L for Aquatic Life waters (3321, 3827).

INDIANA
Indiana has set the following surface water quality criteria for phenols and phenolic compounds: 10 μg/L for the Ohio River and Wabash River, 300 μg/L (daily maximum) for Lake Michigan and contiguous harbor areas, and 10 μg/L for the Grand Calumet River and Indiana Harbor (3827).

IOWA
Iowa has a surface water quality standard of 50 μg/L for phenolic compounds in Class B and C surface waters (3327). Iowa has also set acute criteria for phenols of 50 μg/L for Class C surface waters, 1000 μg/L for Class B cold surface waters, and 2500 μg/L for Class B warm surface waters, and a chronic criterion of 50 μg/L for all Class B surface waters for the protection of aquatic life (3326).

KANSAS
Kansas has an action level of 300 μg/L for phenol in ground-water (3213).

KENTUCKY
Kentucky has a surface water quality criterion of 5 μg/L for phenolic compounds in Warm and Coldwater Aquatic Habitats (3827).

LOUISIANA
Louisiana has water quality criteria for phenols of 5 μg/L for drinking water supply waters, 440 μg/L for marine surface waters, and 50 μg/L for fresh surface waters (3406).

MINNESOTA
Minnesota has surface water quality criteria of 1 μg/L for phenol in Domestic waters and 10 μg/L for phenols in Fisheries and Recreation waters (3827).

MISSISSIPPI
Mississippi requires that the level of phenolic compounds in the public water supply not exceed 1 μg/L (3684). Mississippi also has a surface water quality standard of 50 μg/L for phenolic compounds for fish and wildlife protection (3684).

MISSOURI
Missouri has a water quality criterion for phenol of 1 μg/L for drinking water, 100 μg/L for surface waters for the protection of aquatic life, and ground-water quality standards of 300 μg/L for fast recharge waters and 100 μg/L for slow recharge waters (3457).

NEVADA
Nevada has a water quality criterion for phenolics of 1 μg/L for all surface waters (3827).

NEW HAMPSHIRE
New Hampshire has a drinking water standard of 1 μg/L for phenols (3710). New Hampshire also has a surface water quality standard of 1 μg/L for Class A and B waters and 2 μg/L for Class C waters (3684).

NEW JERSEY
New Jersey sets the maximum concentration levels for phenols in the Delaware River and Bay at the following levels: 5 μg/L for Zones 1, 2 and 3, 20 μg/L for Zone 4, and 10 μg/L for Zones 5 and 6. These are maximum levels that apply unless exceeded due to natural conditions (3498).

NEW YORK
New York has an ambient water quality standard for aquatic life of 5 μg/L for total unchlorinated phenols for all freshwater classes of surface waters (3500). New York has also set an MCL of 50 μg/L for drinking water and a water quality standard of 1 μg/L for phenol and phenolic compounds in ground-water and surface water classed for drinking water supply (3501).

NORTH CAROLINA
North Carolina has a water quality standard of 1 μg/L for phenolic compounds in Class WS-I, WS-II, and WS-III surface waters (3681).

OHIO
Ohio has a surface water quality standard for phenolic compounds of 1 μg/L for Lake Erie Use waters, Public Water Supply waters, Aquatic Life Habitat Coldwaters and Exceptional Warmwaters, and 10 μg/L for Aquatic Life Habitat Warmwaters (3827).

OKLAHOMA
Oklahoma has set a nonenforceable Toxic Substance Goal of 300 μg/L for phenol in public and private water supply surface waters (3534).

OREGON
Oregon has a surface water quality criterion of 1 μg/L for phenols in all surface waters (3827).

PENNSYLVANIA
Pennsylvania has a human health criterion of 300 μg/L for phenol in surface water, and a human health criterion for total phenolics of 5 μg/L measured in surface waters at the point of water supply intake (3561).

RHODE ISLAND
Rhode Island has an acute freshwater quality guideline of 251 μg/L for phenol and a chronic guideline of 5.6 μg/L for the protection of aquatic life in surface waters. These guidelines are enforceable under Rhode Island state law (3590).

SOUTH DAKOTA
South Dakota requires phenol to be nondetectable, using designated test methods, in ground-water (3671).

TENNESSEE
Tennessee sets an effluent limitation of 1.0 mg/L for phenols in effluent from industrial wastewater treatment plants (3827).

UTAH
Utah has a surface water quality criterion of 0.01 mg/L for phenol in Class 3A, 3B, 3C and 3D surface waters (3827).

VIRGINIA
Virginia has a water quality criterion for phenols of 1 μg/L for ground-water and Public Water Supply surface waters, and a chronic criterion of 1 μg/L for phenol in surface water (3135, 3827).

WEST VIRGINIA
West Virginia sets 0.001 mg/L as the maximum concentration secondary contaminant level for phenols in drinking water in the community public water systems (3576).

WISCONSIN
Wisconsin has a human threshold criterion of 2.7 mg/L for phenol in public water supply cold surface waters and 2.8 mg/L in public water supply warm sport fish waters (3842). Wisconsin also has set a taste and odor criterion threshold concentration level of 300 μg/L for phenol in surface waters (3841).

WYOMING
Wyoming has a ground-water quality standard of 1 μg/L for phenol in Class I domestic ground-water. They do not regulate other classes of water, but have a non-degradation rule in case of contamination (3852).

Proposed Regulations

- Federal Programs

  Resource Conservation and Recovery Act (RCRA)
  EPA has proposed that solid wastes be listed as hazardous in that they exhibit the characteristic defined as EP toxicity when the TCLP extract concentration is equal to or greater than 14.4 mg/L phenol. Final promulgation of this Toxicity Characteristic Rule is expected in March 1989 (1565).

- State Water Programs

  MINNESOTA
  Minnesota has proposed a Recommended Allowable Limit (RAL) of 280 μg/L for phenol in drinking water (3451). Minnesota has also proposed a Sensitive Acute Limit (SAL) of 9547 μg/L for phenol in surface waters, and a chronic criterion of 212 μg/L for surface waters. These criteria are for the protection of human health (3452).

  WEST VIRGINIA
  West Virginia has proposed a water quality criterion of 5 μg/L for phenolic materials in Public A waters. Final action is expected in late spring 1989 (3835).

  MOST STATES
  Most states are in the process of revising their water programs and proposing changes in their regulations which will follow EPA's changes when they become final. Contact with the state officer is advised. Changes are projected for 1989-90 (3683).

EEC Directives

Directive on Drinking Water (533)
The mandatory values for phenols (phenol indices) in surface water treatment categories A1, A2 and A3 used or intended for abstraction of drinking water are 0.001, 0.005 and 0.1 mg/L, respectively. Guideline values for phenols (phenol indices) under treatment categories A2 and A3 are 0.001 and 0.01 mg/L respectively. No guideline value is given for treatment category A1.

Directive Relating to the Quality of Water for Human Consumption (540)
The maximum admissible concentration for phenols (phenol indices) is 0.5 μg/L. Excluded from this category are natural phenols which do not react to chlorine. No guideline levels for phenols (phenol indices) are given.

Directive on Ground-Water (538)
Direct and indirect discharge into ground-water of substances which have a deleterious effect on the taste and/or odor of ground-water, and compounds liable to cause the formation of such substances in ground-water and to render it unfit for human consumption shall be subject to prior review so as to limit such discharges.

Directive on Bathing Water Quality (534)
Mandatory values for phenols (phenol indices) in bathing water are: (1) no specific odor and (2) concentrations ≤0.05 mg/L. Guideline values for phenols (phenol indices) suggest concentrations ≤ 0.005 mg/L.

Directive on Fishing Water Quality (536)
Phenolic compounds in both salmonid and cyprinid waters must not be present in such concentrations that they adversely affect fish flavor.

Directive Relating to the Classification, Packaging and Labeling of Dangerous Preparations (Solvents) (544)
Phenol is listed as a Class I/b toxic substance and is subject to packaging and labeling regulations.

Directive on the Discharge of Dangerous Substances (535)
Organohalogens, organophosphates, petroleum hydrocarbons, carcinogens or substances which have a deleterious effect on the taste and/or odor of human food derived from aquatic environments cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries which issue emission standards. A system of zero- emission applies to discharge of these substances into ground-water.

Directive on Marketing and Use of Dangerous Substances (541)
Phenol may not be used in ornamental objects intended to produce light or color effects by means of different phases.

Directive on Toxic and Dangerous Wastes (542)
Any installation establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including phenols and phenol compounds; organic-halogen compounds; chrome compounds, lead compounds, cyanides, ethers and aromatic polycyclic compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such waste, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (787)
Phenol is classified as a toxic substance and is subject to packaging and labeling regulations.

Directive on Transfrontier Shipment of Hazardous Waste (1433)
When the holder of a hazardous waste such as phenol intends to ship it to another member state, authorities of the member states concerned must be provided with information on the source and composition of the waste, measures to be taken to ensure safe transport, insurance against damage and the existence of a contractual agreement with the consignee of the waste. All transfrontier shipments must be properly packed and labeled and must be accompanied by instructions to be followed in the event of danger of accident.

36.1 MAJOR USES

The major use of phenol is as a chemical intermediate in the synthesis of organic chemicals, primarily phenolic resins. Phenol is also utilized in the production of bis-phenol-A, caprolactam, plasticizers, adipic acid, salicylic acid, 2,4-D, alkyl phenols and chlorinated phenols. A small amount is used as a solvent in petroleum refining (939). It is also employed as a disinfectant (3890).

36.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

36.2.1 Transport in Soil/Ground-water Systems

36.2.1.1 Overview

Phenol is expected to be relatively mobile in the soil/ground-water system when present at low concentrations (dissolved in water). Pure phenol is a solid at ambient temperatures (melting point is 41°C) and thus bulk quantities (e.g., from a spill or large dumping) would not be immediately mobile.

Transport pathways can be generally assessed by using an equilibrium partitioning model as shown in Table 36-1.

These calculations predict the partitioning of low soil concentrations of phenol among soil particles, soil water and soil air. The estimates for the unsaturated topsoil model show that while most of the phenol is associated with the stationary soil phase, a significant amount (12.6%) is in the mobile water phase and thus easily leached. Diffusion of phenol vapors through the soil-air pores up to the ground surface would not appear to be a significant loss pathway based upon the model results. (Other data and model results given below, however, show volatilization losses may be significant.) In saturated, deep soils (containing no air and negligible soil organic carbon), a much higher fraction of the phenol is likely to be present in the soil water phase (Table 36-1) and available to be transported with flowing ground water.

The actual distribution of phenol in a model laboratory ecosystem has been measured by Figge et al. (807). Thirty (30) days after the non-sterile ecosystem was inoculated with C-14 labeled phenol, the percentage of the initial dose found in each "compartment" of the ecosystem was as follows: air, 23%; percolating water, 0.03%; soil, 24%; and plants, 43%. Total recovery was 90%. Two-thirds of the phenol "recovered" from the air compartment was identified as $(14)CO_2$ which must have come from the chemical or biological degradation of phenol in the water, soil or plants. Thus, the actual "air" concentrations (meaning the free air above the ecosystem, not confined soil-air) were probably nearer 9%. The relatively large "true" air concentrations are a result of the fact that, during the 30-day test, the air in the test chamber was continuously exchanged, with the exhaust air passing through an absorber unit.

TABLE 36-1
EQUILIBRIUM PARTITIONING CALCULATIONS FOR PHENOL
IN MODEL ENVIRONMENTS[a]

Soil Environment	Estimated Percent of Total Mass of Chemical in Each Compartment		
	Soil	Soil-Water	Soil-Air
Unsaturated topsoil at 25°C[b,c]	87.4	12.6	2.0E-03
Saturated deep soil[d]	13.1	86.9	-

a) Calculations based on Mackay's equilibrium partitioning model (34,35,36); see Introduction in Volume 1 for description of model and environmental conditions chosen to represent an unsaturated topsoil and saturated deep soil. Calculated percentages should be considered as rough estimates and used only for general guidance.
b) Utilized estimated soil sorption coefficient: K_{oc} = 36 (calculated average of data for soils given in reference 806).
c) Henry's law constant taken as 1.3E-06 atm · m^3/mol at 25°C (81).
d) Used sorption coefficient $K_p = 0.001\ K_{oc}$.

Two other modeling studies serve to elucidate the important transport and fate mechanisms for phenol in the natural environment. Jury et al. (808) used a soil chemical screening model to classify chemicals with regard to the importance of volatilization as a loss pathway after soil application (e.g., of a phenol-containing waste). The model assumed uniform application of the chemical to a depth of 10 cm in the soil, a soil-water content of 30% (by volume), and a soil-organic-carbon content of 1.25% (by weight). Under these conditions, the model results led Jury et al. (808) to classify phenol in a "moderately short-lived" group of chemicals having an effective volatilization half-life between 15 and 30 days. The actual half-life calculated for phenol was 21 days.

The second study by Pollard and Hern (809) simulated the transport and fate of phenol in a surface water body (Monongahela River) using the EXAMS model. Some of what was learned will help in understanding soil/ground-water fate and transport. The model predicted oxidation (by photochemically-generated free radicals in the water) and biodegradation to be the most important fate pathways. The model showed volatilization to be an unimportant loss mechanism. Associated field testing showed sediment sorption was also a relatively unimportant process; the field testing provided data that allowed the model to be validated when certain assumptions were made about the concentration of free-radical oxidants.

A number of field and laboratory studies point to the relative mobility and non-persistence of phenol in soil/ground-water systems. In a study of land treatment of phenol-containing wastes, Demirjian et al. (522) found no detectable phenol in the soil at the end of the treatment cycle. Goerlitz et al. (810) found that sorption did not appreciably retard the movement of phenol in the leachate plume from an unlined surface impoundment. Laboratory sorption experiments using soil collected at the 30-m depth at the site also showed no significant sorption of phenol. The researchers did note disproportionate decreases in the downgradient concentration of phenol which were tentatively attributed to biodegradation. Phenol has been found in the leachate plume from a sanitary landfill (811), in peat soils 500 meters from a catchment pit (939), and in ground water (where it persisted 19 months) following a spill of phenol onto a soil consisting primarily of sand, gravel and undifferentiated dolomite (939).

36.2.1.2 Sorption on Soils

Table 36-2 lists several soil sorption constants that have been reported for phenol.

In general, except for the Lake Zoar sediments, the data indicate that phenol is only weakly sorbed by soils containing organic matter. There is essentially no sorption on clays and minerals that contain no organic matter. Nevertheless, in unsaturated topsoils containing significant amounts of organic carbon (2%) and relatively small amounts of water (10% by volume), the model results shown in Table 36-1 show that a significant amount of the phenol may be associated with the stationary soil phase.

There is no ready explanation for the relatively high sorption constant associated with the Lake Zoar sediments. Some degree of excess sorption over that expected for simple hydrophobic sorption to organic matter, due to hydrogen bonding, has been suggested by Boyd (816).

36.2.1.3 Volatilization from Soils

Transport of phenol vapors through the air-filled pores of unsaturated soils can be an important transport mechanism for near-surface soils. This was demonstrated by the model ecosystem and modeling results discussed above (Section 36.2.1.1). However, due to the low value of the Henry's law constant (H) for phenol:

$$H = 7E\text{-}07 \text{ atm} \cdot m^3/\text{mol at } 20°C$$

the vapor phase concentration in soil air will be very low whenever water is present.

TABLE 36-2
SOIL ADSORPTION CONSTANTS REPORTED FOR PHENOL*

Type of Soil	K_{oc}	Comment	Ref.
(Not specified)	27		812
Batcombe Silt Loam	30.2	2.51% OC, pH 6.7	813
Molokai clay	440	0.5% OC, pH 6.2	814
Davidson clay	700	0.3% OC, pH 6.4	814
Ava silty clay	150	0.4% OC, pH 4.5	814
Mohave clay loam	250	0.4% OC, pH 7.8	814
Fanno clay	144	0.9% OC, pH 7.0	814
Captina silt loam	90	0.64% OC, pH 5.4	815
Palouse silt loam	57	2.1% OC, pH 5.4	815
Brookston clay loam	16.1	3.0% OC, pH 5.7	816
Captina silt loam	91	0.64% OC, pH 5.4	817
Palouse silt loam	38.8	2.1% OC, pH 5.4	817
Lake Zoar sediment	2900	Fine fraction, 10.2% OC	818
Lake Zoar sediment	3100	Coarse fraction, 4.2% OC	818
(Generic)	135	Estimated	654
(Generic)	14	Estimated	652
(Generic)	9	Estimated	812
Montmorillonite	--	K_d =1.08E-04, 1/n=0.132	819
Cottage Grove sandstone (38°C)	--	K_d =7E-03, 1/n=1.01	
Silty Clay	--	No adsorption	821
Kaolinite, montmorillonite	--	No adsorption	822
Geothite (a-FeOOH)	--	No adsorption	823

*K_{oc} = soil adsorption constant per unit weight organic carbon.
K_d = Freundlich adsorption coefficient.
1/n = Exponential factor on concentration in Freundlich adsorption equation.
OC = organic carbon content (by weight) of soil.

36.2.2 Transformation Processes in Soil/Ground-water Systems

Phenol is a weak acid (pKa = 9.90) and thus has a slight tendency to dissociate in water with the loss of a hydrogen ion: C_6H_5OH ----> $C_6H_5O^-$ + H^+. In pure water, only 0.13% would be expected to dissociate at pH 7, and 1.3% at pH 8.

Phenol is apparently susceptible to one or more chemical (non-biological) degradation mechanisms that can operate in the soil/ground-water system. Simple hydrolysis (reaction with water), however, does not take place rapidly under environmental conditions. An aqueous hydrolysis rate constant of 8.2-8.5E-09 cu.cm./mole sec has been reported (824). Conrad and Seiler (825) demonstrated a biological degradation of phenol and resulting CO formation, in sterile soils. They speculated that a radical mechanism, most probably initiated by reactions with molecular oxygen, were involved. Such a mechanism is consistent with the speculation of others (10) that phenol could be non-photolytically (and non-biologically) oxidized in oxygen-rich water, especially if certain iron or copper species were present which might catalyze the reaction.

Baker and Mayfield (826) also found that phenol underwent rapid non-biological degradation in sterile silica sand. The rate of this degradation reaction increased with temperature and decreased with concentration. In one test at 26°C, the phenol concentration in the silica sand/water mixture fell from 105 μg/g of silica to 29 μg/g silica after 32 days. Volatilization losses and photodegradation were clearly ruled out. These authors also speculated on an auto-oxidation mechanism that might be catalyzed.

There is good evidence to suggest that photooxidation should be an important degradation mechanism for phenol in aerated, near-surface waters (10, 939, 827).

Numerous studies have clearly shown that phenol is fairly easily biodegraded by microorganisms which are prevalent in the natural environment (10, 939, 806, 828, 829, 830, 831). Several types of microorganisms can use phenol as their sole source of carbon; however, at high phenol concentrations (e.g., above 100 mg/L) the microorganisms may be inhibited or killed. Evidence of the extent or rate of biodegradation at very low concentration (<1 mg/L) is contradictory. Degradation, both aerobic and anaerobic, has been demonstrated in a variety of natural water and natural soil conditions. Thus, it may be concluded that phenol should not persist (more than weeks to a few months at most) in environments with sufficient populations of active microorganisms. Although many rate studies have been carried out (see references 939 and 806 for a listing of data), prediction of biodegradation rate constants for specific environments is still difficult.

36.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

The above discussion of fate pathways suggests that phenol has a low volatility, is weakly adsorbed to soil and has no significant potential for bioaccumulation. Although some data indicate volatilization of this compound from near surface soils does occur, in general, inhalation exposure to phenol from soil is not expected to be a dominant pathway. Phenol is likely to be mobile in ground water, possibly resulting in drinking water exposure via this route. Exposure pathways involving the accumulation of phenol by biota are not likely to be important due to its low bioconcentration factor.

The potential for ground water contamination is demonstrated by the common occurrence of phenol at hazardous waste sites. Mitre (83) reported that phenol has been found at 55 of the 546 National Priority List (NPL) sites. It was detected at 37 sites in ground water, 27 sites in surface water and 3 sites in air. These data indicate that both ground and surface-water pathways of exposure may be important. In the National Organics Monitoring Survey (NOMS) conducted by the USEPA (90), phenol was detected in 2 of 110 raw water supplies, including both surface and ground-water supplies.

The properties of phenol, and its common occurrence in ground water at NPL sites, suggest that exposure through drinking water may result from soil/ground-water systems. In addition, the movement of phenol in ground water may result in other exposure pathways. These pathways would include ingestion exposure through the consumption of surface water as a drinking water supply or dermal exposure through recreational use of surface waters. Bioaccumulation of phenol from surface waters, either by aquatic organisms or domestic animals, is not expected to be a dominant exposure pathway due to the low bioconcentration factor for phenol.

36.2.4 Other Sources of Human Exposure

As phenol is a large-volume industrial chemical, there are a number of other potential sources of human exposure. Exposure through drinking water (other than ground water associated with hazardous waste sites) does not generally appear to be a major source of exposure; phenol was detected in only 2 of 110 raw water supplies (90).

The production and use of phenol, however, has led to its presence in the atmosphere. Brodzinsky and Singh (84) summarized air monitoring data for phenol. They reported 90 data points. No data were available for rural and remote areas. In urban and suburban areas, the median concentration was 0.12 $\mu g/m^3$ (7 data points), and in source-dominated areas, the median concentration was 19 $\mu g/m^3$ (83 data points).

In addition to these environmental exposures, oral exposure to phenol may occur as the result of its use in several medicinal preparations (antiseptic mouthwash and lozenges). It is also a component of a number of medicinal preparations that are

dermally applied, such as cream for burns or poison ivy (940), and it has been injected locally into spinal and perineural spaces or into nerves for the relief of pain and spasticity (3960, 3912). These uses may result in significant exposure to phenol for short periods of product use.

Phenol has been found in some food products. Lustre and Issenberg (832) reported 7 mg/kg phenol in smoked summer sausage and 28.6 mg/kg in smoked pork belly. The authors speculated that the phenol originated from the wood used in processing the meat.

36.3 HUMAN HEALTH CONSIDERATIONS

36.3.1 Animal Studies

36.3.1.1 Carcinogenicity

In a study conducted by the National Cancer Institute, phenol was not carcinogenic for either male or female F344 rats or B6C3F$_1$ mice. Both species were given drinking water containing 2500 or 5000 ppm phenol for 103 weeks. In low-dose male rats, there was an increased incidence of leukemias and lymphomas; the incidence in the high-dose group, however, was not significantly different from that of the control group. There was also no dose-response in female dosed groups. Therefore, evidence that phenol was the cause of these tumors was not clearly established. In mice, no tumor at any site was clearly associated with phenol administration (941).

A number of studies have shown that phenol promotes skin tumors in strains of mice specially inbred for sensitivity to tumor development. Benign tumors developed in these mice after a single application of 75 mg of the carcinogen, 9,10-dimethylbenz(a)anthracene (DMBA), followed one week later by twice weekly applications of 2.5 mg phenol (as a 10% solution in benzene) to the same area for a period of 42 weeks. At 13 weeks, 22 of 23 mice (96%) had papillomas and 73% had carcinomas. The effect of benzene as the solvent must also be considered. Few tumors developed in the mice treated with DMBA alone (3/21 mice with papillomas at 42 weeks) or with phenol alone (5/14 mice with papillomas at one year). Standard inbred strains of mice similarly treated exhibited only a few papillomas (902).

In summary, there are no indications that phenol is carcinogenic by the oral route. Skin application of phenol, however, is tumorigenic in sensitive strains of mice but not in standard inbred mouse strains. This activity appears to be associated with phenol's irritancy and subsequent skin hyperplasia.

36.3.1.2 Genotoxicity

The genotoxic activity of phenol has been evaluated in non-mammalian and mammalian systems. Data from bacterial and yeast studies conflict. Gocke et al.

(942) reported that phenol induced mutations in Salmonella strain TA98 in the presence of activation while other teams of investigators (943, 3780) using four of the five standard strains (TA 1535, 1537, 98 and 100) achieved negative results with and without metabolic activation. Negative results were also obtained in the two strains of the yeast Saccharomyces cerevisiae strain D3 (944) and strain MP1 (3207).

Other non-mammalian assays also yielded mixed results. Sex-linked recessive lethals were not increased among the progeny of Drosophila males fed or injected with phenol (3845); but rainbow trout exposed to a concentration of 0.3 or 0.6 microliters of phenol/L of water for 72 hours had significant increases in chromosome aberrations in gill and kidney cells (3014).

Conflicting results have also been observed in mammalian genotoxicity studies. In vitro, phenol concentrations of 250 to 500 μg/mL, in the presence of mouse microsomes, induced 8-azaguanine resistance in Chinese hamster V79 cells (3554). In addition, phenol induced statistically significant, concentration-dependent increases in sister chromatid exchanges (SCE) in human T-lymphocytes in vitro at concentrations ranging from 5 to 3000 μM (945). The negative results obtained by Jansson et al. (3336) in a similar SCE study may be attributed to the low concentrations tested.

In vivo, phenol did not induce significant increases in chromosomal aberrations or micronuclei, but did cause equivocal genotoxicity in a 5 generation reproductive toxicity study. Male and female mice treated with up to the LD_{30} dose of phenol, either orally or intraperitoneally, did not show any significant increase in chromosomal aberrations in their bone marrow cells (3715).

In two different studies, phenol did not increase the incidences of micronuclei in the bone marrow cells of mice. In one study, male mice were treated orally with 250 mg/kg and sacrificed 30 hours after treatment (3232); in the other, experimental details were not given (3554).

A five-generation study conducted with Porton-strain mice examined the influence of aqueous solutions of phenol on chromosomes in the process of spermatogenesis. Mice in each generation were given daily gavage doses of approximately 0, 6.5, 64 or 640 μg/kg/day for 30 days. Six males and females from each group per generation were then mated. The females continued to receive phenol during pregnancy and lactation. Testes from six males per group for each generation were examined for chromosomal defects in spermatogonia and primary spermatocytes. Dose-related increases in the incidence of aberrations were found in both cell types. Aberrations included chromatid and chromosome breaks, ring chromosomes, centric fusions, acentric fragments, aneuploidy (any deviation from the exact multiple of the haploid number of chromosomes) and polyploidy (more than two full sets of homologous chromosomes). There was also an apparent trend toward increased aberrations in each successive generation. However, the experimental protocol as well as the inadequacy of information presented by the investigation make interpretation of this latter point difficult. The complications associated with interpretation of the results in successive generations do not, however, mitigate the

marked increase in chromosomal aberrations seen in the parental and F_1 generations, i.e., two to four-fold above controls (963). These results are cause for concern in that equivalent human exposures (0.45-4.5 mg/70-kg man/day) could conceivably be ingested by the population at large. Unknown factors, however, such as tissue distribution and DNA repair capabilities of different tissues and species make any discussion of the genetic implications for man more speculative than factual. Further studies such as the effect of gavage administration compared to the more intermittent nature of human exposure via drinking water are needed to clarify the significance of this single report to humans (963).

36.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Minor and Becher (947) found no increase in terata or resorptions in Sprague-Dawley rats given ip injections of 20, 63, or 200 mg of phenol/kg, either on days 9-11 or on days 12-14 of gestation. In another study, phenol was administered to Sprague-Dawley rats by gavage at doses of 100, 333, 667, or 1000 mg/kg on gestational day 11 (3531). In the dams, decreased weight gain was observed at the two higher doses. Among the offspring, viable litter size was not reduced, but postnatal hind limb paralysis, persistent growth retardation, and decreased neonatal renal concentrating ability were observed (doses were not given). Price et al. (3571) administered phenol to rats by gavage at doses of 30, 60, or 120 mg/kg/day during organogenesis. While maternal status, prenatal viability, and fetal morphological development were not affected, average fetal body weight/litter was reduced at 120 mg/kg.

CD-1 mice were given phenol doses of 70, 140, or 280 mg/kg/day by gavage on gestational days 6-15 (3571). Maternal mortality was observed at the high dose, and dose-related incidences of other maternal effects were observed at all doses. Prenatal viability was not affected; however, decreased fetal weight and an increased incidence of cleft palate were observed at 280 mg/kg, the dose that caused maternal lethality. The total incidence of malformations was not increased significantly.

36.3.1.4 Other Toxicologic Effects

36.3.1.4.1 Short-term Toxicity

Disturbance of the central nervous system is the predominant toxic response to phenol regardless of the route of administration. In rats, the oral LD_{50} ranges from 530 to 550 mg/kg (59). An acute lethal dose produces initial increases in pulse and respiration which later become slow, weak, and irregular. After an initial rise, blood pressure falls significantly. The pupils constrict in the early stages but later dilate. Salivation may be evident and dyspnea is marked. Rats usually exhibit muscle twitching and uncoordinated leg movements until death occurs, usually due to respiratory arrest (12). Deichmann (1944) indicated that the severity of intoxication is directly related to the concentration of "free" (as opposed to "conjugated") phenol in blood and tissues (3905).

Cats appear to be the species most susceptible to the effects of phenol due to significant metabolic differences in the manner phenol is detoxified by this species. Oral doses of 50 to 100 mg/kg and intravenous doses of 50 mg/kg (dissolved in water) caused death in all animals tested (950).

In guinea pigs, inhalation exposures of 26-52 ppm, 7 hours daily, 5 days per week for 4 weeks caused weight loss, respiratory difficulty and signs of paralysis. At autopsy, pathologic examination revealed extensive myocardial necrosis and acute lobar pneumonia (951).

Cosgrove and Hubbard (952) reported that the eyes of rabbits were completely destroyed by one drop of 87% phenol in glycerin. However, if the eyes were immediately irrigated with water, corneas remained clear. If irrigation was delayed 10 seconds or longer, 40% of the animals sustained corneal damage. Solutions of 50% phenol in glycerin left in the eyes 10 seconds or longer before irrigation with water resulted in transparent corneas within 3 or 5 days in 30% of the animals. Solutions of 10 or 20% phenol in glycerin gave similar results. In another study, Murphy et al. (953) found that 0.1 mL of 5% phenol solution caused corneal opacities in 4 of 9 rabbits whose eyes were either not irrigated or irrigated with water for 2 minutes following 30 seconds of eye contact with the phenol solution.

The dermal LD_{50} for liquified phenol in rats is 670 mg/kg (0.625 mL/kg) by both occlusive and non-occlusive methods. Severe muscle tremors with twitching developed into generalized convulsions with loss of consciousness 5-10 minutes after administration of the dose in all animals. Severe hemoglobinuria developed 45-90 minutes after phenol application, with the severity increasing as a function of the dose. Skin lesions and edema with subsequent tissue necrosis and discoloration were also noted as well as pathologic evidence of kidney damage in all animals. The lowest dose applied was 0.1 mg/kg (954).

Reports of cardiac toxicity and death in humans treated with phenol as a cosmetic face-peeling agent stimulated a study in rats of the cardiovascular effects of dermally applied phenol (3944). Eight laboratory rats (strain not given) underwent abdominal epilation, Baker's phenol was applied to an area comparable to the human face (about 5% of the total body surface area), and cardiovascular parameters were monitored for about 1 hour. Electrocardiographic (EKG) changes (PVC's, ventricular tachycardia, S-T segment depression, and T-wave inversion) were noted in five of eight animals. Two animals died, one 13 minutes after application (blood phenol level, 6.5 mg%), the other 24 minutes after (blood phenol level, 8.1 mg%). The entire abdomen was then covered with Baker's phenol and the parameters were monitored again. EKG changes were noted in the remaining six animals and all died 1.5 to 35 minutes after application (mean, 19 minutes). Fatal blood levels ranged from 3 to 16.8 mg% with a mean of 7.9 mg%. The effects appeared to involve direct myocardial toxicity (myocardial depression based on decreased cardiac rate and arterial pressure), as well as S-T segment depression and T-wave inversions. Electromechanical dissociation then occurred, and bradycardia electrical activity continued with no resulting myocardial contraction.

36.3.1.4.2 Chronic Toxicity

Damage to the lungs, liver, kidneys and heart has been reported following prolonged administration of phenol. Rabbits exposed to vapor levels of 26 to 52 ppm, 7 hours daily, 5 days per week for 63 exposures in 88 days showed no signs of illness or discomfort. However, post-mortem examination revealed lobular pneumonia, chronic bronchitis, degeneration of the pulmonary blood vessels, myocardial degeneration, and indications of liver and kidney damage. Rats exposed to the same levels for 52 exposures in 74 days exhibited no signs of illness or pathologic changes (951).

Deichmann and Oesper (955) reported no significant effects in rats receiving 21-55 mg/rat/day (about 280 mg/kg for a 200 g rat) in their drinking water for 12 months. However, pathological studies were not done. In another study, rats receiving 135 doses of 50 mg/kg phenol by gavage over a 6-month-period experienced "slight" kidney damage while those receiving 100 mg/kg had "slight to moderate" kidney damage and "very slight" liver changes (939, 3908). The apparent ability of rats to tolerate much larger doses of phenol in drinking water may be due to its rapid metabolism as well as the intermittent nature of dosing, in contrast to exposure by gavage.

36.3.2 Human and Epidemiologic Studies

36.3.2.1 Short-term Toxicologic Effects

Phenol is readily absorbed from all routes of entry, distributed throughout the body, metabolized and rapidly excreted. The biological half-life of phenol in man is approximately 3.5 hours (939). Phenol is also produced endogenously by the degradative action of bacteria on tyrosine in the gut; between 1.5 and 5 mg of phenol are normally excreted per liter of human urine per day (939).

The most frequent adverse effects of phenol reported in humans result from skin contact (949). The skin is a primary route of entry for the solid, liquid and vapor. The vapor readily penetrates the skin with an absorption efficiency equal to that for inhalation (46). Signs and symptoms can develop rapidly with serious consequences including shock, convulsions, cyanosis, coma and death (949). Sax (51) reports that death can occur if 64 square inches of body surface are covered with phenol. Damage to internal organs has also been described. In addition, direct contact with the skin results in chemical burns.

Johnstone and Miller (956) described the case of an ink-manufacturing employee who spilled phenol on his leg, abdomen and chest. Although he immediately flushed the areas with water, he died within 15 minutes. Post-mortem examination revealed extensive first and second degree burns, edema and hyperemia of the lungs, kidneys, pancreas and spleen. In another case, a man died after application of benzyl benzoate (a scabicide) to his body with a brush that had been soaked overnight in an 80% phenol solution. Ten minutes after the application, he collapsed and began

convulsing. He died shortly thereafter. Blood samples were found to contain 4.7 μg/mL phenol (957).

Cardiac arrhythmias have been reported in people undergoing chemical peeling of skin lesions with 40-80% phenol solutions. Arrhythmias are the primary type of morbidity associated with these procedures (958).

The lowest oral lethal dose reported in humans is 140 mg/kg (59); however, ingestion of 65 g of pure phenol or 120 g crude phenol have been survived (12). Ingestion causes severe burns of the mouth and throat, abdominal pain, cyanosis, muscular weakness, coma and death. Tremor, convulsions and muscle twitching may also occur (46). In one case, a woman committed suicide by ingesting 10-20 g of phenol. She became comatose with partial absence of reflexes, skin pallor, accelerated respiration, rapid pulse and dilated pupils. One hour after ingestion, she experienced cardiorespiratory arrest. Attempts at resuscitation were made for 2 hours, but to no avail. Autopsy revealed hyperemia of the tracheal and bronchial membranes. Histologic examination revealed edema of the liver and lungs and hyperemia of the intestines (959).

One incident of environmental poisoning occurred in 1974 when a derailed train spilled 37,900 liters of 100% phenol in rural Wisconsin. Over the next 6 months, phenol concentrations as high as 1130 mg/L were noted in well water. Individuals living near the site who ingested the phenol-contaminated water experienced burning sensations in the mouth, mouth sores, skin rashes, diarrhea and darkened urine (probably from oxidation products of phenol). Exposed individuals had estimated phenol intakes of 10-240 mg/person/day. Physical and laboratory examinations 6 months after the spill revealed no abnormalities in individuals who had consumed the contaminated water (961).

Owing in part to its low volatility, phenol is not considered a serious respiratory hazard (46). Inhalation of 15-52 ppm phenol for 8 hours (with two 30-minute breaks) using a face mask produced no ill effects in 8 human volunteers (960). Various studies have demonstrated that phenol has odor warning properties at concentrations far below those at which toxic effects occur (reviewed in 3898). Using a standardized procedure with trained odor analysts, Leonardos et al. (3923) determined the odor threshold for phenol to be 0.047 ppm volume; the panel of analysts described the odor as "medicinal".

Phenol is irritating to the eyes, nose and throat. Concentrated phenol solutions are severely irritating to the human eye, causing conjunctival and corneal damage. In some cases, the eye lids have been severely damaged. In one case, severe iritis accompanied corneal injury (3913).

36.3.2.2 Chronic Toxicologic Effects

Chronic phenol poisoning is infrequently reported. Severe chronic poisoning in man is characterized by systemic disorders which may include anorexia, vomiting,

excessive salivation, headache, dizziness and skin eruption. Fatalities occur when there is extensive damage to the liver and kidneys (949,12).

Prolonged cutaneous exposure may result in ochronosis, a discoloration of collagenous tissue. NIOSH (949) cites numerous reports of ochronosis occurring in the early part of this century attributed to the use of dressings impregnated with 5-10% phenol solutions for periods ranging from 3 to 24 years. Merliss (962) reported a case of a laboratory worker exposed to phenol, cresol and xylenol both dermally and by inhalation. Signs and symptoms appeared slowly and included loss of appetite and body weight, muscle pain, weakness and dark urine. After 13.5 years of exposure, examination revealed an emaciated individual with an enlarged liver and elevated liver enzyme levels. After exposure was discontinued, recovery was slow. Seven months later he had gained 7.6 kg and his liver was no longer palpable.

36.3.3 Levels of Concern

The USEPA (3770) has established an ambient water quality criterion for the protection of human health for phenol of 3.5 mg/L. This criterion was developed based on the lowest-observed-adverse-effect level (i.e., slight kidney damage) in chronic oral studies with rats, an uncertainty factor of 500 and the assumption that two liters of drinking water are consumed by a 70-kg adult daily.

Subchronic oral studies in rats by Dow Chemical Company demonstrated slight kidney damage at 50 mg/kg (3908). Bruce et al. 1987 (3898) and USEPA (3955) identify this as the oral LOAEL (lowest-observed-adverse effect level) for phenol. Based on the LOAEL and an uncertainty factor of 500, USEPA (3955) calculated an oral Acceptable Intake Subchronic (AIS) of 7.0 mg/man/day for ingested phenol. An oral reference dose (RfD_o) of 600 μg/kg/day has been derived by the USEPA (3744). A reportable quantity (RQ) for phenol of 1000 lbs (454 kg) has been calculated (3885).

OSHA (3539) currently permits exposure to 5 ppm (19 mg/m^3) averaged over an 8-hour work-shift. The ACGIH (3005) recommends the same concentration as a threshold limit value.

36.3.4 Hazard Assessment

Phenol is readily absorbed from all routes of entry. The majority of human lethal values are in the 5-40 g range. Central nervous system disturbances together with peripheral vasodilation result from an acute lethal dose of phenol, leading to sudden collapse, unconsciousness and death due to respiratory arrest. Ingestion of nonlethal amounts of phenol can result in burning in the mouth, mouth sores, headache, vomiting, diarrhea, back pain and production of dark urine.

Concentrations of up to 5000 ppm of phenol in the drinking water of both mice and rats was not carcinogenic for either species (941). Repeated skin application of large amounts of phenol does appear to promote tumor development in sensitive

mouse strains but not in standard inbred strains of mice. The tumorigenic activity of phenol on mouse skin appears to be related to its irritancy and the resulting skin hyperplasia. Neither IARC (803) nor the NTP (883) have classified phenol with regard to carcinogenic activity.

Bacterial mutagenicity tests provide primarily negative findings for phenol. Phenol increased sister chromatid exchanges in human lymphocytes in vitro. The greatest concern, however, is an unconfirmed report of dose-related changes in the chromosomes of mouse spermatogonia and primary spermatocytes following gavage administration of aqueous phenol solutions at dosages as low as 6.5 μg/kg/day (963).

Unknown factors such as tissue distribution and DNA repair capabilities of different tissues and species make any discussion of the genetic implications for humans more speculative than factual. The negative carcinogenic response in lifetime studies with both rats and mice given 5000 ppm phenol in their drinking water plus the fact that phenol is a normal constituent of human tissues and fluids indicate that both humans and laboratory animals can handle long-term, low-level exposures to phenol with no apparent untoward effects. Nevertheless, this particular finding warrants validation in order to clarify the variance of its effect level from other reported effect levels as well as the potential implications of this study to humans if the results are substantiated.

Animal studies suggest no indications of embryotoxic nor teratogenic effects associated with phenol exposure. Slight to moderate kidney damage and slight liver changes have been reported in rats given 135 daily doses of 100 mg/kg phenol by gavage. Rats, however, have been able to tolerate much larger doses in drinking water (55 mg/rat/day or about 280 mg/kg for a 200 g rat) probably due to its rapid metabolism as well as the intermittent nature of dosing in contrast to exposure by gavage.

36.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of phenol concentrations in soil and water requires collection of a representative field sample and laboratory analysis. Soil and water samples are collected in glass containers; extraction of samples should be completed within 7 days of sampling and analysis completed within 30-40 days. In addition to the targeted samples, quality control samples such as field blanks, duplicates, and spiked sample matrices may be specified in the recommended methods.

EPA-approved procedures for the analysis of phenol, one of the EPA priority pollutants, in aqueous samples include EPA Methods 604, 625, and 1625 (65), 8040 and 8250 (63). Prior to analysis, samples are extracted with methylene chloride as a solvent using a separatory funnel or a continuous liquid-liquid extractor. Methods 604 and 8040 also provide for a perfluorobenzyl bromide (PFB) derivatization of the sample extract with additional clean-up procedures if interferences are present in the sample matrix. An aliquot of the concentrated sample extract with or without

derivatization is injected onto a gas chromatographic (GC) column using a solvent flush technique. The GC column is programmed to separate the semi-volatile organics; phenol is then detected with a flame ionization detector (Methods 604 and 8040 without derivatization), as its PFB derivative with an electron capture detector (Methods 604 and 8040 with derivatization) or with a mass spectrometer (Methods 625 and 1625).

The EPA procedures recommended for phenol analysis in soil and waste samples, Methods 8040 and 8250 (63), differ from the aqueous procedures primarily in the preparation of the sample extract. Solid samples are extracted using either soxhlet extraction or sonication methods. Neat and diluted organic liquids may be analyzed by direct injection.

Other methods for the determination of phenol in water include high performance liquid chromatography (HPLC) with electrochemical detection (3589, 3459), with UV absorption (3588), or with fluorescence detection (3502). Spectrophotometric measurement of phenol following reaction with a succinimide reagent has also been described (3023). The HPLC methods use reversed-phase columns for analytical separations and in some cases precolumns to concentrate the samples (3588, 3502). Determinations can be made on-line (3502) or with automated instrumentation (3588). Both fluorescence and electrochemical detection offer very high sensitivity (i.e., sub μg/L). A remote method based on laser induced fluorescence has also been described (3023).

Typical phenol detection limits that can be obtained in waste waters and nonaqueous samples (wastes, soils, etc.) are shown below. The actual detection limit achieved in a given analysis will vary with instrument sensitivity and matrix effects.

Aqueous Detection Limit	Nonaqueous Detection Limit
1.4 μg/L (Method 8040 without derivatization)	94 μg/kg (Method 8040/FID)
22 μg/L (Method 8040 with derivatization)	1.5 μg/g (Method 8040/ECD)
15 μg/L (Method 8250)	1 μg/g (Method 8250)
10 μg/L (Method 1625)	
0.14 μg/L (Method 604 without derivatization)	
2.2 μg/L (Method 604 with derivatization)	
1.5 μg/L (Method 625)	
34 μg/L (3589)	

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APPENDIX 1

USEFUL HANDBOOKS, DATABOOKS, RESPONSE GUIDES AND AIR FORCE DOCUMENTS

A listing of useful handbooks, databooks and response guides, all relating to the release of hazardous or toxic chemicals to the environment, the properties and hazards of the chemicals, initial responses to spills of such chemicals, or subsequent remedial action follow. The contents of each publication is briefly described. The following listing is not intended to be inclusive of all publications of this kind. However, it is felt that the acquisition and central location of these reports (at key Air Force offices) would provide a valuable resource.

- A Method for Determining the Compatibility of Hazardous Wastes

  Authors: H. K. Hatayama et al. (April 1980)

  Available from: U.S. Environmental Protection Agency
  Municipal Environmental Research Laboratory
  Cincinnati, OH
  (EPA Report No. EPA-600/2-80-076)
  (NTIS Report No. PB80-221005)

  Contents: Provides method and chart for defining compatibility of various families of hazardous materials and wastes.

- Accident Management Orientation Guide

  Authors: D. K. Shaver et al. (October 1983)

  Available from: Air Force Rocket Propulsion Laboratory
  Air Force Systems Command
  Edwards Air Force Base
  California 93523
  (Report No. AFRPL-TR-82-075)

  Contents: This document identifies guidelines for mitigating hazards associated with an in-service railroad derailment or a railroad yard accident involving hazardous materials of interest to the Air Force.

- Carbon Adsorption Isotherms for Toxic Organics

  Authors: R. A. Dobbs and J. M. Cohen (April 1980)

  Available from: U.S. Environmental Protection Agency
  Office of Research and Development
  Cincinnati, OH
  (EPA Report No. EPA-600/8-80-023)

  Contents: Provides detailed data on the effectiveness of carbon for removal of organic substances from water.

- Chemical Hazards of the Workplace

  Authors: N. H. Proctor and J. P. Hughes (1978)

  Available from: J. B. Lippincott Company
  Philadelphia, PA

  Contents: Provides data on the toxicological effects of chemicals and suggests medical treatment protocols in more detail than given elsewhere.

- CHRIS Hazardous Chemical Data

  Author: U.S. Coast Guard (1985)

  Available from: Superintendent of Documents
  U.S. Government Printing Office
  Washington, D.C. 20402
  (Stock No. 050-012-00147-2)

  Contents: Provides a wide variety of data on more than 1000 hazardous materials when ordered with various addendums. A separate volume (Stock No. 050-012-00158-8) provides graphs of temperature dependent physical properties.

- **Dangerous Properties of Industrial Materials, 7th edition**

  Author: N. I. Sax, ed. (1989)

  Available from: Van Nostrand Reinhold
  New York, NY

  Contents: A well-known handbook that provides a brief summary of the toxicology and properties of numerous hazardous substances.

- **Dangerous Properties of Industrial Materials Report**

  Author: N. I. Sax, ed. (bimonthly publication)

  Available from: Van Nostrand Reinhold Company
  New York, NY

  Contents: Each bimonthly report provides detailed data on the hazards and environmental effects of several chemicals. Much of the data is from the EPA's Oil and Hazardous Materials-Technical Assistance Data System (OHM-TADS) and similar sources.

- **Emergency Action Guides**

  Authors: P. C. Conlon and A. M. Mason, eds. (1984)

  Available from: Bureau of Explosives
  Association of American Railroads
  1920 L Street N.W.
  Washington, D.C. 20036

  Contents: Provides detailed data and spill response information on each of the 134 materials that comprise over 98 percent of the hazardous commodities transported by rail in the United States.

- **Emergency Handling of Hazardous Materials in Surface Transportation**

  Author: P. J. Student, ed. (1981)

  Available from: Bureau of Explosives
  Association of American Railroads
  1920 L Street N.W.
  Washington, D.C. 20036

  Contents: Provides brief spill response recommendations for each hazardous material regulated by the U.S. Department of Transportation.

- **Emergency Response Guidebook**

  Author: Materials Transportation Bureau (1987)

  Available from: U.S. Department of Transportation
  Materials Transportation Bureau
  Attention: DMT-11
  Washington, DC 20590
  (Publication DOT P5800.3)

  Contents: A guide for initial actions to be taken by emergency service personnel during hazardous material incidents.

- **Fire Protection Guide on Hazardous Materials**

  Author: National Fire Protection Association (1986)

  Available from: National Fire Protection Association
  Batterymarch Park
  Quincy, MA 02269

  Contents: Flash Point Index of Trade Name Liquids Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids (NFPA 325M) Hazardous Chemicals Data (NFPA 49) Manual of Hazardous Chemical Reactions (NFPA491M)

- Groundwater Contamination Response Guide, Volume I: Methodology, Volume II: Desk Reference

  Authors: J. H. Guswa and W. J. Lyman (1983)

  Available from: National Technical Information Service
  Springfield, VA
  (as U.S. Air Force Report ESL-TR-82-39)
  or
  Noyes Publications
  Park Ridge, NJ
  (under the title "Groundwater Contamination and Emergency Response Guide" (1984))*

  Contents: Provides an overview of ground-water hydrology and a current technology review of equipment, methods, and techniques used to investigate incidents of ground water contamination by chemicals.

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*Noyes Publications also contain a reproduction of the report by A. S. Donnigian, Jr. et al.: Rapid Assessment of Potential Ground-Water Contamination Under Emergency Response Conditions, a 1983 report to the U.S. Environmental Protection Agency.

- Ground-Water Hydrology Workbook

  Authors: E.W. Artiglia and G.R. New (1984)

  Available from: USAF Occupational and Environmental Health Laboratory
  Brooks AFB, TX 78235
  (Report No. 84-168EQ111DGB)

  Contents: Summarizes introductory articles in ground-water hydrology of importance to base bioenvironmental engineers involved with the IRP program.

- Guidelines Establishing Test Procedures For The Analysis of Pollutants Under the Clean Water Act, Appendix A.

  Author: U.S. Environmental Protection Agency (1984)

  Available from: Federal Register
  Volume 49(209):43234
  October 26, 1984

  Contents: Methods for analysis of environmental samples.

- Guidelines for the Selection of Chemical Protective Clothing

  Authors: A.D. Schwope et al. (1987)

  Available from: U.S. Environmental Protection Agency
  Washington, D.C.

  Contents: Denotes compatibility of rubber and plastic clothing materials with various chemicals; provides guidelines for clothing selection and use.

- Guidelines for the Use of Chemicals in Removing Hazardous Substances Discharges

  Authors: C. K. Akers, R. J. Pilie and J. G. Michalovic (1981)

  Available from: U.S. Environmental Protection Agency
  Office of Research and Development
  Cincinnati, OH
  (EPA Report No. EPA-600/2-81-205)

  Contents: Report provides guidelines on the use of various chemical and biological agents to mitigate discharges of hazardous substances.

- Handbook for Evaluating Remedial Action Technology Plans

  Authors: J. Ehrenfeld and J. Bass (1983)

  Available from: U.S. Environmental Protection Agency
  Office of Research and Development
  Cincinnati, OH
  (EPA Report No. EPA-600/1-83-076)

  Contents: Provides information on over 50 remedial action technologies for cleanup of chemically-contaminated sites.

- Handbook of Chemical Property Estimation Methods
  (subtitle: Environmental Behavior of Organic Compounds)

  Authors: W. J. Lyman, W. F. Rechl, D. H. Rosenblatt, eds. (1982)

  Available from: McGraw-Hill Book Co.
  New York, NY

  Contents: Provides estimation methods for (and discussion of) 26 environmentally-important properties of organic chemicals.

- Handbook of Environmental Data on Organic Chemicals, 2nd edition

  Author: K. Verschueren (1983)

  Available from: Van Nostrand Reinhold
  New York, NY

  Contents: Provides detailed property and environmental data on numerous organic substances.

- **Handbook of Toxic and Hazardous Chemicals**

  Author: M. Sittig (1985)

  Available from: Noyes Publications
  Park Ridge, NJ

  Contents: Discusses a wide range of topics for numerous chemicals, with special emphasis on toxicology and protective measures.

- **Hazardous Chemicals Data Book, 2nd edition**

  Author: G. Weiss, ed. (1986)

  Available from: Noyes Data Corporation
  Park Ridge, NJ

  Contents: Reproduction of data (physicochemical properties, hazards, toxicity, etc.) related to chemical spill response from (1) CHRIS Hazardous Chemical Data (1978) and (2) Material Safety Data Sheets prepared by Oak Ridge National Laboratory.

- **Herbicide Handbook, 5th edition**

  Author: Weed Science Society of America (1983)

  Available from: Weed Science Society of America
  309 West Clark Street
  Champaign, IL 61820

  Contents: Provides basic information on physiocochemical properties, uses, environmental fate, physiological and biochemical behavior, and toxicological properties for most herbicides in use. (Previous editions may cover out-of-use herbicides.)

- **Manual for the Control of Hazardous Material Spills - Vol. 1: Spill Assessment and Water Treatment Techniques**

  Authors: K. R. Huibregtse et al. (November 1977)

  Available from: U.S. Environmental Protection Agency
  Office of Research and Development
  Cincinnati, OH
  (EPA Report No. EPA-600/2-77-227)

  Contents: Provides both general and specific information on responding to spills of hazardous materials, particularly those into water.

- **Methods to Treat, Control and Monitor Spilled Hazardous Materials**

  Authors: R. J. Pilie et al. (1975)

  Available from: U.S. Environmental Protection Agency
  Industrial Waste Treatment Research Laboratory
  Edison, NJ
  (EPA Report No. EPA-670/2-75-042)

  Contents: Special studies of selected chemical spill response measures plus matrix of possible spill response measures for 250 hazardous liquids.

- **NIOSH Manual of Analytical Methods, 3rd edition**

  Author: Peter M. Eller, ed. (1984)

  Available from: Superintendent of Documents
  U.S. Government Printing Office
  Washington, D.C. 20402

  Contents: Contains sampling and analytical methods for use in industrial hygiene environmental monitoring.

- **NIOSH/OSHA Occupational Health Guidelines for Chemical Hazards**

  Authors: F. W. Mackison et al., eds. (January 1981)

  Available from: Superintendent of Documents
  U.S. Government Printing Office
  Washington, D.C. 20402
  (DHHS (NIOSH) Publication No. 81-123)

  Contents: Provides information on toxicology, chemical properties, first aid, and personal protective clothing and equipment for many OSHA-regulated commodities.

- **Patty's Industrial Hygiene and Toxicology - Vol. 2A,B,C: Toxicology**

  Authors: G.D. Clayton and F.E. Clayton, eds. (1981-1982)

  Available from: John Wiley & Sons
  New York, NY

  Contents: Provides extensive discussion of the properties and toxicology of numerous chemicals.

- **Perry's Chemical Engineers Handbook**

  Authors: R. H. Perry and D. Green, eds. (1984)

  Available from: McGraw-Hill Book Company
  New York, NY

  Contents: Contains extensive data on the properties of chemicals and on their compatibility with various materials of construction (plus numerous other topics).

- **Pesticide Manual, 7th edition**

  Author: C. R. Worthing, ed. (1983)

  Available from: British Crop Protection Council Publications
  Worcestershire WR13 15LP
  ENGLAND

  Contents: Provides a brief review of analysis, uses and toxicity of chemicals and microbial agents used as active components of pest-control products.

- **Post Accident Procedures for Chemicals and Propellants**

  - Interim Report for the Period 8/11/80 to 3/31/81 (September 1982) (Report No. AFRPL-TR-82-031)

  - Interim Report for the Period 4/81 to 1/82 (September 1982) (Report No. AFRPL-TR-82-032)

  - Guidelines Manual (January 1983) (Report No. AFRPL-TR-82-077)

  Authors: D. K. Shaver et al.

  Available from: Air Force Rocket Propulsion Laboratory
  Air Force Systems Command
  Edwards Air Force Base
  California 93523

  Contents: This is a series of manuals providing information and data required to respond to spills of chemicals and propellants of special interest to the Air Force.

- Quality Criteria for Water

  Author: U.S. Environmental Protection Agency (July 1976)

  Available from: Superintendent of Documents
  U.S. Government Printing Office
  Washington, D.C. 20402
  (Stock No. 055-001-01049-4)

  Contents: This is EPA's well-known guide to water quality criteria commonly referred to as the "redbook."

- Registry of Toxic Effects of Chemical Substances

  Authors: R. L. Tatken and R. J. Lewis, Sr., eds. (June 1983)

  Available from: Superintendent of Documents
  U.S. Government Printing Office
  Washington, D.C. 20402
  (DHHS [NIOSH] Publication 83-107)

  Contents: Summarizes results of primarily short-term toxicological experiments for thousands of chemicals.

- Standard Methods for the Examination of Water and Wastewater, 15th edition

  Authors: Arnold Greenberg et al., eds. (1985)

  Available from: American Public Health Association
  1015 18th Street
  Washington, D.C.

  Contents: Methods for analysis of environmental samples.

- **Supplement to Development Document, Hazardous Substances Regulations, FWPCA as Amended 1972**

  Author: U.S. Environmental Protection Agency (November 1975)

  Available from: U.S. Environmental Protection Agency
  Office of Water Planning and Standards
  Washington, D.C. 20460

  Contents: Discusses the environmental effects of numerous water pollutants.

- **Test Methods for Evaluating Solid Waste-Physical Chemical Methods, 3rd edition**

  Author: U.S. Environmental Protection Agency (1987)

  Available from: Superintendent of Documents
  U.S. Government Printing Office
  Washington, D.C. 20460
  (Report No. SW-846)

  Contents: Methods for analysis of environmental samples.

- **TLVs-Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment and Biological Exposure Indices with Intended Changes for 1987-1988**

  Author: American Conference of Governmental Industrial Hygienists (1987)

  Available from: American Conference of Governmental Industrial Hygienists
  6500 Glenway Ave., Bldg. D-5
  Cincinnati, OH 45211

  Contents: This booklet (or the latest version of it) presents recommended exposure limits for airborne concentrations of toxic materials in the working environment.

- **Toxicology of the Eye**

  Author: W. M. Grant (1986)

  Available from: Charles C. Thomas - Publisher
  Springfield, IL

  Contents: An excellent source of information on the effects of numerous chemicals and other substances on the eyes.

- **USAF OEHL Recommended Sampling Procedures**

  Author: USAF Occupational and Environmental Health Laboratory (January 1982)

  Available from: USAF Occupational and Environmental Health Laboratory
  Brooks AFB, TX 78235
  (Limited Distribution)

  Contents: Outlines standardized sampling procedures with appropriate collection and preservation techniques for submission of samples to USAF OEHL for analysis.

- **Water-Related Environmental Fate of 129 Priority Pollutants (2 volumes)**

  Authors: M. A. Callahan et al. (December 1979)

  Available from: U.S. Environmental Protection Agency
  Washington, D.C.
  (EPA Report No. EPA-440/4-79-029a and -029b)
  (NTIS No. PB80-204373 and PB80-204381)

  Contents: Individual chapters address the fate of priority pollutants in the environment.

PERTINENT AIR FORCE PUBLICATIONS FOR THE USAF INSTALLATION RESTORATION PROGRAM

PUBLICATION	COMMENT
AFR 161-8	Establishes USAF permissible exposure limits for chemical substances.
AFR 161-17	Establishes USAF OEHL consultant services in Environmental Engineering, Industrial Hygiene, Occupational Health, Radiation Protection, and Analytical Chemistry.
AFR 161-44	Establishes USAF drinking water standards for common contaminants. For the most part, these are the same as the National Primary and Secondary Drinking Water Standards.
AFR 19-1	Establishes the USAF Environmental Protection Program.
AFR 19-7	Establishes responsibilities for environmental monitoring for Air Force installations. This regulation defines the roles of the Civil Engineer, the Bioenvironmental Engineer, and others with respect to environmental pollution monitoring.
DEQPPM 80-8	DoD implementation of RCRA.
DEQPPM 80-9	DoD guidance on the proper handling, storage, and disposal of PCB and PCB items.
DEQPPM 81-5	DoD guidance on the Installation Restoration Program to identify and evaluate past DoD hazardous material disposal sites on DoD installations and control migration from such sites.
EO 12088	Requires federal compliance with applicable federal, state, and local pollution control standards (procedural and substantiative) the same as any other industry or private person.
GWMR	Quarterly publication on ground-water monitoring remedial actions. Presents technical articles on contaminant transport, analytical methods, sampling methodology, and data interpretation.
IRPMC	Establishes the management concept for the IRP Phase II program.
LEEV LTR	Policy letters formulated by USAF HQ/LEEV.

NCP	Establishes procedures for response to potential for confirmed contamination of our nation.

APPENDIX 2

U.S. AIR FORCE POINTS OF CONTACT FOR THE INSTALLATION RESTORATION PROGRAM

- Mr. Gary D. Vest
  Maj. Patrick T. Fink
  SAF/MIQ
  Washington, D.C. 20330-5000
  AV 227-9297
  Commercial: (202) 696-9297

  Office of the Assistant Secretary of the Air Force
  Deputy for Environment and Safety

  Responsible for overall Air Force IRP guidance.

IRP GROUP

- Maj. Scott L. Smith, Branch Chief
  AV 297-0275
  Responsible for IRP engineering policy formulation.

- Maj. Roy K. Soloman
  AV 297-0275
  Responsible for Environmental Compliance Assessment and Management Program (ECAMP), Environmental Protection Committee, and IRP implementation.

- Col. Raymond A. Malinovsky
  Chief, Environmental Quality Division
  Director of Engineering and Services
  HQ USAF/LEEV
  Bolling Air Force Base
  Washington, DC 20332-5000

- Capt. Gerald L. Hromowyk
  AV 297-0275
  Responsible for spill policy and management information systems.

- Capt. Charles M. Groover
  AV 297-0275
  Responsible for underground storage tanks and training.

- Mr. Earl E. Kneeling
  AV 297-4174
  Responsible for Defense Environmental Restoration Program policy.

- Mr. Jeffery J. Short
  AV 297-0275
  Responsible for Third Party Sites.

- Col. Thayer J. Lewis, Chief
  Bioenvironmental Engineering
  HQ USAF/SGPA
  Bolling AFB, DC 20332-6188
  AV 297-1737
  Commercial: (202) 767-1737

- Lt. Col. Edward W. Artiglia
  AV 297-1738
  Responsible for IPR medical service policy formulation.

- Col. Frank P. Gallagher
  HQ AFESC/RDV
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  AV 970-2097/2098
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  USAF Engineering and Services Center
  Engineering and Services Laboratory
  Environics Division

  Responsible for IRP engineering research and development.

- Mr. Emile Y. Baladi
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  Brooks AFB, TX 78235-5000
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  USAF Occupational and Environmental Health Laboratory Technical Services Division

  Responsible for IRP Phase II technical program management.

- Dr. Jeffrey W. Fisher
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  AV 785-2704
  Commercial: (513) 255-2704

  Harry G. Armstrong Aerospace Medical Research Laboratory Toxic Hazards Division

  Responsible for IRP health effects research.

- Lt. Col. Stanley O. Hewins
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  Brooks AFB, TX 78235-5000
  AV 240-2063
  Commercial: (512) 536-2063

  USAF Occupational and Environmental Health Laboratory Consultant Services Division
  Environmental Health Branch

  Responsible for Toxicology Consultant Service.

- Major Air Command Bioenvironmental Engineers
  See latest edition of the "Worldwide Listing of Bioenvironmental Engineering and Environmental Health Personnel."

  Responsible for implementing IRP policy and management decisions and coordinating with state/local regulatory agencies.

APPENDIX 3

MATH, CONVERSIONS AND EQUIVALENTS

- **Calculation of Air W/V Conversion Factors**

One liter of air at 25 °C (298.16 °K) contains:

$$\frac{(1 \text{ atm})(1 \text{ liter})}{.0821 \text{ liter atm/mole})(298.16 \text{ °K})} = 0.040874 \text{ moles of gas.}$$

Hence, one liter of air contains:

MW x 10^{-6} x 0.040874 grams of a contaminant at 1 ppm.

This is the same as saying 1 m^3 of air contains:

MW x 0.040874 mg of a contaminant at 1 ppm.

For example, chloroform has a MW of 119.39. Thus,

1 ppm = 119.39 x 0.040874 ≈ 4.88 mg/m^3 at 25°C.

- **Conversion for Solutes in Water**

1 mg/L ≈ 1 ppm (by weight).

- **Conversion of Percent in Food, Water or Air to Parts Per Million**

X% = X parts per 100 parts

$$\frac{X}{100} (10^6) = \text{ ppm.}$$

- **Conversion of Parts Per Million in Food or Water to mg/kg bw/day**

Since both food intake and body weight vary with age (and some times, with treatment), there is no single factor that precisely converts parts per million (ppm) in food or water to mg/kg body weight/day. However, by assuming 100% absorption and adopting a set of standard values for each species for daily food, water and air intake

and average body weight, one can convert a ppm dosage level, within reasonable limits, to mg/kg bw/day for the sake of comparisons.

The following standard body weights and intake values were used to convert dietary or respiratory intakes to estimated daily dose rate:

Species	Body Weight (kg)	Food Consumption (g/day)	Approximate Water Intake (mL/day)	Minute Volume (m^3/min)
Human	70	700	2000	7.4×10^{-3}
Mouse	0.025	3	4.5	2.3×10^{-5}
Rat	0.3	15	20	1.0×10^{-4}
Monkey	5	250	500	8.6×10^{-4}
Rabbit	2	60	330	1.1×10^{-3}
Dog	10	250	500	5.2×10^{-3}
Guinea pig	0.5	30	85	1.6×10^{-4}

For example, at a dietary concentration of 1 ppm of Chemical X, an average adult mouse would consume 3 g of food per day or 0.12 mg of Chemical X/kg bw/day. This value was calculated as follows:

Intake (mg/kg bw/day) = food consumption (g/day) x dietary concentration (ppm) x $1g/10^6$ g diet x 1000 mg/g x 1/bw (kg).

- **Calculation of Respiratory Uptake**

Uptake (mg) = Concentration (mg/m^3) x minute volume (m^3/min) x retention factor (assume 1.0 unless value is known) x time (minutes).

- **Temperature Conversions**

The formulas given below were used to convert temperatures from one scale to another.

To convert temperatures given in Celsius to Fahrenheit:

$$°F = 9/5\ (°C) + 32$$

To convert temperatures given in Fahrenheit to Celsius:

$$°C = 5/9\ (°F - 32)$$

APPENDIX 4

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$C_3H_6Cl_2$
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C_3H_6O
Acetone. See Chapter 40.

$C_3H_8O_2$
Methyl Cellosolve®. See Chapter 42.

$C_4H_8Cl_2O$
Bis(2-chloroethyl)ether. See Chapter 33.

C_4H_8O
Methyl ethyl ketone. See Chapter 41.

C_6HCl_5O
Pentachlorophenol. See Chapter 39.

$C_6H_3Cl_3$
1,2,4-Trichlorobenzene. See Chapter 28.

$C_6H_4Cl_2$
1,2-Dichlorobenzene. See Chapter 25.
1,3-Dichlorobenzene. See Chapter 26.
1,4-Dichlorobenzene. See Chapter 27.

$C_6H_4Cl_2O$
2,6-Dichlorophenol. See Chapter 38.

C_6H_5Cl
Chlorobenzene. See Chapter 24.

C_6H_5ClO
o-Chlorophenol. See Chapter 37.

C_6H_6
Benzene. See Chapter 18.

$C_6H_6Cl_6$
Lindane. See Chapter 47.

C_6H_6O
Phenol. See Chapter 36.

$C_7H_6N_2O_4$
2,6-Dinitrotoluene. See Chapter 23.

C_7H_8
Toluene. See Chapter 19.

$C_8H_5Cl_3O_3$
2,4,5-T. See Chapter 61.

$C_8H_6Cl_2O_3$
2,4-D. See Chapter 60.

C_8H_{10}
Ethyl benzene. See Chapter 20.
o-Xylene. See Chapter 21.

m-Xylene. See Chapter 21.
p-Xylene. See Chapter 21.
Xylenes, mixed. See Chapter 21.

$C_8H_{10}O$
2,4-Dimethylphenol. See Chapter 22.

$C_8H_{20}Pb$
Tetraethyl lead. See Chapter 54.

$C_9H_7Cl_3O_3$
2,4,5-TP. See Chapter 62.

$C_{10}H_6Cl_8$
Chlordane. See Chapter 48.

$C_{10}H_8$
Naphthalene. See Chapter 32.

$C_{10}H_{19}O_6PS_2$
Malathion. See Chapter 50.

$C_{12}H_4Cl_4O_2$
2,3,7,8-Tetrachlorodibenzo-p-dioxin. See Chapter 63.

$C_{12}H_{10}N_2O$
N-Nitrosodiphenylamine. See Chapter 35.

$C_{12}H_{14}O_4$
Diethyl phthalate. See Chapter 29.

$C_{12}H_{21}N_2O_3PS$
Diazinon® See Chapter 51.

$C_{14}H_8Cl_4$
DDE. See Chapter 59.

$C_{14}H_9Cl_5$
DDT. See Chapter 57.

$C_{14}H_{10}Cl_4$
DDD. See Chapter 58.

$C_{16}H_{22}O_4$
Di-n-butyl phthalate. See Chapter 30.

$C_{19}H_{20}O_4$
Butyl benzyl phthalate. See Chapter 46.

$C_{21}H_{21}O_4P$
Tri-o-cresyl phosphate. See Chapter 49.

$C_{24}H_{38}O_4$
Di(2-ethylhexyl)phthalate. See Chapter 31.

Molecular Formula Unknown

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Fuel oils
See Chapter 66.

Hydraulic fluid
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JP-4
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Mineral base crankcase oil
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Stoddard solvent
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Synthetic crankcase oil
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*Numeric designation assigned by the American Chemical Society's Chemical Abstracts Service which uniquely identifies a specific chemical compound.

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CZ4499000	26
CZ4500000	25
CZ4550000	27
DA0700000	20
DC2100000	28
EL6475000	41
FG4900000	6
FS9100000	4
GB2955000	53
GS7175000	56
GV4900000	47
HP3500000	63
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IQ0525000	34
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KH7525000	7
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KI8575000	11
KJ2975000	10
KJ3325000	57
KL5775000	42
KN0875000	33
KU9625000	13
KV9360000	15
KV9400000	15
KV9422000	15
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KW2975000	43
KX3850000	17
KX4550000	16
LS8950000	66
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OA5500000	66
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PA6360000	3
PA7350000	2
PA8050000	1
PB6125000	5
PB9800000	48
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No NIOSH Number Assigned:

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*A unique nine-position accession number (two letters and seven numerals) assigned alphabetically to each substance in the Registry of Toxic Effects of Chemical Substances published by the National Institute for Occupational Safety and Health (Reference 47).

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