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The Installation Restoration Program Toxicology Guide

Volume 5

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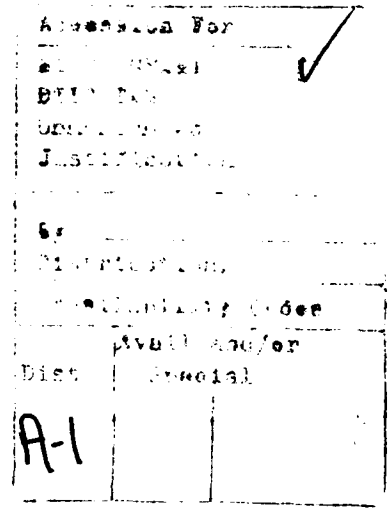
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THE INSTALLATION RESTORATION PROGRAM TOXICOLOGY GUIDE

Volume 5

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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 Human Systems Division 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 Human Systems Division, 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, Harry G. Armstrong Human Systems Division, 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 Harry G. Armstrong Human Systems Division/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).
NA	Not applicable
Narcosis	A state of stupor, unconsciousness or arrested activity.
NCI	National Cancer Institute
ND	No data
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

INTRODUCTION
TOXICOLOGY OF METALS

1.1 Overview

A complete description of the Air Force Installation Restoration Program and its corresponding Toxicology Guide appears in Volume 1. Briefly, the Air Force Installation Restoration Program (IRP) was initiated in December 1981 to implement the Department of Defense Environmental Quality Program Policy Memorandum (DEQPPM) regarding identification and evaluation of hazardous material disposal on DOD sites and to control the migration of these hazardous materials into ground water.

The Air Force IRP Toxicology Guide is an effort by the Harry G. Armstrong Aerospace Research Laboratory to (1) identify those contaminants for which criteria, standards or U.S. EPA-based guidelines are available, (2) provide a ground water contaminant information data base for use at USAF installations where there are no relevant federal, state, or local standards, and (3) provide guidelines to aid in the development of USAF policy and programs for IRP completion.

1.2 Organization

This volume, regarding metals identified by the USAF as being of concern to the IRP, is an extension of the previous four volumes addressing a series of 70 compounds relevant to Air Force installations. Specifically, this volume presents information on cadmium, chromium, mercury, zinc, arsenic, nickel and copper. The general organization is similar to that of the previous volumes, and consists of individual chapters for each metal. Due to the complexity of metal chemistry, each chapter is not limited to merely the elemental form of the metal, but rather information on various metal compounds. It was also necessary to provide some degree of selectivity to avoid overly complex and unwieldly chapters that would contain excessive amounts of extraneous information on compounds of minimal toxicologic or environmental significance. Attention was focused on those metal compounds with high use profiles, those commonly encountered as environmental contaminants, those for which substantial toxicologic data were available, or those for which regulatory data are available. Discussion of the toxic effects of various metals and metal compounds was limited to the elemental metal, the compound per se, or compounds for which the toxic effects could be reasonably attributed to the metal component and not a more hazardous, highly toxic component (e.g., for compounds such as cadmium bromide, nickel cyanide, zinc phosphide, and zinc cyanide, the non-metal components are of much greater toxicologic significance and concern than is the metal).

The organization of individual chapters, described in more detail in the Introduction of Volume 1, is outlined below.

- Summary Chart listing chemical and physical properties, reactivity, chemical symbol or structural and molecular formulas, atomic number or molecular weight, common synonyms, Chemical Abstract and NIOSH registry numbers, and handling precautions. Some data (physico-chemical data, NIOSH and CAS numbers, handling precautions) are unique to a specific metal compounds; therefore, these summary boxes are presented separately for the elemental form and for each individual compound of significance. Summaries of persistence in soil-water systems, exposure pathways and health hazards are also provided but are for the title metal and not individual metal compounds. Similarly, bioconcentration factors are seldom available for a metal compound but rather are based on assessment of the elemental form only.

- Environmental and Occupational Standards and Criteria lists existing environmental air and water standards and criteria and occupational exposure limits. These are usually expressed as a concentration of the metal and not of a specific compound.

- Regulatory Status encompasses proposed and existing regulations in the U.S. at the federal and state level and in the European Economic Community (EEC) countries as of March, 1990. Because this type of legislation is in a constant state of change, the reader is cautioned that future regulations may render some of this information obsolete.

- Major Uses section is meant to serve as a guide only and is not comprehensive. It was usually obtained from published sources.

- Environmental Fate and Exposure Pathways deals with the transport, transformation and fate of the chemicals in soil/ground-water systems. Data on persistence and bioaccumulation are also included. Potential pathways of human exposure, particularly oral and dermal pathways from soil/ground-water systems, are discussed. A section on biological monitoring is also provided for each metal covered in Volume 5.

- Human Health Considerations summarizes acute and chronic effects noted in humans and experimental animals, including cancer, genetic and reproductive hazards and other chronic functional impairments. This section is not intended to cover all reported studies. In general, the doses and schedules are indicated as they appear in the original sources; sometimes units have been converted (see Appendix 3, Math, Conversions and Equivalents) for easier comparisons but are set off in parentheses. Also included are levels of concern (e.g., Reference Doses, Suggested No Adverse Response Levels) and an assessment of hazard, indicating areas of concern associated with exposure to a particular contaminant and the uncertainties involved in defining these concerns.

- Sampling and Analysis provides soil and water sampling analysis procedures required or recommended by regulatory agencies. In most cases, technology is such that only the elemental form is measured and not a particular metal compound.

Each metal has been assigned a chemical-specific number (i.e., 71 through 76), and the chapter pages for each metal are numbered accordingly (e.g., 71-1, 71-2). It must be noted that any one chapter (record) will address the elemental form of the metal as well as various metal compounds. The elemental form of the metal has been used as chapter and page headings, with the Chemical Abstract Service name listed as the first synonym under common synonyms at the beginning of each chapter.

Four indices have been included as keys to chapters. These are based on:

- Chemical names, recognized common names and a few tradenames (Index 1); this list of synonyms is not comprehensive
- Molecular formula or chemical symbol (Index 2)
- Chemical Abstracts Registry Numbers (Index 3)
- National Institute of Occupational Safety and Health Numbers (Index 4)

Unless otherwise specified, temperatures are given in degrees Celsius (centigrade). Data are generally reported in metric units.

A listing of handbooks, data books, response guides and USAF documents which may be useful to USAF personnel for IRP completion is given in Appendix 1. Air Force points of contact for the IRP are listed in Appendix 2. Appendex 3 contains mathematical formulas and conversion factors used for comparison of data from different health effect studies. Appendix 4 contains the addresses, telephone numbers and contacts for the State Water Agencies.

1.3 Metal Speciation and Environmental Considerations

Persistence of a toxic substance is of major concern to the environmental toxicologist. In this respect, metals present a relatively unique situation among toxic chemicals in that they are not destroyed and may undergo various interconversions (e. g. interconversion between organic and inorganic) depending on environmental conditions such as pH and organic content of soil or water. By virtue of these changes in form, and the polyvalent nature of metals, their reactivity with both nonbiological and biological systems may be quite variable. The speciation (physicochemical form) of the metal also complicates interpretation of quantitative data regarding total metal concentration because the contribution of the reactive (toxic) form may not be accurately determined. Metal species may include free aquated ions, metal ions complexed by inorganic anions, and metal ions complexed by organic ligands such as humic acid, amino acids, and fulvic acids (8010). Generally,

both the concentration and the chemical form of a metal determine its effect in the environment.

Metal speciation and toxicity in water environments has been reviewed by Morrison et al. (8006). In addition to speciation playing an important role in the bioavailability and potential toxicity of a metal, it is also important in geochemical and biological interactions in the environment (Figure 1-1).

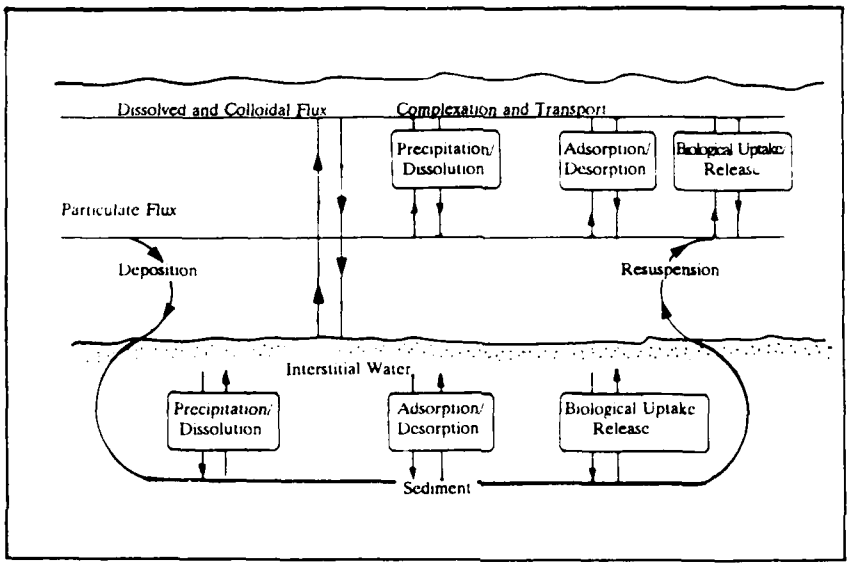


FIGURE 1-1

GEOCHEMICAL-BIOLOGICAL INTERACTIONS AFFECTING TRACE ELEMENT SPECIATION

Source: Adapted from Bourg and Mouvet (8011)

These interactions are important in determining the accumulation and mobilization of metals in the environment, in determining the existence and potential availability of toxic or non-toxic forms, and for proportioning a measured concentration between toxic and non-toxic forms. Therefore, an assessment of the potential effects on the environment must entail information on the processes in which the metal may participate. These processes may include formation of nontoxic complexes, hydrolysis, precipitation, adsorption, chemosorption, ion exchange, and redox processes (8002). Obviously, these factors will vary depending on the metal or metal compound, and the soil and water conditions of a specific area.

Another important aspect of speciation is a differential in speciation and accumulation of metals between environmental waters and bottom sediments of waterways. Morrison et al. (8006) note the significance of toxic metals in sediments

of lakes, rivers, and coastal waters even when metal concentrations of the water comply with established criteria. As depicted in Figure 1-1, sediment content is affected by numerous factors and may exhibit a significantly different profile of metal species than that of the body of water. Although characterization of the sediment metals is possible, it is currently very difficult to assess the toxicity and bioavailability of these forms.

1.4 Metal Toxicology and Essentiality

Metallic elements are found in living organisms and many are essential nutrients required in trace amounts for a variety of biological functions. Metals are especially important in enzyme systems where they function as activators and cofactors. Additionally, metals serve as structural components and are involved in physiological functions for control of excitable membranes and tissues. Excessive levels of metals are known to adversely affect a wide variety of tissues, organs, and functions. The scope of toxic effects of metals ranges from acute, overt signs and symptoms of toxicity such as abdominal pain, gastrointestinal disorders and renal failure to chronic and more subtle manifestations of biochemical changes, histopathology, or neurological and behavioral dysfunctions. A classic example of the latter is the emotional and psychological disturbances seen in individuals exposed to mercury.

Although the toxicity of many metals is well documented, defining levels relative to essentiality and toxicity often becomes difficult. Seventeen elements are known to be essential in human nutrition and include sodium, potassium, magnesium, calcium, chromium, molybdenum, manganese, iron, cobalt, copper, zinc, phosphorus, sulfur, selenium, fluorine, chlorine, and iodine. Other elements such as nickel are essential in animal nutrition but their importance in human nutrition has not yet been established (8004). If optimum levels of metals in the body are exceeded, biological responses are altered resulting in adverse effects. In simplistic terms, toxicity results from an excess accumulation of the metal in the living system. This burden is due, in part, to the fact that metals can not be degraded, but their oxidation state may be altered. If the organism is unable to reduce this excess by increased usage, excretion or sequestration, or by conversion to a less toxic form, toxic sequlae will result.

A common feature regarding essentiality and toxicity of metals is the competitive or cooperative interdependencies among metals, with one another and with nonmetals, and with organic and inorganic molecules. For example, an excess of Zn^{2+} may inhibit Cu^{2+} absorption, and the toxicity of Cd^{2+} may be enhanced by a Zn^{2+} deficiency. The discriminative uptake and utilization of metals by physiologic systems is an ongoing topic of research. An interdependency among approximately 30 elements in the mammalian organism has been documented (8003, 8005).

1.4.1 Metal Speciation and Toxicity

Metal speciation is intimately related to toxicity and it is known that the interaction of metals with intracellular targets is very dependent on oxidation state and speciation. Some metals may covalently bond with carbon atoms to form organometallic compounds, the toxicity of which may differ greatly from inorganic forms of the metal. Generally, soluble forms exhibit greater toxicity whereas lipid soluble complexes are relatively stable and less likely to dissociate to a toxic free ion form (8006, 8012). However, metal alkyl compounds will readily enter the cell and are only slowly transformed into inorganic salts resulting in prolonged excretion times and different toxicity profiles. For example, the soluble nickel compounds such as nickel acetate, nickel sulfate hexahydrate and nickel chloride have greater bioavailablity than relatively insoluble forms, and methylmercury exerts primarily neurotoxic effects while mercuric chloride is a renal toxicant. A dramatic disparity in reactivity is exhibited by two forms of nickel oxide, with black nickel oxide being reactive and green nickel oxide being inert and refractory. Overall, speciation is instrumental in determining the absorption, disposition, bioavailability, and toxicity of a given metal.

Many biological systems may not differentiate metals on a basis other than oxidation state. In essence, this results in a specific function (e.g. intracellular transport) "seeing" and utilizing potentially toxic metals as an essential element. For example, many processes in the mammalian organism will readily utilize lead in place of calcium, ultimately resulting in neurological toxic effects, and algae may accumulate arsenic in place of phosphorus especially in phosphorus-deficient waters.

1.4.2 Mechanism of Action of Metal Toxicity

An in depth discussion of the mechanism of metal toxicity is beyond the scope of this volume and, therefore, only a cursory overview of this complex topic is provided. The chemistry and toxicology of metals are discussed in depth in volumes edited by Sigel and Seiler (8005) and a series of volumes edited by Friberg et al. (8009). The toxic effects of most metals are ultimately the result of intracellular activity (e.g., binding with sulfhydryl groups or macromolecules) and require some type of interaction with the plasma membrane for entry into the cell. This entry may be via facilitated transport (cadmium, arsenic) or via diffusion (elemental mercury). Some metals such as inorganic mercury (Hg^{2+}) and chromium (Cr^{6+}), however, are strong oxidizers and can produce ultrastructural and/or biochemical alterations in the membrane and do not require entry into the cell to exert toxic effects. Intracellular toxicity may include ultrastructural aberrations, reductions in cell division, compromised metabolic functions resulting in reduced energy production or utilization, and deficiencies in transport functions. The mitochondrion is a major target of toxicity for many metals, probably a result of the many biological processes involving transport and energy production occurring in this organelle. Additionally, some metals are thought to adversely affect lysosome membrane stability which may

result in release of lysosomal enzymes and subsequent loss of structural and functional integrity of the cell.

1.4.3 Factors Influencing Metal Toxicity

As with most toxic substance, numerous factors may influence the toxicity of any one metal. As previously noted, metals may interact with one another in a biological system, and their toxicity may be influenced by other nutritional factors. A number of investigators have reported on the propensity of selenite to reduce the toxic effects of inorganic mercury. Excess cadmium may alter copper metabolism, and excessive intake of molybdenum has been shown to result in a copper deficiency. The cellular uptake and biological effects of lead, cadmium, and arsenic were individually altered by concomitant dietary exposure of rats to tolerated doses of these metals (8015). For example, concomitant exposure to lead and cadmium resulted in a decrease in blood and tissue burdens of lead without a reduction in lead-induced biological effects. In this same study, it was shown that cadmium exposure increased renal and hepatic zinc concentrations, arsenate exposure increased tissue copper concentrations, and lead produced changes in tissue concentrations of zinc. In some mammalian tissues, copper and zinc are competitive in biochemical processes. An increased absorption and consequent increase in toxicity of lead and mercury may result from low protein diets. Vitamin C has been shown to reduce cadmium and lead toxicity but may increase retention of mercury. Lead toxicity is known to be enhanced by dietary deficiencies in calcium, iron, and possibly zinc (8013).

1.4.4 Detoxication Mechanisms

Although the cellular targets for metal toxicity are varied, protection and detoxication mechanisms do exist. Metallothioneins are low molecular weight cytoplasmic proteins which are capable of binding metals as mercaptide complexes. These cysteine-containing proteins have been identified in mammalian liver and kidneys, and efficiently bind free metals, thus reducing or preventing their toxic effects (8001, 8008). The inducibility of metallothionein by exposure to cadmium was described by Nordberg et al. (8008) who demonstrated that pre-exposure to low doses of cadmium resulted in a protective effect against higher subsequent doses. Metal-protein complexes have been reported for several metals. These metal-protein complexes may be stable and soluble in aqueous media or some may be insoluble and actually form histologically discernable tissue deposits.

Another protective mechanism is that of intranuclear inclusion bodies relative to the renal toxicity of lead (8014). These bodies contain lead-protein complexes that sequester lead, thereby protecting more sensitive organelles. The presence of these bodies may also be early markers of lead exposure.

1.4.5 Carcinogenicity of Metals

A number of metals (arsenic, chromium, cadmium and nickel) have been shown to be carcinogenic in humans and/or animals. In vitro assays such as the Ames test

have not shown as high a degree of predictability for metals as for organic compounds (8002, 8003). As with other aspects of toxicity, biological, or environmental effects, the carcinogenic potential of a metal may be dependent upon the particular compound (speciation). The fact that some metal compounds appear to be carcinogenic whereas others containing the same metal do not, may be a function of absorption, distribution and metabolism kinetics, and/or bioavailability. Nickel subsulfide is known to be a pulmonary carcinogen but not all nickel-containing compounds have demonstrated this effect. Nonetheless, for health hazard assessment, the metal per se is usually considered the potential carcinogen regardless of the chemical form in which occurs.

1.5 References

8000 Costa, M. 1980. Metal Carcinogenesis Testing, Principles and In Vitro Methods. The Humana Press, Clifton, N. J., p. 71.

8001 Goyer, R.A. 1984. Metal-protein complexes in detoxication process. In: Clinical Chemistry and Clinical Toxicology, Vol. 2. Brown, S.S. ed. Academic Press, New York.

8002 Jensen, S.E.; Jensen, A. 1984. Processes of metal ions in the environment. In: Metal Ions in Biological Systems, Vol. 18. Sigel, H., ed., Marcel Dekker, Inc., New York. pp. 61-103.

8003 Klaassen, C.D.; Amdur, M.O.; Doull, J., eds. 1986. Casarett and Doull's Toxicology. 3rd Ed., Macmillan Publ. Co., New York, pp. 586-587.

8004 Martin, R.B. 1988. Bioinorganic chemistry of toxicity. In: Handbook on Toxicity of Inorganic Compounds. Sigel, H.; Seiler, H.G., eds. Marcel Dekker, Inc., New York. p. 15.

8005 Sigel, H.; H.G. Seiler. 1988. Handbook on the Toxicity of Inorganic Compounds. Marcel Dekker, Inc. New York.

8006 Morrison, G.M.P.; Batley, G.E.; Florence, T.M. 1989. Metal speciation and toxicity. Chemistry in Britain 25:791-796.

8007 Nordberg, G.F. 1972. Cadmium metabolism and toxicity. Environ. Physiol. Biochem. 2: 7-36.

8008 Nordberg, G.F; Parizek, J.; Pershagen, G.; Gerhardsson, L. 1986. Factors influencing effects and dose-response relationships of metals. In: Handbook on the Toxicology of Metals, Friberg et al., eds., Vol. 1. Elsevier, New York. pp.175-205.

8009 Friberg, L.; G.F. Nordberg; V.B. Vouk. 1986. Handbook on the Toxicology of Metals. Vol. 1-2. Elsevier, New York.

8010 Sposito, G. 1984. Distribution of potentially hazardous trace metals. In: Metal Ions in Biological Systems, Vol. 20. Sigel, H. ed., Marcel Dekker, Inc. New York. pp. 1-20.

8011 Bourg, A.C.M.; C. Mouvet. 1984. Complexation of trace elements in natural waters. Kramer, C.J.M.; J.C. Duinker, eds. Martinus Nihoff, The Hague.

8012 Florence, T.M. 1986. Electrochemical approaches to trace element speciation in waters: A review. Analyst 111:489-505.

8013 Mahaffey, K.R.; J.A. Michaelson. 1980. The interaction between lead and nutrition. In: Low level lead exposure: The Clinical Implications of Current Research, Needleman, H.E., ed., Raven Press, New York.

8014 Goyer, R.A. 1971. Lead and the kidney. Curr. Topics Pathol. 55:147-176.

8015 Mahaffey, K.B.; S.G. Capar; B.C. Gladen; B.A. Fowler. 1981. Concurrent exposure to lead, cadmium, and arsenic. J. Lab. Clin. Med. 98:463-481.

COMMON SYNONYMS:	CAS. Reg. No.: 7440-43-9 NIOSH No.: EU 9800000 EPA Hazardous Waste No.: D006
Cadmium metal C.I. 77180 Colloidal cadmium Kadmium (German)	Chemical Symbol: Cd

REACTIVITY (4403, 4506)

Cd is slowly oxidized by moist air to form CdO. It reacts readily with dilute HNO_3; reacts slowly with hot HCl; does not react with alkalies; is soluble in ammonium nitrate solutions; is flammable in powder form.

PHYSICO-CHEMICAL DATA

• Atomic Weight: 112.41	(4403)
• Atomic Number: 48	(4403)
• Group and Valence: 2b, 2	(4403)
• Physical State: Solid	(4403)
• Color: Silver-White	(4400)
• Odor: ND	
• Odor Threshold: ND	
• Density: 8.6	(4400)
• Melting Point: 320.9°C	(4400)
• Flash point: Not flammable	
• Flammable Limits: NA	
• Autoignition temperature: NA	
• Vapor Pressure: 1.4 mm at 400°C, 16 mm at 500°C	(4404)
• Saturated Concentration in Air: ND	
• Solubility in water: Insoluable	
• Viscosity: m pa.s (=dyn/cm), 400°C: 2.16	(4402)

PHYSICO-CHEMICAL DATA (Cont.)

- Surface Tension, mN/m (=dyn/cm), 330°C: 564 (4404)
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid-Cd^{2+} Complex at pH 8): 4.57- 5.08 (4401)
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: 3.0E+03 (fish); 2.5E+05 (4473)
  (marine invertebrates); 9E+02-1.6E+02 (shellfish) (4486)

HANDLING PRECAUTIONS (4404)

Most cases of acute Cd poisoning result from inhalation of dust or fumes. Inhalation exposure to cadmium dusts and fumes increases the body burden of cadmium but oral exposure is of greater concern regarding long-term effects. Protection should be provided by a properly designed exhaust ventilation system, or for intermittent exposures, by individual filtered or air-supplied respirator. Immediate medical attention should be obtained after severe exposure to fumes that are formed at vaporization temperatures in welding or brazing.

COMMON SYNONYMS:	CAS. Reg. No.: 543-90-8 NIOSH No.: EU 9810000 EPA Hazardous Waste No.: D006
Cadmium acetate Cadmium salt Bis(acetoxy)cadmium Cadmium acetate (DOT) Cadmium diacetate C.I. 77185	Chemical Formula: $C_4H_6CdO_4$

REACTIVITY (4468)

Toxic fumes of cadmium oxide may be released in fires. No additional information regarding the reactivity of this compound was located.

PHYSICO-CHEMICAL DATA

• Molecular weight: 116.25	(4481)
• Physical State: Solid, monoclinic crystals	(4481)
• Color: Colorless	(4481)
• Odor: Odor of acetic acid	(4481)
• Odor Threshold: ND	
• Density: 2.341	(4402)
• Melting Point: 256°C	(4402)
• Boiling Point: Decomposes	(4481)
• Flash Point: Not flammable	(4486)
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Very soluble	(4402)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Log K (Stability Constant for Humic Acid-Cd^{2+} Complex at pH 8): 4.57-5.08	(4401)
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (4486)
Avoid contact with solid and dust. Wear dust respirator and rubber overclothing (including gloves).

COMMON SYNONYMS:	CAS. Reg. No.: 7789-42-6 NIOSH No.: EU9935000 EPA Hazardous Waste No.: D006
Cadmium bromide (anhydrous) Cadmium bromide dimer Cadmium dibromide	Chemical Formula: Br_2Cd

REACTIVITY (4486)

Toxic fumes of cadmium oxide may be released in fires. No additional information regarding the reactivity of this compound was located.

PHYSICO-CHEMICAL DATA

• Molecular weight: 272.22	(4403)
• Physical State: Solid, hexagonal, pearly flakes	(4482)
• Color: Yellow	(4482)
• Odor: ND	
• Odor Threshold: ND	
• Density: 5.192 g/cm^3	(4404)
• Melting Point: 568°C	(4404)
• Boiling Point: 963°C	(4404)
• Flash Point: Not flammable	(4486)
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: 95 g/100 g at 18°C	(4404)
• Viscosity: NA	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): NA	
• Log K (Stability Constant for Humic Acid-Cd^{2+} Complex at pH 8): 4.57-5.08	(4401)
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (4486)
Avoid contact with solid and dust. Wear dust respirator and rubber overclothing, including gloves, goggles or face shield.

COMMON SYNONYMS:	CAS. Reg. No.: 10108-64-2 NIOSH No.: EV 0175000 EPA Hazardous Waste No.: D006
Cadmium chloride (anhydrous) Caddy Cadmium dichloride Kadmiumchlorid (German) Vi-cad Dichlorocadmium	Chemical Formula: $CdCl_2$

REACTIVITY (4486)

Reacts violently with BrF_3 and K. When heated to decomposition, it emits very toxic fumes of Cd and Cl^-.

PHYSICO-CHEMICAL DATA

• Molecular weight: 183.30	(4403)
• Physical State: Solid, hexagonal crystals	(4481)
• Color: Colorless	(4481)
• Odor: Odorless	(4482)
• Odor Threshold: NA	
• Density: 4.05 g/cm^3	(4404)
• Melting Point: 568°C	(4404)
• Boiling Point: 980°C	(4404)
• Flash Point: Not flammable	(4486)
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: 10 mm at 656°C	(4481)
• Saturated Concentration in Air: ND	
• Solubility in Water: 128.6 g/100 g at 18°C	(4404)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): NA	
• Log K (Stability Constant for Humic Acid-Cd^{2+} Complex at pH 8): 4.57-5.08	(4401)
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (4486)

The personal protective equipment required are safety glasses, rubber gloves and a respirator with the proper filter.

COMMON SYNONYMS:	CAS. Reg. No.: 10022-68-1 NIOSH No.: EV 1750000 EPA Hazardous Waste No.:
Cadmium nitrate Cadmium dinitrate	Chemical Formula: $Cd(NO_3)_2$

REACTIVITY (4486)

Not reactive with water. May release toxic fumes of Cd and NO_x in fire. Will increase the intensity of a fire when in contact with combustible material.

PHYSICO-CHEMICAL DATA

• Molecular weight: 236.43	(4403)
• Physical State: Solid	(4403)
• Color: White	(4486)
• Odor: Odorless	(4486)
• Odor Threshold: NA	
• Density: ND	
• Melting Point: 350°C	(4481)
• Boiling Point: Decomposes	(4486)
• Flash Point: Not flammable	(4486)
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: 109 g/100g at 0°C	(4404)
• Viscosity: NA	
• Surface Tension: NA	
• Log (Octanol-Water Partition Coeff.): NA	
• Log K (Stability Constant for Humic Acid): ND	
• Soil-Water Distribution Coeff.: NA	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (4486)

Avoid contact with compound or inhalation dust or fumes. Wear rubber gloves, goggles, and dust mask.

COMMON SYNONYMS:	CAS. Reg. No.: 1306-19-0 NIOSH No.: EV 1925000 EPA Hazardous Waste No.: D006
Cadmium oxide NCI-C02551 Cadmium fume Cadmium monoxide Aska-Rid	Chemical Formula: CdO

REACTIVITY (4486)

Toxic cadmium oxide fumes may be released in fires. No additional information was found.

PHYSICO-CHEMICAL DATA

- Molecular weight: 128.40 (4404)
- Physical State: Solid, crystalline or amorphous (4404)
- Color: Rust-brown (4404)
- Odor: Odorless (4482)
- Odor Threshold: NA
- Density: 8.2 g/cm^3 (4404)
- Melting Point: Decompose at 1540°C (4404)
- Boiling Point: 1559°C (4481)
- Flash Point: Not flammable (4486)
- Flammable Limits: ND (4486)
- Autoignition Temperature: ND (4486)
- Vapor Pressure: 1 mm at 1000°C (4481)
- Saturated Concentration in Air: ND
- Solubility in Water: 9.6×10^{-4} g/100 g (4404)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid-Cd^{2+} Complex at pH 8): 4.57-5.08 (4401)
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4486)
Avoid contact with solid and dust. Wear a dust respirator.

COMMON SYNONYMS:	CAS. Reg. No.: 2223-93-0 NIOSH No.: RG1050000 EPA Hazardous Waste No.: ND
Cadmium stearate Alaixol 11 Cadmium distearate Cadmium octadecanoate Kadmiumstearat (German) Octodecanoic acid Cadmium salt SCD Stearic acid, cadmium salt Cadmium soap	Chemical Formula: $C_{18}H_{36}O_2 \cdot ½Cd$

REACTIVITY

No information was located regarding the reactivity of this compound.

PHYSICO-CHEMICAL DATA (4482)

- Molecular weight: 681.48
- Physical State: Solid, powder
- Color: White
- Odor: Slight fatty odor
- Odor Threshold: ND
- Density: 1.21
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Negligible
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4482)
Wear self-contained breathing apparatus and full protective clothing.

COMMON SYNONYMS:	CAS. Reg. No.: 10124-36-4 NIOSH No.: EV 2800000 EPA Hazardous Waste No.: ND
Cadmium sulfate No common synonyms	Chemical Formula: $CdSO_4$

REACTIVITY (4486)

Not reactive with water. May release toxic cadmium oxide fumes in fire.

PHYSICO-CHEMICAL DATA

- Molecular weight: 208.7 (4403)
- Physical State: Solid (4403)
- Color: White (4486)
- Odor: Odorless (4486)
- Odor Threshold: NA
- Density: 4.69 (4404)
- Melting Point: 1000° C (4404)
- Boiling Point: Decomposes (4486)
- Flash Point: Not flammable (4486)
- Flammable Limits: NA
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 76.6 g/100 g (4404)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4486)

Avoid contact with compound or inhalation of dust or fumes. Wear rubber gloves, goggles, and dust mask.

PERSISTENCE IN THE SOIL-WATER SYSTEM

Cadmium is most mobile in acidic soils with a pH range of 4.5 to 5.5, while in alkaline soil Cd is rather immobile. In soils developed under the influence of humid climate, Cd is more likely to migrate down the profile than to accumulate in the surface horizon.

PATHWAYS OF EXPOSURE

Contamination of topsoil constitutes the most critical environmental pathway for Cd exposure. Major pathways to agricultural topsoil are phosphate fertilizer, emissions deposition, irrigation water, and sewage sludge landspreading. Oral ingestion represents the single most important source of Cd in man, and cigarette smoking represents another major source of Cd intake.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure:

With Cd inhalation, an asymptomatic period of 4-8 hr may precede the clinical illness. The symptoms are as follows:

1. Metallic taste in the mouth and headache.
2. Shortness of breath, chest pain, cough with foamy or bloody sputum.
3. Weakness, leg pains.
4. Intense pulmonary edema possibly leading to death by asphyxiation.
5. Gradual resolution of pulmonary edema (over a period of a few days) and development of fever, with persistence of cough, chest pain and dyspnea for one or more weeks. Physical signs of pneumonic consolidation.
6. Late kidney and/or liver damage has followed respiratory exposures in industry, usually due to increased body burden of cadmium.

With ingestion of Cd an asymptomatic period of 0.5 to 1 hr may precede the clinical illness. The symptoms are as follows:

1. Severe nausea, vomiting, diarrhea and abdominal cramps and salivation.
2. Headache, muscular cramps, vertigo, and perhaps convulsions (rarely).
3. Exhaustion, collapse, shock and death, usually within a period of 24 hr.
4. The gradual evolution of signs and symptoms of liver and kidney damage should be anticipated but are rarely seen in man.

Acute Toxicity Studies:

Inhalation:

LC_{Lo}	39 mg/m^3/20 min.	(cadmium)	Human	(4484)
LC_{Lo}	170 mg/m^3	(cadmium)	Mouse	(4484)
LC_{90}	420 mg/m^3/30 min.	(cadmium chloride)	Dog	(4484)
LC_{50}	2300 mg/m^3	(cadmium chloride)	Mouse	(4484)
TC_{Lo}	40 µg/m^3	(cadmium oxide)	Man	(4484)
LC_{50}	15 gm/m^3/10 min.	(cadmium oxide)	Monkey	(4484)
LC_{50}	3 gm/m^3/10 min.	(cadmium oxide)	Dog	(4484)
LC_{50}	3 gm/m^3/15 min.	(cadmium oxide)	Guinea pig	(4484)
LC_{50}	340 mg/m^3/10 min.	(cadmium oxide)	Mouse	(4484)
LC_{50}	780 mg/m^3/10 min.	(cadmium oxide)	Rat	(4484)
LC_{50}	3 gm/m^3/15 min.	(cadmium oxide)	Rabbit	(4484)
TC_{Lo}	147 mg/m^3/35 min.	(cadmium stearate)	Woman	(4485)
LC_{50}	130 mg/m^3/2 hrs.	(cadmium stearate)	Rat	(4485)

HEALTH HAZARD DATA

Oral:

LD_{50} 890 mg/kg	(cadmium)	Mouse	(4484)
LD_{50} 225 mg/kg	(cadmium)	Rat	(4484)
LD_{Lo} 5 mg/kg	(cadmium)	Rabbit	(4484)
LD_{Lo} 3 gm/kg	(cadmium chloride)	Woman	(4484)
LD_{50} 63 mg/kg	(cadmium chloride)	Guinea pig	(4484)
LD_{50} 60 mg/kg	(cadmium chloride)	Mouse	(4484)
LD_{50} 88 mg/kg	(cadmium chloride)	Rat	(4484)
LD_{Lo} 70 mg/kg	(cadmium chloride)	Rabbit	(4484)
LD_{50} 72 mg/kg	(cadmium oxide)	Mouse	(4484)
LD_{50} 590 mg/kg	(cadmium stearate)	Mouse	(4485)
LD_{50} 1125 mg/kg	(cadmium stearate)	Rat	(4485)

Dermal:

LD_{Lo} 233 mg/kg (cadmium chloride)	Guinea pig(4484)

Long-Term Effects: Renal tubular dysfunction; centrilobular emphysema and bronchitis.

Pregnancy/Neonate Data: Embryotoxic and teratogenic in many mammalian species. No evidence as human teratogen.

Genotoxicity Data: Conflicting data for in vitro assays. Generally negative in mamalian in vivo assays.

Carcinogenicity Classification:

IARC — 2B (limited evidence for carcinogenicity to humans, sufficient evidence for carcinogenicity to animals)
NTP — Cadmium oxide subchronic rat and mouse studies in progress
EPA — B1 (probable human carcinogen); inhalation route

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS REGULATORY STATUS (as of 01-MAR-90)

AIR EXPOSURE LIMITS:

Standards

• OSHA (8-hr TWA):	Cd fume 0.1 mg/m^3; ceiling, 0.3 mg/m^3 Cd dust 0.2 mg/m^3; ceiling, 0.6 mg/m^3
• OSHA STEL (15-min):	ND
• AFOSH PEL (8-hr TWA):	Cd fume 0.1 mg/m^3 Cd dust 0.2 mg/m^3

Criteria

• NIOSH IDLH (30-min):	ND
• NIOSH REL (10-hr TWA):	Cd fume 0.3 mg/m^3 ceiling Cd dust 0.6 mg/m^3
• NIOSH STEL (15-min ceiling):	ND
• ACGIH TLV® (8-hr TWA):	Cd 0.01 mg/m^3
• ACGIH STEL (15-min):	ND

WATER EXPOSURE LIMITS:

Drinking Water Standards (4523)

- MCLG (proposed): 5 µg/L
- MCL (proposed): 5 µg/L
- NIPDWR: 10 µg/L

EPA Health Advisories and Cancer Risk Levels (4523)

- 1-day (child): 40 µg/L
- 10-day (child): 40 µg/L
- Long term (child): 5 µg/L
- Long term (adult): 20 µg/L
- Lifetime (adult): 5 µg/L

WHO Drinking Water Guideline (4483)

- 0.005 mg/L

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS REGULATORY STATUS (as of 01-MAR-90) (Cont.)

EPA Ambient Water Quality Criteria (4490)

- **Human Health**
  - — 10 µg/L, based on ingestion of contaminated drinking water only.
  - — 10 µg/L based on ingestion of aquatic organisms and contaminated drinking water. Values are based on hardness of 100 mg/L $CaCO_3$
- **Aquatic Life**
  - — Freshwater species
    max.: 3.9 E-03 mg/L
    24 hr: 1.1 E-03 mg/L
  - — Saltwater species
    max.: 0.043 mg/L
    24 hr: 9.3 E -03 mg/L

REFERENCE DOSES: (4487)

- Inhalation: ND
- Oral: 5E-04 mg/kg/day (water)
  1E-03 mg/kg/day (food)

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- **Federal Programs**

Clean Water Act (CWA)
Cadmium acetate, cadmium bromide, and cadmium chloride have been designated hazardous substances with a reportable quantity (RQ) limit of 4.54 kg (10 lbs) (7015, 7016). Cadmium and its compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (7017, 7018). Effluent limitations for cadmium exist in the following point source categories: electroplating (7025), inorganic chemicals manufacturing (7019), nonferrous metals manufacturing (7020), steam electric power generating (7021), metal finishing (7026), ore mining and dressing (7023), battery manufacturing (7027), and electrical and electronic components (7024). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)
Cadmium is on the list of 83 contaminants required to be regulated under the SDWA Amendments of 1986 (7050). Under the National Interim Primary Drinking Water Regulations, the maximum contaminant level (MCL) is set at 5 µg/L for cadmium in drinking water. This applies to community water systems (7051). In states with an approved Underground Injection Control program, a permit is required for the injection of cadmium-containing wastes designated as hazardous under RCRA (7054).

Resource Conservation and Recovery Act (RCRA)
Cadmium and its compounds are listed as hazardous waste constituents (7079). A non-specific source of cadmium-containing hazardous waste streams is wastewater treatment sludge from electroplating operations (#F006) (7075, 7077). Waste streams from the following industries contain cadmium and are listed as specific sources of hazardous waste: primary production of steel in electric furnaces (#K061), primary copper production (#K064), primary lead smelting (#K065), primary zinc production (#K066), and secondary lead smelting (#K069, #K100) (7076, 7077). Solid wastes containing cadmium are listed as hazardous, in that they exhibit the characteristic defined as EP toxicity, when the TCLP extract concentration of cadmium is equal to or greater than 1.0 mg/L (7074). Cadmium is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels. Effective August 8, 1988, cadmium-containing

REGULATORY STATUS (as of 01-MAR-90)

waste streams with the hazardous waste numbers F006, K061 (waters containing less than 15% zinc), K064, K065, K066, K069 and K100 are prohibited from land disposal and underground injection unless designated treatment standards or the statutory no migration standards are met. Effective August 8, 1990, cadmium-containing hazardous waste stream number K061 waters containing 15% or greater zinc are prohibited from land disposal or underground injection unless designated treatment standards or the statutory no migration standards are met. Site-specific variances can be obtained for soil and debris contaminated with hazardous waste (7084). Effective August 8, 1990, liquid wastes containing cadmium at concentrations greater than or equal to 100 mg/L are prohibited from underground injection (7083). For groundwater protection, the maximum concentration of cadmium-containing hazardous waste allowed in groundwater is 0.01 mg/L (7080). Cadmium 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 (7082). Used oil that is burned for energy recovery may not contain greater than 2 ppm cadmium (7067).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

The following cadmium compounds are designated as hazardous substances under CERCLA and have a reportable quantity (RQ) limit of 4.54 kg (10 lbs): cadmium acetate, cadmium bromide and cadmium chloride. Reportable quantities have also been issued for RCRA hazardous waste streams containing cadmium, but these depend on the concentration of the chemical in the waste stream (7064). Cadmium oxide and cadmium stearate are designated as extremely hazardous substances under SARA Title III Section 302. Under Sections 311 and 312, any facility at which cadmium oxide or cadmium stearate are present in an amount greater than or equal to 500 pounds or in excess of their threshold planning quantities of 100 pounds for cadmium oxide and 1000 pounds for cadmium stearate, must notify state and local emergency planning officials. If any of these cadmium compounds are released from a facility in excess of their reportable quantities (RQs), local emergency planning officials must be notified (7060). Under SARA Title III Section 313, manufacturers, processors, importers, and users of cadmium compounds must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

REGULATORY STATUS (as of 01-MAR-90)

Occupational Safety and Health Act (OSHA)
Employee exposure to cadmium fume (as Cd) shall not exceed an 8-hour time-weighted average (TWA) of 0.1 mg/m^3. Exposure shall also not exceed a ceiling level of 0.3 mg/m^3 at any time during an 8-hour work-shift. Employee exposure to cadmium dust (as Cd) shall not exceed an 8-hour time-weighted average (TWA) of 0.2 mg/m^3. Exposure shall also not exceed a ceiling level of 0.6 mg/m^3 (7000). These limits for cadmium dust and fume are Transitional Limits. OSHA is in the process of setting final limits and has proposed new permissible exposure limits (PEL) (see Proposed Regulations section)(7002). In the unanticipated event that the proposed rule for these substances is not finalized by December 31, 1992, the Transitional limits would be continued as the final rule limits (7000). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate, certain hazardous waste treatment, storage, and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

Clean Air Act (CAA)
EPA has given notice of its intent to list cadmium as a hazardous air pollutant for which it will establish emission standards under Section 112 of the Clean Air Act. However, as of November, 1989, all action on this rule making has been placed on hold indefinitely (7048).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated cadmium, cadmium acetate, cadmium bromide, and cadmium chloride as hazardous materials, subject to requirements for packaging, labeling and transportation. Cadmium has a reportable quantity (RQ) limit of 0.454 kg (1 lb); the RQ for the other cadmium compounds is 4.54 kg (10 lbs) (7010).

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds, mercury or cadmium compounds, as well as the dumping of oils or known or suspected carcinogens, mutagens, or teratogens is prohibited except when they are present as trace

REGULATORY STATUS (as of 01-MAR-90)

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 (7009).

Food, Drug, and Cosmetic Act (FDCA)
The level for cadmium in bottled drinking water is 0.01 mg/L. This level is identical to the maximum contaminant level (MCL) given under the Safe Drinking Water Act (7070).

- **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:

FLORIDA
Florida has set the following criteria for cadmium in surface waters: 5 μg/L for Class II (shellfish propagation or harvesting) fresh waters and Class III (fish and wildlife, recreation) marine waters; 0.8 μg/L for Class I (potable water supply) and Class III fresh waters with a hardness of less than 150 mg/L $CaCO_3$; 1.2 μg/L for Classes I and III fresh waters with hardness greater than 150 mg/L $CaCO_3$ (7112).

NEW YORK
New York has set an unenforceable guidance value of 2.7 μg/L for cadmium in marine surface waters (7119).

NORTH CAROLINA
North Carolina has surface water criteria of 0.4 μg/L for fresh waters designated trout waters, 2.0 μg/L for fresh waters designated non-trout waters, and 5 μg/L for all tidal saltwaters to protect aquatic life (7113).

VERMONT
Vermont has set a preventive action limit of 2.5 μg/L for cadmium in groundwater. Vermont's enforcement standard, however, is the same as the federal MCL, 5 μg/L (7114).

WISCONSIN
Wisconsin has set a preventive action limit of 1 μg/L for cadmium in groundwater (7116).

REGULATORY STATUS (as of 01-MAR-90)

VIRGINIA
Virginia has a water quality criterion of 0.0004 mg/L for cadmium in groundwater (7115).

- **Federal Programs**

Safe Drinking Water Act (SDWA)
The Environmental Protection Agency (EPA) has proposed a maximum contaminant level (MCL) and a maximum contaminant level goal (MCLG) of 0.005 mg/L for cadmium in drinking water. This would apply to community water systems and non-community non-transient (NTNC) water systems. Final action on this proposal is expected by January, 1991 (7049).

Resource Conservation and Recovery Act (RCRA)
EPA has proposed emission rate screening limits for cadmium in the burning of hazardous waste in boilers and industrial furnaces. Limits vary as a function of device type and thermal capacity. Final action on this proposed rule is expected by December, 1990 (7110).

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
EPA has proposed that cadmium oxide and cadmium stearate, listed as extremely hazardous substances under SARA, be listed as CERCLA hazardous substances, with a reportable quantity (RQ) of 4.54 kg (10 lbs). Final action on this rule is expected by September, 1990 (7065, 7066).

Occupational Safety and Health Act (OSHA)
The Department of Labor (DOL) has proposed two 8-hour time-weighted average permissible exposure limits (TWA PEL) of 5 and 1 $\mu g/m^3$ as alternatives for all cadmium compounds. DOL also proposed a 15-minute short-term exposure limit (STEL) for all cadmium compounds of five times the TWA PEL, and an action level of 2.5 $\mu g/m^3$ for a TWA PEL of 5 $\mu g/m^3$ and 0.5 $\mu g/m^3$ for a TWA PEL of 1 $\mu g/m^3$. Ancillary provisions for employee protection are also proposed. Final action on this proposal is expected by December, 1990 (7011).

Clean Air Act (CAA)
EPA has given notice of its intent to list cadmium as a hazardous air pollutant for which it will establish national emission standards under the Clean Air Act. However, all action on this rule making has been placed on hold indefinitely (7048).

REGULATORY STATUS (as of 01-Mar-90)

- **State Water Programs**

  No proposed regulations are pending. 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 1990-91 (7058).

EEC Directives

Directive on Drinking Water (7086)
The mandatory values for cadmium in surface water treatment categories A1, A2 and A3 used or intended for abstraction if drinking water are 0.005 mg/L. Guideline values for categories A1, A2 and A3 are 0.001 mg/L.

Directive on Bathing Water Quality (7087)
There are no mandatory values for cadmium or guideline values.

Directive on Discharge of Dangerous Substances (7088)
Cadmium 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 the substances into ground water.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for cadmium specify that the concentration of each substance in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of cadmium in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive on Ground Water (7091)
To ensure the effective protection of groundwater in the Community it is necessary to limit the discharge of cadmium in groundwater. The purpose of this directive is to prevent pollution of groundwater substances belonging to substances listed in the Annex of this directive. Cadmium shall be subject to prior review so as to limit discharge into groundwater. Member states may grant authorization, provided that all technical precautions for preventing groundwater pollution by cadmium has been observed.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
The maximum admissible concentration for cadmium is 50 µg/L. There are no guideline levels for cadmium.

REGULATORY STATUS (as of 01-MAR-90)

Directive on Toxic and Dangerous Wastes (7093)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including cadmium and cadmium compounds shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such wastes, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Cadmium is classified as a toxic substance and is subject to packaging and labeling regulations. Cadmium may contain a stabilizer. If the stabilizer changes the dangerous properties of this substance, substance should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

Directive on Limit Values and Quality Objectives for Cadmium Discharges (7103)
Industrial discharges of cadmium, with the exception of industrial plants manufacturing phosphoric acid or fertilizer must comply with limit values, quality objectives, methods of measurement and monitoring procedures defined in Annexes I, II, III, and IV of this directive. This directive lays down limit values for zinc mining, lead and zinc refining, cadmium metal and non-ferrous metal, and electroplating industries; and manufacturers of cadmium compounds, pigments, stabilizers, and primary and secondary batteries. Authorizations may only be granted to new plants if they apply the standards corresponding to the best technical means available in the elimination of pollution.

Directive on the Combating of Air Pollution From Industrial Plants (7108)
Cadmium and cadmium compounds are considered heavy metals and are classified as polluting substances in Annex II of this directive. This directive requires member states to ensure that the types of industrial plans listed in Annex I receive authorization before operation or substantial alteration. Industrial plants which produce or use cadmium or cadmium compounds for its operation must require prior authorization by the competent authorities. An authorization may be issued only when the competent authority is satisfied that: (1) all appropriate preventive measures against air pollution have been taken; (2) the use of the plant should not cause significant air pollution, particularly from the emission of substances in Annex II; and all air quality limit values applicable are taken into account.

REGULATORY STATUS (as of 01-MAR-90)

EEC Directives-Resolutions

Resolution on a Revised List of Second-Category Pollutants (7094)
Cadmium is one of the second-category pollutants to be studied by the Commission in the program of action of the European Communities on Environment in order to reduce pollution and nuisances in the air and water. Risks to human health and the environment, limits of pollutants levels in the environment, and determination of quality standards to be applied will be assessed.

EEC Directives-Proposed

Proposal for a Council Directive on the Dumping of Waste at Sea (7099)
EEC has proposed that dumping of cadmium and its compounds at sea be prohibited.

EEC Directives-Decisions

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7105)
The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials which must be eliminated; Part III substances, include less persistence organic substances and heavy metals, which must be reduced or eliminated, as appropriate; discharges must be subject to approval by representatives of the contracting party.; and Part III, radioactive substances and waste discharges must be forestalled and, as appropriate, eliminated.

EEC Council Decision on Marine Pollution By Mercury and Cadmium (7106)
This decision mandates the EEC Community to comply with programs of emission standards, limit values, quality objectives, reference methods of measurement, monitoring procedures and time limits laid down in the PARCOM Decisions by directives 76/464/EEC, 83/513/EEC and 814/156 EEC. It applies to mercury and cadmium discharges by sectors other than the chlor-alkali electrolysis industry.

71.1 MAJOR USES

One major use of cadmium is for the electroplating of steel to improve its corrosion resistance. Cadmium is also used in low-melting-point alloys, nickel-cadmium batteries, nuclear control rods, as an alloying ingredient to copper, power transmission wire, and TV phosphors. It is also used as the basis of pigments for ceramic glazes, machinery enamels, and baking enamels, as a fungicide, and in photo-electric cells (4406, 4506).

71.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

71.2.1 Transport in Soil/Ground-water Systems

71.2.1.1 Overview

In soil, cadmium may be present as free cadmium compounds or in solution as the Cd^{2+} ion dissolved in soil water (4426). Cadmium is most mobile in acidic soils with a pH range of 4.5 to 5.5, while in alkaline soil cadmium is rather immobile. The concentration of cadmium in the soil solution is relatively low and is reported to be in the range of 0.2 to 6 µg/L (4428).

In soils developed under the influence of a humid climate, cadmium is more likely to migrate down the profile than to accumulate in the surface horizon; thus the enrichment of cadmium observed in topsoils may be related to contamination effects (4428). The differences in concentrations of cadmium in normal and contaminated soils of several countries are shown presented in the U.S. EPA (4477). In normal (non-contaminated) soils throughout the world, the average cadmium content ranges from 0.016 to 1.4 ppm. For contaminated soils, the cadmium content ranges from 0.41 to 72 ppm.

Cadmium interacts strongly with sulfhydryl groups such as in cysteine.
In natural waters, the organic matter present, such as amino acids, aminosugars, polysaccharides, aliphatic and aromatic hydroxy and carboxylic acids, also contains suitable donor atoms for complex formation with cadmium (4407).

Gardner (4408) mentions that fresh ground water generally contains a greater portion (up to 90%) of free Cd(+2) ions than sewage effluents (62-71%), whereas humic acid complexes may account for only 37-29% of total cadmium.

In the management of cadmium-enriched cropland the most reliable methods for reducing cadmium availability was the layering of unpolluted soil over polluted soil to a depth of 30 cm (4428).

71.2.1.2 Sorption on Soils

Adsorption on soil and sediments greatly affects the mobility of cadmium in the environment. Two important mechanisms in the process are specific adsorption and

ion exchange. Often there is a correlation between the adsorption of cadmium and the cation exchange capacity (CEC) of the soil (4401). When cadmium is held to soil mineral or organic constituents by cation exchange, it is not readily leached from soil by rainwater. For cadmium held by cation exchange, the major reaction for its release is as follows:

$$(soil^{2-})(Cd^{2+}) + 2H^{+} \rightarrow (soil^{2-})(H^{+}) + Cd^{2+},$$

where ($soil^{2-}$) represents cation exchange functionalities in the soil. Thus high soil acidity would favor the release of Cd^{2+} and its uptake by plants (4426).

At low environmental concentrations of cadmium, the most important mechanism is specific adsorption to calcite ($CaCO_3$) and hydrous oxides of iron and aluminum (4401). The behavior of cadmium in soil and sediments is controlled by adsorbents such as clay minerals, carbonate minerals, oxides, and to a lesser extent, organic matter (4401).

The presence of anions also affects cadmium adsorption. For example, sulfate and chloride ions reduce adsorption by amorphous $Fe(OH)_3$, and chloride reduces adsorption by clay minerals, lepidocrocite (α-FeOOH), silica, and alumina. However, ligands, such as thiosulfate, humic acid, nitriloacetate, glycine, tartrate and phosphate increase cadmium adsorption (4401).

The adsorption of cadmium is also influenced by competition by other metal cations: the presence of Ca^{+2}, Mg^{+2} and trace metal cations reduces adsorption by soils, clay minerals, Fe and Mn oxides, and alumina (4401). Ranges of adsorption constants for cadmium on soils and sediments are presented by Bodek et al. (4401).

71.2.1.2.1 Adsorption to Sediments and Residence Time

Adsorption to sediments increases with pH and beyond a threshold point, i.e., pH $\geq$7 in the case of cadmium, virtually all the metal ion is sorbed (4407). Muhlbaier and Tisue (4409) prepared a cadmium budget for southern Lake Michigan and estimated that the residence time for cadmium in water was 8.5 years, and the input rate was 2.5 times greater than the combined rates of sedimentation and outflow.

71.2.1.3 Volatilization from Soils

It was shown that a strain of Pseudomonas produced trace amounts of a volatile cadmium species from inorganic Cd(II) in the presence of Vitamin B_{12} (4410). However, in the soil cadmium is not reduced or methylated by organisms. Thus, unlike mercury and arsenic, microorganisms do not produce more soluble and volatile forms of cadmium (4426).

71.2.2 Transformation Processes in Soil/Ground-water Systems

Cadmium is a sulfophilic and oxyphilic element. At pH values encountered in the environment multiple hydrolysis of cadmium occurs. At pH 9 cadmium begins to hydrolyse, forming $Cd(OH)^{+}$ species. When no precipitating ions are present, Cd^{2+} will

be available for sorption onto suspended solids and complexation with organic matter and will be transported in these forms (4407).

Since cadmium cannot be destroyed, an appropriate strategy in cases of contamination would be to steer cadmium away from air, surface water and topsoil toward the deeper soil strata where its potential for return to the biosphere would be more restricted (4476).

71.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

Contamination of topsoil constitutes the most critical environmental pathway for cadmium exposure. Major pathways to agricultural topsoil are phosphate fertilizer, emissions deposition, irrigation water, and sewage sludge landspreading (4476). Other sources of pollution by cadmium include by-products of metal processing (particularly the refining of zinc), mine wastes, electroplating wastes, and pesticides (4410).

Cadmium is bioconcentrated by both aquatic and terrestrial organisms (4426). Callahan et al. (4473) report that the bioconcentration factor (ppm in the organism on a wet-weight basis divided by ppm in the water) for cadmium ranges from 1,000 for freshwater and marine plants up to 3,000 for freshwater and marine fish. Lu et al. (4501) found that bioaccumulation of cadmium was strongly correlated with the cation exchange capacity of the test soils in the organism's environment. As cation exchange capacity increased, bioaccumulation of cadmium decreased.

The largest component of human exposure arises from the consumption of edible portions of plants that have bioconcentrated cadmium, or in the case of tobacco, from inhaling the combustion emissions; the other major component involves consumption of animals (or animal products) fed with terrestrial vegetation (4476). Children may also be exposed through ingestion of contaminated soil (4415).

A survey of eight municipal landfills suggested that such landfills did not usually result in groundwater contaminated with hazardous levels of cadmium (4476). Also a survey of 50 industrial solid waste disposal sites did not implicate cadmium as one of the metals of concern (4476). Exposure through drinking water in general is considered minor (4476).

71.2.4 Other Sources of Human Exposure

The inhalation of cadmium-containing dusts and fumes contribute to the acute toxic effects of cadmium but increasing the body burden via ingestion of foods, water, and mucociliary transport will contribute to the long-term effects such as renal toxicity.

Ingestion of food represents the single most important source of cadmium in man, especially in non-smokers (4477). Cadmium is found in many staple foods. Schroeder and Balassa (4412) reported large quantities of cadmium in shellfish, particularly oysters and lobsters, and appreciable amounts in wheat, corn, and oat grains

Table 71-1

Food Groups by Mean Cadmium Content and Their Contribution to Daily Cadmium Intake

Food Group	Concentration, ppm Mean	Cadmium intake µg/day	Percent of total daily diet	Contribution to daily cadmium intake, %
Leafy vegetables	0.051	3.18	2.0	6.2
Potatoes	0.046	9.11	7.0	17.8
Fruits	0.042	9.38	7.4	18.3
Grains	0.028	11.66	12.6	22.8
Oils, fats, and shortning	0.027	1.36	1.8	2.7
Root vegetables	0.021	0.76	1.2	1.5
Garden Fruits	0.019	1.71	3.0	3.4
Meats and poultry	0.0093	2.49	9.9	4.9
Sugars and adjuncts	0.0083	0.68	2.8	1.3
Legume vegetables	0.006	0.42	2.5	0.8
Beverages	0.0057	6.49	23.9[a]	12.7
Dairy	0.005	3.94	25.9	7.7

[a]Includes water
Source: (4446)

and their products, in pork and beef kidney and liver, in apple cider, various vegetables, and in fresh, roasted peanuts. Table 71-1 shows the cadmium content of some food groups and their contribution to daily cadmium intake (4477). Cadmium was also found in the tissues of game animals such as deer, squirrel, rabbit and grouse (4411).

Cadmium may be absorbed from ingestion of the metal lost from glazes on ceramic table and cooking ware, and from chewing pencils or toys containing cadmium pigments (4415).

Another major source of cadmium exposure in man is from cigarette smoking (4477). Westcott and Spencer (4417) noted that a packet of 20 plain cigarettes yielded about 6 µg cadmium in the inhaled main-stream smoke. Oberdörster (4423) hypothesized that on the assumption of a cadmium content of 1.6 µg/cigarette, 10% being inhaled with mainstream smoke and 50% being deposited, a one-pack-per-day smoker may deposit an average of 1.6 µg of cadmium/day.

Exposure to cadmium from drinking water has been considered minor (4476), but it should be mentioned that the presence of cadmium was detected in a number of water sources including unpiped spring, pond, river and public reservoirs; piped water from public places, laboratories and private homes (4411). Meranger et al. (4478) quoted an arithmetic mean of 0.05 µg/L for cadmium found in Canadian drinking water, while Konz and Walker (4479) mention that most drinking waters probably do not contain more than 1 µg cadmium/L. There is concern over cadmium in soft drinking water with low alkalinity, because this water (where the pH may be 5 or 6) would tend to dissolve cadmium and lead from water lines and from soft solder used in connecting lines (4477).

Friberg and Elinder (4416) report that exposure of humans to cadmium occurs in occupations involving the refining of metal ores or use of corrosion-resistant coatings, alloys, pigments, plastics, batteries and photographic materials. It has been estimated by NIOSH (cited in 4426) that 1,500,000 workers in the United States may be exposed to cadmium through occupational exposure. This was based on a survey of occupational hazards in industries such as those listed above.

Cadmium in airborne dusts may be inhaled. The overall absorption through the lungs is probably between 13% and 19% of the total inhaled, or less than 0.06 µg/day (4415). Ambient air concentrations from industrial emissions currently do not appear to pose much risk to the general population; however, in certain cases increases in cadmium body burden might be expected for individuals residing near certain types of sources (4477).

The possibility of human exposure from high concentrations of environmental cadmium was seen in Shipham Parish, Somerset, England where the cadmium content of garden soil was 87 ppm compared with the UK average of 2 ppm. Cadmium content was elevated in leafy vegetables such as cabbage, kale, spinach, lettuce, rhubarb and celery. Evidence for a health risk was however inconclusive (4415).

71.2.5 Biological Monitoring

Biological monitoring of cadmium is summarized by the Agency for Toxic Substances and Disease Registry (4426). The biological samples in which cadmium may be measured include blood/plasma, urine, hair, liver and kidney, and muscle tissue. Atomic absorption spectroscopy may be used for measuring cadmium in blood/plasma, urine, hair, and soft tissues. The detection limits vary, ranging from less than 1 ng/mL to several micrograms/L depending on the tissue sample and sample preparation procedure. Cadmium in tissues may be measured in vivo by neutron activation analysis or x-ray fluorescence (4520).

71.3 HUMAN HEALTH CONSIDERATIONS

71.3.1 Animal Studies

71.3.1.1 Carcinogenicity

The first evidence of a local carcinogenic effect after subcutaneous injection of cadmium was reported by Haddow et al. (4414), who found sarcomas in rats after administration of a cadmium-containing ferritin compound. Local tumors in animals were also described by Heath et al. (4418) after intramuscular injection of 0.014-0.028 g cadmium powder in 0.4 ml fowl serum. Heinrich (4413) presented a tabular summary of 22 investigations from 1961-1983, in which cadmium administered by the subcutaneous or intramuscular route, as cadmium, $CdCl_2$, $CdSO_4$, CdO, CdS, and Cd-Ferritin, in doses of 0.2-40 mg/animal, caused local sarcomas as well as Leydig cell testicular tumors.

A survey of nine investigations (1958-1980) on oral intake of cadmium in food or drinking water, or after administration by stomach tube, in mouse, rat or dog, with the maximum cadmium dose of 4 mg/kg b.w./week for 18 months (mouse) and 50 mg/L drinking water for 2 years (rat) and with studies ranging from 1.5 to 4 years, showed no treatment-related increase of tumor incidences, even though the cadmium dose applied was very high (4413).

The carcinogenic effects of cadmium by the inhalation route were investigated by Hadley et al. (4419). Following exposure of rats to 60 µg/L CdO for 30 minutes, they found lung tumors in 1/34 rats after one year. Heering et al. (4420) exposed rats to 20 $\mu g/m^3$ of $CdCl_2$ to rats for 18 months and found lung tumors in 5/10 rats. However, no details were available for the lung tumor incidence in control animals.

In the experiments of Takenaka et al. (4421), rats were exposed to $CdCl_2$ at a concentration of 12.5, 25, or 50 $\mu g/m^3$ (mass median aerodynamic diameter 0.55 µm) for 18 months. After an additional 13 months of observation, primary lung carcinomas were found in a dose-response relationship. At an exposure concentration of 12.5 $\mu g/m^3$, lung carcinomas developed in 15.4% of the animals; at 25 $\mu g/m^3$ it was 52.6%, and at 50 $\mu g/m^3$, lung carcinomas developed in 71.4% of the animals. There were no lung tumors in the control animals. Histologically, the tumors seen in the experimental animals were adenocarcinomas, epidermoid carcinomas, mucoepidermoid carcinomas and combined epidermoid and adenocarcinomas.

In the study of Sanders and Mahaffey (4422) the carcinogenicity of CdO was evaluated by intratracheal instillation of the compound into male rats. Small particles of CdO (count median diameter 0.5 µm) suspended in saline were instilled at a dose of 25, 50 or 75 µg at weekly intervals. The experimental time was approximately 2.5 years. Two rats in the 50 µg group developed adenocarcinomas (not statistically significant). However, there was a significant increase ($P < 0.05$) in the incidence of mammary gland fibroadenomas in all cadmium-treated groups compared to controls. The authors postulated that the failure to induce a significant increase in lung tumors

may have been related to the method of administration, since it had been found that 80% of an instilled CdO dose was cleared from rat lung with a half-life of 4 hr.

Cadmium does not appear to be carcinogenic by ingestion. The greatest reasonable potency for cadmium by ingestion was estimated as 0.0017 (4427). A review of the pulmonary carcinogenicity of cadmium appears in Oberdörster(4508).

Recent studies by Sunderman (4514) provided evidence for cadmium (Cd^{++}) replacing zinc (Zn^{++}) in DNA-binding proteins. Such perturbations in these proteins may provide a molecular basis for cadmium carcinogenicity. This study is described in more detail in section 71.3.1.2.

71.3.1.2 Genotoxicity

Conflicting data are present with regard to the induction by cadmium of DNA damage and mutagenicity in bacteria and yeast. In a review by Degraeve (4424) it was reported that in the rec assay in Bacillus subtilis strains H17 and M45, positive results were obtained with $CdCl_2$ and $CdSO_4$, whereas $Cd(NO_3)_2$ gave less evident results. In Escherichia coli (try$^-$) cadmium salts were inactive. In five strains of Salmonella typhimurium (TA98, TA100, TA 1535, TA 1537, TA1538), in which histidine reversions were studied, negative results were obtained with or without activation. Treatment of Saccharomyces cerevisiae cells with cadmium caused toxicity but not mutagenicity (4430). Degraeve (4424) citing the works of Ramel and Friburg (4433) and Sorsa and Pfeifer (4434) reported that cadmium was not mutagenic in Drosophila melanogaster.

Almost all genotoxicity experiments with cadmium carried out on mammals in vivo gave negative results (4424). Cadmium did not induce an increase in the number of sperm abnormalities in male mice (4438). Sutou et al. (4435) administered $CdCl_2$ orally at dose levels of 0.1, 1.0 or 10.0 mg/kg/day for 9 weeks to male rats. Following mating with two females/week for 6 weeks, it was found that there were no significant differences in the average numbers of corpora lutea, total implantations, pre-implantation losses, late deaths or total deaths/female. However, cadmium acetate transformed Syrian hamster embryo cells (4437).

Cadmium was shown to be mutagenic in the mouse lymphoma assay by both Amacher and Paillet (4431) and Oberly et al. (4504).

The U.S. EPA (4427) reviewed data on the mutagenicity of cadmium and reported that cadmium had been tested in a variety of mutagenicity tests with both negative and positive results obtained. Because a variety of endpoints and protocols had been used, the U.S.EPA mentioned that a resolution of the apparently conflicting data was not currently possible. Several of the positive results were observed at concentrations in which some cytotoxicity was apparent, and it was suggested that the mutagenic effect of cadmium may be an indirect one (4427).

In reviewing data from in vitro studies, Sunderman (4514) indicated that cadmium could replace zinc as a structural element in the "finger-loop" structure of some DNA-binding proteins. These proteins are involved in site-specific binding to double-

stranded DNA and, thereby provide a mechanism for regulation of genetic transcription. The replacement of zinc by cadmium results in aberrations in the structure and function of these finger-loops that could result in altered protein formation and genotoxicity.

71.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Ferm and Carpenter (4429) were the first to demonstrate cadmium teratogenicity. Following treatment of golden hamster females on the 8th day post-coitum with an i.v dose of 2 mg/kg cadmium sulfate, they observed a high increase in the rate of resorptions and malformed embryos. The abnormalities of the face ranged from simple cleft to complete obliteration of normal facial architecture. There was also anophthalmia, exencephaly, limb defects, and rib fusion.

Chernoff (4430) found that the subcutaneous injection of 12 mg/kg $CdCl_2$ induced up to 50% fetal mortality and 70% abnormalities in rats. Among the abnormalities were micrognathia, cleft palate, club foot, and small lungs.

Prigge (4463) exposed rats to 0.2, 0.4, or 0.6 mg/m^3 cadmium (compound not given in citation) for 24 hr/day during pregnancy and observed decreased fetal weight in the high-dose group.

Baranski (4456) exposed rats to 0.02 or 0.16 mg/m^3 of cadmium oxide (5 hours/day, 5 days/week, for 5 months preceding, and then continuing during mating and gestation). Viability of the offspring of dams that were exposed to 0.16 mg cadmium/m^3 before and during gestation was significantly ($P < 0.05$) reduced. Cadmium exposure also resulted in a significant ($P < 0.05$) reduction of motor activity in 3-month-old male and female pups from the 0.16 mg cadmium/m^3 group and in male offspring from the 0.02 mg cadmium/m^3 group.

In a second study, Baranski (4457) exposed rats to 0.02, 0.16 or 1.0 mg/m^3 of cadmium oxide (5 hours/day, 5 days/week for 4-6 months) preceding and during mating and continuing through gestation. Effects on fertility were observed only at the highest exposure concentration, which was directly toxic to the dam.

Kutzman et al. (4460) investigated the effects of cadmium chloride inhalation in rats. The rats were exposed to 0, 0.3, 1.0 or 2.0 mg cadmium/m^3 as cadmium chloride aerosol for 6 hours/day, 5 days/week for 62 days. Reproductive fitness was determined 6 days after final exposure. Eight male rats from each exposure chamber were individually housed with two unexposed females, and eight female rats from each chamber were each caged with a single unexposed, proven male. It was found that concentrations of 0.3 and 1.0 mg cadmium/m^3 did not affect reproductive fitness (viable embryos, early deaths [resorptions], or preimplantation losses) in these rats.

Sutou et al. (4458) investigated the effects of cadmium on the reproductive potential of Sprague-Dawley rats. They administered 0.1, 1.0. or 10.0 mg/kg/day cadmium orally for 6 weeks to four groups of rats (14 males and 14 females/group). Males and females within each group were mated 6 days/week for 3 weeks. Cadmium

was administered during the mating period. Pregnant females were administered cadmium during the gestation period and killed on the 20th day of gestation for examination of pups for teratogenicity. It was found that administration of 1.0 mg/kg/day of cadmium for 6 weeks caused a slight decrease in the number of total implants and live fetuses, but there was no significant difference from the controls. However, the 10.0 mg/kg group showed a significant difference ($P < 0.01$) from the controls in these parameters.

Cadmium-induced ovarian toxicity was reported by Rehm and Waalkes (4466) in hamsters, mice and rats following a single subcutaneous injection of 20-47.5 μmol/kg of $CdCl_2$. The animals were examined from 24 hr to 8 weeks after treatment. Syrian hamsters were the most susceptible to $CdCl_2$-induced ovarian hemorrhagic necrosis, while only one of four strains of mice tested (DBA/2NCr) showed significant ovarian hemorrhages, and only at doses producing lethal liver toxicity. In rats, there was dose- and age-dependent toxicity in the ovaries, uterus, cervix and liver.

In vitro teratogenicity tests using the Dugesia regeneration assay, the Hydra reaggregation assay, and the Xenopus embryo assay indicated cadmium chloride not to be teratogenic (4521).

71.3.1.4 Other Toxicologic Effects

Several comprehensive reviews of cadmium toxicity are available (4411, 4446). The major toxic effect from increased body burden of cadmium is renal toxicity. Other toxic effects of cadmium include, hepatic injury, lung damage after inhalation exposure, altered immune response and bone defects (4426, 4432). Although cadmium-induced hypertension has been reported in rodents (4467), this topic is very controversial.

71.3.1.4.1 Short-term Toxicologic Effects

Hepatic effects

Following the kidney, the next highest tissue levels of cadmium are found in the liver, after both acute and chronic exposure (4426). When exposure is to low doses of cadmium, most of the cadmium in liver is bound to metallothionein (MT), and signs of liver injury are not seen. However, higher doses of cadmium result in saturation of MT-binding capacity, leading to injury (4426).

Dudley et al. (4455), in a time course study, injected rats i.v. with 3.9 mg cadmium/kg and found after 1 hr, foci of parenchymal cell swelling and increased percentage of mitotic figures in hepatocytes. After 4, 6, 8, and 10 hr there were numerous pyknotic nuclei, necrotic hepatocytes, and lymphocytic infiltration. Other experiments by these investigators showed that cadmium-induced toxicity was dose-dependent (as well as time-dependent), and the authors pointed out that the lethality in rats given large i.v. doses may have been caused by hepatic failure.

Lung effects

Martin and Witschi (4505) showed that lung injury was induced in male BALB/c mice exposed for one hour to 4.9 µg/L cadmium chloride aerosols. The lung injury was assessed by measurement of hydroxyproline, [^{14}C]-thymidine incorporation into DNA, and histopathology. It was also shown that the injury could be prolonged and augmented by the administration of 80% oxygen.

Renal effects

Rehm and Waalkes (4517) reported that the hamster is uniquely susceptible to acute effects of cadmium on the kidney but that this effect is not related to high concentrations of the test agent (cadmium chloride) or low levels of metallothionein in the kidney. These experiments showed that subcutaneous injection of $CdCl_2$ (30 to 50 µmol/kg) resulted in renal lesions 12 to 24 hours later (60% incidence in both sexes). No such lesions were observed in rats and mice administered $CdCl_2$ even at lethal doses.

Ocular effects

A study by Yoshizuka et al. (4518) reported that intraperitoneal injection of cadmium sulfate (1.8 mg/kg/day) to pregnant Wistar rats on gestational days 15 through 18 resulted in corneal edema characterized by prominent swelling of the mitochondria and the occurrence of intra- and intercellular vacuoles in the corneal endothelium. This effect was not observed in nonpregnant rats receiving the same treatment or in controls. Other than the possible involvement of hormones, no explanation for this effect was possible.

71.3.1.4.2 Subchronic and Chronic Toxicity

Both the lung and kidney are known target organs for the toxicity of cadmium, and although renal toxicity has been observed following oral or inhalation exposure, pulmonary toxicity has been detected only after inhalation exposure (4507, 4508). This phenomenon may be due, in part, to the difference in the toxicokinetics for these two exposure routes. It has been shown that gastrointestinal absorption of cadmium is only 6% whereas pulmonary absorption may exceed 95% of the deposited dose (4508). The pulmonary toxicity of cadmium has been thoroughly reviewed by Oberdorster (4508).

An age-dependent accumulation of cadmium in rats was reported by Rummler et al. (4519). Sister pairs of female rats exposed to cadmium chloride in the drinking water (31.5 mg Cd/L) for 1, 4, 7, or 10 months demonstrated a decreased accumulation of cadmium and other metal ions with increasing age, most likely attributed to a decrease in water consumption relative to body weight. However, high levels of cadmium were detected in cell nuclei, a situation possibly resulting from the similarity between Ca^{++} and Cd^{++}.

Hypertension

Cadmium was first reported to cause hypertension in the 1960s, and several studies on the effects of cadmium on the cardiovascular system have since been conducted. Schroeder (4515), in an initial epidemiologic study, reported high cadmium levels in hypertensive individuals. Further evidence of cadmium-induced hypertension was provided by a study reporting that cadmium-induced hypertension in rats was reversed following removal of the cadmium by a chelating agent (4516). Balaraman et al. (4467) reported a significant ($P < 0.01$) elevation of blood pressure in female albino rats treated intraperitoneally for two weeks with 0.5 or 1.0 mg/kg cadmium chloride. Kopp et al. (4445) found that the effect of cadmium acetate on the cardiovascular system of rats was dose-dependent. Cadmium acetate, at concentrations of 0.01-50 ppm was administered in drinking water to Long Evans rats for 18 months. It was found that average systolic blood pressure increased at the 0.5 ppm (10-20 µg/kg body weight/day) level, while exposures to higher concentrations of cadmium lowered blood pressure. However, cadmium-induced hypertension in humans remains controversial because hypertension is not prevalent in cadmium poisoning situations. Increased levels of cadmium have been noted in persons dying of hypertensive disease, but in other groups of humans who were known to have been exposed to cadmium, the incidence of hypertension was not above normal (4426).

Immunological effects

Studies on the immunological effects of cadmium in rats and mice show that, depending on the dose, cadmium may increase or decrease immunological response to foreign antigens (4432). For example Malave and De Ruffino (4447) exposed C57BL/6 mice to 50, 200, or 300 ppm of cadmium as cadmium chloride in the drinking water for 3-4 or 9-11 weeks. They found that exposure at 50-200 ppm at both time periods increased the ability of the animals to form antibodies to sheep red blood cells, while 300 ppm exposure for 9-11 weeks decreased the antibody response to sheep red blood cells.

Renal effects

The kidney is the primary target organ of cadmium following oral or inhalation exposure (4508), but chronic cadmium exposure seldom leads to end-stage renal disease or increased mortality. The main problem associated with renal cadmium intoxication is not the proteinuria per se, but rather the effect on other tubular functions such as mineral absorption (4426). Adverse effects on the kidneys have been observed in experimental animals exposed to cadmium in their diet (4462), or in drinking water (4461).

In studies on rats, Wilson et al. (4462) demonstrated that ingestion of cadmium can result in toxic effects on the kidneys. Rats were placed on diets containing 0.0031, 0.0062, 0.0125, 0.025 and 0.05% cadmium as cadmium chloride for 100 days. The rats in the two highest dose groups showed anatomical changes in the pancreas, liver, kidney and spleen. The kidneys of animals in these groups showed some swelling and granulation of the epithelium of the convoluted tubules, and formation of hyaline and

granular casts. There was no detectable abnormality in the glomeruli. The animals that received 0.0125% cadmium showed similar but more marked changes in the kidneys than those described for the high-dose groups, and in animals receiving 0.0062% there were less marked but definite changes. (The relatively slight changes in animals receiving the largest doses can probably be explained by the short survival time of the rats). The organs of rats receiving the smallest doses of cadmium were nearly normal. The changes in the organs were roughly proportional to the amounts of cadmium received (except for animals in the highest dose groups).

Stowe et al. (4461) studied the effects of orally administered cadmium as cadmium chloride (160 ppm in drinking water for 200 days) in two strains of rabbits, Flemish Giant and New Zealand White (10 males of each). The cadmium intake averaged 14.9 mg/kg/day in the treated group while the controls drank normal tap water. Growth of both strains was significantly retarded ($P < 0.05$) and both strains showed significantly ($P < 0.01$) higher neutrophil counts and lower lymphocyte counts than the controls. Histological examination of the kidneys revealed extensive interstitial fibrosis and coagulation necrosis of the proximal tubules.

Goyer et al. (4465) studied cadmium nephrotoxicity in rats injected s.c. with 0.6 mg/kg/day $CdCl_2$ for 5 days/week for 2, 4, 6, or 8 weeks. The earliest ultrastructural changes occurred in treated animals in proximal cells after 4 weeks. After 8 weeks there were foci of proximal tubular degeneration and regeneration, small inflammatory cell infiltrations, and bands of interstitial fibrosis.

Hepatic effects

Stowe et al. (4461), as mentioned above, exposed rabbits to an average of 14 mg cadmium/kg/day for 200 days and observed biliary hyperplasia, focal mononuclear inflammatory cells, and periportal fibrosis in the hepatic parenchyma of treated animals.

Lung effects

Kutzman et al. (4460) studied the effects of cadmium inhalation in Fischer-344 rats. Twenty male rats were used for assessing pulmonary effects, eight males for pathology, eight males and eight females for reproductive studies, and 10 males for cytogenetic assessments. The rats were exposed to 0, 0.3, 1.0 or 2.0 mg cadmium/m^3 as cadmium chloride aerosol for 6 hours/day, 5 days/week for 62 days. The volume median diameter (VDM) in the 0.3 mg cadmium/m^3 chamber was 0.66 µm with a geometric standard deviation (σ_g) of 1.10, and the VDM in both the 1.0 and 2.0 mg cadmium/m^3 chamber was 0.73 µm with a σ_g of 1.15. All the animals in the 2.0-mg cadmium/m^3 chamber died within the first 45 exposure days. In both the 0.3 and 1.0 mg cadmium/m^3 groups, adverse effects were centered around the terminal bronchioles. The response consisted of type II cell hyperplasia and infiltration of macrophages, mononuclear cells and polymorphs constituting microgranulomas. There was proliferation of fibroblasts to form foci of fibrosis, and this was more pronounced in the 1 mg cadmium/m^3 group. Lesions related to cadmium exposure were not observed in the other organs examined.

A study by Princi and Geever (4459) showed no adverse effects of cadmium on the lungs of dogs following inhalation of two different cadmium compounds. Ten dogs were exposed to cadmium oxide, 10 to cadmium sulfide and 10 controls were exposed to air in different chambers. The cadmium concentrations varied between 3 and 7 mg/m^3, with an average concentration of 4 mg/m^3. The dogs were exposed for 6 hours/day, 5 days/week for 1,102 hours (average) for cadmium oxide and 895 hours (average) for cadmium sulfide. No particles over 5 microns were seen, and 98% of the particles were < 3 microns. The hematological findings of the exposed dogs did not vary to any marked degree from those of the controls after more than 12 months of exposure. The cadmium levels of the blood and urine of the cadmium sulfide-exposed dogs were significantly lower than those found in the cadmium oxide-exposed dogs. This is consistent with the fact that cadmium oxide is much more readily soluble in body fluids than is cadmium sulfide, and therefore more readily absorbed (4459). Autopsies of the dogs exposed to both compounds, at the end of the exposure period, revealed no tubular damage in the kidneys, no pulmonary fibrosis or emphysema of the lungs, and no pathologic changes in the livers.

71.3.2 Human and Epidemiologic Studies

71.3.2.1 Short-term Toxicologic Effects

The chief pulmonary effect of cadmium exposure is centrilobular emphysema and bronchitis, resulting from several years of occupational exposure to CdO fumes and dust, and cadmium pigment dust. *Lung damage is* possible at CdO fume levels below 100 $\mu g/m^3$ of workplace air, depending on length of exposure. Bonnell (4502) reported on cases of emphysema in workers chronically exposed to cadmium oxide, while surveys by Thun et al. (4425) and Armstrong and Kazantzis (4503) show increased mortality from respiratory disease among populations occupationally exposed to cadmium.

Acute cadmium toxicity may result from inhalation of cadmium dusts and fumes and from ingestion of cadmium salts. Cadmium compounds are much less lethal when swallowed than when inhaled, mainly because they induce vomiting, and thus are not retained. Although as little as 10-20 mg of soluble cadmium salts have produced severe toxic symptoms when ingested, death probably results from several hundred mg by the oral route (4482). With cadmium inhalation, an asymptomatic period of 4-8 hr may precede the clinical illness. The symptoms are as follows:

1. Metallic taste in the mouth and headache;
2. Shortness of breath, chest pain, cough with foamy or bloody sputum.
3. Weakness, leg pains;
4. Intense pulmonary edema possibly leading to death by asphyxiation;
5. Gradual resolution of pulmonary edema (over a period of a few days) and development of fever, with persistence of cough, chest pain and dyspnea for one or more weeks; physical signs of pneumonic consolidation;
6. Late kidney and/or liver damage has followed respiratory exposures in industry (4482).

With ingestion of cadmium an asymptomatic period of ½ to 1 hr may precede the clinical illness. The symptoms are as follows:

1. Severe nausea, vomiting, diarrhea and abdominal cramps and salivation;
2. Headache, muscular cramps, vertigo, and perhaps convulsions (rarely);
3. Exhaustion, collapse, shock and possibly death, usually within a period of 24 hr;
4. The gradual evolution of signs and symptoms of liver and kidney damage should be anticipated but are rarely seen in man (4482).

71.3.2.2 Chronic Toxicologic Effects

The long-term low level effects of cadmium following respiratory or oral intake are usually associated with occupational exposures (4411). In industry, toxic fumes emanating from melting, pouring, and handling operations of cadmium, mainly as the oxide, may cause "metal fume fever". Arena (4448) describes chronic effects of inhaled cadmium as total or partial loss of smell, coughing, labored breathing, depressed appetite, weight loss, and in many instances, a yellow staining of the teeth and generalized irritability. Liver, kidney, and hematopoietic tissue may be involved. Fatigue, dental caries, gastrointestinal upset, pallor, and in 2 of 5 cases, a low level of hemoglobin, were also observed (4411).

In some humans chronically exposed to high levels of cadmium, painful bone disorders, including osteomalacia, osteoporosis, and spontaneous bone fracture have been observed. These symptoms have been most studied in postmenopausal women in a cadmium-contaminated area of Japan where the affliction is known as Itai-Itai disease.

Itai-Itai (ouch-ouch) disease has been described by Friberg et al., (4446) as an "expression of chronic cadmium poisoning". In 1967, over 20% of women of 50 years or older living in areas of high soil cadmium concentration downstream of the Kamioka zinc/cadmium mine in Toyana Prefecture, Japan, were reported to be suffering from lumbar and leg pains with bone tenderness, susceptibility to multiple fractures and extreme skeletal deformation, hypochromic anemia, increased levels of alkaline phosphatase, reduced levels of serum phosphate, proteinuria, glycosuria, damage to the intestinal mucous membrane, and decreased ability to absorb fats. The causal factors were thought to be malnutrition and the drinking of water and eating of rice contaminated with high levels of cadmium. Because of the association with age and malnutrition, the symptoms in this population were probably not caused by cadmium exposure alone (4415) although in the review of Dunnick and Fowler (4432) it is concluded that oral ingestion of cadmium played the most important role in the development of Itai-Itai disease.

The kidney is considered the main target organ affected by chronic cadmium exposure, and renal dysfunction as the critical effect. The renal dysfunction is manifested in terms of tubular proteinuria (with elevated excretion of the protein ß-microglobulin), followed by aminoaciduria, glycosuria, and other signs of kidney damage.

Renal tubular dysfunction is irreversible once it has proceeded to the point of pronounced proteinuria (4477). Friberg et al. (4446) has estimated that humans will not experience kidney damage until the concentration of cadmium in the renal cortex exceeds 200 μg/g.

In Liège, Belgium, where airborne cadmium was associated with smelting operations, Lauwerys and De Wals (4429) reported a prevalence of renal dysfunction in elderly women from the locality of the smelters compared with women of the same age from another industrial area, Charleroi, that was much less polluted by cadmium.

Mason (4522) conducted a study of workers having exposure (greater than one year) to cadmium oxide fumes. Specifically, an evaluation was made of the pituitary-testicular endocrine axis and endpoints of renal toxicity. Based on the measurement of serum testosterone, luteinizing hormone and follicular-stimulating hormone, no significant differences were observed between the reference group and the cadmium oxide-exposed group. However, there were highly significant differences in urinary retinol-binding protein and plasma greatinine indicating cadmium-induced damage to the renal tubules. Additionally, a diminished glomerular filtration rate was also observed for the exposed workers.

The importance of cadmium in human hypertension remains uncertain. Above-average concentrations of cadmium has been observed in persons dying of hypertensive disease, but on the other hand in some groups of humans who were known to have been exposed to cadmium the incidence of hypertension was not above normal (4426).

Epidemiological studies of cadmium relating to carcinogenesis of the respiratory tract have been summarized in tabular form by Oberdörster (4423). One recent study by Thun et al. (4425), which is an update of Lemen's earlier study (4449), included 602 workers who had been employed at a cadmium production plant between 1940 and 1969 for at least 6 months. The vital status of the workers was studied through 1978. The workers were exposed to cadmium oxide (as dust and fume), cadmium sulfate, and cadmium sulfide. A comparison of cause-specific mortality rates with rates of a modified life-table system developed by NIOSH showed that mortality from respiratory cancer was significantly increased among cadmium workers employed for two or more years. This observation was based on 16 lung cancer cases observed versus seven expected. The authors also studied 576 workers hired on or after January 1926, and found that lung cancer mortality increased with increasing cumulative exposure. The result was significant for workers with a cumulative exposure of greater than 2920 mg-days/m^3. The standard mortality ratio for this group was 280. Confounding factors, such as exposure to arsenic and smoking habits of the workers, were taken into account. This study is the only detailed report that suggests that inhaled cadmium is a human lung carcinogen and confirms the earlier findings of Lemen et al. (4449), based on a subgroup of the same worker cohort. An evaluation of the confounding factors by the U.S.EPA Carcinogen Assessment Group indicated that the assumptions and methods used in accounting for them may not be valid. Since the SMRs observed were low and there was a lack of clear cut evidence of the cadmium exposure only, the study was considered to supply only limited evidence of human carcinogenicity (4468).

An excess lung cancer risk was reported in the studies of Varner (4469), Sorahan and Waterhouse (4470) and Armstrong and Kazantzis (4468), but these were also compromised by the presence of other carcinogens or by small population size (4487).

The studies of Kipling and Waterhouse (4471), Lemen et al. (4449), Holden (4472) and Sorahan and Waterhouse (4470) concerning workers exposed to cadmium dust or fumes, provided evidence of a statistically positive association with prostate cancer, but the total number of cases was small in each of these studies. The study of Thun et al. (4425), described earlier, did not show an excess risk of prostatic cancer among those workers, and other authors have found an increased risk of prostatic carcinomas in CdO exposed workers only when occupational exposure was combined with smoking (4424).

In some cases where lung cancer was reported, a high level of cadmium was observed in liver, kidney, and blood of the patients (4454).

71.3.2.3 Genotoxicity

In human and mammalian cells in vitro cadmium produced chromosomal aberrations (4439, 4440).

With regard to the production of chromosomal aberrations in exposed persons, the evidence was conflicting. O'Riordan et al. (4444) reported on chromosome studies in peripheral lymphocytes from 40 men employed in the manufacture of cadmium pigments. The results were compared with those on 13 men from the same factory (not directly subjected to cadmium), and on 285 persons not working in the factory. There were no statistically significant differences in the incidence of chromosomal or chromatid aberrations between the different groups. Bui et al. (4443), on examining four Japanese patients with Itai-Itai disease did not find conclusive evidence of chromosomal damage. However, Shiraishi and Yosida (4441) found a dramatic increase in the frequencies of chromosome lesions in blood lymphocytes of seven females suffering from Itai-Itai disease. Shiraishi (4442) confirmed these results in a later experiment with a larger number of patients.

71.3.3 Levels of Concern

OSHA (4488) has established an 8-hr TWA of 0.1 mg/m^3 for cadmium fumes and 0.2 mg/m^3 for cadmium dust, and ceiling levels of 0.3 and 0.6 mg/m^3 have been set for these forms, respectively. An 8-hr TLV of 0.01 mg cadmium/m^3 has been recommended by ACGIH (4493). For water exposure limits AN NIPDWR of 10 µg/L is established, and an MCL and MCLG of 5 µg/L have been established by the U.S. EPA (4523), and a Drinking Water Guideline of 0.005 mg/L is indicated by the World Health Organization (4483). Drinking water concentrations of cadmium indicative of levels that would not be anticipated to cause adverse health effects have been provided by the U.S. EPA (4491) and are: 40 µg/L, 40 µg/L, and 5 µg/L for 1-day, 10-days, and longer-term exposure for children; and 20 µg/L and 5 µg/L for longer-term and lifetime exposure for adults.

Ambient water quality criteria established by the U.S. EPA (4490) for the protection of human health are 10 µg/L based on ingestion of contaminated drinking water only and for ingestion of aquatic organisms and contaminated drinking water. For protection of freshwater aquatic life, water concentrations of 3.9E-03 and 1.1E-03 mg/L have been established for acute and chronic exposure, respectively. For protection of marine species these criteria are 4.3E-02 and 9.3E-03 mg/L for acute and chronic exposure, respectively. A reportable quantity (RQ) of 1 lb. for cadmium and 10 lbs for cadmium compounds, and an oral RfD of 5E-04 mg/kg/day (water) and 1E-03 mg/kg/day (food) have also been established for cadmium (4487).

IARC (4436) classifies cadmium in Group 2B (limited evidence for carcinogenicity in human, sufficient evidence in animals), and the U.S. EPA (4427) considers cadmium a B1 carcinogen (based on inhalation exposure), indicating limited evidence in humans and sufficient evidence in animals.

71.3.4 Hazard Assessment

The weight of evidence on the carcinogenicity of cadmium was evaluated by U.S. EPA who concluded that cadmium was a probable human carcinogen (Group B1) by the inhalation route (4426). This classification was based on limited evidence of carcinogenicity from epidemiological studies and sufficient evidence of carcinogenicity in animals. There were not sufficient data to classify cadmium for carcinogenicity by the oral route (4426).

U.S.EPA calculated the lung cancer risk associated with cadmium from two studies. In the study of Thun et al. (4425) a dose-dependent increase in mortality from respiratory cancer was reported for males occupationally exposed to cadmium, and in the study of Takenaka et al. (4421) there was a dose-dependent increase in lung cancer frequency in rats exposed to $CdCl_2$ aerosols. A summary of lung cancer risk estimates from these data is given in Table 71-2.

Although the risk estimate based on the animal data is higher (and thus more conservative) than the risk estimate based on the human data, the Carcinogen Assessment Group considered the latter more reliable for environmentally exposed humans.

Table 71-2.

Summary of Lung Cancer Risk Estimates for Inhalation Exposure to Cadmium

Parameter	Rats (4421)	Humans (4425)
Mathematical procedure	Linearized multistage	Maximum likelihood
Unit risk[a]		
Point estimate	5.5×10^{-2}	
95% Upper bound	9.2×10^{-2}	1.8×10^{-3}
95% Lower bound	1.7×10^{-4}	3.5×10^{-3}
Risk-specific Concentration[b]		
Risk level	Concentration ($\mu g/m^3$)	
10^{-4}	1.0×10^{-3}	2.9×10^{-2}
10^{-5}	1.0×10^{-4}	2.9×10^{-3}
10^{-6}	1.0×10^{-5}	2.9×10^{-4}

[a]The risk associated with lifelong inhalation exposure to 1 $\mu g/m^3$
[b]The concentration of cadmium in air associated with a specific excess lifetime risk of lung cancer - calculated using the upper 95% confidence limit from each study.

Source: U.S.EPA 1985 (4427)

71.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of cadmium concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following sequence of reagents to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is required for solid samples other than storage

at 4°C until sample analysis. All samples should be analyzed within 180 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (4510).

Analytical methods available for analyzing inorganic cadmium in water, soils and waste include atomic absorption (Methods 213.1 and 213.2) and inductively coupled plasma atomic emission spectrometry (Method 200.7) techniques. Depending upon the analytical method, treatment with acid or a combination of acid with hydrogen peroxide is used to digest the samples. Sample preparation procedures specific to each analytical technique are described in Methods 200.0, and 200.7 for aqueous samples (4510) and Methods 3005, 3010, 3020, 3040, and 3050 for solid or waste samples. Quality control samples should be processed with the samples to determine whether analyte losses have occurred during the sample dissolution procedure (4511).

The atomic absorption techniques are probably the most common procedures for determining the concentration of cadmium in water, soil and waste samples. Following the appropriate digestion of the sample, a representative aliquot of the digestate is atomized by either directly aspirating it into a flame or by charring it in a graphite tube furnace. The absorption of hollow cathode or electrodeless discharge lamp radiation at 228.8 nm will be proportional to the cadmium concentration. The detection ranges are 0.05-2 mg/L and 0.5-10 µg/L for the flame and the furnace atomic absorption techniques,respectively. In a U.S. EPA study, sample results using the graphite furnace technique were reproducible to within 4% for water samples containing less than 10 µg/L cadmium. Recovery ranged from 96-99% in the samples. In an interlaboratory study of six aqueous samples, the standard deviation between laboratory results using the flame technique was 23-360%. The bias in results compared to the true values ranged from -2 to 135% (4510).

U.S. EPA has recently approved the use of the inductively coupled plasma (ICP) atomic emission method for determining compliance with existing National Primary Drinking Water Regulations (4513). The technique is based upon the simultaneous or sequential multi-element measurement of atomic emission of trace metals. A preserved and/or digested sample is nebulized to form an aerosol that is introduced into a high temperature plasma where atomic excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma and are dispersed by a grating spectrometer. The line intensities, which are a measurement of elemental concentrations, are monitored by photomultiplier tubes. Optical compensation techniques are used to correct for spectral interferences. In an U.S. EPA evaluation of the reproducibility and accuracy of the ICP method, the mean percent relative standard deviation for triplicate analysis of 22 elements was found to be 9%. The mean percent recovery of spiked elements for all waste samples was 93% (4510).

Detection Limit	Method
4 µg/L (aqueous & nonaqueous)	200.7
5 µg/L (aqueous & nonaqueous)	213.1
0.1 µg/L (aqueous & nonaqueous)	213.2

71.5 REFERENCES

Note: The numbering sequence of the references reflects the order of references as they appear in the master bibliography.

4400. Friberg, L.; Kjellström, T.; Nordberg, G.F. 1986. Cadmium. In: Handbook on the Toxicology of Metals, 2nd edition. L. Friberg, G.F. Nordberg and V. Vouk, eds. New York: Elsevier. pp 130-184.

4401. Environmental Inorganic Chemistry. Properties, Processes, and Estimation methods. I. Bodek, W. J. Lyman, W. F. Reehl and D. H. Rosenblatt, eds. New York: Pergamon Press.

4402. Weast, R.C. 1984-1985. CRC Handbook of Chemistry and Physics. Boca Raton, Florida: CRC Press, Inc.

4403. Windholz, M. Ed. 1983. The Merck Index. An encyclopedia of chemicals, drugs, and biologicals. 10th ed. Rahway, NJ: Merck & Co., Inc.

4404. Hollander, M. L.; Carapella, S.C., Jr. 1978. Cadmium and cadmium alloys. In: Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed. Volume 4. pp. 387-396. M. Grayson and D. Eckroth, eds. New York: John Wiley and Sons.

4405. Fleischer, M. et al. 1974. Environmental impact of cadmium: a review by the panel on hazardous trace substances. Environ. Health Perspec. 7: 253-323.

4406. Van Nostrand's Scientific Encyclpedia. 1983. 6th ed. D.M. Considine ed. New York: Van Nostrand Reinhold Co.

4407. Moore J. W.: Ramamoorthy, S. 1983. Heavy metals in natural waters. Applied monitoring and impact assessment. New York: Springer-Verlag.

4408. Gardiner, J. 1984. The chemistry of cadmium in natural water. I. A study of cadmium complex formation using the cadmium specific ion electrode. Water Research 8: 23-30 (Cited in 4407).

4409. Muhlbaier, J.; Tisue, G.D.. 1981. Cadmium in the southern basin of Lake Michigan. Water, Air and Soil Pollution 15:45-59 (Cited in 4407).

4410. Iverson, W. P.; Brinckman, F.E. 1978. Microbial metabolism of heavy metals. Water Poll. Microbiol. 2: 201-213.

4411. Flick, D.F.; Kraybill, H.F.: Dimitroff, J.M. 1971. Toxic effects of cadmium: a review. Environ. Res. 4: 71-85.

4412. Schroeder, H.A.; Balassa, J.J. 1961. Abnormal trace metals in man: cadmium. J. Chronic Dis. 14: 236-258 (Cited in 4411).

4413. Heinrich, U. 1988. Carcinogenicity of cadmium - overview of experimental and epidemiological results and their influence on recommendations for concentrations in the occupational area. In Cadmium. Third IUPAC Cadmium Workshop, Juelich, FRG, August 1985. M. Stoeppler and M. Piscator eds. Berlin: Springer-Verlag.

4414. Haddow, A; Dukes, C.E.; Mitchley, B.C.V.. 1961. Carcinogenicity of iron preparations and metal-carbohydrate complexes. Rep. Brit. Emp. Cancer Campgn. 39:74 (Cited in 4413).

4415. Philipp, R. 1985. Cadmium-risk assessment of an exposed residential population: a review. J. R. Soc. Med.: Vol 78: 328-333.

4416. Friberg, L.; Elinder, C.G. 1983. In: Encyclopedia of Occupational Health and safety. 3rd edition. L. Parmeggiani, ed. International Labour Office, Geneva. pp 356-357 (Cited in 4415).

4417. Westcott, D.T.; Spencer, D. 1974. Beiträge zur Tabak Forschung 7: 217-221 (cited in 4415).

4418. Heath, J.C.; Daniel, M.R.; Dingle, J.T.; Webb, M. 1962. Cadmium as a carcinogen. Nature (London) 193:592-593.

4419. Hadley, J.G.; Conklin, A.W.; Sanders, C.L. 1979. Systemic toxicity of inhaled cadmium oxide. Toxicol. Lett. 4: 107-111.

4420. Heering, H.; Oberdörster, G.; Hochrainer, D.; Baumert, H-P. 1979. Learning behavior and memory of chronically cadmium exposed rats and organ distribution of cadmium. In: Commission of the European Communities. Health effects of heavy metals. Brussels. Doc. XII/ENV/64/79, pp 61-62.

4421. Takenaka, S.; Oldiges, M.; König, H.; Hochrainer, D.; Oberdörster, G. 1983. Carcinogenicity of cadmium chloride aerosols in W rats. JNCI 70: 367-373.

4422. Sanders, C.L.; Mahaffey, J.A. 1984. Carcinogenicity of single and multiple intratracheal instillations of cadmium oxide in the rat. Environ. Res. 33: 227-233.

4423. Oberdörster, G. 1986. Airborne cadmium and carcinogenesis of the respiratory tract. Scand. J. Environ. Health 12:523-537.

4424. Degraeve, N. 1981. Carcinogenic, teratogenic and mutagenic effects of cadmium. Mutat. Res. 86: 115-135.

4425. Thun, M.T.; Schnorr, T.M; Smith, A.B.; Halperin, W.E.; Lemen, R.A. 1985. Mortality among a cohort of US cadmium production workers - An update. J. Natl. Cancer Inst. 74: 325-333.

4426. Agency for Toxic Substances and Disease Registry (ATSDR). 1989. Toxicological profile for cadmium. ATSDR, U.S. Public Health Service. ASTDR/TP-VV/08.

4427. United States Environmnetal Protection Agency (U.S. EPA). 1985. Updated mutagenicity and carcinogenicity assessment of cadmium. Office of Health and Environmental Assessment, Washington, DC. EPA/600/8-83/025F.

4428. Kabata-Pendias, A.; Pendias, H. 1986. Trace elements in soils and plants. Boca Raton, Florida: CRC Press, Inc. pp. 109-119.

4429. Lauwerys R.; De Wals, P. 1981. Environmental pollution by cadmium and mortality from renal diseases. Lancet 1: 383.

4430. Putrament, A.; Baranowska, H.; Ejchart, A.; Jachymczyk, J. 1977. Manganese mutagenesis in yeast, VI. Mn^{2+} uptake, with DNA replication and ER induction. Comparison with other divalent cations. Molec. Gen. Genet. 151: 69-76. (Cited in 4424).

4431. Amacher, D.E.; Paillet, S.C. 1980. Induction of trifluorothymidine-resistant mutants by metal ions i L5178Y/TK^{+}/ cells. Mutat. Res. 78:279-288 (cited in 4426).

4432. Dunnick, J.K.; Fowler, B.A. 1988. Cadmium. In: Handbook on Toxicity of Inorganic Compounds. H.G. Seiler and H. Sigel, eds. New York: Marcel Dekker, Inc. Chapter 4. pp. 155-174.

4433. Ramel, C.; Friberg, K. 1974. In: L. Friberg, M. Piscator and G. Nordberg. Eds. Cadmium in the Environment, 2nd edition. CRC Press p.133 (cited in 4424).

4434. Sorsa, M.; Pfeifer, S. 1973. Effects of cadmium development time and prepupal puffing pattern of Drosophila melanogaster. Hereditas 75: 273-277 (cited in 4424).

4435.. Sutou, S.; K. Yamamoto; H. Sendota et al. 1980. Toxicity, fertility, teratogenicity, and dominant lethal tests in rats administered cadmium subchronically. 1. Toxicity studies. Ecotoxicl. Environ. Safety 4: 39-50 (cited in 4436).

4436. International Agency for Research on Cancer (IARC). 1982. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Supplement 4. Chemicals, Industrial Processes and Industries Associated with Cancer in Humans, Lyon, France.

4437. DiPaolo, J.A.; Casto, B.C. 1979. Quantitative studies of in vitro morphological transformation of Syrian hamster cells by inorganic metal salts. Cancer Res. 39: 1008-1013 (cited in 4436).

4438. Bruce, W.; Heddle, J. 1979. The mutagenic activity of 61 agents as determined by the micronucleus, Salmonella and sperm abnormality assays. Can. J. Genet. Cytol. 21: 319-334.

4439. Gasiorek, K.; Bauchinger, M. 1981. Chromosome changes in human lymphocytes after separate and combined treatment with divalent salts of lead, cadmium, and zinc. Environ. Mutagenesis 3: 513-518 (cited in 4436).

4440. Deaven, L.L.; Campbell, E.W. 1980. Factors affecting the induction of chromosomal aberrations by cadmium in Chinese hamster cells. Cytogenet. Cell Genet. 26: 251-260 (cited in 4436).

4441. Shiraishi, Y.; Yosida, T. 1972. Chromosomal abnormalities in cultured human leucocyte cells from Itai-Itai disease patients. Proc. Japan Acad. 48:248-251 (cited in 4424).

4442. Shiraishi, Y. 1975. Cytogenetic studies in 12 patients with Itai-Itai disease. Humangenetik 27: 31-44 (cited in 4424).

4443. Bui, T.H.; J. Lindsten; Nordberg, G. 1975. Chromosome analysis of lymphocytes from cadmium workers and Itai-Itai patients. Environ. Res. 9: 187-195 (cited in 4424).

4444. O'Riordan, M,; Hughes, E.; Evans, H. 1978. Chromosome studies on blood lymphocytes of men occupationally exposed to cadmium. Mutat. Res. 58: 305-311 (cited in 4424).

4445. Kopp, S.J; Glonek, T.; Perry, H.M., Jr.; Erlanger, M.; Perry, E.F. 1984. Cardiovascular actions of cadmium at environmental exposure levels. Science 217: 837-839.

4446. Friberg, L; Piscator, M.; Nordberg, G.F.; Kjellström, T. 1974. Cadmium in the Environment. 2nd ed. Ohio: CRC Press.

4447. Malave, I.; De Ruffino, D.T. 1984. Altered immune response during cadmium administration in mice. Toxicol. Appl. Pharmacol. 74: 46-56.

4448. Arena, J.M. 1963. Poisoning Chemistry - Symptoms and Treatment. pp. 92, 127. Springfield, Ill.: Thomas (cited in 4411).

4449. Lemen, R.A; Lee, J.S.; Wagoner, J.K.; Wagoner, H.P.; Blejer, H.P. 1976. Cancer mortality among cadmium production workers. Ann. N.Y. Acad. Sci. 271: 273-279 (cited in 4423 and 4424).

4450. Potts, C. 1965. Cadmium proteinuria. The health of battery workers exposed to cadmium oxide dust. Ann. Occup. Hyg. 8:55-61.

4451. Kipling, M.; Waterhouse, J. 1967. Cadmium and prostatic carcinoma. Lancet 1:730-731 (cited in 4424).

4452. Kolonel, L. 1976. Association of cadmium with renal cancer. Cancer 37: 1782-1787 (cited in 4424).

4453. Kolonel L.; Winkelstein, W. 1977. Cadmium and prostatic carcinoma. Lancet 2: 566-567 (cited in 4424).

4454. Morgan, J. 1970. Cadmium and zinc abnormalities in bronchogenic carcinoma. Cancer 25:1394-1398 (cited in 4424).

4455. Dudley, R.E.; Svoboda, D.J.; Klaassen, C.D. 1982. Acute exposure to cadmium causes severe liver injury in rats. Toxicol. Appl. Pharmacol. 65:302-313.

4456. Baranski, B. 1984. Behavioral alterations in offspring of female rats repeatedly exposed to cadmium oxide by inhalation. Toxicol. Lett. 22:53-61.

4457. Baranski, B. 1985. Effect of exposure of pregnant rats to cadmium on prenatal and postnatal development of the young. J. Hyg. Epidem. Microbiol. Immunol. 29:253-262 (cited in 4426).

4458.. Sutou, S.; Yamamoto, K.; Sendota, K.; Sugiyama, M. 1980. Toxicity, fertility, teratogenicity, and dominant lethal tests in rats administered cadmium subchronically. II. Fertility, teratogenicity, and dominant lethal tests. Ecotoxicl. Environ. Safety 4: 51-56.

4459. Princi, F.; Geever, E.F. 1950. Prolonged inhalation of cadmium. Arch. Ind. Hyg. 1:651-661.

4460. Kutzman, R.S.; Drew, R.T.; Shiotsuka, R.N.; Cockrell, B.Y. 1986. Pulmonary changes resulting from subchronic exposure to cadmium chloride aerosol. J. Toxicol. Environ. Health 17: 175-189.

4461. Stowe, H.D.; Wilson, M.; Goyer, R.A. 1972. Clinical and morphologic effects of oral cadmium toxicity in rabbits. Arch. Path. 94:389-405.

4462.. Wilson, R.H.; Cox, J.A. Jr. 1941. Effects of continued cadmium feeding. J. Pharm. Exp. Ther. 71: 222-235.

4463. Prigge, E. 1978. Inhalative cadmium effects in pregnant and fetal rats Toxicology 10:297-309 (cited in 4426).

4465. Goyer, R.A.; Miller, C.R.; Zhu, S-Y.; Victery, W. 1989. Non-metallothionein-bound cadmium in the pathogenesis of cadmium nephrotoxicity in the rat. Toxicol. Appl. Pharmacol. 101:232-244.

4466. Rehm, S.; Waalkes, M.P. 1988. Cadmium-induced ovarian toxicity in hamsters, mice, and rats. Fund. Appl. Toxicol. 10:635-647.

4467.. Balaraman, R.; Gulati, O.D.; Bhatt, J.D.; Rathod, S.P.; Hemavathi, K.G. 1989. Cadmium-induced hypertension in rats. Pharmacology 38: 226-234.

4468. Armstrong, B.G.; Kazantzis, G. 1983. The mortality of cadmium workers. Lancet, June 25, 198: 1425-1427 (cited in 4487).

4469. Varner, M.O. 1983. Updated epidemiologic study of cadmium smelter workers. Presented at the Fourth International Cadmium Conference. Unpublished. (cited in 4487).

4470.. Sorahan, T.; Waterhouse, J.A.H. 1983. Mortality study of nickel-cadmium battery workers by the method of regression models in life tables. Br. J. Ind. Med. 40:293-300 (cited in 4487).

4471. Kipling, M.D.; Waterhouse, J.A.H. 1967. Cadmium and prostatic carcinoma. Lancet 1: 730 (cited in 4487).

4472. Holden, H. 1980. Further mortality studies of workers exposed to cadmium fumes. Presented at Seminar on Occupational Exposure to Cadmium, March 20. 1980, London, England (cited in 4487).

4473.. Callahan, M.A.; Slimak, M.W.; Gable, N.W. et al. 1979. Water-Related Fate of Priority Pollutants. U.S. Environmental Protection Agency, Office of Planning and Standards. Washington, DC. EPA-440/4-79-029a. pp. 9-1 - 9-20.

4476. United States Environmental Protection Agency. (U.S. EPA). 1985. Cadmium Contamination of the Environment: An Assessment of Nationwide Risk. Washington, DC. EPA-440/4-85-023.

4477. United States Environmental Protection Agency. (U.S. EPA). 1981. Health Assessment Document for Cadmium. Environmental Criteria and Assessment Office, Research Triangle Park NC. EPA-600/8-81-023.

4478. Meranger, J.C.; Subramian, K.S.; Chalifoux, C. 1981. Survey for cadmium, cobalt, chromium, copper, nickel, lead, zinc, calcium, and magnesium in Canadian drinking water supplies. J. Assoc. Off. Anal. Chem. 64: 44 (cited in 4426).

4479. Konz, J.; Walker, P. 1979. An assessment of cadmium in drinking water from a multi-media perspective. McLean VA: The Mitre Corp. (Sponsor: Environmental Protection Agency) (cited in 4426).

4480. McGraw-Hill Encyclopedia of Science and Technology. 1977. Vol.2. Lapedes, D.N. ed.

4481.. Sax, N.I.; Lewis, R.L., Sr. 1989. Dangerous Properties of Industrial Materials. 7th ed. Vol. 2. New York, Van Nostrand Reinhold.

4482. Hazardous Substances Data Bank. 1989.

4483. World Health Organization. 1984. Guidelines for Drinking Water Quality. Vol.1. Recommendations. World Health Organization, Geneva.

4484. Registry of Toxic Effects of Chemical Substances. 1987. Volume 2. D.V. Sweet (ed.). U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control. National Institute for Occupational Safety and Health.

4485. Registry of Toxic Effects of Chemical Substances. 1987. Volume 3. D.V. Sweet (ed.). U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control. National Institute for Occupational Safety and Health.

4486. Hazardous Chemicals Data Book. 1980. G. Weiss ed. New Jersey: Noyes Data Corporation.

4487. United States Environmental Protection Agency. 1989. IRIS. Integrated Risk Information System. U.S. Environmental Criteria and Assessment Office, Cincinnati, OH.

4488. United States Environmental Protection Agency. 1989. Rules and Regulations. Fed Reg. 54 (12), Thursday, January 19

4489. United States Environmental Protection Agency. (U.S. EPA). 1989. National Primary and Secondary Drinking Water Regulations. Fed. Register 54 (97), Monday, May 22.

4490. United States Environmental Protection Agency. (U.S. EPA) 1987. Quality Criteria for Water. Office of Water Regulations and Standards. Washington, DC. EPA 440/5-86-001.

4491. U. S. Environmental Protection Agency. (U.S. EPA). 1988. Office of Drinking Water, Final Health Advisories.

4492. National Institute for Occupational Safety and Health (NIOSH) Recommendations for Occupational Safety and Health Standards. 1988. U.S. Department of Health and Human Services, National Institute for Occupational Safety and health, Centers for Disease Control, Atlanta, GA.

4493. ACGIH. 1986. Documentation of the Threshold Limit Values and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists Inc., Cincinnati, OH.

4500. National Institute for Occupational Safety and Heaith. (NIOSH) 1984. Current Intelligence Bulletin 42. Cadmium. Atlanta, Ga: National Institute for Occupational Safety and Health, Centers for Disease Control (cited in 4426).

4501. Lu, P.Y.; Metcalf, R.L.; Furman, R.; Vogel, R.; Hasset, J. 1975. Model ecosystem studies of lead and cadmium and of urban sewage sludge containing these elements. J. Environ Quality 4: 505-509.

4502. Bonnell, J.A. 1955. Emphysema and proteinuria in men casting copper-cadmium alloys. Br. J. Ind. Med. 12: 181-197.

4503.. Armstrong, B.G.; Kazantzis, G. 1985. Prostatic cancer and chronic respiratory and renal disease in British cadmium workers: A case-control study. Br. J. Ind. Med. 42:540-545.

4504. Oberly, T.J.; Piper, C.E.; McDonald, D.S. 1982. Mutagenicity of metal salts in the L5178 Y mouse lymphoma assay. J. Toxicol. Environ. Health 9:367-376 (cited in 4426).

4505. Martin, F.M.; Witschi, H.P. 1985. Cadmium-induced lung injury: cell kinetics and long-term effects. Toxicol. Appl. Pharmacol. 80:215-227.

4506. Hawley, G.G. 1981. The Condensed Chemical Dictionary. 10th ed. New York: Van Nostrand Reinhold Co.

4507. Oberdorster, G. 1990. Toxicokinetic and dosimetric considerations for inhaled and ingested cadmium compounds: implications for lung and kidney toxicity. Abstract presented at U.S. EPA Principles of Route-to-Route Extrapolation. p 29., Hilton Head, South Carolina, March 19-21.

4508.. Oberdorster, G. 1989. Pulmonary toxicity and carcinogenicity of cadmium. J. Am. Coll. Toxicol. 8: 1251-1263.

4509. Federal Register, Vol. 50, No. 219, November 13, 1985, pp. 46936-46982. "40 CFR Part 141, National Primary Drinking Water Regulations; Synthetic Organic Chemicals, Inorganic Chemicals and Microorganisms; Proposed Rule".

4510. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983.

4511. Test Methods for Evaluation of Solid Waste, U.S. EPA SW-846, November 1986, Third Ed.

4512. Federal Register, Vol. 53, No. 33, February 19, 1988,pp. 5142-5147. "40 CFR Parts 141 and 143, National Primary Drinking Water Regulations, Analytical Techniques".

4513. Sittig, M. 1981. Handbook of Toxic and Hazardous Chemicals. Noyes Publications: Park Ridge, New Jersey, pp. 119-122.

4514. Sunderman, F.W., Jr. 1990. Cadmium substitution for zinc in finger-loop domains of gene-regulating proteins as a possible mechanism for the genotoxicity and carcinogenicity of cadmium compounds. Toxicol. Environ. Chemistry 27:131-141.

4515. Schroeder, H.A. 1965. Cadmium as a factor in hypertension. J. Chronic Dis. 18:647-656.

4516. Schroeder, H.A.; Nason, A.P.; Mitchener, M. 1968. Action of chelate of zinc on trace metals in hypertensive rats. Am. J. Physiol. 214:796-800.

4517. Rehm, S.; Waalkes, M.P. 1990. Acute cadmium chloride-induced renal toxicity in the Syrian hamster. Toxicol. Appl. Pharmacol. 104:94-105.

4518. Yoshizuka, M.; McCarthy, K.J.; Kaye, G.I.; Fujimoto, S. 1990. Cadmium toxicity to the cornea of pregnant rats: electron microscopy and x-ray microanalysis. The Anatomical Record 227:138-143.

4519. Rummler, H.-G.; Classen, H.-G.; Schimatschek, H.F. et al. 1990. Age-dependent accumulation of cadmium in rats exposed to contaminated drinking water; interactions with zinc and copper and subcellular Cd distribution in kidney cells. J. Trace Elem. Electrolytes Health Dis. 3:217-223.

4520. Scott, M.C.; D.R. Chettle. 1986. In vivo elemental analysis in occupational medicine. Scan. J. Work Environ. Health 12:81-96. (as cited in 4426).

4521. Sabourin, T.D.; R.T. Faulk; L.B. Goss. 1985. The efficacy of three non-mammalian test systems in the identification of chemical teratogens. J. Appl. Toxicol. 5: 227-233.

4522. Mason, H.J. 1990. Occupational cadmium exposure and testicular endocrine function. Human Exp. Toxicol. 9:91-94.

4523. United States Environmental Protection Agency (U.S. EPA). 1990. Drinking water and health advisories. November, 1990.

7000. Occupational Safety and Health Administration (OSHA). 1989. Air contaminants: final rule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7003. Occupational Safety and Health Administration (OSHA). 1989. Hazardous waste operations and emergency response; final rule. 29CFR1910.120, Fed. Regist., 3/6/89, 54:9294-9336.

7009. United States Environmental Protection Agency (U.S. EPA). 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT). 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7011. United States Environmental Protection Agency (U.S. EPA). 1980. List of pollutants and applicability of part 61; inorganic arsenic. 40CFR61.01, Fed. Regist., 6/5/80, 45:37886.

7012. United States Environmental Protection Agency (U.S. EPA). 1986. National emission standards for inorganic arsenic emissions from glass manufacturing plants. 40CFR61.160-165, Fed. Regist., 8/4/86, 51:28025, as amended 51:35355.

7013. United States Environmental Protection Agency (U.S. EPA). 1986. National emission standards for inorganic arsenic emissions from primary copper smelters. 40CFR61.170-177, Fed. Regist., 8/4/86, 51:28029.

7014. United States Environmental Protection Agency (U.S. EPA). 1986. National emission standards for inorganic arsenic emissions from arsenic trioxide and metallic arsenic production facilities. 40CFR61.180-186, Fed. Regist., 8/4/86, 51:28033, as amended 51:35355.

7015. United States Environmental Protection Agency (U.S. EPA). 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. United States Environmental Protection Agency (U.S. EPA). 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. United States Environmental Protection Agency (U.S. EPA). 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. United States Environmental Protection Agency (U.S. EPA). 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. United States Environmental Protection Agency (U.S. EPA). 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020. United States Environmental Protection Agency (U.S. EPA). 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. United States Environmental Protection Agency (U.S. EPA). 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7023. United States Environmental Protection Agency (U.S. EPA). 1981. Timber products manufacturing point source category. 40CFR429, Fed. Regist., 1/26/81, 46:8285.

7025. United States Environmental Protection Agency (U.S. EPA). 1981. Electroplating point source category. 40CFR413, Fed. Regist., 1/28/81, 46:9467, as revised 1983, 48:43681 and 32483.

7026. United States Environmental Protection Agency (U.S. EPA). 1983. Metal finishing point source category. 40CFR433, Fed. Regist., 7/15/83, 48:32485 as revised 1983, 48:41410 and 43682.

7029. United States Environmental Protection Agency (U.S. EPA). 1982. Textile mills point source category. 40CFR410, Fed. Regist., 9/2/82, 47:38819.

7048. United States Environmental Protection Agency (U.S. EPA). 1985. Assessment of cadmium under section 112 of the Clean Air Act. 40CFR61.01, Fed. Regist., 10/16/85, 50:42000.

7049. United States Environmental Protection Agency (U.S. EPA). 1989. National primary and secondary drinking water regulations; proposed rule. 40CFR141-143, Fed. Regist., 5/22/89, 54:22062-22160.

7050. United States Environmental Protection Agency (U.S. EPA). 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7051. United States Environmental Protection Agency (U.S. EPA). 1975. Maximum contaminant levels for inorganic contaminants. 40CFR141.11, 12/24/75, 40:59570, as amended 1980, 45:57342 and 1982, 47:10998 and 1986, 51:11410.

7054. United States Environmental Protection Agency (U.S. EPA). 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. United States Environmental Protection Agency (U.S. EPA). 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7060. United States Environmental Protection Agency (U.S. EPA). 1987. Extremely hazardous substance list and threshold planning quantities. 40CFR355 (SARA Title III Section 302), Fed. Regist., 4/22/87, 52:13395, as revised 1987, 52:48073 and 1988, 53:5574.

7064. United States Environmental Protection Agency (U.S. EPA). 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7065. United States Environmental Protection Agency (U.S. EPA). 1989. Designation of extremely hazardous substances as CERCLA hazardous substances; proposed rule. 40CFR302, Fed. Regist., 1/23/89, 54:3388.

7066. United States Environmental Protection Agency (U.S. EPA). 1989. Reportable quantity adjustments; proposed rule. 40CFR302 and 355, Fed. Regist., 8/30/89, 54:3598

7067. United States Environmental Protection Agency (U.S. EPA). 1985. Burning of waste fuel and used oil fuel in boilers and industrial furnaces. 40CFR266.40, Fed. Regist., 11/29/85, 50:49205.

7070. Food and Drug Administration (FDA). 1977. Bottled drinking water standards. 21CFR103.35, Fed. Regist., 3/15/77, 42:14325, as last amended 1984, 49:10090.

7074. United States Environmental Protection Agency (U.S. EPA). 1980. Characteristic of EP toxicity. 40CFR261.24, Fed. Regist., 5/19/80, 45:33119, as amended 1981, 46:35247.

7075. United States Environmental Protection Agency (U.S. EPA). 1981. Hazardous wastes from non-specific sources. 40CFR261.31, Fed. Regist., 1/16/81, 46:4617, as last amended 1986, 51:6541.

7076. United States Environmental Protection Agency (U.S. EPA). 1981. Hazardous wastes from specific sources. 40CFR261.32, Fed. Regist., 1/16/81, 46:4618, as last amended 1988, 53:35420.

7077. United States Environmental Protection Agency (U.S. EPA). 1981. Basis for listing hazardous waste. 40CFR261 Appendix VII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:35421.

7079. United States Environmental Protection Agency (U.S. EPA). 1981. Hazardous constituents. 40CFR261 Appendix VIII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:43881.

7080. United States Environmental Protection Agency (U.S. EPA). 1982. Groundwater protection: concentration limits. 40CFR264.94, Fed. Regist., 7/26/82, 47:32350, as amended 1983, 48:14294.

7082. United States Environmental Protection Agency (U.S. EPA). 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7083. United States Environmental Protection Agency (U.S. EPA). 1988. Hazardous waste injection restrictions: waste specific prohibitions. 40CFR148.10-16, Fed. Regist., 8/16/88, 53:30908, as amended 1988, 53:41602 and 1989, 54:25422 and 26647.

7084. United States Environmental Protection Agency (U.S. EPA). 1988. Waste specific prohibitions - first third wastes. 40CFR268.33, Fed. Regist., 8/17/88, 53:31217.

7086. Council of European Communities Directive on Drinking Water,16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7087. Council of European Communities Directive on Bathing Water Quality, 8 December 1975 (76/160/EEC-OJ L31, 5 February 1976, amended by 1851).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7091. Council of European Communities Directive on Groundwater, 17 December 1979 (80/68/EEC-OJ L20, 26 January 1980).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7093. Council of European Communities Directive on Toxic and Dangerous Waste, 20 March 1978, amended by 1851.

7095. Council of European Communities Directive on Classification, Packaging and Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7099. Proposal or a Council Directive on the Dumping of Waste at Sea, Comm (85) 373 Final, 4 July 1985.

7102. Council of European Communities Directive on Disposal of Waste Oils, 16 June 1975 (75/439/EEC, OJ L 194, July 25, 1975, p. 23, amended by 387L0101 (OJ L 042, December 2, 1987, p. 43).

7103. Council Directive on Limits Values and Quality Objectives for Cadmium Discharges, 85/513/EEC, 26 September 1983.

7105. Council Decision Concluding the Convention for the Prevention of Marine Pollution From Land-Based Sources, 75/437/EEC, 3 March 1975.

7106. Council Decision - Marine Pollution by Mercury and Cadmium, 85/613/EEC, 1985.

7108. Council Resolution on a Community Program to Combat Environmental Pollution by Cadmium, 88/C 30/01, 25 January 1988.

7110. United States Environmental Protection Agency (U.S. EPA). 1989. Burning of hazardous waste in boilers and industrial furnaces; proposed rule. 40CFR260-1,264-6,270-1, Fed. Regist., 10/26/89, 54:43718.

7112. Occupational Safety and Health Administration (OSHA). 1990. Occupational exposure to cadmium; proposed rule. 29CFR1910, Fed. Regist., 2/6/90, 55:4052.

7112. Florida Department of Environmental Regulation. 1989. Florida Water Quality Standards, Chapter 17-3, effective 12/20/89.

7113. North Carolina Department of Natural Resources and Community Development. 1989. Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina, 15NCAC 2B.0200-0218, effective 10/1/89.

7114. Vermont Department of Water Resources. 1988. State of Vermont Ground Water Protection Rule and Strategy, Chapter 12:101-710, effective 9/29/88.

7115. Virginia Water Control Board. 1988. Commonwealth of Virginia Water Quality Standards, VR 680-21-00, effective 11/1/88.

7116. Wisconsin Department of Natural Resources. 1988. Wisconsin Chapter NR140, Groundwater Quality, effective 10/88.

7119. New York State Department of Environmental Conservation. 1987. Memorandum: New York Ambient Water Quality Standards and Guidance Values, 4/1/87.

COMMON SYNONYMS:	CAS. Reg. No. 7440-47-3 NIOSH No.: GB4200000 EPA Hazardous Waste No.: D007
Chromium metal Chrome	Chemical Symbol: Cr

REACTIVITY (5400, 5401, 5402)

Chromium metal is not oxidized by either moist or dry air. It reacts with hydrochloric, hydrofluoric, and sulfuric acid, but not with nitric acid. Chromium is attacked by caustic alkalies, and molten lithium at 180°C. Chromium reacts violently with ammonium nitrate, hydrogen peroxide, and bromine pentafluoride

PHYSICO-CHEMICAL DATA

• Atomic Weight: 51.996		(5403)
• Atomic Number: 24		
• Group and Valence: VIb, 0		
• Stable Isotopes (Natural Abundance, %):	50, 4.35%; 52, 83.79%; 53, 9.50%; 54, 2.36%	(5403)
• Molecular Weight: 51.996		(5401)
• Physical State: Solid, very hard cube		(5401)
• Color: Steel gray		(5401)
• Odor: ND		
• Odor Threshold: ND		
• Density: 7.20 g/mL at 28°C		(5401)
• Melting Point: 1857 ± 20°C		(5401)
• Boiling Point: 2672°C		(5401)
• Flash Point: ND		
• Flammable Limits: ND		
• Autoignition Temperature: ND		
• Vapor Pressure: 1 mm Hg at 1610°C		(5400)
• Saturated Concentration in Air: ND		

PHYSICO-CHEMICAL DATA (Cont.)

- Solubility in Water: Insoluble (5401)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 7788-98-9 NIOSH No.: ND EPA Hazardous Waste No.: ND
Ammonium chromate Neutral ammonium chromate	**Chemical Formula:** $(NH_4)_2CrO_4$

REACTIVITY (5404)

Ammonium chromate is a powerful oxidizer. It decomposes when heated, emitting NH_3 and NO_x.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 152.07	(5401)
• Physical State: Solid, monoclinic, acicular crystals	(5401, 5403)
• Color: Yellow	(5401)
• Odor: ND	
• Odor Threshold: ND	
• Density: 1.91 g/mL at 12°C	(5401)
• Melting Point: Decomposes at 180°C	(5401)
• Boiling Point: NA	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Very soluble, 40.5 g/100 mL at 30°C, decomposes in hot water	(5401)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No. 7789-09-5 NIOSH No.: HX7650000 EPA Hazardous Waste No.: ND
Ammonium dichromate Ammonium bichromate	Chemical Formula: $(NH_4)_2Cr_2O_7$

REACTIVITY (5402, 5404)

Ammonium dichromate is an unstable oxidizer and it reacts with reducing agents. Confined ammonium chromate undergoing thermal decomposition will explode.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 252.06	(5401)
• Physical State: Solid, monoclinic prismatic crystals	(5403)
• Color: Bright orange-red	(5403)
• Odor: Odorless	(5403)
• Odor Threshold: ND	
• Density: 2.15 g/mL at 25°C	(5401)
• Melting Point: Decomposes at 170°C	(5401)
• Boiling Point: NA	
• Flash Point: ND	
• Flammable Limits: Flammable	(5403)
• Autoignition Temperature: 190°C	(5402)
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Very soluble, 30.8 g/100 mL at 0°C, 89 g/100 mL at 30°C	(5401)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No. 13765-19-0 NIOSH No.: GB2750000 EPA Hazardous Waste No.: U032
Calcium chromate Calcium chromate(VI) Calcium chrome yellow Calcium chromium oxide C.I. 77223 C.I. Pigment yellow 33 Yellow ultramarine Gelbin	Chemical Formula: $CaCrO_4$ (occurs in hydrated forms)

REACTIVITY (5404)

Calcium chromate is a powerful oxidizer. It burns violently if mixed with boron and ignited.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 156.09	(5403)
• Physical State: Solid, monoclinic or rhombic crystals	(5403)
• Color: Yellow	(5403)
• Odor: ND	
• Odor Threshold: MD	
• Density: 2.89 g/mL	(5402)
• Melting Point: ND	
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Sparingly soluble	(5403)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No. 1333-82-0 NIOSH No.: GB6650000 EPA Hazardous Waste No.: D007
Chromium trioxide Chromic acid, solid Chromium oxide Chromic anhydride Chromic(VI) acid	Chemical Formula: CrO_3

REACTIVITY (5402, 5403, 5404, 5405)

Chromium trioxide is a powerful oxidizer of alcohols and numerous other organic substances. It can react violently, resulting in explosion or combustion on contact with a variety of organic and inorganic compounds with or without heat. Explosions occur on contact with compounds such as acetic acid, acetic anhydride, acetaldehyde, benzene, and dimethyl ether. Combustion occurs on contact with acetone, methanol, ethanol, ethylene glycol, to name a few. Violent reactions occur on contact with glycerol, selenium, acetylene, etc. Chromium trioxide is incompatible with combustible materials, such as, paper, wood, plastics, aluminum, etc.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 99.99	(5401)
• Physical State: Solid, rhombic crystals, flakes, or granular powder	(5401, 5403)
• Color: Red	(5401)
• Odor: Odorless	(5402)
• Odor Threshold: NA	
• Density: 2.70 g/mL	(5401)
• Melting Point: 196°C	(5401)
• Boiling Point: Decomposes	(5401)
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Very soluble, 61.7 g/100 mL at 0°C, 67.45 at 100°C	(5401)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No. 7758-97-6 NIOSH No.: GB2975000 EPA Hazardous Waste No.: D007
Lead chromate Chrome yellow Paris yellow C.I. Pigment Yellow 34 C.I. 77600	Chemical Formula: CrO_4Pb

REACTIVITY (5402, 5404)

Lead chromate and sulfur mixtures are pyrophoric, and lead chromate and tantalum is a pyrotechnic composition. Mixing lead chromate and aluminum dinitronaphthalene is an exothermic reaction releasing considerable energy. A potentially explosive reaction occurs when lead chromate is mixed or blended with azo dyes such as dinitroaniline orange, and chlorinated para red. When lead chromate is heated to decomposition, toxic fumes of lead are released.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 323.19 (5401)
- Physical State: Solid, monoclinic crystals, or powder (5401, 5403)
- Color: Yellow or orange-yellow (5401, 5403)
- Odor: ND
- Odor Threshold: ND
- Density: 6.13 mg/mL at 15°C (5401)
- Melting Point: 844°C (5401)
- Boiling Point: Decomposes (5401)
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temp: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Practically insoluble, 5.8E-06 g/100mL at 25°C (5401)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 14307-35-8 NIOSH No.: ND EPA Hazardous Waste No.: D007
Lithiun chromate Lithium chromate(VI) Ammonium bichromate Chromium lithium oxide	Chemical Formula: (Li_2CrO_4)

REACTIVITY (5404)

Lithium chromate can cause a potentially explosive reaction with zirconium at temperatures above 400° C.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 129.87 (5403)
- Physical State: Solid, crystal powder (5403)
- Color: Yellow (5403)
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temp: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Very soluble (5403)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 7789-00-6 NIOSH No.: GB2940000 EPA Hazardous Waste No.: ND
Potassium chromate Potassium chromate (VI) Neutral potassium chromate Chromate of potassium Tarapacaite	Chemical Formula: K_2CrO_4

REACTIVITY (5402, 5404)

Potassium chromate is a powerful oxidizer. It is incompatible with oxidizable organics and combustible materials, such as paper, wood, plastics, aluminum, etc. Potassium chromate emits toxic fumes of K_2O when heated.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 194.19 (5401)
- Physical State: Solid, rhombic crystals (5401)
- Color: Lemon-yellow (5401)
- Odor: Odorless (5401)
- Odor Threshold: ND
- Density: 2.732 g/mL at 18°C (5401)
- Melting Point: 968.3°C (5401)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: Zero (5402)
- Saturated Concentration in Air: ND
- Solubility in Water: Very soluble, 62.9 g/100 mL at 20°C, 79.2 g/100 mL at 100°C (5401)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 7778-50-9 NIOSH No.: HX7680000 EPA Hazardous Waste No.: ND
Potassium dichromate Potassium bichromate Potassium dichromate(VI) Bichromate of potash Iopezite	Chemical Formula: $K_2Cr_2O_7$

REACTIVITY (5402, 5404)

Potassium dichromate is a powerful oxidizer. It causes violent reactions (explosion or combustion) on contact with a variety of inorganic and organic substances, such as hydrazine, hydroxylamine, acetone plus sulfuric acid, ethylene glycol, boron plus silicon, and iron. Potassium dichromate readily ignites combustible materials, such as paper, wood, plastics, aluminum, etc.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 294.18 (5401)
- Physical State: Solid, monoclinic or triclinic crystals (5401)
- Color: Red (5401)
- Odor: Odorless (5402)
- Odor Threshold: NA
- Density: 2.676 g/mL at 25°C compared with water at 4°C (5401)
- Melting Point: 398°C (5401)
- Boiling Point: Decomposes as 500°C (5401)
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Soluble, 4.9 g/100 mL at 0°C, 102 g/100 mL at 100°C (5401)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 7789-06-2 NIOSH No.: GB3240000 EPA Hazardous Waste No.: NA
Strontium chromate Strontium chromate(VI) Chromic acid, strontium salt C.I. Pigment yellow 33 Strontium yellow Deep lemon yellow	Chemical Formula: $SrCrO_4$

REACTIVITY (5402)

No specific data for strontium chromate. Chromates react explosively with hydrazine and are incompatible with many organics, oxidizable, and combustible materials.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 203.61 (5401)
- Physical State: Solid, monoclinic crystals (5401)
- Color: Yellow (5401)
- Odor: ND
- Odor Threshold: ND
- Density: 3.895 g/mL at 15°C (5401)
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Low solubility, 0.12 g/100 mL at 15°C, (5401)
  3 g/100 mL at 100 °C
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 13530-65-9 NIOSH No.: GB3290000 EPA Hazardous Waste No.: D007
Zinc chromate Chromic acid, zinc salt Basic zinc chromate Zinc chromate(VI) hydroxide Zinc yellow Zinc chrome (anticorrosion) Buttercup yellow C.I. Pigment Yellow 36 C.I. 77955	**Chemical Formula:** Approx. $ZnCrH_2O_4$

REACTIVITY (5402)

Zinc chromate may be incompatible with combustible, organic, or other oxidizable materials

PHYSICO-CHEMICAL DATA

• Molecular Weight: 183.39	(5404)
• Physical State: Solid	(5402)
• Color: Yellow	(5402)
• Odor: Odorless	(5402)
• Odor Threshold: ND	
• Density: 3.40	(5402)
• Melting Point: ND	
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Insoluble in cold water	(5402)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No. 1066-30-4 NIOSH No.: AG2975000 EPA Hazardous Waste No.: ND
Chromic acetate Chromic acetate(III) Chromium acetate Chromium triacetate	Chemical Formula: $Cr(CH_3COO)_3$ (occurs in hydrated forms)

REACTIVITY (5402)

Chromic acetate emits acrid smoke and irritating fumes when heated.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 229.14 (5402)
- Physical State: Solid, powder, plates, or needles depending on hydration (5403)
- Color: Gray-green, violet, blue-violet depending on hydration (5403)
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Monohydrate is slightly soluble and hexahydrate is readily soluble (5403)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 10025-73-7 NIOSH No.: GB5425000 EPA Hazardous Waste No.: ND
Chromic chloride Chromium chloride Chromium(III)chloride Chromium trichloride Puratronic chromium chloride C.I. 77295	Chemical Formula: $CrCl_3$ (occurs in hydrated form)

REACTIVITY (5402, 5404)

Chromic chloride is extremely unstable. It reacts violently with lithium in a nitrogen atmosphere. Chromic chloride emits toxic fumes of Cl^- when heated

PHYSICO-CHEMICAL DATA

• Molecular Weight: 158.36	(5401)
• Physical State: Solid, hexagonal crystalline scales	(5403)
• Color: Violet	(5403)
• Odor: ND	
• Odor Threshold: ND	
• Density: 2.76 at 15°C	(5401)
• Melting Point: ~1150°C	(5401)
• Boiling Point: Sublimates at 1300°C	(5401)
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Insoluble in cold water, slightly soluble in hot water	(5401)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No. 10101-53-8 NIOSH No.: GB7200000 EPA Hazardous Waste No.: D007
Chromic sulfate Chromium sulfate Chromium(III) sulfate C.I. 77305	Chemical Formula: $Cr_2(SO_4)_3$ (occurs in hydrated forms)

REACTIVITY (5402)

Insoluble chromium salts are potentially incompatible with strong oxidizers

PHYSICO-CHEMICAL DATA

- Molecular Weight: 392.20, (5403)
- Physical State: Solid (5403)
- Color: Peach (5403)
- Odor: ND
- Odor Threshold: ND
- Density: 3.012 g/mL (5403)
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Practically insoluble (5403)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No. 10049-05-5 NIOSH No.: EPA Hazardous Waste No.:
Chromous chloride Chromium dichloride Chromium(II)chloride	Chemical Formula: $CrCl_2$ (occurs in hydrated forms)

REACTIVITY (5402, 5403)

Chromous chloride [Cr(II)] is a powerful reducing agent; it is rapidly oxidized to Cr(III) in moist air. A potentially hazardous incompatibility exists with water.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 122.90	(5401)
• Physical State: Solid, needles	(5401)
• Color: White	(5401)
• Odor: Odorless	(5403)
• Odor Threshold: ND	
• Density: 2.878 g/mL at 25°C	(5401)
• Melting Point: 824°C	(5401)
• Boiling Point: 1300	(5402)
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: Essentially zero, except water of crystallization	(5402)
• Saturated Concentration in Air: ND	
• Solubility in Water: Very soluble in cold and hot water	(5401)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (5406)

CHROMIC ACID AND CHROMATES (Chromium VI compounds: ammonium chromate, ammonium dichromate, calcium chromate, chromium trioxide, lithium chromate, potassium chromate, potassium dichromate, strontium chromate, zinc chromate, lead chromate)

Carcinogenic chromium VI compounds: According to NIOSH (5406) these compounds include any and all chromium VI compounds not listed below as noncarcinogenic. EPA (5407, 5408) did not label chromium VI compounds as carcinogenic or noncarcinogenic:

* At any detectable concentration: any self-contained breathing apparatus with a full facepiece and operated in a pressure-demand or other positive pressure mode, or any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode * Protective clothing, gloves, face shields to prevent contact with skin * Dust- and splash-proof safety goggles to prevent contact with eyes.

Noncarcinogenic chromium VI compounds (According to NIOSH (5406), noncarcinogenic chromium VI compounds are monochromates and dichromates of hydrogen, lithium, sodium, potassium, rubidium, cesium and ammonia and chromium (VI)oxide (chromium trioxide).

* 0.25 mg/m^3: any supplied-air respirator, any self-contained breathing apparatus, or any dust and mist respirator except single-use and quarter-mask respirators * 0.625 mg/m^3: any powered air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter or any supplied-air respirator operated in a continuous flow mode * 1.25 mg/m^3: Any air-purifying full facepiece respirator with a high-efficiency particulate filter and acid gas cartridge(s), any powered air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter, any self-contained breathing apparatus with a full facepiece, or any supplied-air respirator with a full facepiece * 25 mg/m^3: any supplied-air respirator with a half-mask and operated in a pressure-demand or other positive pressure mode * 50 mg/m^3: any supplied-air respirator with a full facepiece and operated in a pressure-demand or other positive pressure mode * unknown or IDLH conc.: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode or any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode * Escape: any air-purifying full facepiece respirator with a high-efficiency particulate filter and acid gas cartridge(s) or any appropriate escape-type self-contained breathing apparatus * Protective clothing, gloves, face shields to prevent contact with skin * Dust- and splash-proof safety goggles to prevent contact with eyes.

HANDLING PRECAUTIONS (Cont.)

CHROMIUM METAL AND INSOLUBLE SALTS (chromium; lead chromate is totally insoluble but is also listed as a chromium VI compound):

* 2.5 mg/m^3: any dust and mist respirator except single-use respirators * 5 mg/m^3: any dust and mist respirator except single-use and quarter-mask respirators, any supplied-air respirator, or any self-contained breathing apparatus * 12.5 mg/m^3: any powered air-purifying respirator with a dust and mist filter or any supplied-air respirator operated in a continuous flow mode * 25 mg/m^3: any air-purifying full facepiece respirator with a high-efficiency particulate filter and acid gas cartridge(s), any powered air-purifying respirator with a high-efficiency particulate filter, any self-contained breathing apparatus with a full facepiece, or any supplied-air respirator with a full facepiece * 500 mg/m^3: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode * Unknown or IDLH conc.: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode or any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode * Escape: any air-purifying full facepiece respirator with a high-efficiency particulate filter and acid gas cartridge(s) or any appropriate escape-type self-contained breathing apparatus * Protective clothing, gloves, face shields to prevent contact with skin * Dust- and splash-proof safety goggles to prevent contact with eyes.

HANDLING PRECAUTIONS (Cont)

SOLUBLE CHROMIC AND CHROMOUS SALTS (chromic acetate, chromic chloride, chromic sulfate, chromous chloride):

* 2.5 mg/m^3: any dust and mist respirator except single-use respirators * 5 mg/m^3: any dust and mist respirator except single-use and quarter-mask respirators, any supplied-air respirator, or any self-contained breathing apparatus * 12.5 mg/m^3: any powered air-purifying respirator with a dust and mist filter or any supplied-air respirator operated in a continuous flow mode * 25 mg/m^3: any air-purifying full facepiece respirator with a high-efficiency particulate filter and acid gas cartridge(s), any powered air-purifying respirator with a high-efficiency particulate filter, any self-contained breathing apparatus with a full facepiece, or any supplied-air respirator with a full facepiece * 250 mg/m^3: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode * Unknown or IDLH conc.: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode or any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode * Escape: any air-purifying full facepiece respirator with a high-efficiency particulate filter and acid gas cartridge(s) or any appropriate escape-type self-contained breathing apparatus * Protective clothing, gloves, face shields to prevent contact with skin * Dust- and splash-proof safety goggles to prevent contact with eyes.

PERSISTENCE IN THE SOIL-WATER SYSTEM

The environmental fate of chromium is influenced primarily by sorption in soils and sediments and by precipitation and speciation in natural waters. Hexavalent chromium is generally soluble and mobile in soil and natural waters, while trivalent chromium readily precipitates with carbonates, hydroxides, and sulfides to form insoluble, generally immobile compounds. In the soil and aquatic environments, chromium is expected to persist for several years.

PATHWAYS OF EXPOSURE

The major routes of exposure to chromium are food intake for the general population (dietary intake of up to 60 μg/day has been reported) and inhalation for workers in the chromium industry [airborne Cr(VI)] concentrations of up to 1000 $\mu g/m^3$ have been reported.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure:

Inhalation: Cr(VI) compounds: Various types of upper respiratory effects (including runny or stuffy nose, nosebleed, phlegm, cough, laryngitis, and effects on the nasal septum ranging from mild irritation to ulcerations to frank perforations.
Oral: Chromium trioxide and other Cr(VI) compounds: Ulceration of the gastrointestinal tract, renal failure, anemia, respiratory difficulty, tachycardia, hepatic failure, CNS effects.
Dermal: Cr(VI) compounds: Skin dermatitis and ulcerations (chrome holes).

Acute Toxicity Studies:

Inhalation:

LC_{50}:	5 mg/m^3	(zinc chromate)	Human	(5404)
LC_{50}:	94 mg/m^3	(potassium dichromate)	Rat	(5404)
LC_{50}:	158 mg/m^3; 4 hr	(ammonium dichromate)	Rat	(5409)
LC_{50}:	31.5 mg/m^3; 2 hr	(chromic chloride)	Mouse	(5404)
TC_{Lo}:	0.11 mg/m^3	(chromium trioxide)	Hamster	(5404)

Oral:

LD_{Lo}:	71 mg/kg	(chromium)	Human	(5404)
LD_{50}:	54 mg/kg	(ammonium dichromate)	Rat	(5409)
LD_{50}:	80 mg/kg	(chromium trioxide)	Rat	(5404)
LD_{50}:	11.26 g/kg	(chromic acetate)	Rat	(5411)
LD_{50}:	1.87 g/kg	(chromous chloride)	Rat	(5411)
LD_{50}:	57 mg/kg	(potassium dichromate)	Rat	(5409)
LD_{50}:	3118 mg/kg	(strontium chromate)	Rat	(5404)
LD_{50}:	127 mg/kg	(chromium trioxide)	Mouse	(5404)
LD_{50}:	12 g/kg	(lead chromate)	Mouse	(5404)
LD_{50}:	180 mg/kg	(potassium chromate)	Mouse	(5410)
LD_{50}:	300 mg/kg	(potassium chromate)	Mouse	(5410)
TD_{Lo}:	1600 mg/kg	(potassium chromate)	Mouse	(5404)
LD_{50}:	190 mg/kg	(potassium dichromate)	Mouse	(5404)
LD_{Lo}:	163 mg/kg	(potassium dichromate)	Guinea Pig	(5404)
LD_{Lo}:	2829 mg/kg	(potassium dichromate)	Dog	(5404)

HEALTH HAZARD DATA (Cont.)

Dermal:

LD_{Lo}: 2 g/kg	(chromic chloride)	Rat	(5404)
LD_{50}: 1.64 g/kg	(ammonium dichromate)	Rabbit	(5409)
LD_{50}: 1.17 g/kg	(potassium dichromate)	Rabbit	(5409)
LD_{Lo}: 1 g/kg	(chromic chloride)	Rabbit	(5404)
LD_{Lo}: 202 mg/kg	(chromic chloride)	Guinea pig	(5404)

Long-Term Effects:

Inhalation:

Calcium chromate: Causes respiratory irritation and inflammation
Potassium dichromate: Causes respiratory irritation and inflammation
Chromium, ammonium chromate, ammonium dichromate, chromic acetate, chromic chloride, chromic sulfate, chromium trioxide, chromous chloride, lead chromate, lithium chromate, potassium chromate, strontium chromate, zinc chromate: ND

Oral:

Long-term effects due to oral exposure to any chromium compound have not been reported.

Pregnancy/Neonate Data:

Chromium trioxide: Teratogenic and fetotoxic in hamsters by parenteral routes
Chromic chloride: Teratogenic and fetotoxic in hamsters by parenteral routes
Chromium, ammonium chromate, ammonium dichromate, calcium chromate, chromic acetate, chromic sulfate, chromous chloride, lead chromate, lithium chromate, potassium chromate, potassium dichromate, strontium chromate, zinc chromate: ND

HEALTH HAZARD DATA (Cont.)

Genotoxicity Data:

Chromium:	No data for mutagenicity; limited evidence for in vivo clastogenicity
Ammonium chromate:	Sufficient evidence for mutagenicity and clastogenicity
Ammonium dichromate:	Sufficient evidence for mutagenicity and clastogenicity
Calcium chromate:	Sufficient evidence for mutagenicity and clastogenicity
Chromic acetate:	Negative evidence for mutagenicity; limited or conflicting evidence for clastogenicity
Chromic chloride:	Negative evidence for mutagenicity; limited or conflicting evidence for clastogenicity
Chromic sulfate:	Negative evidence for mutagenicity; limited or conflicting evidence for clastogenicity
Chromium trioxide:	Sufficient evidence for mutagenicity and clastogenicity
Lead chromate:	No data for genotoxicity; inadequate data for clastogenicity
Potassium chromate:	Sufficient evidence for mutagenicity and clastogenicity
Potassium dichromate:	Sufficient evidence for mutagenicity and clastogenicity
Strontium chromate:	Sufficient evidence for mutagenicity and clastogenicity
Zinc chromate:	No data for mutagenicity; inadequate data for clastogenicity
Lithium chromate, chromous chloride:	ND

HEALTH HAZARD DATA (Cont.)

Carcinogenicity Classification:

IARC — Group 1 (carcinogenic for humans) for chromium VI compounds; Group 3 (not classifiable as to its carcinogenicity to humans) for chromium III compounds and chromium metal (5412).

NTP — No data

EPA — Group A (carcinogenic to humans) by the inhalation route for chromium VI compounds; Chromium III and II compounds have not been evaluated; data are not available for evaluating the carcinogenicity of chromium by the oral route (5408)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards

- OSHA TWA (8-hr TWA): Chromium metal: 1 mg/m^3 (as Cr)
  Chromium II compounds: 0.5 mg/m^3 (as Cr)
  Chromium III compounds: 0.5 mg/m^3 (as Cr)
- OSHA (ceiling): Chromic acid and chromates: 0.1 ppm (as CrO_3)
- STEL (15-min): ND
- AFOSH PEL: (8-hr TWA) Chromium metal: 1 mg/m^3 (as Cr)
  Chromium II compounds: 0.5 mg/m^3;
  Chromium III compounds: 0.5 mg/m^3;
- AFOSH PEL: (15-min ceiling): Chromic acid and chromates: 0.1 ppm (as CrO_3)

Criteria

- NIOSH IDLH (30-min): Chromium metal and insoluble salts: 500 mg/m^3 (as Cr)
  Chromic acid and chromates: 30 mg/m^3 (as CrO_3)
  Soluble chromic and chromous salts: 250 mg/m^3 (as Cr)
- NIOSH REL (10-hr TWA):
  Carcinogenic chromium VI [any and all chromium (VI) materials not included in the noncarcinogenic group below]: 1 $\mu g/m^3$

  Noncarcinogenic Chromium VI [monochromates and dichromates of hydrogen, lithium, sodium, potassium, rubidium, cesium, and ammonium and chromium (VI) oxide]: 25 $\mu g/m^3$

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- NIOSH STEL (15-min ceiling): Noncarcinogenic chromium (VI): 50 $\mu g/m^3$
- ACGIH TLV (8-hr TWA): Chromium metal: 0.5 mg/m^3

  Chromium II compounds: 0.5 mg/m^3 (as Cr)
  Chromium III compounds: 0.5 mg/m^3 (as Cr)
  Chromium VI compounds:
  Water soluble: 0.05 mg/m^3
  Certain water insoluble (confirmed human carcinogen): 0.05 mg/m^3 (as Cr)
- ACGIH STEL (15-min): None recommended

WATER EXPOSURE LIMITS:

Drinking Water Standards (5414)

- Total Chromium:
  NIPDWR (current MCL): 0.05 mg/L
  MCLG (proposed): 0.1 mg/L
  MCL (proposed): 0.1 mg/L

EPA Health Advisories and Cancer Risk Levels (5415)

- The EPA has developed nonregulatory concentrations of drinking water contaminants that would not result in adverse health effects over specified durations of exposure. The Health Advisories for chromium (as total Cr) are as follows:

  — 1-day (child): 1 mg/L
  — 10-day (child): 1 mg/L
  — longer-term (child): 0.2 mg/L
  — longer-term (adult): 0.8 mg/L
  — lifetime (adult): 0.1 mg/L
  — Cancer Group: D (oral route)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WHO Drinking Water Guideline (5416)

- A health-based guideline value of 0.05 mg/L (as total Cr) is proposed for drinking water. A daily per capita consumption of two liters of water was assumed.

EPA Ambient Water Quality Criteria (5417)

- **Human Health**

  — Chromium III compounds: Based on ingestion of water and contaminated aquatic organisms, the ambient water quality criterion is 170 mg/L. Based on ingestion of contaminated aquatic organisms alone, the ambient water quality criterion is 3433 mg/L.

  — Chromium VI compounds: Based on ingestion of water and contaminated aquatic organisms, the ambient water quality criterion is recommended to be the same as the NIPDWR of 0.05 mg/L [total Cr(VI)]. A value based on the ingestion of contaminated aquatic organisms alone was not derived.

- **Aquatic Life**

  — Freshwater species

  Acute toxicity: Chromium III compounds: no unacceptable effects if the 1-hr average concentration (in µg/L) does not exceed the numerical value given by $e^{(8190[\ln(\text{hardness})]+3.688)}$ more than once every 3 years on the average. Chromium VI compounds: no unacceptable effects if the 1-hr average concentration does not exceed 16 µg/L [as Cr(VI)] more than once every 3 years on the average.

  Chronic toxicity: Chromium III compounds: no unacceptable effects if the 4-day average concentration of Cr(III) (in µg/L) does not exceed the numerical value given by $e^{(0.8190[\ln(\text{hardness})]+1.561)}$ more than once every 3 years on the average. Chromium VI compounds: no unacceptable effects if the 4-day average concentration does not exceed 11 µg/L [as Cr(VI)] more than once every 3 years on the average.

  — Saltwater species

  Acute toxicity: Chromium III compounds: no criterion established. Chromium VI compounds: no unacceptable effects if the 1-hr average concentration does not exceed 1100 µg/L [as Cr(VI)] more than once every 3 years on the average.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

Chronic toxicity: Chromium III compounds: no criterion established. Chromium VI compounds: no unacceptable effects if the 4-day average concentration does not exceed 50 µg/L [as Cr(VI)] more than once every 3 years on the average.

REFERENCE DOSES: (5408)

- **Inhalation:** No data
- **Oral:**

  Chromium III compounds: 1 mg/kg/day (as an insoluble salt)

  Chromium VI compounds: 5 µg/kg/day [as Cr(VI)]; this RfD is limited to metallic chromium VI of soluble salts

- **Recommended Safe and Adequate Dietary Intake (5545)**

  — Adults, 50-200 µg/day
  — Children, 11+ yr old, 50-200 µg/day
  — Children, 7-10 yr old, 50-200 µg/day
  — Children, 4-6 yr old, 30-120 µg/day
  — Children, 1-3 yr old, 20-80 µg/day
  — Infants, 0.5-1 yr old, 20-60 µg/day
  — Infants, 0-0.5 yr old, 10-40 µg/day

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- **Federal Programs**

Clean Water Act (CWA)

The following chromium compounds have been designated as hazardous substances and have a reportable quantity (RQ) limit of 4.54 kg (10 lbs): ammonium bichromate, ammonium chromate, calcium chromate, chromic acid, lithium chromate, potassium chromate, potassium bichromate, sodium bichromate, sodium chromate, and strontium chromate. Chromic acetate, chromic sulfate, and chromous chloride are also designated hazardous substances and have an RQ of 454 kg (1000 lbs) (7015, 7016). Chromium and chromium compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and to effluent standards and guidelines (7017, 7018). Effluent limitations for effluents containing total chromium have been set in the following point source categories: textile mills (7029), electroplating (7025), organic chemicals, plastics and synthetic fibers (7030), inorganic chemicals manufacturing (7019), petroleum refining (7031), iron and steel manufacturing (7032), nonferrous metals manufacturing (7020), steam electric power generating (7021), ferroalloy manufacturing (7033), leather tanning and finishing (7034), rubber manufacturing (7035), timber products manufacturing (7022), metal finishing (7026), battery manufacturing (7027), coil coating (7036), porcelain enameling (7037), aluminum forming (7038), copper forming (7039), electrical and electronic components (7024), and nonferrous metals forming and metal powers (7028). Effluent limitations specific to effluents containing hexavalent chromium have been set in the following point source categories: inorganic chemicals manufacturing (7019), petroleum refining (7031), iron and steel manufacturing (7032), and ferroalloy manufacturing (7033). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Safe Drinking Water Act (SDWA)
Chromium is on the list of 83 contaminants required to be regulated under the SDWA Amendments of 1986 (7050). Under the National Interim Primary Drinking Water Regulations, the maximum contaminant level (MCL) is set at 0.05 mg/L for chromium in drinking water. This applies to community water systems (7051). In states with an approved Underground Injection Control program, a permit is required for the injection of chromium-containing wastes designated as hazardous under RCRA (7054).

Resource Conservation and Recovery Act (RCRA)
The following chromium compounds are listed as hazardous waste constituents under RCRA: chromium and its compounds, and calcium chromate (#U032) (7079). Calcium chromate is also listed as a toxic hazardous waste (7078). Nonspecific sources of chromium-containing wastes are: wastewater treatment sludges from electroplating operations (#F006) and from the chemical conversion of aluminum (#F019) (7075, 7077). Waste streams from the following industries contain chromium and are listed as specific sources of hazardous wastes: inorganic pigments production (#K002-K008), petroleum refining (#K048-K051), iron and steel industry (#K061,#K062), secondary lead smelting (#K069, #K100), ink formulation (#K086), and emission control dust/sludge from ferroalloy production (#K090, #K091) (7076, 7077). Solid wastes containing chromium are listed as hazardous, in that they exhibit the characteristic defined as EP toxicity, when the TCLP extract concentration of chromium is equal to or greater than 5.0 mg/L (7074). Chromium is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels. The following effective dates for prohibition of land disposal have been set for the designated chromium-containing waste streams: August 8, 1988 - waste numbers F006, K061 (waters containing less than 15% zinc), K062, K069, K100; June 8, 1989 - waste numbers K005, K007; August 8, 1990 - waste numbers K048-K051, K061 (waters containing 15% zinc or greater). These wastes are prohibited from land disposal or underground injection unless respective treatment standards or the statutory no migration standards are met. Site-specific variances can be obtained for soil and debris contaminated with hazardous waste (7068, 7084). Chromium-containing hazardous wastes K090 and K091 from the ferroalloy production (smelting) industry were newly-listed on

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

September 13, 1988, and so subject to immediate land disposal restriction (7069). Effective August 8, 1990, liquid wastes containing hexavalent chromium at concentrations greater than or equal to 500 mg/L are prohibited from underground injection (7083). For groundwater protection, the maximum concentration of chromium-containing hazardous waste allowed in groundwater is 0.05 mg/L (7080). Chromium 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 (7082). Used oil that is burned for energy recovery may not contain greater than 10 ppm chromium (7067).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

Chromium compounds designated as hazardous substances under CERCLA and their corresponding reportable quantity (RQ) limits include: chromic acid, strontium chromate, calcium chromate, sodium chromate, sodium bichromate, potassium chromate, potassium bichromate, lithium chromate, ammonium chromate, *ammonium bichromate*, 4.54 kg (10 lbs); chromic acetate, chromic sulfate, and chromous chloride 454 kg (1000 lbs); and chromium, 2270 kg (5000 lbs) Reportable quantities have also been issued for RCRA hazardous waste streams containing chromium, but these depend on the concentration of the chemical in the waste stream (7064). Chromic chloride is designated an extremely hazardous substances under SARA Title III Section 302. Under Sections 311 and 312, any facility at which chromic chloride is present in excess of its threshold planning quantity of one pound must notify state and local emergency planning officials. If chromic chloride is released from a facility in excess of its reportable quantity (RQ), local emergency planning officials must be notified (7060). Under SARA Title III Section 313, manufacturers, processors, importers, and users of chromium compounds must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
Pesticide registration standards for chromated arsenicals have been issued by EPA (7004).

Occupational Safety and Health Act (OSHA)
Employee exposure to chromium (II) or (III) compounds shall not exceed an 8-hour time-weighted average (TWA) of 0.5 mg/m^3 (as Cr). Employee exposure to chromium metal shall not exceed an 8-hour time-weighted average (TWA) of 1.0 mg/m^3 (as Cr) (7000). Employee exposure to chromic acid and chromates shall not exceed a ceiling level of 0.1 mg/m^3 (as CrO_3) at any time during an 8-hour work-shift (7000). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate, certain hazardous waste treatment, storage, and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

Clean Air Act (CAA)
EPA gives notice of its intent to list either chromium or hexavalent chromium as a hazardous air pollutant for which it will establish emission standards under Section 112 of the Clean Air Act. A decision on this rulemaking will be made by March of 1991 (7047).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated the following chromium compounds as hazardous materials, subject to requirements for packaging, labeling and transportation: ammonium bichromate, ammonium chromate, calcium chromate, chromic acetate, chromic acid, chromic sulfate, chromium, chromous chloride, lithium chromate, potassium chromate, potassium bichromate, sodium chromate, sodium bichromate, and strontium chromate. Reportable quantity (RQ) limits have been set at 454 kg (1000 lbs) for chromic acetate, chromic sulfate, and chromous chloride, 2270 kg (5000 lbs) for chromium, and 4.54 kg (10 lbs) for the remaining compounds (7010).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of oils or 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 (7009).

Food, Drug, and Cosmetic Act (FDCA)
The level for chromium in bottled drinking water is 0.05 mg/L. This level is identical to the maximum contaminant level (MCL) given under the Safe Drinking Water Act (7070). Several chromium compounds, listed under 21 CFR175, are approved for use as indirect food additives as components of adhesives and coatings (7072).

- **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:

NORTH CAROLINA
North Carolina has set a water quality criterion of 20 μg/L, applicable to all tidal saltwaters, to protect aquatic life (7113).

VERMONT
Vermont has set a preventive action limit of 25 μg/L for chromium in groundwater. The enforcement standard, however, is 50 μg/L, the same as the federal MCL (7114).

WEST VIRGINIA
West Virginia has set the following water quality criteria for surface waters: 10 μg/L for warmwaters B1 and B3; 7.2 μg/L for troutwaters B2 (7123).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

WISCONSIN

Wisconsin has set the following criteria for hexavalent chromium in surface waters for the protection of aquatic life: 14.2 μg/L acute toxicity criterion; 9.74 μg/L chronic toxicity criterion (7124). Wisconsin also has a preventive action limit of 5 μg/L for chromium in groundwater (7116).

Proposed Regulations

- Federal Programs

Safe Drinking Water Act (SDWA)

The Environmental Protection Agency (EPA) has proposed a maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) of 0.1 mg/L for chromium in drinking water. This applies to community water systems and non-transient non-community (NTNC) water systems. Final action on this proposal is expected by December, 1990 (7049).

Resource Conservation and Recovery Act (RCRA)

EPA has proposed that chromium-containing hazardous waste streams from the chemical conversion of aluminum industry (#F019) and inorganic pigments production (#K002-K004,#K006,#K008) be prohibited from land disposal or underground injection, effective May 8, 1990, unless designated treatment standards or the statutory no migration standards are met. Final action on this rule is expected by May, 1990 (7085). EPA has proposed emission rate screening limits for hexavalent chromium in the burning of hazardous waste in boilers and industrial furnaces. Limits vary as a function of device type and thermal capacity. Final action on this rule is expected by December, 1990 (7110).

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

EPA has proposed that chromic chloride, listed as an extremely hazardous substance under SARA, be listed as a CERCLA hazardous substance, with a reportable quantity (RQ) of 0.454 kg (1 lb). Final action on this rule is expected by September, 1990 (7065, 7066).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Clean Air Act (CAA)
EPA intends to list either chromium or hexavalent chromium as a hazardous air pollutant for which it will develop national emission standards. Action on this rulemaking is expected by March, 1991 (7047).

- **State Water Programs**

No proposed regulations are pending. 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 1990-91 (7058).

EEC Directives

Directive on Drinking Water (7086)
The mandatory values for total chromium in surface water treatment categories A1, A2 or A3 are 0.05 mg/L. There are no guideline values.

Directive on Bathing Water Quality (7087)
Mandatory values for chromium in bathing water are: (1) no specific odor and (2) concentrations ≤0.05 mg/L.

Directive on Discharge of Dangerous Substances (7088)
Chromium cannot be discharged into inland surface waters, territorial waters or internal coastal waters without prior authorization from member countries issuing emission standards. A system of zero-emission applies to discharge of the substances into ground water.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for chromium specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level having harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of chromium in shellfish must be so limited that it contributes to the high quality of shellfish product.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive on Ground Water (7091)
To ensure the effective protection of groundwater in the community, it is necessary to limit the discharge of chromium into groundwater. The purpose of this directive is to prevent pollution of groundwater substances belonging to substances listed in the Annex of this directive. Chromium shall be subject to prior review so as to limit discharge into groundwater. Member states may grant authorization, provided that all technical precautions for preventing groundwater pollution by chromium have been observed.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
The maximum admissible concentration for chromium is 50 µg/L. No guide level is given.

Directive on Toxic and Dangerous Wastes (7093)
Any installation, establishment, or undertaking that produces, holds and/or disposes of certain toxic and dangerous wastes including chromium and chrome compounds (with carcinogenic effects) shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such wastes, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Chromic oxychloride, chromium trioxide, and chromyl chloride are classified as corrosive and oxidizing substances and is subject to packaging and labeling regulations. Hydrogen cyanide may contain a stabilizer. If the stabilizer changes the dangerous properties of this substance, substance should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

Proposal for a Council Directive on Water Quality Objectives for Chromium (7097)
EEC has proposed that the concentration of dissolved chromium in fresh water be below 5-50 µg/L depending on water hardness. For sea water, the upper limit would be 15 µg/L. The proposal would not regulate chromium in ground water or drinking water. Implementation of the program would be completed by 15 September 1991.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive on Disposal of Waste Oils (7102)
Establishments collecting and/or disposing of chromium waste oils must carry out these operations so that there will be no avoidable risk of water, air, or soil pollution. A permit from the competent authority must be registered and adequately supervised for collecting, disposal and regenerating waste oils. PCBs and PCTs must not be present in amounts greater than 50 ppm in regenerated waste oil. Emission limit values must not exceed 5 mg/m^3.

Directive on the Combating of Air Pollution From Industrial Plants (7104)
Chromium and chromium compounds are considered heavy metals and are classified as polluting substances in Annex II of this directive. This directive requires member states to ensure that the types of industrial plans listed in Annex I receive authorization before operation or substantial alteration. An authorization may be issued only when competent authority is satisfied that: (1) all appropriate preventive measures against air pollution have been taken; (2) the use of the plant should not cause significant air pollution, particularly from the emission of substances in Annex II; and all applicable air quality limit values are taken into account.

EEC Directives-Decisions

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7105)

The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials must be eliminated; Part II substances, includes chromium and its compounds that seem less noxious or are more readily rendered harmless by natural processes. Discharges must be subject to approval by representatives of the contracting party.

72.1 MAJOR USES

Elemental chromium is not found in nature (5418). The most important chromium ore, chromite ($FeOCr_2O_3$), is never found in pure form (5419), but contains varying amounts of silica and small amounts of other compounds and, in some cases, the iron oxide may be replaced with magnesium oxide. Chromium and other metals may occupy the same site in different proportions (5420). In 1987, world production of chromite totaled an estimated 12.12 million short tons. Although no chromite ore was mined in the U.S., 0.56 million short tons were consumed domestically (5421). Ferrochromium is produced from the ore, either by the reduction of chromium compounds or electrolytically. In 1987, world production of chromium ferroalloys totaled approximately 3.11 million short tons, of which 0.44 million tons were consumed domestically (5421).

According to 1987 figures, chromium is used mainly in the metallurgical and chemical industries (505,449 tons of chromite used) and in the refractory industry (50,416 tons used) (5421). In the metallurgical industry, chromium is used mainly in the production of stainless steels, alloy cast irons, nonferrous alloys and other miscellaneous materials (5422); in the chemical industry, chromite is used in the pigment, paint, tanning, and dyeing processes (5423); and in the refractory industry, chromite is used to make refractory bricks to line metallurgical furnaces (5421). Ferrochromium alloys and other chromium-containing materials are used in the production of stainless steel (82%), full-alloy steel (7%), and superalloys (3%), and for other end uses (8%) (5421).

72.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

The sources of chromium in the environment are both natural and anthropogenic. Chromium levels in rock samples from all over the world range from 20 to 2,000 ppm (5418). High chromium content is associated mainly with ultramafic and mafic rocks, while lower chromium levels are found in acid igneous and sedimentary rocks (5424). Because the composition of soil is influenced by the composition of the parent rock from which it is formed, the background level of chromium in soil varies considerably (5418). Soils on serpentines may contain as much as 0.2 to 0.4% chromium, while sandy soils and histosols have the lowest levels (~ 7-15 ppm); the overall mean chromium content is calculated to be 54 ppm for surface soils of the U.S. and 65 ppm for world-wide soils (5424). Chromium tends to accumulate in soils to which industrial wastes and municipal sludges are applied. In one study, chromium levels of 113 ppm (an increase from 43 ppm) were detected after 80 years of irrigation with sewage sludge containing 112 ppm chromium (5425) and in another, levels of the metal ranging from 214 to 399 ppm were detected in surface horizons of sludged farmland (5426, 5427, 5428).

Using emissions factors and statistics on global production or consumption of industrial goods, Nriagu and Pacyna (5429) calculated the world wide emissions of trace metals to the atmosphere, water, and soil. Total atmospheric emissions of chromium, mainly from coal combustion, steel and iron manufacturing, and cement production, were estimated to be 7.3-53.6 x 10^6 kg/yr. Total emissions into aquatic ecosystems, discharged mainly from domestic wastewater, metal manufacturing processes, and dumping of sewage sludge, were estimated to be 45-239 x 10^6 kg/yr. Total emissions into soils, primarily from

coal and bottom fly ash, commercial products such as pesticides, and animal wastes (manure), were estimated to be 4.84-13.09 x 10^8 kg/yr (5429).

The environmental fate of chromium in soils and sediments is influenced primarily by sorption (which includes the physical process of adsorption and a number of chemical processes called chemosorption (5430)). Sorption can be complicated by redox reactions. The half-life of chromium in soils could be several years (5407, 5431). Hertel (5423) estimated that, depending on climatic conditions and soil properties, chromium deposited in the soil in sewage sludge could disappear either slowly (7% disappearance in 8 years) or more rapidly (75% disappearance within 3 years).

Chromium in natural waters arises from mineral weathering processes, soluble organic chromium, sediment load, precipitation, and industrial pollution (5418). The fate of chromium in water is governed by precipitation and speciation. Speciation includes acid base dissociation, complexation, and redox reactions. All of these environmental processes occur in parallel (5430). Estimations of the residence time of chromium in groundwater were not found; however, the metal is expected to persist in lake water for approximately 4.6-18 years (5422).

72.2.1 Transport in Soil/Ground-water Systems

72.2.1.1 Overview

The characteristic oxidation states of chromium are positive II, III, and VI, the most stable of which is Cr(III) (5418). As chromium is weathered from minerals, it initially exists in the environment as Cr(III). Nearly all Cr(VI) in the environment is man-made, the result of contamination by industrial emissions (5432, 5423). Cr(VI) is mobile in the soil and is toxic to plants and animals (5424), while Cr(III), generally immobile in soil, is less toxic (5418).

The movement/sorption of chromium in the soil is influenced by various factors such as chemical form and oxidation state of the metal, the presence of organic matter, exchangeable ions, and/or reducing agents, soil pH and texture, and the formation of soluble complexes, especially those resulting from the anaerobic decomposition of plant material in flooded soils (5422, 5433).

In natural waters, most of the soluble, generally mobile, chromium, which accounts for only a small percentage of total chromium, is hexavalent (5418). Trivalent chromium, on the other hand, readily precipitates with carbonates, hydroxides, and sulfides to form insoluble compounds and is generally immobile in ground water (5434).

Chromium levels in both surface and ground water are usually very low (in the picogram/mL range), requiring the use of sensitive analytical methods. In one study, the movement of sludge-borne metals in an agricultural landscape was monitored after 10 years of annual sludge applications. In spite of massive chromium loadings, chromium losses were low and were associated only with sediment losses, suggesting that Cr(VI) would probably not leach into groundwater in significant quantities (5435). In another study, however, Cr(VI) was detected in the ground water of Paradise Valley, Arizona at

concentrations as high as 220 ppb (5436). The presence of Cr(VI) in the Arizona ground water (pH 7.8 to 9, Eh 0.4 v to 2.5 v) was attributed to low carbon dioxide levels and silicate hydrolysis.

72.2.1.2 Sorption on Soils

Trivalent chromium bonds with oxygen, nitrogen, and sulfur and forms many organic complexes (5418); it also adsorbs to hydroxides of other metals to form insoluble compounds that are very stable in soils. It appears that a small amount of Cr(III) in soil can be oxidized to Cr(VI) (5418, 5437, 5433), probably due to the presence of manganese oxides in the soil (5438). Some of the Cr(VI) formed in this way will be sorbed, some will be reduced, and some may be leached into ground water or drainage water. Runoff could remove both soluble and insoluble precipitate resulting in final deposition to either a different land area or body of water (5422).

Hexavalent chromium is water soluble and can be both stable and mobile in soils that are sandy and contain low levels of organic matter (5437, 5433); however, Cr(VI) may also be reduced to Cr(III) or absorbed depending on such factors as soil pH and soil texture. The stable Cr(VI) species, chromate (CrO_4^{-2}) and dichromate ($Cr_2O_7^{-2}$), form soluble salts which are mobile and potentially toxic (5439, 5420). Under anaerobic conditions, these species are rapidly reduced to Cr(III) and are precipitated as oxides and hydroxides. Hexavalent chromium is not sorbed significantly by metal oxides or clays, but is strongly sorbed by activated carbon, indicating possible affinity for organic matter in the environment (5439). Increased levels of organic matter may induce the formation of soluble organic complexes reducing the degree of adsorption of both Cr(III) and Cr(IV) (5440). Hexavalent chromium can be coprecipitated with aluminum hydroxide over the pH range of about 7 to 9.4 (5441).

The effects of pH on the adsorption of chromium in soil are generally significant. Griffin et al. (5442) observed that in the presence of clay minerals, the adsorption of Cr(III) increased as pH increased, while the adsorption of Cr(VI) decreased as pH increased. Thirty to three-hundred times more Cr(III) was adsorbed onto the clay than was Cr(VI), corresponding to the adsorption of hydrolyzed Cr(III) species on cation exchange sites. However, at low pH and low concentration where the solubility of Cr(III) is increased, strong specific adsorption on manganese and iron occurs (5420). The effects of low pH on the sorption of Cr(VI) are not clearcut. One experiment demonstrated that as pH decreased, Cr(VI) sorption increased and, furthermore, the sorbed chromium was desorbed at pH 10-11, apparently as Cr(VI) (5438). In another study, the movement of chromium in silt loam of pH 4.5 was limited to the top 5 cm of soil, but moved deeper in soil adjusted to pH 7.6 (5443). There is other evidence, however, that Cr(VI) is mobilized in acid (pH 3-5) as well as alkaline soils (pH 10-11) (5424).

Using thin layer chromatography, Khan et al. (5444) examined the various factors that influence the mobility of heavy metals through Indian Red Soil. The mobility of chromium, which was high in this system, was thought to be governed by the formation of highly stable and soluble chromium-soil organic matter (SOM) complexes which were readily translocated through the soil. The investigators observed that the decomposition of soil organic matter greatly increased the mobility of chromium whereas a rise in pH of

the soil water system caused a decrease. Initial addition of all anions (Cl^-, HCO_3^-, CO_3^{--}, SO_4^{--}, PO_4^{---}, and MoO_4^{--}) apparently enhanced mobility but as the levels of SO_4^{--}, PO_4^{---}, and MoO_4^{--} increased, mobility was reduced. Compared with other metals, the mobility of chromium tested in soils saturated with different exchangeable cations was high, and in the following order: H-soil>Na-soil>K-soil>Mg-soil>Ca-soil. The high mobility of chromium in H-soil was attributed to a reduction of the soil pH from 5.7 to 2.5.

72.2.1.3 Volatilization from Soils

No data were found to indicate that chromium volatilizes from the soil; however, the metal may be transported to the atmosphere as an aerosol (5422).

72.2.2 Transformation Processes in Soil/Ground-water Systems

72.2.2.1 Soil

Organic matter in soil reduces Cr(VI) to Cr(III) (5445, 5443, 5433) and/or organic chromium compounds may be formed, more than likely as the hexavalent chromium is reduced by organic matter, rather than by the direct interaction of Cr(III) and organic matter (5418).

As was mentioned previously, Cr(III) can undergo oxidation to Cr(VI) under certain conditions (5418, 5437). Studies by Eary and Rai (5472) indicated that Cr(III) in leachates from coal fly ash disposal sites (pH <6) would react with MnO_2 to be converted to Cr(VI). However, it is likely that the converted Cr(VI) would subsequently be reduced to Cr(III) in the underlying soil and possibly precipitated as $Cr(OH)_2$, resulting in a small net concentration of Cr(VI).

No data were found to indicate that chromium undergoes biological alterations in the soil; however, Francis and Dodge (5446) observed the microbial dissolution of chromium from coal beneficiation residues (fines fraction and filter cake) under aerobic and anaerobic conditions. Based on the amount of metal released from the residues during incubation with native aerobic and anaerobic flora, approximately 55% of the chromium was mobilized from the fines fraction under aerobic conditions, while ~2% was mobilized under anaerobic conditions. From the filter cake, ~24% was mobilized under aerobic conditions and 26% under anaerobic conditions.

72.2.2.2 Ground Water

The fate of chromium in the aquatic environment is determined primarily by chemical speciation (5439). Conditions that support Cr(VI) will maintain chromium in a soluble form in the water, while conditions that support Cr(III), the most stable form, will induce the precipitation and adsorption of chromium in sediments. At the same time, small amounts of Cr(III) may remain in solution as soluble complexes (5422). Chromous ion [Cr(II)] is not stable in water; $Cr(OH)_2$ precipitates at approximately pH 6 and is easily oxidized (5447).

Metals tend to undergo hydrolysis by water, and then exist as one or more ionic species (5434). In the aqueous environment, Cr(III) polymerizes slowly, complicating its hydrolysis behavior. Cr(III) produces the mononuclear species $CrOH^{+2}$, $Cr(OH)_2^{+}$, $Cr(OH)_4^{-}$, the neutral species $Cr(OH)_3^{O}$, and the polynuclear species, $Cr_2(OH)_2$ and $Cr_3(OH)_4^{+5}$, that form more slowly (5447). The accumulation of Cr(III) in sediments is the result of the hydrolysis of Cr(III) complexes to insoluble hydroxides, particularly $Cr(OH)_3$ (5439).

Hexavalent chromium exists in aqueous solution as a component of a complex anion, either chromate (CrO_4^{-2}), hydrochromate ($HCrO_4^{-}$), or dichromate ($Cr_2O_7^{-2}$), depending on pH. All of these forms are very soluble (5448) and quite mobile in the aquatic environment. Because dichromate concentration is not significant at pH values usually observed in most natural waters, the prevalent form of the Cr(VI) in waters of pH>6 is the chromate ion, CrO_4^{-2} (5439). Table 72-1 lists pK values for Cr(III) and Cr(VI) aqueous species.

Chromium(III) complexes with a number of ligands such as water, fluoride, ammonia, cyanide, thiocyanate, oxalate, sulfate, and numerous organic compounds (reviewed in 5420). The complexes may exist as cationic or anionic complexes, depending on the charge and number of ligands attached. At neutral or basic pH, Cr(III) forms polynuclear complexes via hydroxo- or oxo-bridge linkages (reviewed in 5420). These complexes are kinetically inert and may persist in solution for relatively long periods, even under conditions that may make them thermodynamically unstable (reviewed in 5420).

As in soil, Cr(III) and Cr(VI) in natural waters are readily interconvertible, under certain conditions (5449). Apparently, Cr(VI) can be reduced by Fe(II), dissolved sulfides, and certain organic compounds with sulfhydryl groups, while Cr(III) can be oxidized by a large excess of MnO_2 and at a slower rate by oxygen. However, the oxidation of Cr(III) to Cr(VI) would not be a significant process in natural waters were the pH range is usually between 6 and 9 (5422).

Chromium hydroxide and Cr(III) precipitated with iron oxides are thought to be the solubility-controlling solids in some natural waters (5440). At pH >5 the precipitation of chromium hydroxide is probably the dominant fate of chromium in natural waters (5439). As pH increases, solubility decreases; at pH 8.5 the solubility product for the hydroxide is 2.9×10^{-29} (5450). Solubility is also dependent on other water characteristics such as hardness, alkalinity and salinity.

Barium, lead, and silver chromates readily precipitate from solution; lead chromate is most likely the species that controls the solubility of Cr(VI) in the environment (5440).

No data were found to indicate that chromium would undergo biological alteration in groundwater systems. However, there is evidence that bacterial action can convert it into a slightly more soluble form (5432).

Table 72-1

Values of Acid Dissociation Constants for Chromium Species

Species	pk_1	pk_2	pk_3	pk_4	References
H_2CrO_4	0.74	6.5	—	—	(5471)
Cr^{+3}	4.2	6.2	8.3	9.1	(5470)

[a]The terminology assumes an aq subscript on each species, which refers to the fact that the ion is an aqueous solution. The acid dissociation contants thus refer to loss of H^+ from successive water molecules.

Values are given as $pk_1 = -\log k_1$. Temperature is 20-25°C and ionic strength is 0.0M.

Source: (5451)

72.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

Chromium participates in glucose and cholesterol metabolism and therefore is essential to man and animals (5452). Food intake is a major source of chromium for animals and humans (5423). Chromium is present in all plants, including food plants, and is usually taken up through the roots or leaves (5423). Only chelated chromium compounds appear to be translocated from these points of absorption (5423) and there is no evidence that hexavalent chromium is translocated at all (5418). Chromium levels found in plants are usually fairly low and consistent, ranging from 0.02 to 0.2 ppm (dry weight), but they may vary considerably in food plants, ranging from 0.02-14 ppm (dry weight) in the edible parts of vegetables (5453). However, plants growing in areas of serpentine or chromite deposits can accumulate up to 0.35% chromium (dry weight) (5454, 5455). It is estimated that <1% of plant chromium is biologically available (5418).

Chromium added to the soil is expected to have a minimal effect on the concentration of the metal in foods and feeds (5418). This was demonstrated by Mejstrik and Svacha (5456), who investigated the concentrations, in and on crop plants, of heavy metals released into the atmosphere from the combustion of coal or lignite. Measurements were made in the vicinities of two fossil fuel power plants, PPH and PPM, and a nuclear power plant, NPPD. Concentrations were determined in different species of agricultural plants from the local environment (within a radius of 1-15 mi) and were compared with corresponding concentrations in soils and fallout. Because of the presence of serpentine soils indigenous to NPPD, the chromium content was three times higher (173.1 µg/g) there than at PPM or PPH. Only 40% of the chromium deposition could be attributed to fallout from the power plant. However, the total average chromium content of plant samples did not correlate with the high chromium content of NPPD soils, the plant values from this area being lower than the plant values from the two power plants. In sugar beet roots and oat seed chromium content was elevated (0.8-2.8 µg/g dry wt. and 0.5-2.4 µg/g dry wt., respectively), while in wheat seed it was low (0.1-0.3 µg/g dry wt). In the group of above ground

samples did not correlate with the high chromium content of NPPD soils, the plant values from this area being lower than the plant values from the two power plants. In sugar beet roots and oat seed chromium content was elevated (0.8-2.8 µg/g dry wt. and 0.5-2.4 µg/g dry wt., respectively), while in wheat seed it was low (0.1-0.3 µg/g dry wt). In the group of above ground samples, chromium content was elevated in sugar beet leaves (PPH, 2.0 µg/g dry wt.), grasses (PPH, 4.2 µg/g dry wt.) and oat straw (NPPD, 2.0 µg/g dry wt.).

The presence of chromium in groundwater could lead to the exposure of humans via drinking water. Drinking water, which normally contains low chromium concentrations of 5 µg/L or less, has been found to contain on rare occasions concentrations of 20 µg/L (5457). Trivalent chromium is rarely detected in water that has been chlorinated, and it has been suggested that most chromium present in drinking water is hexavalent (5448). Although Cr(III) could be oxidized to Cr(VI) during chlorination of water (particularly at pH 5.5-6.0), this would not be of concern with drinking water because of the low concentrations of Cr(III) and natural organics that are usually present in drinking water (5422). Based on water consumption of 2 L/day, it is estimated that the daily intake of chromium in water might vary from <10 µg to 40 µg/day on rare occasions (5432).

72.2.4 Other Sources of Human Exposure

Potentially hazardous occupational exposures to chromium can occur during the production of dichromate, during the use of chromates in the chemical, stainless-steel, refractory and chromium-plating industries, and during the production and use of alloys (5419). Welders may also be at risk for exposure to the chromium in stainless and acid-stable steel, and in anticorrosive paints (5458, 5459, 5460). The most important route of entry in occupational exposure is via inhalation (5423).

The U.S. National Institute for Occupational Safety and Health estimated that in 1975, 175,000 U.S. workers were exposed to Cr(VI) in 104 occupations and that in 1973, 15,000 workers in the U.S. were potentially exposed to Cr(VI) trioxide mist (5423). The range of airborne Cr(VI) concentrations (µg/m^3) in various industries as reported by Stern (5460) are as follows: stainless steel welding (50-400), chromate production (100-500), chrome plating (old plants [50-1000]; new plants [5-25]), ferro-chrome (10-140), chrome pigment (60-600), tanning (10-50, as Cr[III] only).

Non-occupational exposure of the general population to chromium has many sources, diet being the main one (5419). The following intake rates of chromium via ingestion and inhalation have been estimated: none in fish; 60 µg/day in other foods; 0.2 µg/day in water; and 0.1 µg/day by inhalation (5461). Higher rates of intake from food of 280 µg/day, along with 4 and 0.28 µg/day from water and air, respectively, have also been estimated (5462).

Urban air concentrations of chromium for 1969 were estimated at <10-100 ng/m^3, while pre-1974 values for rural stations were 10 ng/m^3, or less (5463). Most chromium in the air will be in the form of fine particles, approximately half of which could be deposited in the respiratory tract (5432).

Foods other than plants, such as meat and unrefined sugar, are important sources of chromium, while fish, vegetable oil and fruits contain smaller amounts. Both trivalent and hexavalent chromium are found in foods (5432), some of which may have leached from plated or stainless steel utensils used in food preparation. Levels vary from non-detectable to about 0.5 mg/kg wet weight for most items (5419).

Surgically implanted hip or knee prostheses are also of concern as potential sources of human exposure to chromium. In one study, hip or knee porous-coated prostheses fabricated of cobalt-chromium were implanted in 28 patients, and serum and urine samples were taken at intervals ranging from 1 day to 2.5 years after surgery (5544). The samples were assayed for cobalt, chromium, and nickel concentrations and the results were compared with those from two control groups (only chromium concentrations are considered here). Average chromium concentrations in patients with hip or knee prostheses were never significantly increased ($p>0.05$) over the preoperative values or the corresponding postoperative values in control patients with Ti-Al-V prostheses; however, one patient exhibited increased concentrations of chromium in serum and urine (0.61 µg/L and 1.8 µg/g creatinine, respectively; presurgery averages, 0.06 µg/L for serum and 0.4 µg/g creatinine for urine) 22 months after surgery. Three other patients had sporadically increased urine chromium concentrations, but without increased serum chromium. The investigators suggested that such elevations of chromium in body fluids may be indicative of loosening or corrosion of implanted prostheses, and that, in spite of the paucity of positive data for chromium in body fluids, chromium levels in the tissues surrounding the implants could be significantly increased.

Background levels of chromium were measured in tissues from the carcasses of livestock (bovine, porcine, and poultry tissues) (5464). Levels of chromium in bovine muscle (663-867 µg/kg) did not change significantly with age over ~6 years; likewise, there were no age-related increases in kidney levels (867-1000 µg/kg). In porcine carcasses, levels of 242 and 715 µg/kg for muscle and kidney, respectively, were detected. Levels of chromium were measured in poultry carcasses from several locations in Ontario. In poultry, muscle concentrations were 1146 and 987 µg/kg for chickens under and over 14 weeks old, respectively, while liver concentrations were 1007 and 1396 µg chromium/kg.

For fish and seafood, the following levels of chromium have been detected: (1) in the tissues of sea scallop (Placopecten magellanicus) from 19 sites in the area of two ocean disposal sites located off the U.S. mid-Atlantic coast, 0.89 to 6.88 ppm/dry weight (5465); in oysters (Crassostrea virginica) taken from the area surrounding three marinas in coastal South Carolina, 0.3 to 2.0 mg/kg in 13/54 samples tested (5466); and (3) in the dorsal muscle of white suckers (Catostomus commersoni) and brown bullheads (Ictalurus nebulosus), both bottom-feeding omnivores (mean concentration in white suckers, 0.05 µg/g dry wt; mean concentration in brown bullheads, 0.05 µg/g dry wt) (5467). The fish were collected in two lakes known to have elevated sediment concentrations of the elements. To study the potential for biomagnification, several good potential food sources (insects, crayfish, fingerling bullheads) and the gut contents of the bullheads were analyzed for the presence of the metal and the biomagnification ratio (BR) was calculated from the ratio of the average concentration found in fish muscle to the average concentrations found in its foods and gut contents of the bullheads. The BR values for chromium were

0.07 for insects, 0.35 for crayfish, and 0.24 for fingerling bullheads, indicating no potential for biomagnification.

Bioconcentration factors for chromium, defined as the ratio of the concentration of the element in the organism in ppm (wet wt.) divided by the concentration of the element in water (ppm) have been summarized by Callahan et al. (5439). The highest values of 1,600-4,000 were derived (in increasing order) for benthic algae, zooplankton, marine plants and invertebrates, freshwater invertebrates, and freshwater plants. Lower values of 70-440 were determined for fish muscle, crustacean muscle, freshwater fish, mollusc viscera, and marine fish. Although some accumulation does occur at all levels of the food chain, these concentration factors further suggest that biomagnification does not occur. Chromium is accumulated in aquatic and marine biota more than in ambient water and less than in sediments (5439).

One other source of exposure to chromium is cigarettes which reportedly contain 0.24-14.6 mg of chromium/kg (5452, 5468), or 1.4 µg/cigarette (5469). Assuming that only a small fraction of the chromium will be inhaled and perhaps only half of that will be deposited in the lung, it is estimated that chromium retained by smoking 20 cigarettes a day would not exceed a few micrograms per day (5432).

72.2.5 Biological Monitoring

Chromium is an essential element required for normal glucose tolerance. The daily intake ranges from 5-115 µg, only 1-25% of which is absorbed from the gastrointestinal tract (5474). The normal serum chromium level averages about 0.16 µg/L (range=0.04-0.35 µg/L) in healthy individuals (5475, 5476). Normal chromium concentrations in urine average 4-5 µg/L and the urinary excretion rate ranges from 1.6-21 µg/day (5463). Urinary chromium concentrations in occupationally exposed subjects range from 30-200 µg/L in welders (5459).

Chromium in urine is a good indicator of exposure to chromium VI, but not to chromium III. Serum chromium increases after exposure to chromium III chromium VI, however, accumulates in RBCs (5422). As a measure of exposure, urinary chromium levels correlate well with air concentrations of chromium, especially with high air concentrations of chromium VI (5474, 5422). The correlation breaks down at the low exposure concentration. ATSDR (5422) summarized methods for analyzing chromium in biological samples.

1.3 HUMAN HEALTH CONSIDERATIONS

The data presented in this section concerns many chromium compounds most of which are hexavalent (Cr(VI)) or trivalent (Cr(III)). For the most part, the human data are obtained from studies of occupational exposure in various industries, namely, those involved with the primary production of chromium compounds (hexavalent and trivalent compounds of varying solubilities), chromeplating (chromium trioxide), the production and use of chromium pigments (strontium, lead, and zinc chromates), and the ferrochromium industry (chromium oxide). The data indicate that the hazards of exposure to chromium

compounds can be associated with the industry, but not always with specific compounds.

Data concerning mammalian toxicity of chromium compounds are extensive. Pertinent reviews are as follows: NIOSH (5413), IARC (5477), U.S. EPA (5478), U.S. EPA (5407, 5479, 5480, 5422). In addition, sodium chromate was addressed in the Installation Restoration Program Toxicology Guide, Volume 3, Chapter No. 53.

72.3.1 Animal Studies

72.3.1.1 Carcinogenicity

Long-term studies conducted with chromium compounds have shown very few toxicologic effects and no neoplastic effects when the compounds are administered orally to laboratory animals. Compounds tested include potassium chromate [Cr(VI)], chromic chloride [Cr(III)] (5481), and chromic oxide [Cr(III)] (5482).

Several studies have been conducted in which chromium compounds were administered by inhalation or by intratracheal instillation. Baetjer et al. (5483) exposed mice and rats by inhalation or intratracheal injection to mixed chromate dust containing both Cr(III) and Cr(VI). Lung carcinomas were not induced and the incidence of lung adenomas was not increased in either mice or rats. Mice exposed intratracheally to basic potassium zinc chromate or barium chromate did not develop lung carcinomas or show an increase in the incidence of lung adenomas. Hueper and Payne (5484) injected rats intratracheally with 2 mg of calcium chromate, strontium chromate, or zinc chromate every 2 months for 5 injections, and the animals were observed for 2 years. No lung tumors developed.

Bronchiogenic carcinomas were not induced in rabbits, guinea pigs or rats exposed to a mixed chromate dust plus potassium dichromate (2 days/week), sodium chromate mist (1 day/week), or chromate dust with sodium chromate leached out and 1% potassium chromate added (1 day/week). The animals were exposed 4-5 hr/day for their entire lifetime. Rabbits and guinea pigs receiving mixed chromate dust containing both zinc and lead chromate at 1% concentration in saline intratracheally at 3-month intervals for a total of three to five injections for rabbits and six injections for guinea pigs also did not develop bronchiogenic carcinomas. In addition, rats receiving intratracheal injections of mixed roast chromate dust containing 0.6% potassium dichromate monthly for 16 months and mice receiving zinc chromate intratracheally every 6 weeks for 6 injections did not develop bronchiogenic carcinomas (5485).

Nettesheim et al. (5486), however, reported a fourfold increase in the incidence of pulmonary adenomas in mice exposed by inhalation to 13 mg/m^3 of calcium chromate dust (5 hr/day, 5 days/week) for their lifetime. A suppression in the tumor response was seen in mice infected with PR8 viruses and exposed to calcium chromate. Half the animals also received 100R whole body X-irradiation prior to chromate exposure, which alone caused an increase in the incidence of lung tumors that was not additive with that induced by calcium chromate.

Rats exposed by inhalation to sodium dichromate dust or to the slightly soluble chromium oxide (Cr_5O_{12}) containing both Cr(VI) and Cr(III) in a ratio of 3:2 for 18 months showed a very weak tumor response (5487). Two lung adenomas, one lung adenocarcinoma and one malignant tumor of the pharynx were induced in animals exposed to the highest concentration of sodium dichromate (100 $\mu g/m^3$) and one adenoma developed in animals exposed to chromium oxide. Lee et al. (5488) reported that rats exposed to 0.54-22 mg/m^3 of chromium dioxide [Cr(IV)] 6 hr/day, 5 days/week for 2 years developed a unique tumor in the lungs described as a cystic keratinizing squamous cell carcinoma (2/108 females; none in males). According to Lee et al. (5488), these tumors developed from metaplastic squamous cells in areas of alveolar bronchiolarization adjacent to alveolar ducts.

72.3.1.2 Genotoxicity

De Flora et al. (5489) reviewed 700 results for 32 pure chromium chemicals or industrial chromium products and some chromium complexes that were assayed in 130 experimental systems having different genetic endpoints and/or targets. The data for these compounds were analyzed based on oxidation state and solubility of the compounds in water or the experimental media; the different categories of compounds are as listed below.

HEXAVALENT CHROMIUM COMPOUNDS

HIGHLY SOLUBLE	SOLUBLE	POORLY
Potassium dichromate	Calcium chromate	Zinc chromate
Sodium dichromate	Strontium chromate	Lead chromate
Ammonium dichromate	Basic zinc chromate	Basic lead chromate
Potassium chromate		Barium chromate
Sodium chromate		
Ammonium chromate		
Chromium trioxide		

TRIVALENT CHROMIUM COMPOUNDS

HIGHLY SOLUBLE	SOLUBLE	POORLY SOLUBLE
Chromic chloride	Basic chromic sulfate	Chromic oxide
Chromic acetate	Chromic phosphate	Cupric chromite
Chromic sulfate	Chromium alum	Chromic hydroxide
Chromic nitrate	Chromite ore	

The highly soluble Cr(VI) compounds were mostly, but not always consistently positive in acellular systems (isolated DNA or isolated nuclei). Highly soluble Cr(VI) compounds were consistently positive in bacteria, yeast, insect, and mammalian cells in vitro, inducing either DNA damage, mutations, sister chromatid exchanges (SCE) or chromosomal aberrations. Cr(VI) compounds were also genotoxic in whole animal assays

resulting in SCEs, chromosomal aberrations, induction of micronuclei, and induction of dominant lethals. The results for soluble Cr(VI) compounds were comparable to the highly soluble compounds, and the poorly soluble or insoluble compounds were sometimes positive in mammalian cells without acid or alkali solubilization, but for the most part, solubilization was required. Nevertheless, mutagenicity data are extremely limited or poorly soluble or insoluble chromium compounds.

Cr(III) compounds generally gave negative results or were less potent than Cr(VI) compounds in intact cells; these compounds were consistently positive in acellular systems. The positive results of Cr(III) compounds could have been due to contamination with Cr(VI) compounds, nonspecific effects at the high concentration required for a positive effect, endocytosis during the prolonged exposure time required, experimental conditions that altered cell membranes and allowed more efficient penetration, or experimental artifacts (5489). Metallic chromium can be phagocytized by hamster fibroblasts, but did not induce cell transformation. Fumes of metallic chromium inhaled by rats induced SCEs and chromosomal aberrations in peripheral lymphocytes (5489). According to De Flora et al. (5489) some oxidation of the chromium could have occurred.

In a human study conducted by Sarto et al. (5490), chromosomal aberrations and SCEs were analyzed in peripheral lymphocytes of workers exposed to chromium trioxide while using the "bright" chromeplating or the "hard" chromeplating process. Workers using the bright process were also exposed to nickel, whereas those using the hard chromeplating process were not. Among exposed workers using the two bright chromeplating process, the number of chromatid-type and chromosome-type aberrations and the total number of aberrations were significantly higher than those of controls (healthy donors). Among hard chromplaters, the number of chromatid-type aberrations were not increased, but the chromosome-type and the total number of aberrations were significantly increased. Increased chromosomal aberrations were associated with duration of exposure ($\leq$3 years vs. >3 years) for bright chromeplaters only. The frequency of SCEs was significantly higher among chromeplaters than among controls, especially among the young workers. The frequency of SCEs was also linearly associated with urinary chromium level and positively associated with smoking history. A multiple correlation showed a high frequency of SCEs among young workers with high urinary chromium levels. Nagaya et al. (5491) reported that the frequency of SCEs in a group of hard chromeplaters was not significantly higher than in the controls (unexposed workers), but a significantly higher frequency of SCEs was found among smokers, whether they were in the control or exposed groups.

It is believed that the mechanism which accounts for the genotoxic activity of Cr(VI) compounds and the general inactivity of Cr(III) compounds is related to the ability of anionic chromates of Cr(VI) to be taken up by cells via the general anion channel protein and the inability or inefficiency of cationic Cr(III) uptake by cells. Through a reduction process involving cytoplasmic electron donors (NADPH or NADH) and cytosolic, microsomal, and mitochondrial enzymes, Cr(VI) is reduced to Cr(V) and Cr(IV) intermediates and then to Cr(III), which can interact with the genetic material within the cells (5489).

72.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

No oral or inhalation studies were found on the developmental or reproductive effects of chromium compounds. The following is a summary of the effects as a result of parenteral administration of chromium compounds.

Danielsson et al. (5492) reported that radioactive sodium dichromate [Cr(VI)] injected into pregnant mice was more efficiently taken up by the fetus than radioactive chromic chloride [Cr(III)]. During the organogenesis stage (day 8-11) of gestation, Cr(VI) was distributed evenly in embryonic tissues, whereas Cr(III) was not detected by autoradiography. By day 12-15 (mid-gestation) fetal uptake of Cr(VI) was increased (about 12% of maternal serum concentration) and Cr(III) was still low (about 0.4% of maternal serum concentration). Fetal uptake during late gestation (day 16-18) was about 19% for Cr(VI) and 0.8% for Cr(III), with a particularly higher uptake in the calcified areas of the fetal skeleton. Maternal uptake was especially high in the renal cortex for Cr(VI), but both Cr(VI) and Cr(III) were seen in the skeleton, liver, kidneys, ovaries, brain, and muscle. Matsumoto et al. (5493) noted maternal uptake in liver, kidneys, and spleen of pregnant mice injected intraperitoneally with chromic chloride.

Gale (5494) injected one noninbred and five inbred strains of hamsters intravenously with 5 mg/kg of chromium trioxide [Cr(VI)] or with demineralized distilled water (controls) on day 8 of gestation and sacrificed the animals on day 15 for examination. The most frequent abnormalities were cleft palate in the noninbred strain and in two of the inbred strains, hydrocephalus in the noninbred strain, external abnormalities (edema, omphalocele, tail bud abnormalities and encephalocele) in the same strains as cleft palates, and increased resorptions in the noninbred strain. The frequencies of abnormalities and resorptions were not statistically significant in the other three inbred strains. This study showed that a Cr(VI) compound is developmentally toxic, but these effects may be genetically determined.

Female mice injected subcutaneously with 0, 9.76 or 19.52 mg Cr/kg of chromic chloride [Cr(III)] every other day from day 0 to day 16 of gestation showed no significant effects on the fetuses when killed on day 18 (5493). A dose of 19.52 mg Cr/kg injected intraperitoneally on day 7, 8 or 9 caused the highest frequency of fetal deaths when injected on day 9 and the highest frequency of malformations when injected on day 8. Malformations included exencephaly, open eyelids, cleft palates, and fused ribs.

Iijima et al. (5495) showed that radioactive chromic chloride [Cr(III)] injected intraperitoneally into mice on day 8 of gestation is taken up by the fetus and that nonradioactive chromic chloride (19.5 mg Cr/kg as $CrCl_3 \cdot 6H_2O$) injected intraperitoneally on day 8 of gestation resulted in cell death within the neuroepithelium 8 hr after injection and defects in the neural tube 24 hr after injection.

72.3.1.4 Other Toxicologic Effects

72.2.1.4.1 Short-term Toxicologic Effects

The oral LD_{50}s reported for soluble Cr(VI) compounds range from 54 mg/kg for ammonium dichromate in the rat (5409) to 300 mg/kg for potassium chromate in the mouse (5410). For low solubility or insoluble Cr(VI) compounds the LD_{50}s range from 3.118 to 12 g/kg in the rat and mouse, respectively (5404). The LD_{50} for the trivalent chromic acetate is 11.26 g/kg in the rat and for the divalent chromous chloride [Cr(II)], it is 1.87 g/kg in the rat (5411).

Lethal doses of sodium chromates, potassium dichromate and ammonium dichromate cause systemic toxic effects of hypoactivity, lacrimation, mydriasis, diarrhea, and changes in body weight. Gross necropsy effects include pulmonary congestion, fluid in the stomach and intestine, and erosion and discoloration of the gastrointestinal mucosa (5409). Symptoms resulting from lethal doses of chromium trioxide include cyanosis, tail necrosis, diarrhea, and gastric ulcers (5496). No studies were found on the effects of acute exposure to sublethal doses of chromium compounds administered orally.

The kidney has been reported to be the main target of short-term exposure to trivalent and hexavalent chromium compounds administered parenterally to laboratory animals, with effects occurring at 1-2 mg/kg (5407). Renal damage has also been reported in humans exposed to chromium compounds occupationally or by accidental or intentional ingestion, indicating that the kidney is also a target for chromium toxicity in humans. The liver also appears to be a target for both Cr(III) and Cr(VI) compounds, but Cr(VI) compounds are more toxic to the liver (5497). The following study showing renal toxicity in rats injected subcutaneously with potassium dichromate is included.

Gumbleton and Nicholls (5498) conducted a study on the effects of single sublethal doses potassium dichromate administered by subcutaneous injection to assess renal damage (function and integrity) in male Wistar rats as measured by in vivo noninvasive technique based on the analysis of proteins and enzymes in urine. The release of tissue enzymes into urine is an early and sensitive indicator of renal toxicity (5498). Rats were injected with doses of 0, 3, 6, 10, 15, or 20 mg/kg and evaluated 52-72 hr after injection (dose-response study) or they were injected with 20 mg/kg and evaluated from 4 hr to 9 days after injection (time-response study). The analyses included the following enzymes: aspartate aminotransferase (AST) and lactate dehydrogenase (LDH) (cytosolic enzymes), N-acetyl-ß-D-glucosamidase (NAG) (lysosomal enzyme) τ-glutamyl transferase (τ-GT), alkaline phosphatase (AP), and leucine aminopeptidase (LAP) (brush border enzymes). Cytosolic and lysosomal enzymes showed elevated excretion rates between 10-20 mg/kg, and the brush border enzymes were unchanged. Potassium dichromate caused necrosis of the proximal tubules in the outer cortex of the kidney, which became more severe with dose; necrosis of the inner cortex was seen at the highest dose. AP was lost from the outer cortex and became progressively more severe with dose; AP was lost from the inner cortex at the highest dose. The time-response study showed transient elevation of AST, LDH, NAG, AP, τ-GT, and LAP. Necrosis of the proximal tubules in the outer renal cortex became progressively more severe through day 3 and recovery was noted on day 6. A transient loss of AP from the inner and outer renal cortex was noted.

Studies on the lethality of chromium compounds by inhalation show LC_{50}s ranging from 5 mg/m^3 in humans for zinc chromate (5404) to 94 mg/m^3 for potassium dichromate (5409) to 158 mg/m^3 for ammonium dichromate in the rat (5409). Clinical signs of toxicity include respiratory distress and irritation and body weight loss (5409).

In a study by Johansson et al. (5499, 5500), no effects were observed on the morphology of the lungs in rabbits exposed to aerosols of sodium chromate [0.9 mg Cr(VI)/m^3] or to chromium nitrate [0.6 mg Cr(III)/m^3], 6 hr/day, 5 days/week, for 4-6 weeks. Pulmonary macrophages accumulated in intraalveolar or intrabronchiolar spaces as nodules and appeared as "naked" granulomas. The macrophages were enlarged, multinucleated, or vacuolated. Sodium chromate affected the morphology of the macrophages, but chromium nitrate affected both the morphology and function of the macrophages.

Both Cr(VI) and Cr(III) compounds can be absorbed from the skin, and the degree of absorption appears to be a function of valence state, anionic form and concentration and pH of the solution (5407). Gad et al. (5409) calculated dermal LD_{50} values for New Zealand rabbits to which 1.0-2.0 g/kg of ammonium dichromate or potassium dichromate was wetted with physiological saline and applied topically. The LD_{50} was 1.86 g/kg for ammonium dichromate in male rabbits and 1.34 g/kg in female rabbits; for potassium dichromate, the LD_{50}s are 1.15 g/kg for male rabbits and 1.40 g/kg for female rabbits. The clinical effects due to applying lethal doses of these Cr(VI) compounds to the skin include dermal necrosis, eschar formation, dermal corrosion, diarrhea, hypoactivity, and dermal edema and erythema. Dermal corrosion and irritation potential of the compounds was tested by applying the dry salt, because the wetted compounds had the potential to be extremely irritating in a standard 24-hr primary dermal irritation test (5409). Therefore, they used a 4-hr treatment protocol with 48-hr observation time. Under these conditions, potassium dichromate was not corrosive or irritative as a dry solid; it caused irritation, but no corrosion, when wetted. Ammonium dichromate was not corrosive either as a dry solid or when wetted, but did cause irritation that was more pronounced when wetted.

The induction of chromium hypersensitivity in laboratory animals, especially guinea pigs has been reviewed by U.S. EPA (5407). Both Cr(III) and Cr(VI) compounds are capable of evoking a reaction. The order of potency for various Cr(III) compounds evoking allergic reactions in guinea pigs is as follows: chromic chloride > chromic nitrate > chromic sulfate > chromic acetate > chromic oxalate (5501). The vehicle used for the test appears to affect the ability of chromium compounds to induce hypersensitivity. Schwarz-Speck and Grundmann (5502) demonstrated that sensitization in guinea pig could be induced by chromium sulfate [Cr(III)] dissolved in the detergent Triton X-100 and by potassium dichromate [Cr(VI)] dissolved in an aqueous solution. Mor et al. (5503) failed to demonstrate hypersensitivity in BALB/c mice using potassium dichromate dissolved in Triton or methanol. Potassium dichromate as a 1% solution in dimethyl sulfoxide (DMSO) applied topically in a one step protocol (applied on day 0 and 1, ear challenged on day 7) induced hypersensitivity in one of three groups of BALB/c mice. A stepwise sensitization protocol (topical application on day 0 and 1, 8 and 9, 17 and 18; ear challenge on day 23) using 1% potassium dichromate in DMSO induced hypersensitivity in BALB/c mice and in the random bred ICR mice.

72.3.1.4.2 Subchronic and Chronic Toxicity

Very few studies have been conducted on the subchronic or chronic oral toxicity of chromium compounds. Ivankovic and Preussman (5482) conducted a 90-day subchronic feeding study in BD rats administered bread containing 0, 2, or 5% chromic oxide [Cr_2O_3, Cr(III), pigment]. The 2% diet supplied a total dose of 72-75 g/kg and the 5% diet supplied 160-170 g/kg. No effects on hematology, clinical chemistry, or urinalysis values were observed, and no gross or microscopic lesions were found. Ivankovic and Preussman (5482) noted that the color of the feces indicated significant fecal excretion of the pigment. They found that 4.9-5.0 g (83-85%) of a single administered dose of 5.9 g of chromic oxide was recovered in the feces within 4 days of dosing, indicating that very little of chromic oxide was absorbed from the gastrointestinal tract. Nettesheim et al. (5486) reported that mice subchronically exposed by inhalation to 30 mg/m^3 of calcium chromate [Cr(VI)] showed a rapid loss of weight, fatty liver, distended and atrophic intestines, and early death.

MacKenzie et al. (5481) conducted a chronic study in which Sprague-Dawley rats were administered 0, 0.45, 2.2, 4.5, 7.7, or 11 ppm of chromium as potassium chromate [Cr(VI)] in drinking water for 1 year. Chromium was absorbed from the gastrointestinal tract and accumulated in liver, kidney, bone, and spleen, but compound-related gross or microscopic lesions were not found. Additional groups of animals received 0 or 25 ppm of chromium as potassium chromate or chromic chloride [Cr(III)] for 1 year. Chromium was absorbed and accumulated in the various tissues; about nine times more chromium accumulated in tissues of animals receiving potassium chromate than in those receiving chromic chloride. Compound-related gross or microscopic effects were not observed. Anwar et al. (5504) reported that dogs given 0, 0.45, 2.25, 4.5, 6.75, or 11.2 ppm of chromium as potassium chromate for 4 years accumulated chromium in the liver, kidney, and spleen, but no toxic effects attributable to chromium exposure were found.

No gross or microscopic effects attributable to chromium were found in BD fed rats bread into which 0, 1, 2, or 5% chromic oxide [Cr(III)] was incorporated (5482). The animals received the compound 5 days/week for 2 years. The total doses were 360 g/kg (1%), 720 g/kg (2%), and 1800 g/kg (5%).

Baetjer et al. (5483) exposed C57 Black, Swiss, and A strain mice and Wister and McCollum hybrid rats by inhalation to mixed chromate dust containing both Cr(III) and Cr(VI) at concentrations of 1 to 2 mg/m^3 (mice) or 2 to 3 mg/m^3 (rats) measured as chromium trioxide. The animals were exposed 4 hr/day, 5 days/week until death or sacrifice. Only an increase in the incidence of pneumonia was noted in exposed mice that died; no exposure-related effects were noted in the lungs of the rats.

Steffee and Baetjer (5485) exposed 8 rabbits, 50 guinea pigs, and 78 rats to mixed chromate dust containing potassium dichromate (Cr(VI)] and sodium chromate (Cr(VI)] at concentrations of 3 to 4 mg/m^3 (measured as CrO_3), 4 to 5 hr/day, 4 days/week for their entire lifetime or until "sign of illness appeared." Nasal perforations were noted in 25 percent of the rabbits and rats; guinea pigs were not examined for nasal lesions. Microscopic examination of the lungs showed a characteristic foreign body-type inflammatory reaction, especially in rats. Granulomas, bronchopneumonia, alveolar and

interstitial inflammation, hyperplasia or hypertrophy of the alveolar epithelium, and/or interstitial fibrosis were seen in all species. No significant systemic effects were noted.

Nettesheim et al. (5486) noted severe toxic effects in C57Bl/6 mice exposed to 13 mg/m^3 of calcium chromate ($CaCrO_4$), 5 hr/day, 5 days/week for their entire lifetime. Animals exposed for 6 months or more showed dramatic effects in the respiratory tract characterized by bronchial epithelial changes ranging from necrosis to atrophy or marked hyperplasia. Massive inflammatory infiltration into the subepithelial tissues was noted. Bronchial epithelial cells proliferated down into the alveolar region ("bronchiolarization"). Alveolar proteinosis, associated with distension of terminal bronchioli and alveoli, resembling emphysema was also noted.

Lee et al. (5488) exposed male and female Sprague-Dawley rats to chromium dioxide [Cr(IV)] 0.5 mg (stabilized), 0.5 mg (unstabilized), or 25 of CrO_2 mg/m^3 (nominal concentrations) for 6 hr/day, 5 days/week for 2 years. The effects, characterized as a nuisance dust reaction at 25 mg/m^3 are as follows: accumulation of dust-laden macrophages, Type II pneumonocyte hyperplasia, slight collagen fibrosis, alveolar bronchiolarization, foamy macrophage response, cholesterol granulomas, alveolar proteinosis, and minute fibrotic pleurisy.

Glaser et al. (5487) exposed male Wistar rats by inhalation to the slightly soluble chromium oxide (Cr_5O_{12}) at 100.8 μg Cr/m^3 containing both Cr(VI) and Cr(III) in a ratio of 3:2. The animals were continuously exposed (22 to 23 hr/day) 7 days/week for 18 months and observed for an additional 12 months. The blood leukocyte count was slightly increased, and the red blood cell, hematocrit, and hemoglobin counts were significantly increased. Relative lung weights were significantly increased, and histopathological examination showed accumulation of pigment-loaded macrophages in the alveolar and peribronchial regions. In addition, an eosinophilic substance accumulated in the alveolar lumen of three rats and focal thickened septa were seen in three rats, along with interstitial fibrosis in two of the same rats. The investigators attributed these effects to the retention of chromium in the lungs, which they calculated to be 19 percent of the total chromium deposited during the entire exposure period.

72.3.2 Human and Epidemiologic Studies

72.3.2.1 Short-term Toxicologic Effects

The effects of acute oral exposure to chromium have been documented in a case study of a 44-year old Hispanic male who ingested a liquid identified as chromic acid (5505). The patient was tachycardiac and tachypneic and had signs of abdominal tenderness on admission to the hospital. Effects observed during a 28-day hospitalization were as follows: persistent metabolic acidosis, hypotension leading to acute renal tubular necrosis, respiratory difficulty, severe anemia, extensive ulcerations of the esophagus, stomach, and duodenum, and decreased peristalsis. The patient died at home, probably from severe gastrointestinal hemorrhage. Overdose of chromium was confirmed by extremely high levels of chromium in the plasma and urine. According to Saryan and Reedy (5505, citing information from 5506), Cr(VI) compounds causes abdominal pain and vomiting, followed by oliguria due to acute tubular necrosis attributed to a direct toxic

effect on renal tubular epithelial cells. These effects are seen in almost all cases of overdosage. Hepatic failure develops; gastrointestinal hemorrhage, intravascular hemolysis and uremia cause a marked drop in hemoglobin; and CNS effects may result directly or indirectly from hepatic and renal failure. Autopsy findings include necrosis, hemorrhage and fatty degeneration of the liver, cerebral edema, and meningoencephalitis. Potassium dichromate in doses of 0.5-0.8 g (5506) and 1-2 g of chromic acid are reported to be lethal in humans; but other reports claim that recovery occurs after doses as large as 5-15 g (5505).

Short-term inhalation or dermal exposure to chromium compounds can cause some of the same nonneoplastic effects as long-term exposure (See section 72.3.2.2). Upper respiratory tract, pulmonary, and dermal lesions are often seen. In addition, challenge by inhalation with chromium sulfate [Cr(III)] induced asthmatic effects (5507) and challenge with sodium chromate (Cr(VI)) induced an anaphylactoid reaction in workers with prior exposure to chromium (5508). According to Franchini and Mutti (5509), the kidney should be regarded as the critical target for chromium, where exposure causes acute tubular necrosis and renal failure.

Systemic poisoning has been reported after extensive burns with hot chromic acid (5505).

72.3.2.2 Chronic Toxicologic Effects

Numerous studies regarding the effects of long-term exposure to chromium compounds in humans by inhalation are available; many of these are epidemiology studies using morbidity and mortality as endpoints, but some are surveys that evaluated the health hazards of chromium exposure in various industries. In most cases, the subjects or cohorts were exposed to a mixture of both Cr(VI) and Cr(III) compounds. A few studies have addressed exposure to chromium compounds by the oral route, and the occurrence of skin lesions due to dermal contact with chromium compounds are frequently addressed in health hazard surveys.

There is some evidence that chromium deficiency leads to impaired glucose tolerance and weight loss (5510, 5511). Consequently, oral studies in humans involved improvement of glucose tolerance in diabetic or hyperglycemic patients given 150-1000 µg/day of chromic chloride [Cr(III)] or brewers yeast (the highest natural source of biologically active chromium) for periods ranging from 1-12 months. Improvements, which were sometimes sporadic or unpredictable have been noted (5510). Serum cholesterol levels also showed a decline in the diabetic and hyperglycemic patients (5510).

72.3.2.2.1 Epidemiology Studies

Machle and Gregorius (5512) reported that of 193 deaths occurring among chromate production workers at seven plants, 66 (21.8%) were due to cancer and 42 (63.8%) of which were due to lung cancer. If the deaths due to lung cancer were excluded, the cancer deaths were not higher than expected compared with other industrial workers insured by Metropolitan Life (controls). The death rate due to lung cancer for the various

plants ranged from 18-50 times the expected rate. With respect to age, the death rate was elevated 20-70 times for workers ≤50 years of age and 10-40 times for workers ≥50 years old. In addition, these authors reported that the mean duration of exposure prior to onset of cancer was 14.5 years. Machle and Gregorius (5512) suggested that bichromates, chromic acid, and basic chromic sulfate were not associated with lung cancer, because workers at a plant where these compounds were handled experienced no deaths due to cancer. Monochromates, however, were associated with lung cancer.

Other studies conducted over the years have shown associations between exposure to chromium compounds in industries either producing or using chromium and excess deaths due to lung cancer. The results of some of these are discussed below.

Brinton et al. (5513) reported excess deaths due to cancer of the respiratory system and to other causes, among workers at seven chromate producing plants. Taylor (5514) conducted a study on a cohort of 1212 workers who were employed at three chromate producing plants from 1937-1940 and followed up through 1960. They observed that the overall standardized mortality ratio (SMR) for five-year time intervals between 1937 to 1960 ranged from 468 to 1865 for deaths due to respiratory cancer; the overall SMR for 1937-60 was 851. Civilian males were used as referents. In addition, deaths due nonneoplastic respiratory diseases were elevated, with SMRs ranging from 92 to 628 for five-year time intervals and an overall SMR of 242.

A study conducted by Hayes et al. (5515) on a cohort of 2101 employees (1803 were hourly workers) who worked at a chromium production plant from 1945-74 and who had worked for at least 90 days showed an excess in deaths due to lung cancer. Of a total of 404 deaths (SMR=0.92), 86 died of cancer (SMR=1.02); 59 died of lung cancer (SMR=2.02, significant); 17 died of nonneoplastic respiratory diseases (SMR=0.67); and 9 died of diseases of the genitourinary system (SMR=1.49, nonsignificant). A case-control study showed that the relative risk was significantly elevated for workers in the special products and bichromate departments, where they were exposed to soluble hexavalent chromium compounds. Braver et al. (5516) estimated the cumulative exposures to Cr(VI) in this plant and determined that cumulative exposures of 670 and 354 $\mu g/m^3$-years (hired between 1945-49 and 1950-59, respectively) for short durations were associated with an SMR of 1.8 for lung cancer. Cumulative exposures of 3647 and 2930 $\mu g/m^3$-years (hired between 1945-49 and 1950-59, respectively) were associated with SMRs of 3.0 and 3.4, respectively. According to Braver et al. (5516), there is a potential for excess lung cancer risk at the current permissible exposure limits for Cr(VI) of 52 $\mu g/m^3$, because workers could accumulate exposures similar to those estimated in this study.

Two other studies, one of British workers at three plants (5517) and one of Japanese workers (5518), showed that the death rate due to lung cancer was significantly elevated among workers involved in the manufacture of chromium compounds. The study in British workers also showed that 31 deaths due to chronic bronchitis and 2 deaths due to nasal cancer at one plant were significantly higher than expected (5517). The morbidity rate due to exposure to chromium was also studied in the Japanese workers, but was not found to be significantly increased among workers exposed to chromium (5518). The British workers were engaged in producing sodium chromate from insoluble chromium in chromite

ore and the Japanese workers were engaged primarily in producing Cr(VI) compounds or Cr(III) compounds from Cr(VI) compounds.

Hayes (5519) reviewed data on the association of chromium exposure in the primary chromium production industry and respiratory cancer and concluded that the risks appear to be extremely high and may be specific to this industry, possibly due to exposure to the moderately soluble calcium chromate. He also stated that the workers may be exposed to Cr(III) and Cr(VI) compounds of varying solubilities.

Occupational exposure to chromium compounds occur during electroplating (chromeplating) using chromium trioxide (chromic acid). Several epidemiologic studies have been conducted on mortality rate among chromeplaters. Franchini et al. (5520) studied a cohort consisting 116 hard chromeplaters and 62 bright chromeplaters, with subcohorts based on those with ≤10 years and >10 years of exposure. Franchini et al. (5520) reported average air concentrations were 7 $\mu g/m^3$ near the bath and 3 $\mu g/m^3$ in the middle of the room. Urinary chromium concentrations varied over the years and ranged from 4-116 μg/g of creatinine (1974-76), 1-28 μg/g of creatinine (1977-79) and 1-14 μg/g of creatinine (1980-81) in hard chromeplaters. In bright chromeplaters, the urinary chromium concentrations ranged from 1-16 μg/g of creatinine (1977-79) and 1-9 μg/g of creatinine (1980-81). The mean age of the cohort was 39.9 years and the mean duration of exposure was 13.6 years. Among those with a latency ≤10 years, the observed/expected deaths were 15/15.4 for total deaths, 8/4.2 for malignant neoplasms ($p<0.07$), 3/0.9 for lung cancer ($p<0.06$), and 4/1.4 for gastrointestinal cancer ($p<0.05$). Among those with a latency >10 years, the observed/expected deaths were 12/12.3 for total deaths, 7/3.5 for malignant neoplasms ($p<0.07$), 3/0.8 for lung cancer ($p<0.05$), and 3/1.2 for gastrointestinal cancer (p-value not given). Almost all the total deaths and all the lung cancer deaths occurred among hard chromeplaters. According to Gomes (5521) hard chromplaters use hot chromic acid and may be exposed to high concentrations of its fumes or vapors.

Okubo and Tsuchiya (5522) reported no deaths due to lung cancer among a cohort of 889 Japanese chromeplaters who had worked at least 6 months and were followed up for 5.2 years. Excess deaths (compared with unexposed platers, clerical and unskilled workers) due to all causes were not observed for these workers, but the investigators reported that complete data were obtained for only 70.5% of the cohort and the possibility of misclassifying exposed platers as unexposed was possible. Silverstein et al. (5523) reported an increased proportional mortality rate due to lung cancer among electroplaters (chrome and nickel) and die-casters and no excess deaths due to noncancer causes, whereas Royle (5524) reported a significant increase in the total malignant neoplasms among chromeplaters, but no excess in deaths due specifically to lung cancer or to nonneoplastic causes. According to Hayes (5519) the results regarding an association between exposure to chromium trioxide in the chromeplating industry and respiratory cancer is still inconclusive even though some studies show positive results.

Workers in chromate pigment factories also have higher risk of dying from lung cancer. Langard and Norseth (5525) reported three deaths (only 0.79 were expected using all deaths in Norway for comparison) due to lung cancer among 24 workers who had been employed at a chromate pigment factory for ≥3 years. The workers were exposed mainly

to zinc chromate dust and small amounts of sodium dichromate. The estimated exposure for the workers dying of lung cancer was 0.5-1.5 mg Cr/m^3 for 6-8 years. Frentzel-Beyme (5526) noted excess lung cancer deaths among workers at five factories producing lead and zinc chromates compared with the mortality figures for the regions in which the factories were located. The increased risk was significant for only one factory. Frentzel-Beyme (5526) was not able to associate the increased cancer risk specifically with either lead or zinc chromate. In a study conducted by Davies (5527) on a cohort of 1152 workers at three chromate pigment factories, however, excess deaths due to lung cancer were not noted at the factory producing lead chromate only. In the two factories in which both lead and zinc chromates were produced, significant increases in the number of lung cancer deaths were noted especially among those categorized as having high or medium exposure, indicating that zinc chromate is associated with increased risk of lung cancer. Hayes (5519) stated that it is unclear whether differences in relative solubilities of the insoluble lead chromate and the poorly soluble zinc chromate could account for differences in their carcinogen activity.

A follow-up study on the association between the incidence of cancer or mortality due to cancer and exposure to chromium in the ferrochromium industry was conducted by Langard et al. (5528). A previous study (5529) showed a association between long-term employment in ferrochromium furnaces and lung and prostate cancer, whereas another study did not show an association (5530). The ferrochromium furnace operators were exposed to 0.3-24 mg/m^3 of general dust and 0.04-0.29 mg/m^3 of total chromium. Among ferrochromium workers the number of observed/expected death was 10/6.5 due to lung cancer and 12/7.68 due to prostate cancer. There were also five deaths due to renal cancer, whereas only 1.83 were expected. These deaths were not attributed to exposure to chromium. According to Hayes (5519), exposure to other contaminants occur in this industry, and any excess in respiratory cancer may be due to anyone of a combination of these exposures.

72.3.3.2.2. Health Hazard Studies

The ulcerative properties of chromium compounds, due to the irritating and corrosive properties of hexavalent chromium, have been known for over a hundred years. According to Bidstrup (5531), ulceration of the skin was described in 1827 and ulceration of the nasal mucosal membrane was described in 1863. Since then many studies have been conducted on the medical status of workers exposed to chromium in chromium production plants, chromeplating plants, and the ferrochromium industry. Air concentrations in the breathing zones of workers exposed to chromium vary considerably from levels below to levels considerably above the TLV. Poor personal hygiene has been reported as a problem among chromeplaters. Consequently, self contamination of the upper respiratory tract exacerbates the clinical manifestations of the nasal lesions often seen in these workers, even under conditions in which the air concentrations for chromium are below the TLV. The nasal lesions seen in workers exposed to chromium vary from simple nasal irritation to ulceration and frank perforation of the nasal septum (5531).

The effects of chromium exposure on 97 chromate production workers exposed to chromite ore [Cr(III)] and sodium chromates and dichromates at concentrations up to 1.0 mg Cr/m^3 were described by Mancuso (5532). A number of effects were found to be more

prevalent in exposed workers than in the 37 controls consisting of 33 cement plant workers and 4 office workers at the chromate plant who were exposed to concentrations up to 0.08 mg Cr/m^3. The most frequently observed lesions in chromate workers were nasal perforations (62.9%) and chronic rhinitis (86.6%). Nasal polyps and laryngitis were also seen in chromate workers. Among chromate workers, urinary chromium levels varied from 0 to 38 µg/dL, with an average in production and maintenance workers of 5.1 µg/dL. Urinary chromium levels ranged from 0-3.5 µg/dL in office workers and 0-1.0 µg/dL in cement workers.

In a study by Kleinfeld and Rosso (5533), all nine chromeplaters exposed to chromic acid at concentrations ranging from 0.18 to 1.4 mg CrO_3/m^3 for 0.5-12 months had upper respiratory tract lesions ranging from nasal itching and soreness to septal ulcerations and perforations. Gomes (5521) reported that the frequency of more severe upper respiratory tract lesions was higher in hard chromeplaters who used hot chromic acid compared with the frequency in brilliant chromeplaters who use cold chromic acid. The chromic acid levels were as high as 1.4 mg/m^3. Other findings among these workers included coughing and expectoration, sneezing, rhinorrhea, nosebleed, and pruritus. Self contamination probably contributed to the frequency and severity of the lesions.

In a NIOSH (National Institute for Occupational Safety and Health) health hazard survey, no upper respiratory lesions were found among 32 chromeplaters (20 employed for ≥5 years) who used the cold chromic acid process and were exposed to concentrations ranging from undetectable to 6 µg/m^3 (5534).

Another NIOSH health hazard survey of 37 chromeplaters who used the hot chromic acid process and had been employed from 0.3 months to 11 years revealed nasal lesions ranging from shallow erosions to frank perforations in 35 chromeplaters (5535). Air concentrations in the breathing zones for exposed workers were 7.1 µg/m^3 (total chromium) and 2.9 µg/m^3 [Cr(VI)] compared with 0.1 µg/m^3 (total chromium) and 0.3 µg/m^3 [Cr(VI)] for controls. These data were also reported by Cohen and Kramskowski (5536).

In a more recent study, Lindberg and Hedenstierna (5537) examined 104 chromeplaters (exposed to chromic acid) from 13 different factories and who had been employed from 0.1-36 years (median = 4.5 years) and 138 controls consisting of automobile mechanics and 19 office workers. Three exposure groups were identified: (1) a "low exposure" group, <2 µg Cr(IV)/m^3 as chromic acid only; (2) a "high exposure" group, ≥2 µg Cr(IV)/m^3 ranging up to 20 µg/m^3 as chromic acid only; and (3) mixed-exposure group, 0.2 to 1.7 µg/m^3 of chromic acid and other pollutants. Runny or stuffy nose, "lot of blow out", nosebleed, and "phlegm in the throat" was reported for the high-exposure group and diffuse nasal symptoms for the low-exposure group. Smeary or crusty nasal mucosa, atrophied mucosa, and reddened or swollen mucosa, but no nasal ulcerations or perforations were seen in the low-exposure group. Among workers exposed to high concentrations, a reddened, smeary, crusty or atrophied mucosa, nasal ulcerations, and nasal perforations were seen. Lung function tests showed no short- or long-term effects in the low-exposure group, but significant transient decreased values for FVC, $FEV_{1.0}$, and FEF_{25-75} were seen in the high-exposure group.

One study presented evidence of a possible systemic lesion (hepatic damage) in chromeplaters (5538). The workers had been employed for 6 months to 5 years and were excreting chromium in their urine. Four workers had nasal lesions and four had mild to moderate abnormalities in results of hepatic tests and mild to moderate abnormalities in their liver biopsies. One worker had acute hepatitis with jaundice and histopathological changes similar to toxic hepatitis. These findings have not been reported by other investigators and are, therefore, unconfirmed.

Foa et al. (5539) reported that workers exposed to chromium oxide [Cr(III)] in the ferrochromium industry had urinary chromium values <5 μg/g of creatinine and showed no evidence of renal damage as measured by various clinical tests. Franchini and Mutti (5509), however, reported urinary excretion of renal antigen ((detected by monoclonal antibodies and used as a measure of renal damage) exceeding the upper limit of the controls in 10/43 dichromate production workers. Workers with the higher urinary chromium values had antigen levels more twice the control level. In a study by Haglind et al. (5540), ferrochromium workers were shown to have some evidence of pulmonary dysfunction of the small airways.

Lesions due to dermal contact with chromic acid have been noted among chromeplaters. These lesions are characteristic of dermal contact with chromic acid or chromates and are sometimes referred to as "chrome holes." Gomes (5521) conducted a survey of 303 chrome workers exposed to chromic acid, 35 working with hard chrome, 223 with brilliant chrome, and 45 with chrome brighteners. Cutaneous ulcerations were frequent among all chrome workers, but more frequent among those working with cold chromic acid (brilliant chrome and chrome brighteners) than among those working with hot chromic acid (hard chrome). The cutaneous lesions were small to large painful skin ulcers occurring on the hands, forearms, arms, and feet. Dental lesions were also noted, particularly among the hard chrome workers exposed to vapors of chromic acid.

Markel and Lucas (5534) reported that 2/32 chromeplaters had active chrome ulcers. The lesion was on the finger of one worker and on the foot of another worker who had worn boots saturated with chromate solution. Four workers mentioned past chrome ulcerations or dermatitis. Cohen (5535) found skin ulcers in 5/37 chromeplaters. The ulcers were on the hands and appeared as single or multiple, centrally ulcerated papules that penetrated the underlying soft tissues; the base of the lesion was covered with an exudate or a crust. The ulcers usually occurred 6-12 months after starting work. In a survey of 997 chromeplaters conducted by Royle (5541), the frequency of skin ulcers increased significantly with duration of exposure. The frequency was 6.4% for those exposed <1 year, 21.3% for those exposed for 1-5 years, and 32.0% for those exposed to >5 years.

72.3.3 Levels of Concern

The ambient water quality criteria are 0.05 and 170 mg/L (ingestion of water and contaminated aquatic organisms) and the RfDs are 0.35 and 70 mg/day for hexavalent and trivalent chromium, respectively (5417). EPA (5408) classified chromium VI compounds as Group A by the inhalation route, but data are not available for evaluating the potential carcinogenicity of chromium by the oral route. IARC (5412) classified chromium metal

and chromium III compounds as Group 3 carcinogens and chromium VI compounds as Group 1. The lifetime health advisory is 0.1 mg/L (total Cr) (5414) and the national interim primary drinking water standard (current MCL) for chromium is 0.05 mg/L (total Cr); the proposed MCLG and MCL are both set at 0.1 mg/L (total Cr) (5415). The WHO drinking water guideline is 0.05 mg/L (total Cr) (5416).

EPA (5414) classified hexavalent chromium compounds as Group A (inhalation route); the inhalation slope factor is $4.1E+01(mg/kg/day)^{-1}$ and the inhalation unit risk is $1.2E-05(mg/m^3)^{-1}$.

The OSHA (7000) standards are 1 mg/m^3 (as Cr) for chromium metal, 0.5 mg/m^3 (as Cr) for divalent and trivalent chromium compounds for an 8-hour workshift. For chromic acid (chromium trioxide) and chromates, a ceiling of 0.1 ppm (as CrO_3) has been set.

72.3.4 Hazard Assessment

Trivalent chromium compounds are not biologically available, and therefore appear to pose no threat to human health. Hexavalent chromium compounds, on the other hand, are absorbed from the respiratory and gastrointestinal tracts and can cross biological membranes, where they are readily reduced to the trivalent form. Consequently, hexavalent chromium compounds do pose a threat to human health.

Potassium dichromate in doses of 0.5-0.8 g and chromic acid in doses of 1-2 g are reported to be lethal in humans, but recovery has been claimed after doses as large as 5-15 g. Acute ingestion of chromium compounds causes corrosive effects on the gastrointestinal tract (abdominal pain, vomiting, ulcerations of the esophagus, stomach and duodenum, and decreased peristalsis) and renal failure due to acute renal tubular necrosis. Hepatic and CNS effects have also been reported (5505). Acute or short-term inhalation exposure to chromium compounds affects the upper respiratory tract, lungs, and skin. Asthma and anaphylactoid reactions have also been noted (5507).

Hexavalent chromium compounds are considered to be carcinogenic to humans, resulting in increased mortality due to respiratory cancer (5407, 5412). Epidemiology studies have presented evidence of increased mortality due to respiratory cancer among workers in chromate production plants (5512, 5513, 5515, 5517, 5518), which has been attributed to calcium chromate (5519). Studies of chromeplaters exposed primarily to chromium trioxide have produced conflicting results, but the preponderance of the evidence suggests that increased mortality due to respiratory cancer is not associated with this industry. Increased mortality due to respiratory cancer is associated with the chromate pigment industry in which workers are exposed to lead and/or zinc chromate (5525, 5526, 5527). An association between exposure to chromium in the ferrochromium industry and cancer of the lungs and prostate has been suggested (5529, 5528), but confirmation awaits further evidence.

Nonneoplastic effects due to occupational exposure to chromium is seen primarily in the upper respiratory tract. These lesions occur as simple nasal irritation to mucosal ulceration to frank perforation of the nasal septum (5531). These lesions are characteristic of chromium exposure and have been seen in chromate production workers (5532), but

are most prevalent in chromeplaters (5533, 5535, 5536, 5537). The prevalence and severity of these lesions have been attributed, in part, to poor hygienic practices among workers. Some renal damage has been reported in ferrochromium workers (5539). Characteristic dermal lesions seen among workers handling chromic acid and chromates are painful skin ulcers occurring on the hands, forearms, arms, and feet (5521, 5534, 5541).

Genotoxicity studies have shown that highly soluble and soluble hexavalent chromium compounds are mutagenic and clastogenic, but there is no evidence that poorly soluble or insoluble hexavalent compounds are genotoxic, probably due to biological unavailability. There is conflicting evidence regarding the genotoxicity of trivalent chromium compounds. Metallic chromium fumes may be clastogenic in vivo, but there are no data regarding its mutagenicity (5489). Data regarding developmental toxicity of chromium compounds administered by oral or inhalation routes are not available in the literature, but there is evidence that both hexavalent and trivalent chromium compounds are teratogenic and fetotoxic by parenteral routes (5494, 5493).

72.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of total chromium concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following reagents in the sequence given to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is required for solid samples other than storage at 4° C until sample analysis. All samples should be analyzed within 180 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (5542).

Analytical methods available for analyzing total chromium in water, soils and waste include atomic absorption (Methods 218.1, 218.2 and 218.3) and inductively coupled plasma atomic emission spectrometry (Method 200.7) techniques. Depending upon the analytical method, treatment with acid or a combination of acid with hydrogen peroxide is used to digest the samples. Sample preparation procedures specific to each analytical technique are described in Methods 200.0, 200.7, and 218.3 for aqueous samples (5542) and Methods 3005, 3010, 3020, 3040, and 3050 for solid or waste samples. Quality control samples should be processed with the samples to determine whether analyte losses have occurred during the sample dissolution procedure (5543).

The atomic absorption techniques are probably the most common procedures for determining the concentration of total chromium in water, soil and waste samples. Following the appropriate digestion of the sample, a representative aliquot of the digestate is atomized by either directly aspirating it into a flame or by charring it in a graphite tube furnace. The absorption of hollow cathode or electrodeless discharge lamp radiation at 357.9 nm will be proportional to the total chromium concentration. The detection ranges are 0.5-10 mg/L and 5-100 µg/L for the flame and the furnace atomic absorption techniques,respectively. In a EPA study, sample results using the graphite furnace technique were reproducible to within 0.5% for water samples containing less than 77 µg/L Cr. Recovery ranged from 97-102% in the samples. In an interlaboratory study using 6 synthetic samples, the standard deviation among laboratory results ranged from 28-105% when the direct aspiration flame technique was used. The bias of results when compared to the true values ranged from -3.1 to 37.7% (5542).

EPA has recently approved the use of the inductively coupled plasma (ICP) atomic emission method for determining compliance with existing National Primary Drinking Water Regulations (5546). The technique is based upon the simultaneous or sequential multi-element measurement of atomic emission of trace metals. A preserved and/or digested sample is nebulized to form an aerosol that is introduced into a high temperature plasma where atomic excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma and are dispersed by a grating spectrometer. The line intensities, which are a measurement of elemental concentrations, are monitored by photomultiplier tubes. Optical compensation techniques are used to correct for spectral interferences. In an EPA evaluation of the reproducibility and accuracy of the ICP method, the mean percent relative standard deviation for triplicate analysis of 22 elements was found to be 9%. The mean percent recovery of spiked elements for all waste samples was 93% (5542).

Detection Limit	Method
7 µg/L (aqueous & nonaqueous)	200.7
50 µg/L (aqueous & nonaqueous)	218.1
1 µg/L (aqueous & nonaqueous)	218.2
1 µg/L (aqueous only)	218.3

72.5 REFERENCES

Note: The numbering sequence of the references reflects the order of references as they appear in the master bibliography.

5400. Westbrook, J.H. 1979. Chromium and Chromium Alloys. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Vol. 6, M. Grayson and D. Eckroth, Ed., New York: John Wiley and Sons. pp. 54-82.

5401. Weast, R.C.; Astle, M.J.; Beyer, W.H., Eds. 1988. CRC Handbook of Chemistry and Physics, 69th ed., Boca Raton, FL: CRC Press, Inc.

5402. Hazardous Substances Data Bank (HSDB). 1989. National Library of Medicine, Bethesda, MD.

5403. Windholz, M.; Budavari, S.; Blumetti, R.F.; Otterbein, E.S., Eds. 1983. The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals, 10th ed. New Jersey: Merck and Co., Inc.

5404. Sax, N.I.; Lewis, R.J., Eds. 1989. Dangerous Properties of Industrial Materials, 7th ed., New York: Van Nostrand Reinhold Co.

5405. Hartford, W.H. 1979. Chromium Compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Vol. 6, M. Grayson and D. Eckroth, Ed. New York: John Wiley and Sons. pp. 82-120.

5406. National Institute for Occupational Safety and Health (NIOSH). 1985. NIOSH Pocket Guide to Chemical Hazards. Washington, D.C.: U.S. Government Printing Office. DHHS (NIOSH) Publ. No. 85-114.

5407. U.S. Environmental Protection Agency (U.S. EPA). 1984. Health Assessment Document for Chromium. Final Report. Environmental Criteria and Assessment Office. Research Triangle Park, NC. EPA-600/8-83-014F. PB85-115905.

5408. U.S. Environmental Protection Agency (U.S. EPA). 1988. EPA Cover Sheets for Chromium(VI) and Chromium(III). IRIS (Integrated Risk Assessment Information System), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH.

5409. Gad, S.C.; Powers, W.J.; Dunn, B.J.; et al. 1986. Acute toxicity of four chromate salts. In: Proc. Chromium Symp. 1986: An Update. May 20-21, 1986, D.M. Serrone, Ed. Sponsored and published by Industrial Health Foundation, Inc. Pittsburgh, PA. pp. 43-58.

5410. Shindo, Y.; Toyoda, Y.; Kawamura, K.; et al. 1989. Micronucleus test with potassium chromate(VI) administered intraperitoneally and orally to mice. Mutat. Res. 223:403-406.

5411. Smyth, H.F.; Carpenter, C.P.; Weil, C.S.; et al. 1969. Range-finding toxicity data: List VII. Am. Ind. Hyg. Assoc. J. 30:470-476.

5412. International Agency for Research on Cancer (IARC). 1987. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans: Overall Evaluation of Carcinogenicity: An Updating of IARC Monographs Volumes 1 to 42. Suppl. 7, Lyon, France. pp. 165-168.

5413. National Institute for Occupational Safety and Health (NIOSH). 1975. Criteria for a recommended standard...Occupational exposure to chromium (VI). U.S Department of Health, Education, and Welfare. Public Health Service, Center for Disease Control.

5414. U.S. Environmental Protection Agency (U.S. EPA). 1989. National Primary and Secondary Drinking Water Standards. Proposed Rule. May 22, 1989. Office of Drinking Water, Office for Water and Waste Management. Federal Register 54:22062.

5415. U.S. Environmental Protection Agency (U.S. EPA). 1990. Drinking Water Regulations and Health Advisories. Office of Drinking Water, Office for Water and Waste Management, Washington, D.C.

5416. World Health Organization (WHO). 1984. Guidelines for Drinking-Water Quality: Recommendations. Vol. 1, Geneva. pp. 47-58.

5417. U.S. Environmental Protection Agency (U.S. EPA). 1987. Quality Criteria for Water 1986. Office of Water Regulations and Standards, Washington, D.C. EPA-440/5-86-001.

5418. Cary, E.E. 1982. Chromium in air, soil and natural waters. In: Biological and Environmental Aspects of Chromium. LangÅrd, S., Ed. New York: Elsevier Biomedical Press, pp. 49-62.

5419. Langard, S.; Norseth, T. 1986. Chromium. In: Handbook on the Toxicology of Metals, Vol. II, 2nd ed. Friberg, L.; Nordberg, G.F.; Vouk, V., Eds. New York: Elsevier, pp. 185-205.

5420. McComish, M.F.; Ong, J.H. 1988. Trace metals: chromium. In: Environmental Inorganic Chemistry. Properties, Processes, and Estimation Methods. Bodek, I; Lyman W.J.; Reehl, W.F.; Rosenblatt, D.H.; Walton, B.T.; Conway, R.A., Eds. New York: Pergamon Press, pp. 7.6-1 - 7.6-12.

5421. Papp, J.F. 1989. Chromium. In: Minerals Yearbook. Washington, DC: U.S. Government Printing Office, pp. 215-231.

5422. Agency for Toxic Substances and Disease Registry (ATSDR). 1989. Toxicological Profile for Chromium. U.S. Public Health Service. Chamblee, GA.

5423. Hertel, R.F. 1986. Sources of exposure and biological effects of chromium. In: Environmental Carcinogens Selected Methods of Analysis, Vol. 8. Lyon: International Agency for Research on Cancer, pp. 79-92. IARC Scientific Publications No. 71.

5424. Kabata-Pendias, A.; Pendias, H. 1984. Trace Elements in Soils and Plants. Boca Raton, FL: CRC Press, pp. 1-68, 193-199.

5425. El Bassam, N.; Poelstra, P; Frissel, M.J. 1975. Chrom und Quecksilber in einem seit 80 Jahren mit stadtischen Abwasser Berieselten Boden. A. Pflanzenernaehr. Bodenkd. 3:309. (Cited in 5424)

5426. Beckett, P.H.T.; Davis, R.D.; Brindley, P.; Chem, C. 1979. The disposal of sewage sludge onto farmland: the scope of the problem of toxic elements. Water Pollut. Control 78:419. (Cited in 5424)

5427. Diez, Th.; Rosopulo, A. 1976. Schwermetallgehalte in Boden und Pflanzen nach extrem hohen Klarschlammgaben. Sonderdruck Landw. Forsch. 33:236. (Cited in 5424)

5428. Hemkes, O.J.; Kemp, A.; Broekhoven, L.W. 1980. Accumulation of heavy metals in the soil due to annual dressing with sewage sludge. Neth. J. Agric. Sci. 28:228. (Cited in 5424)

5429. Nriagu, J.O., Pacyna, J.M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333:134-139.

5430. Jorgensen, S.E; Jensen, A. 1984. Processes of metal ions in the environment. In: Methal Ions in Biological Systems. Sigel, H., ed. New York: Marcel Dekker, Inc., pp.61-103.

5431. U.S. Environmental Protection Agency (U.S. EPA). 1985. Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge: Chromium. Washington, DC: U.S. EPA, Office of Water Regulations and Standards, p. 3-2.

5432. World Health Organization (WHO). 1984. Chromium. In: Guidelines for Drinking-Water Quality, Vol. 2. Geneva: World Health Organization, pp. 91-96.

5433. Bloomfield, C.; Pruden, G. 1980. Title not given. Environ. Poll. 23:103-114. (Cited in 5418)

5434. Aller, L.; Bennett, T.; Lehr, J.H.; Petty, R.J. 1985. Drastic: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrologic Settings. Ada, OK: Office of Research and Development, U.S. Environmental Protection Agency, pp. 131-163. EPA 600/2-85/018. PB 85-228146.

5435. Dowdy, R.H.; Bidwell A.M.; Clapp, C.E. 1987. Trace metal movement in an agricultural watershed. International Conference on Heavy Metals in the Environment, Vol. 1., New Orleans, Sept. 1987. Lindberg, S.E.; Hutchinson, T.C., Eds. pp. 384-386.

5436. Robertson, F.N. 1975. Title not given. Ground Water 13:516-527. (Cited in 5418)

5437. Frissel, M.J.; Poelstra, P.; Reiniger, P. 1975. In: The Behaviour of Chromium in Aquatic and Terrestrial Food Chains. Luxembourg, pp.27-42. (Cited in 5418)

5438. Bartlett, R.; James, B. 1979. Behavior of chromium in soils: III. Oxidation. J. Environ. Qual. 8:31-35. (Cited in 5420)

5439. Callahan, M.A.; Slimak, M.W.; Gabel, N.W. et al. 1979. Chromium. In: Water-Related Environmental Fate of 129 Priority Pollutants, Vol. 1. Washington, DC: Office of Water and Waste Management, U.S. Environmental Protection Agency, pp. 10-1-10-10.

5440. Rai, K.; Zachara, J.; Schwab, A.; Schmidt, D.G; Rogers, J. 1984. Chemical Attenuation Rates, Coefficients and Constants in Leachate Migration. Volume 1:A Critical Review, Report EA-3356 to EPRI by Pacific Northwest Laboratories (Battelle Institute), Richland, WA. (Cited in 5420)

5441. Novikov, A.I. 1959. Title not given. Zh. Neorg. Khim. 4:979-983. (Cited in 5418)

5442. Griffin, R.A.; Au, A.K.; Frost, R.R. 1977. Effect of pH on adsorption of chromium from landfill-leachate by clay minerals. J. Environ. Sci. Health A12:431-449. (Cited in 5439)

5443. Cary, E.E.; Allaway, W.H.; Olson, O.E. 1977. Title not given. Agric. Food chem. 25:305-309. (Cited in 5418)

5444. Khan, S.; Nandan, D.; Khan, N. 1982. The mobility of some heavy metals through Indian red soil. Environ. Pollut. (Series B) 4:119-125.

5445. Bartlett, R.; Kimball, J.M. 1976. Behavior of chromium in soils: II. Hexavalent forms. J. Environ. Qual. 5:383-385. (Cited in 5418)

5446. Francis, A.J.; Dodge, C.J. 1987. Anaerobic microbial dissolution of toxic metals from energy residues. International Conference on Heavy Metals in the Environment, Vol. 1., New Orleans, Sept. 1987. Lindberg, S.E.; Hutchinson, T.C., Eds. pp. 427-429.

5447. Baes, C.F.; Mesmer, R.E. 1976. The Hydrolysis of Cations. New York: John Wiley & Sons. (Cited in 5420)

5448. Towill, L.E.; Shriner, C.R.; Drury, J.S.; Hammons, A.S.; Holleman, J.W. 1978. Reviews of the environmental effects of pollutants; III. Chromium. Oak Ridge, TN: Oak Ridge National Laboratory, pp. 12-36. (Cited in 5439 and 5432)

5449. Schroeder, D.C.; Lee, G.F. 1975. Potential transformations of chromium in natural waters. Water, Air, Soil Pollut. 4:355-365.

5450. Shivas, S.A.J. 1980. Factors affecting the oxidation state of chromium disposed in tannery waters. J. Am. Leather Chem. Assoc. 75:42-48. (Cited in 5420)

5451. Birkett, J.D.; Bodek, I.; Glazer A.E. et al. 1988. Description of individual processes. In: Environmental Inorganic Chemistry. Bodek, I.; Lyman, W.J.; Reehl, W.F.; Rosenblatt, D.H.; Walton, B.T.; Conway, R.A., Eds. Now York: Pergamon Press. pp. 2.7-12 - 2.7-13.

5452. Schroeder, H.A.; Balassa, J.J.; Tipton, I.H. 1962. Abnormal trace metals in man: chromium. J. Chron. Dis. 15:941. (Cited in 5424 and 5419)

5453. Bowen, H.J.M. 1979. Environmental Chemistry of the Elements. New York: Academic Press, p. 333. (Cited in 5424)

5454. Mertz W.; Angino, E.E.; Cannon, H.L.; Hambidge, K.M.; Voors, A.W. 1974. Chromium. In: Geochemistry and the Environment. Vol. 1, Mertz, W. Ed. Washington, DC: N.A.S., p. 29. (Cited in 5424)

5455. Petrunina, N.S. 1974. Geochemical ecology of plants from provinces of high trace element contents. In: Problems of Geochemical Ecology of Organisms. Moscow: Izd. Nauka, p. 57. (Cited in 5424)

5456. Mejstrik, V.; Svacha, J. 1988. Concentrations of Co, Cd, Cr, Ni, and Zn in crop plants cultivated in the vicinity of coal-fired power plants. Sci Total Environ. 72:57-67.

5457. National Research Council (NRC). 1974. Chromium. Washington, DC: National Academy of Sciences. (Cited in 5432)

5458. Ruf, J. 1970. Title not given. Zentralbl. Arbeitsmed. Arbeitsschutz 20:11. (Cited in 5419)

5459. Gylseth, B.; Gundersen, N.; Langard, S. 1977. Evaluation of chromium exposure based on a simplified method for urinary chromium determination. Scand. J. Work Environ. Health 3:28-31. (Cited in 5419 and 5474)

5460. Stern, R.M. 1982. Chromium compounds; production and occupational exposure. In: Biological and Environmental aspects of chromium. Langard, S., Ed. New York: Elsevier, pp. 5-47.

5461. Bennett, B.G. 1986. Exposure assessment for metals involved in carcinogenesis. In: Environmental Carcinogens Selected Methods of Analysis. O'Neill, I.K., Schuller, P., Fishbein, L., Eds. Lyon: International Agency for Research on Cancer, pp. 115-127.

5462. Fishbein, L. 1976. Title not given. J. Toxicol. Environ. Health 2:77-109. (Cited in 5419)

5463. National Academy of Sciences (NAS). 1974. Medical and Biologic Effects of Environmental Pollutants. Chromium. NAS, Washingtron, D.C.

5464. Frank, R.; Stonefield, K.I.; Luyken, H.; Suda, P. 1986. Survey of elemental contents in two organs of slaughtered bovine, porcine and avian specimens. Environ. Monit. Assess. 6:259-265.

5465. Pesch, G; Reynolds, B.; Rogerson, P. 1977. Trace metals in scallops from within and around two ocean disposal sites. Mar. Pollut. Bull. 8:224-228.

5466. Marcus, J.M.; Thompson, A.M. 1986. Heavy metals in oyster tissue around three coastal marinas. Bull. Environ. Contam. Toxicol. 36:587-94

5467. Heit, M.; Klusek, C.S. 1985. Trace element concentrations in the dorsal muscle of white suckers and brown bullheads from two acidic Adirondack lakes. Water, Air, Soil Pollut. 25:87-96.

5468. Al-Badri, J.S.; Sabir, S.M.; Shehab, K.M.; Jalil, M.; Al-Rawi, H. 1977. Title not given. Iraqi J. Sci. 18:34-44. (Cited in 5419)

5469. Ministry of Supply and Services. 1979. Guidelines for Canadian drinking water quality. Quebec: Ministry of Supply and Services. (Supporting documentation) (Cited in 5432)

5470. Perrin, D.D. 1981. Ionization Constants of Inorganic Acids and Bases in Aqueous Solutions. IUPAC Chemical Data Series, No. 29. New York: Pergamon Press. (Cited in 5451)

5471. Gordon, A.J.; Ford, R.A. 1972. The Chemist's Companion. New York:John Wiley and Sons. (Cited in 5451)

5472. Eary, L.M.; Rai, D. 1987. Kinetics of chromium(III) oxidation to chromium (VI) by reaction with manganese oxide. Environ. Sci. Technol. 21:1187-1193. (Cited in 5422)

5473. American Conference of Governmental Industrial Hygienists (ACGIH). 1988-89. Threshold Limit Values and Biological Exposure Indices for 1989-1990. Cincinnati, Ohio.

5474. Baselt, R.C., Ed. 1988. Biological Monitoring Methods for Industrial Chemicals. 2nd. ed. Littleton, MA:PSG Publ. Col, Inc. pp. 82-84.

5475. Versieck, J.; Hoste, J.; Barbier, F.; et al. 1978. Determination of chormium and cobalt in human serum by neutron activation analysis. Clin. Chem. 24:303-308. (Cited in 5474)

5476. Kayne, F.J.; Komar, G.; Laboda, H.; Vanderlinde, R.E. 1978. Atomic absorption spectrophotometry of chromium in serum and urine with a modified Perkin-Elmer 603 atomic absorption spectrophotometer. Clin. Chem. 24:2151-2154. (Cited in 5474)

5477. International Agency for Research on Cancer (IARC). 1980. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans: Some Metals and Metallic Compounds. Vol. 23, Lyon, France. pp. 205-323.

5478. U.S. Environmental Protection Agency (U.S. EPA). 1980. Ambient Water Quality Criteria for Chromium. Prepared by Environmental Criteria and Assessment Office. Cincinnati, OH. Prepared for the Office of Water Regulations and Standards, Criteria and Standards Division, Washington, D.C. EPA-440/5080-035. PB81-117467.

5479. U.S. Environmental Protection Agency (U.S. EPA). 1984. Health Effects Assessment for Hexavalent Chromium. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. Prepared for the Office of Emergency and Remedial Response, Washington, DC. EPA-540/1-86-019.

5480. U.S. Environmental Protection Agency (U.S. EPA). 1984. Health Effects Assessment for Trivalent Chromium. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. Prepared for the Office of Emergency and Remedial Response, Washington, DC. EPA-540/1-86-035.

5481. MacKenzie, R.D.; Byerrum, R.U.; Decker, C.F.; Hoppert, C.A.; Langham, R.F. 1958. Chronic toxicity studies II. Hexavalent and trivalent chromium administered in drinking water to rats. Arch. Ind. Health 18:232-234.

5482. Ivankovic, S.; Preussmann, R. 1975. Absence of toxic and carcinogenic effects after administration of high doses of chromic oxide pigment in subacute and long-term feeding experiments in rats. Fd. Cosmet. Toxicol. 13:347-351.

5483. Baetjer, A.M.; Lowney, J.F.; Stefee, H.; Budacz, V. 1959. Effect of chromium on incidence of lung tumors in mice and rats. Arch. Ind. Health. 20:124-135.

5484. Hueper, W.C.; Payne, W.W. 1962. Experimental studies in metal carcinogenesis: Chromium, nickel, iron, arsenic. Arch. Environ. Health 5:445-462.

5485. Steffee, C.H.; Baetjer, A.M. 1965. Histopathologic effects of chromate chemicals. Report of studies in rabbits, guinea pigs, rats, and mice. Arch. Environ. Health 11:66-75.

5486. Nettersheim, P.; Hanna, Jr., M.G.; Doherty, D.G.; Newell, R.F.; Hellman, A. 1971. Effect of calcium chromate dust, influenza virus, and 100 R whole-body X radiation on lung tumor incidence in mice. J. Natl. Cancer Inst. 47:1129-1138.

5487. Glaser, U.; Hochrainer, D.; Klöppel, H.; Oldiges, H. 1986. Carcinogenicity of sodium dichromate and chromium (VI/III)oxide aerosols inhaled by male Wistar rats. Toxicol. 42:219-232.

5488. Lee, K.P.; Ulrich, C.E.; Geil, R.G.; Trochimowicz, H.J. 1988. Effects of inhaled chromium dioxide dust on rats exposed for two years. Fund. Appl. Toxicol. 10:125-145.

5489. De Flora, S.; Bagnasco, M.; Serra, D.; Zanacchi, P. 1990. Genotoxicity of chromium compounds. A review. Mutat. Res. 238:99-172.

5490. Sarto, F.; Cominato, I.; Bianchi, V.; Levis, A.G. 1982. Increased incidence of chromosomal aberrations and sister chromatid exchanges in workers exposed to chromic acid (CrO_3) in electroplating factories. Carcinogenesis 3:1011-1016.

5491. Nagaya, T.; Ishikawa, N. Hata, H. 1989. Sister chromatid exchange analysis in lymphocytes in workers exposed to hexavalent chromium. Br. J. Ind. Med. 46:48-51.

5492. Danielsson, B.R.G.; Hassoun, E.; Dencker, L. 1982. Embryotoxicity of chromium: Distribution in pregnant mice and effects on embryonic cells in vitro. Arch. Toxicol. 51:233-245.

5493. Matsumoto, N.; Iijima, S.; Katsunuma, H. 1976. Placental transfer of chromic chloride and its teratogenic potential in embryonic mice. J. Toxicol. Sci. 2:1-13.

5494. Gale, T.F. 1982. The embryotoxic response to maternal chromium trioxide exposure in different strains of hamsters. Environ. Res. 29:196-203.

5495. Iijima, S.; Matsumoto, N.; Lu, C.-C. 1983. Transfer of chromic chloride to embryonic mice and changes in the embryonic mouse neuroepithelium. Toxicology 26:257-265.

5496. Kobayashi, H. 1976. Toxicological studies on chromium. Acute toxicities of chromium trioxide. Tokyo Toritsu Eisei Kenkyusho Kenkyu Nempo; 27:119-123. (Cited in 5422)

5497. Tandon, S.K.; Saxena, D.K.; Gaur, J.S.; Chandra, S.V. 1978. Comparative toxicity of trivalent and hexavalent chromium. Alterations in blood and liver. Environ. Res. 15:90-99.

5498. Gumbleton, M.; Nicholls, P.J. 1988. Dose-response and time-response biochemical and histological study of potassium dichromate-induced nephrotoxicity in the rat. Fd. Chem. Toxicol. 26:37-44.

5499. Johansson, A.; Robertson, B.; Curstedt, T.; Camner, P. 1986. Rabbit lung after inhalation of hexa- and trivalent chromium. Environ. Res. 41:110-119.

5500. Johansson, A.; Wiernik, A.; Jarstrand, C.; Camner, P. 1986. Rabbit alveolar macrophages after inhalation of hexa- and trivalent chromium. Environ. Res. 39:372-385.

5501. Scheiner, D.M.; Katz, S.A. 1973. Chromium complexes and allergic eczematous chromium dermatitis. Rev. Latinoam. Quim. (Mexico) 3:160-172. (Cited in 5407)

5502. Schwartz-Speck, M.; Grundmann, H.P. 1972. Experimental sensitization of guinea pigs with trivalent and hexavalent chromium. In-vivo and in-vitro reactions. Arch. Derm. Forsch. 242:273-284.

5503. Mor, S.; Ben-Efraim, S.; Leibovici, J; Ben-David, A. 1988. Successful contact sensitization to chromate in mice. Int. Arch. Allergy Appl. Immunol. 85:452-457.

5504. Anwar, R.A.; Langham, R.F.; Hoppert, C.A.; Alfredson, B.V.; Byerrum, R.U. 1961. Chronic toxicity studies III. Chronic toxicity of cadmium and chromium in dogs. Arch. Environ. Health 3:456-460.

5505. Saryan, L.A.; Reedy, M. 1988. Chromium determinations in a case of chromic acid ingestion. J. Anal. Toxicol. 12:162-164.

5506. Schillf, H.; Weidmann, P.; Weiss, M.; Massry, S.G. 1982. Dialysis treatment of acute chromium intoxication and comparative efficacy of peritoneal versus hemodialysis in chromium removal. Miner. Electrolyte Metab. 76:28-35. (Cited in 5505)

5507. Novey, H.S.; Habib, M.; Wells. I.D. 1983. Asthma and IgE antibodies induced by chromium and nickel salts. J. Allergy Clin. Immunol. 72:407-412.

5508. Moller, D.R.; Brooks, S.M.; Bernstein, D.I.; et al. 1986. Delayed anaphylactoid reaction in a worker exposed to chromium. J. Allergy Clin. Immunol. 77:451-456.

5509. Franchini, I; Mutti, A. 1988. Selected toxicological aspects of chromium(VI) compounds. Sci. Total Environ. 71:379-387.

5510. Guthrie, B.E. 1982. The nutritional role of chromium. In: Biological and Environmental Aspects of Chromium, S. Langard, Ed. New York:Elsevier. pp. 118-148.

5511 Hamilton, J.W.; Wetterhahn. K.E. 1988. Chromium. In: Handbook on Toxicity of Inorganic Compounds, H.G. Seiler and H. Sigel, Eds. New York:Marcel Dekker, Inc. pp. 239-250.

5512. Machle, W.; Gregorius, F. 1948. Cancer of the respiratory system in the United States chromate-producing industry. Public Health. Rep. 63:1114-1127.

5513. Brinton, H.P.; Frasier, E.S.; Koven, A.L. 1952. Morbidity and mortality experience among chromate workers. Public Health Rep. 67:835-847.

5514. Taylor, F.H. 1966. The relationship of mortality and duration of employment as reflected by a cohort of chromate workers. Am. J. Public Health 56:218-229.

5515. Hayes, R.B.; Lilienfeld, A.M.; Snell, L.M. 1979. Mortality in chromium chemical production workers: A prospective study. Int. J. Epidemiol. 8:365-374.

5516. Braver, E.R.; Infante, P.; Chu, K. 1985. An analysis of lung cancer risk from exposure to hexavalent chromium. Teratog. Carcinog. Mutag. 5:365-378.

5517. Alderson, M.R.; Rattan, N.S.; Bidstrup, L. 1981. Health of workmen in the chromate-producing industry in Britain. Br. J. Ind. Med. 38:117-124.

5518. Satoh, K.; Fukuda, Y.; Torii, K.; Katsuno, N. 1981. Epidemiological study of workers engaged in the manufacture of chromium compounds. J. Occup. Med. 23:835-838.

5519. Hayes, R.B.. 1988. Review of occupational epidemiology of chromium chemicals and respiratory cancer. Sci. Total Environ. 71:331-339.

5520. Franchini, I.; Magnani, F.; Mutti, A. 1983. Mortality experience among chromeplating workers. Initial findings. Scand. J. Work Environ. Health 9:247-252.

5521. Gomes, E.R. 1972. Incidence of chromium-induced lesions among electroplating workers in Brazil. Ind. Med. 41:21-25.

5522. Okubo, T.; Tsuchiya, K. 1979. Epidemiological study of chromium platers in Japan. Biol. Trace Element Res 1:35-44.

5523. Silverstein, M.; Mirer, F.; Kotelchuck, D.; Silverstein, B.; Bennett, M. 1981. Mortality among workers in a die-casting and electroplating plant. Scand. J. Work Environ. Health 7(Suppl 4):156-165.

5524. Royle, H. 1975. Toxicity of chromic acid in the chromium plating industry (1). Environ. Res. 10:39-53.

5525. Langard, S.; Norseth, T. 1975. A cohort study of bronchial carcinomas in workers producing chromate pigments. Br. J. Ind. Med. 32:62-65.

5526. Frentzel-Beyme, R. 1983. Lung cancer mortality of workers employed in chromate pigment factories. A multicentric European epidemiological study. Cancer Res. Clin. Oncol. 105:183-188.

5527. Davies, J.M. 1984. Lung cancer mortality among workers making lead chromate and zinc chromate pigments at three English factories. Br. J. Ind. Med. 41:158-169.

5528. Langard, S.; Andersen, A.; Ravnestad, J. 1990. Incidence of cancer among ferrochromium and ferro silicon workers: an extended observation period. Br. J. Ind. Med. 47:14-19.

5529. Langard, S.; Andersen, A.; Gylseth, B. 1980. Incidence of cancer among ferrochromium and ferrosilicon workers. Br. J. Ind. Med. 37:114-120. (Cited in 5528)

5530. Axelsson, G.; Rylander, R.; Schmidt, A. 1980. Mortality and tumour incidence among ferrochromium workers. Br. J. Ind. Med. 37:121-127. (Cited in 5528)

5531. Bidstrup, P.L. 1983. Effects of chromium compounds on the respiratory system. In: Chromium: Metabolism and Toxicity, D. Burrows, Ed. Boca Raton, FL:CRC Press, Inc. pp. 31-50.

5532. Mancuso, T.F. 1951. Occupational cancer and other health hazards in a chromate plant: A medical Appraisal. II. Clinical and toxicologic aspects. Ind. Med. Surg. 20:393-407.

5533. Kleinfeld, M.; Rosso, A. 1965. Ulcerations of the nasal septum due to inhalation of chromic acid mist. Ind. Med. Surg. 34:242-243.

5534. Markel, H.L.; Lucas, J.B. 1973. Health Hazard Evaluation/Toxicity Determination Report 72-106-44. Hazard Evaluation Services Branch, Division of Technical Services. National Institute for Occupational Safety and Health. Cincinnati, Ohio. PB229-159.

5535. Cohen, S.R.; Davis, D.M.; Kramkowski, R.S. 1974. Clinical manifestations of chromic acid toxicity: Nasal lesions in electroplate workers. Cutis 13:558-568.

5536. Cohen, S.R.; Kramskowski, R.S. 1973. Health Hazard Evaluation/Toxicity Determination Report 71-118-104. National Institute for Occupational Safety and Health. Cincinnati, Ohio. PB232-740.

5537. Lindberg, E.; Hedenstierna, G. 1983. Chrome plating: Symptoms, findings in the upper airways and effects on lung function. Arch. Environ. Health 38:367-374.

5538. Pascale, L.R.; Waldstein, S.S.; Engbring, G.; Dubin, A.; Szanto, P.B. 1952. Chromium intoxication with special reference to hepatic injury. J. Am. Med. Assoc. 149:1385-1389.

5539. Foa, V.; Riboldi, L.; Patroni, M.; et al. 1988. Effects derived from long-term low-level chromium exposure in ferro-alloy metallurgy. Study of absorption and renal function in workers. Sci. Total Environ. 71:389-400.

5540. Haglind, P.; Bake, B.; Schmidt, A. 1981. Lung function in ferrochromium workers in Sweden. Eur. J. Respir. Dis., Suppl 62, No.113:84-85.

5541. Royle, H. 1975. Toxicity of chromic acid in the chromium plating industry (2). Environ. Res. 10:141-163.

5542. U.S. Environmental Protection Agency (U.S. EPA). 1983. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020.

5543. U.S. Environmental Protection Agency. (U.S.EPA). 1986. Test Methods for Evaluation of Solid Waste. U.S.EPA, SW-846, November 1986, 3rd ed.

5544. Sunderman, W.F., Jr.; Hopfer S.M.; Swift, T. et al. 1989. Cobalt, chromium, and nickel concentrations in body fluids of patients with porous-coated knee or hip prostheses. J Orthopaed. Res. 7:307-315.

5545. National Research Council. 1989. Recommended Daily Allowances. 10th ed. National Academy Press, Washington, D.C.

5546. U.S. Environmental Protection Agency (U.S. EPA). 1988. National Primary Drinking Water Regulations, Analytical Techniques. Federal Register 53:5142-5147.

7000. Occupational Safety and Health Administration (OSHA). 1989. Air contaminants: final rule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7003. Occupational Safety and Health Administration (OSHA). 1989. Hazardous waste operations and emergency response; final rule. 29CFR1910.120, Fed. Regist., 3/6/89, 54:9294-9336.

7004. U.S. Environmental Protection Agency (U.S. EPA). 1989. Notice of issuance of pesticide registration standards. Fed. Regist., 2/22/89, 54:7740.

7009. U.S. Environmental Protection Agency (U.S. EPA). 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT). 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7015. U.S. Environmental Protection Agency (U.S. EPA). 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. U.S. Environmental Protection Agency (U.S. EPA). 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. U.S. Environmental Protection Agency (U.S. EPA). 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. U.S. Environmental Protection Agency (U.S. EPA). 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. U.S. Environmental Protection Agency (U.S. EPA). 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020. U.S. Environmental Protection Agency (U.S. EPA). 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. U.S. Environmental Protection Agency (U.S. EPA). 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7022. U.S. Environmental Protection Agency (U.S. EPA). 1981. Timber products manufacturing point source category. 40CFR429, Fed. Regist., 1/26/81, 46:8285.

7024. U.S. Environmental Protection Agency (U.S. EPA). 1983. Electrical and electronic components point source category. 40CFR469, Fed. Regist., 4/8/83, 48:15394, as revised 1983, 48:45250.

7025. U.S. Environmental Protection Agency (U.S. EPA). 1981. Electroplating point source category. 40CFR413, Fed. Regist., 1/28/81, 46:9467, as revised 1983, 48:43681 and 32483.

7026. U.S. Environmental Protection Agency (U.S. EPA). 1983. Metal finishing point source category. 40CFR433, Fed. Regist., 7/15/83, 48:32485 as revised 1983, 48:41410 and 43682.

7027. U.S. Environmental Protection Agency (U.S. EPA). 1984. Battery manufacturing point source category. 40CFR461, Fed. Regist., 3/9/84, 49:9134 and 13879, as revised 1986, 51:30816.

7028. U.S. Environmental Protection Agency (U.S. EPA). 1985. Nonferrous metals forming and metal powders point source category. 40CFR471, Fed. Regist., 8/23/85, 50:34290, as revised 1986, 51:2884.

7029. U.S. Environmental Protection Agency (U.S. EPA). 1982. Textile mills point source category. 40CFR410, Fed. Regist., 9/2/82, 47:38819.

7030. U.S. Environmental Protection Agency (U.S. EPA). 1987. Organic chemicals, plastics, and synthetic fibers point source category. 40CFR414, Fed. Regist., 11/5/87, 52:42568, as amended 1989, 54:27351.

7031. U.S. Environmental Protection Agency (U.S. EPA). 1982. Petroleum refining point source category. 40CFR419, Fed. Regist., 10/18/82, 47:46446.

7032. U.S. Environmental Protection Agency (U.S. EPA). 1982. Iron and steel manufacturing point source category. 40CFR420, Fed. Regist., 5/27/82, 47:23284, as amended 1984, 49:21032 and 24726.

7033. U.S. Environmental Protection Agency (U.S. EPA). 1974. Ferroalloy manufacturing point source category. 40CFR424, Fed. Regist., 2/22/74, 39:6809 and 17841, as revised 1979, 44:50744.

7034. U.S. Environmental Protection Agency (U.S. EPA). 1982. Leather tanning and finishing point source category. 40CFR425, Fed. Regist., 11/23/82, 47:52870, as revised 1983, 48:30116 and 1988, 53:9182.

7035. U.S. Environmental Protection Agency (U.S. EPA). 1974. Rubber manufacturing point source category. 40CFR428, Fed. Regist., 2/21/74, 39:6662 as revised 1975, 40:2344.

7036. U.S. Environmental Protection Agency (U.S. EPA). 1982. Coil coating point source category. 40CFR465, Fed. Regist., 12/1/82, 47:54244, as revised 1984, 49:33648.

7037. U.S. Environmental Protection Agency (U.S. EPA). 1982. Porcelain enameling point source category. 40CFR466, Fed. Regist., 11/24/82, 47:53184, as revised 1985, 50:36543.

7038. U.S. Environmental Protection Agency (U.S. EPA). 1983. Aluminum forming point source category. 40CFR467, Fed. Regist., 10/24/83, 48:49149, as revised 1984, 49:11631.

7039. U.S. Environmental Protection Agency (U.S. EPA). 1983. Copper forming point source category. 40CFR468, Fed. Regist., 8/15/83, 48:36957 and 50719, as revised 1986, 51:22521.

7047. U.S. Environmental Protection Agency (U.S. EPA). 1985. Intent to list chromium or hexavalent chromium as a hazardous air pollutant. 40CFR61.01, Fed. Regist., 6/10/85, 50:24317.

7049. U.S. Environmental Protection Agency (U.S. EPA). 1989. National primary and secondary drinking water regulations; proposed rule. 40CFR141-143, Fed. Regist., 5/22/89, 54:22062-22160.

7050. U.S. Environmental Protection Agency (U.S. EPA). 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7051. U.S. Environmental Protection Agency (U.S. EPA). 1975. Maximum contaminant levels for inorganic contaminants. 40CFR141.11, 12/24/75, 40:59570, as amended 1980, 45:57342 and 1982, 47:10998 and 1986, 51:11410.

7054. U.S. Environmental Protection Agency (U.S. EPA). 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. U.S. Environmental Protection Agency (U.S. EPA). 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7060. U.S. Environmental Protection Agency (U.S. EPA). 1987. Extremely hazardous substance list and threshold planning quantities. 40CFR355 (SARA Title III Section 302), Fed. Regist., 4/22/87, 52:13395, as revised 1987, 52:48073 and 1988, 53:5574.

7064. U.S. Environmental Protection Agency (U.S. EPA). 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7065. U.S. Environmental Protection Agency (U.S. EPA). 1989. Designation of extremely hazardous substances as CERCLA hazardous substances; proposed rule. 40CFR302, Fed. Regist., 1/23/89, 54:3388.

7066. U.S. Environmental Protection Agency (U.S. EPA). 1989. Reportable quantity adjustments; proposed rule. 40CFR302 and 355, Fed. Regist., 8/30/89, 54:35988.

7067. U.S. Environmental Protection Agency (U.S. EPA). 1985. Burning of waste fuel and used oil fuel in boilers and industrial furnaces. 40CFR266.40, Fed. Regist., 11/29/85, 50:49205.

7068. U.S. Environmental Protection Agency (U.S. EPA). 1989. Waste specific prohibitions - second third wastes. 40CFR268.34, Fed. Regist., 6/23/89, 54:26594.

7069. U.S. Environmental Protection Agency (U.S. EPA). 1988. Identification and listing of hazardous waste; metal smelting operations; final rule. 40CFR261 and 302, Fed. Regist., 9/13/88, 53:35412.

7070. Food and Drug Administration (FDA). 1977. Bottled drinking water standards. 21CFR103.35, Fed. Regist., 3/15/77, 42:14325, as last amended 1984, 49:10090.

7072. Food and Drug Administration (FDA). 1977. Indirect food additives; adhesives and components of coatings. 21CFR175, Fed. Regist., 3/15/77, 42:14534, as revised 42:56728.

7074. U.S. Environmental Protection Agency (U.S. EPA). 1980. Characteristic of EP toxicity. 40CFR261.24, Fed. Regist., 5/19/80, 45:33119, as amended 1981, 46:35247.

7075. U.S. Environmental Protection Agency (U.S. EPA). 1981. Hazardous wastes from non-specific sources. 40CFR261.31, Fed. Regist., 1/16/81, 46:4617, as last amended 1986, 51:6541.

7076. U.S. Environmental Protection Agency (U.S. EPA). 1981. Hazardous wastes from specific sources. 40CFR261.32, Fed. Regist., 1/16/81, 46:4618, as last amended 1988, 53:35420.

7077. U.S. Environmental Protection Agency (U.S. EPA). 1981. Basis for listing hazardous waste. 40CFR261 Appendix VII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:35421.

7078. U.S. Environmental Protection Agency (U.S. EPA). 1980. Discarded commercial chemical products and their hazardous waste numbers. 40CFR261.33, Fed. Regist., 11/25/80, 45:78529 and 78541, as last amended 1988, 53:43881 and 43884.

7079. U.S. Environmental Protection Agency (U.S. EPA). 1981. Hazardous constituents. 40CFR261 Appendix VIII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:43881.

7080. U.S. Environmental Protection Agency (U.S. EPA). 1982. Groundwater protection: concentration limits. 40CFR264.94, Fed. Regist., 7/26/82, 47:32350, as amended 1983, 48:14294.

7082. U.S. Environmental Protection Agency (U.S. EPA). 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7083. U.S. Environmental Protection Agency (U.S. EPA). 1988. Hazardous waste injection restrictions: waste specific prohibitions. 40CFR148.10-16, Fed. Regist., 8/16/88, 53:30908, as amended 1988, 53:41602 and 1989, 54:25422 and 26647.

7084. U.S. Environmental Protection Agency (U.S. EPA). 1988. Waste specific prohibitions - first third wastes. 40CFR268.33, Fed. Regist., 8/17/88, 53:31217.

7085. U.S. Environemntal Protection Agency (U.S. EPA). 1989. Land disposal restrictions for third third scheduled wastes; proposed rule. 40CFR 148,261,264-5,268,271, Fed. Regist., 11/22/89, 54:48372.

7086. Council of European Communities Directive on Drinking Water, 16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7087. Council of European Communities Directive on Bathing Water Quality, 8 December 1975 (76/160/EEC-OJ L31, 5 February 1976, amended by 1851).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7091. Council of European Communities Directive on Groundwater, 17 December 1979 (80/68/EEC-OJ L20, 26 January 1980).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7093. Council of European Communities Directive on Toxic and Dangerous Waste, 20 March 1978, amended by 1851.

7095. Council of European Communities Directive on Classification, Packaging and Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7097. European Economic Community Commission Proposal for a Council Directive on Water Quality Objectives for Chromium. Comm (85) Final, 18, December, 1985.

7102. Council of European Communities Directive on Disposal of Waste Oils, 16 June 1975 (75/439/EEC, OJ L 194, July 25, 1975, p. 23, amended by 387L0101 (OJ L 042, December 2, 1987, p. 43).

7104. Council Directive on the Combating of Air Pollution from Industrial Plants, 84/360/EEC, 228 June 1984.

7105. Council Decision Concluding the Convention for the Prevention of Marine Pollution From Land-Based Sources, 75/437/EEC, 3 March 1975.

7110. U.S. Environmental Protection Agency (U.S. EPA). 1989. Burning of hazardous waste in boilers and industrial furnaces; proposed rule. 40CFR260-1,264-6,270-1, Fed. Regist., 10/26/89, 54:43718.

7113. North Carolina Department of Natural Resources and Community Development. 1989. Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina, 15NCAC 2B.0200-0218, effective 10/1/89.

7114. Vermont Department of Water Resources. 1988. State of Vermont Ground Water Protection Rule and Strategy, Chapter 12:101-710, effective 9/29/88.

7116. Wisconsin Department of Natural Resources. 1988. Wisconsin Chapter NR140, Groundwater Quality, effective 10/88.

7123. West Virginia Water Resources Board. 1989. State of West Virginia Water Quality Standards, effective 4/28/89.

7124. Wisconsin Department of Natural Resources. 1989. Wisconsin Chapter NR105, Surface Water Quality Criteria for Toxic Substances, effective 3/1/89.

COMMON SYNONYMS:	CAS. Reg. No.: 7439-97-6 NIOSH No.: OV4550000 EPA Hazardous Waste No.: U151
Mercury metal and vapor Quicksilver Liquid silver	Chemical Symbol: Hg

REACTIVITY (4200, 4201)

Mercury may explode on contact with 3-bromopropyne, alkynes plus silver perchlorate, ethylene oxide, lithium, methylsilane plus oxygen, peroxyformic acid, chlorine dioxide, and tetracarbonylnickel plus oxygen. It forms explosive products with ammonia and methyl azide. Mercury vapor ignites on contact with boron diiodophosphide. Mercury may also reacts violently with acetylenic compounds, metals (aluminum, calcium, potassium, sodium, rubidium), Cl_2, ClO_2, CH_3N_3, Na_2C_2, and nitromethane. Mercury may react with nitric acid, and hot concentrated sulfuric acid, but not with dilute hydrochloric acid, cold sulfuric acid, or alkalies. Mercury is stable at ordinary temperatures, with no reaction with air, ammonia, carbon dioxide, nitrous oxide, or oxygen. Mercury combines readily with halogens and sulfur and is attacked only by sulfuric acid. It is dissolved by dilute or concentrated nitric acid forming either mercurous or mercuric salts, depending on the conditions.

PHYSICO-CHEMICAL DATA

- Atomic Weight: 200.59 (4201)
- Atomic Number: 80 (4201)
- Group and Valence: Group 2b; 0 (4201)
- Molecular Weight: NA
- Physical State: Heavy metallic liquid (4201)
- Color: Silver-white (4201)
- Odor: Odorless (4203)
- Odor Threshold: NA
- Density: 13.5462 g/cm^3 (20° C) (4204)

PHYSICO-CHEMICAL DATA (Cont.)

• Melting Point: -38.87°C	(4204)
• Boiling Point: 356.58°C	(4204)
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: 2E-03 mm Hg (20°C)	(4201)
• Saturated Concentration in Air: 18 mg/m^3 (24°C)	(4203)
• Solubility in Water: 0.28E-06 mol/L (25°C)	(4203)
• Viscosity: 1.55 mPa·sec (20°C)	(4202)
• Surface Tension: 480.3 dyn/cm (0°C)	(4202)
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No.: 2235-25-8 NIOSH No.: OW3750000 EPA Hazardous Waste No.: ND
Ethylmercuric phosphate Ethylmercury phosphate EMP	Chemical Formula: $CH_3CH_2HgOPO(OH)_2$

REACTIVITY (4200)

Ethylmercuric phosphate emits fumes of Hg and PO_x upon heating.

PHYSICO-CHEMICAL DATA (4200)

- Molecular Weight: 326.65
- Physical State: ND
- Color: ND
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: ND
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 1600-27-7 NIOSH No.: AI8575000 EPA Hazardous Waste No.: D009
Mercuric acetate Mercury acetate Mercury(II)acetate Mercuriacetate Mercuryl acetate Mercury diacetate Mercuric diacetate Diacetoxymercury	Chemical Formula: $Hg(CH_3COO)_2$

REACTIVITY (4201)

If left standing, aqueous solutions of mercuric acetate decomposes yielding a yellow precipitate. It is also sensitive to light. See other mercuric salts.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 318.70	(4201)
• Physical State: Solid, crystals or crystalline powder	(4201)
• Color: White	(4203)
• Odor: Slight acetic or vinegar-like odor	(4201, 4203)
• Odor Threshold: ND	
• Density: 3.270 g/cm^3	(4204)
• Melt Point: 78-100°C; decomposes	(4203, 4204)
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	

PHYSICO-CHEMICAL DATA (Cont.)

- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Soluble in cold water, 25 g/100 mL (10°C); very soluble in hot water, 100 g/100 mL (100°C) (4204)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 7487-94-7 NIOSH No.: OV9100000 EPA Hazardous Waste No.: D009
Mercuric chloride Mercury chloride Mercury(II)chloride Mercury bichloride Mercury perchloride Mercuric bichloride Mercuric dichloride	Chemical Formula: $HgCl_2$

REACTIVITY (4200)

Mercuric chloride forms the explosive mercury fulminate with aci-nitromethanide + acid. It decomposes to emit toxic fumes of Hg when heated.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 271.52 (4201)
- Physical State: Solid, crystals, granules, or powder (4201)
- Color: White (4201)
- Odor: Odorless (4203)
- Odor Threshold: ND
- Density: 5.44 g/cm^3 (25°C); liquid 4.44 g/cm^3 (280°C) (4204)
- Melt Point: 276°C (4204)
- Boiling Point: 302°C (4204)
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: 0.1 mm Hg (100°C); 3 mm Hg (150°C) (4205)
- Saturated Concentration in Air: ND
- Solubility in Water: 6.9 g/100 mL (20°C); 48 g/100 mL (100°C) (4204)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 592-04-1 NIOSH No.: OW1515000 EPA Hazardous Waste No.: D009; P030; D003
Mercuric cyanide Mercury(II)cyanide Mercury dicyanide Dicyanomercury Cianurina	Chemical Formula: $Hg(CN)_2$

REACTIVITY (4200, 4206)

Mercuric cyanide is a friction- and impact-sensitive explosive; it is incompatible with fluorine, magnesium, and sodium nitrite. Mercuric cyanide reacts vigorously, producing flames when gently heated with fluorine. Contact with acids and acid salts may cause immediate formation of toxic and flammable hydrogen cyanide gas. Toxic fumes of Hg, NO_x, and CN^- are emitted upon heating to decomposition. Decomposition may occur on exposure to light.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 252.65 (4201)
- Physical State: Solid, tetragonal crystal or powder (4201)
- Color: Colorless crystals, white powder (4201)
- Odor: Odorless (4201)
- Odor Threshold: ND
- Density: 3.996 g/cm^3 (4204)
- Melting Point: Decomposes at 320° C (4201)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Solubility in Water: Soluble in cold water and hot water, 9.3 g/100 mL (14° C), 33 g/100 mL (100° C) (decomposes) (4204)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 628-86-4 NIOSH No.: OW4050000 EPA Hazardous Waste No.: ND
Mercury fulminate Mercury(II)fulminate Fulminate of mercury (dry)	Chemical Formula: $Hg(CNO)_2$

REACTIVITY (4200)

Mercury fulminate self explodes. It is an explosive sensitive to flame, heat, impact, friction, intense radiation, or contact with sulfuric acid. It emits toxic fumes of Hg and NO_x upon heating.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 284.62	(4204)
• Physical State: Solid, cubic crystals or powder	(4204, 4203)
• Color: White or gray	(4204, 4203)
• Odor: ND	
• Odor Threshold: ND	
• Density: 4.42 g/cm^3	(4204)
• Melting Point: Explodes	(4204)
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temp: ND	
• Vapor Pressure: ND	

PHYSICO-CHEMICAL DATA (Cont.)

- Saturated Concentration in Air: ND
- Solubility in Water: Slightly soluble in cold water, soluble in hot water (4204)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 10045-94-0 NIOSH No.: OW8225000 EPA Hazardous Waste No.:
Mercuric nitrate Mercury nitrate Mercury(II)nitrate Mercury penetrate Nitric acid, mercury(II)salt	Chemical Formula: $Hg(NO_3)_2$

REACTIVITY (4200)

Mercury may form explosive mercury acetylide when reacted with acetylene, explosive mercury fulminate when reacted with ethanol, and unstable explosive product when reacted with isobutene, and explosive mixtures with phosphine, potassium cyanide, and sulfur. It reacts violently with phosphinic acid, hypophosphoric acid, unsaturated hydrocarbons, and aromatics. Mercury reacts vigorously with petroleum. It decomposes upon heating and emits toxic fumes of Hg and NO_x.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 324.66 (4201)
- Physical State: Crystal powder or deliquescent (4201)
- Color: White or slightly yellow (4201)
- Odor: Like nitric acid (4201)
- Odor Threshold: ND
- Density: 4.39 g/cm^3 (4204)
- Freeze/Melt Point: Decomposes (4204)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temp: ND
- Vapor Pressure: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Saturated Concentration in Air: ND
- Solubility in Water: Very soluble in cold water; decomposes in hot water (4204)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 21908-53-2 NIOSH No.: OW8750000 EPA Hazardous Waste No.: D009
Mercuric oxide Mercury(II)oxide Mercuric monoxide Mercuric oxide, red Mercuric oxide, yellow	Chemical Formula: HgO

REACTIVITY (4200)

Red and yellow mercuric oxide are identical chemically, but the red form is less reactive. Explosive reactions can occur when mercuric oxide comes in contact or is mixed with the following: acetyl nitrate (contact), butadiene + ethanol + iodine (35°C), chlorine + hydrocarbons (such as methane and ethylene), metals [such as sodium-potassium alloys (on impact), magnesium (on heating) and phosphorus (on heating or impact)], nonmetals [such as phosphorus (on heating or impact) or sulfur (on heating)], reducing agents (such as hydrazine hydride and phosphinic acid), and hydrogen peroxide + nitric acid (forms explosive mercury(II)peroxide). Violent reactions occur with diboron trifluoride, hydrogen trisulfide, and methanethiol. Vigorous reactions occur with disulfur dichloride and hydrogen peroxide and an incandescent reactions with phospham.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 216.61 (4201)
- Physical State: Solid, crystalline powder or scale (4201, 4205)
- Color: Red when heated, yellow upon cooling; yellow when particles are ≤5 μm and red when particles are >8 μm (4201)
- Odor: Odorless (4201)
- Odor Threshold: NA
- Density: 1.1 (at 4°C); 11.1 (at 20°C) (4204, 4203)
- Melting Point: Decomposes (500°C) (4204)
- Boiling Point: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Practically insoluble, 5.3E-03 g/100 mL (25°C), 3.95E-02 g/100 mL (100°C) (4204)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 7783-35-9 NIOSH No.: OX0500000 EPA Hazardous Waste No.: ND
Mercuric sulfate Mercury sulfate Mercury persulfate Mercury bisulfate Mercury(II)sulfate	Chemical Formula: $HgSO_4$

REACTIVITY (4200, 4203)

Absorption of gaseous hydrogen chloride on mercuric sulfate becomes violent at 125°C. Mercuric sulfate emits toxic fumes of Hg and SO_x upon heating.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 296.70	(4201)
• Physical State: Solid, granules or crystal powder	(4201)
• Color: White	(4201)
• Odor: Odorless	(4201)
• Odor Threshold: ND	
• Density: 6.47 g/cm^3	
• Melting Point: Decomposes	(4204)
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: Nonflammable	(4203)
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Decomposes in cold water	(4204)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No.: 592-85-8 NIOSH No.: XL1550000 EPA Hazardous Waste No.: ND
Mercuric thiocyanate Mercuric sulfocyanate Mercuric sulfocyanide Mercury dithiocyanate Mercury(II)thiocyanate	Chemical Formula: $Hg(SCN)_2$

REACTIVITY (4200, 4203)

Mercuric thiocyanate emits toxic fumes of Hg, NO_x, and SO_x upon heating. See other mercury(II) salts. Thiocyanates may emit highly toxic fumes of cyanide when heated to decomposition or on contact with acid or acid fumes.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 316.75	(4204)
• Physical State: Solid, powder or crystal usually in radially arranged needles	(4201)
• Color: White	(4204)
• Odor: Odorless	(4203)
• Odor Threshold: ND	
• Density: ND	
• Melting Point: 165°C, decomposes	(4203)
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: Nonflammable	(4204)
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	

PHYSICO-CHEMICAL DATA (Cont.)

- Solubility in Water: Slightly soluble, 0.07 g/100 mL (25° C); soluble in hot water; soluble with decomposition in boiling water (4204, 4203)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 10415-75-5 NIOSH No.: OW8000000 EPA Hazardous Waste No.: D009
Mercurous nitrate Mercury protonitrate Mercury(I)nitrate Nitric acid, mercury(I) salt	Chemical Formula: $Hg_2(NO_3)_2$

REACTIVITY (4203)

Mixtures of mercurous nitrate and phosphorus explodes violently when struck with a hammer. Mixtures of mercurous nitrate and carbon decomposes explosively at high temperature. Mercurous nitrate may cause fire if it comes in contact with wood or paper.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 525.19	(4201)
• Physical State: Solid, crystals	(4201)
• Color: Colorless	(4201)
• Odor: Slight odor of nitric acid	(4201)
• Odor Threshold: ND	
• Density: 4.78 g/cm^3	(4201)
• Melting Point: 70°C, with decomposition	(4201)
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Soluble in 13 parts water containing 1% nitric acid	(4201)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

COMMON SYNONYMS:	CAS. Reg. No.: 151-38-2 NIOSH No.: OV6300000 EPA Hazardous Waste No.: ND
Methoxyethyl mercuric acetate Acetato (2-methoxyethyl)mercury	Chemical Formula: $CH_3O(CH_2)_2HgCH_2COOH$

REACTIVITY (4200)

Methoxyethyl mercuric acetate emits toxic fumes of Hg upon heating.

PHYSICO-CHEMICAL DATA (4200)

- Molecular Weight: 318.74
- Physical State: Solid, crystals
- Color: ND
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Soluble in water
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 502-39-6 NIOSH No.: OW1750000 EPA Hazardous Waste No.: ND
Methylmercuric dicyandiamide Cyano(methylmercuri)-guanidine Mercury, (3-cyanoguanidino)methyl- Methylmercury dicyanamide Methylmercuric cyanoguanidine MEMA	Chemical Formula: $CH_3HgCNCNNHNH_2$

REACTIVITY (4200)

Methylmercuric dicyandiamide emits toxic fumes of Hg and NO_x upon heating.

PHYSICO-CHEMICAL DATA (4200)

- Molecular Weight: 298.72
- Physical State: ND
- Color: ND
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Saturated Concentration in Air: ND
- Solubility in Water: ND
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 22967-92-6 NIOSH No.: OW6320000 EPA Hazardous Waste No.: ND
Methylmercury Methyl-mercury (1+) Methylmercury(II) cation Methylmercury ion Methylmercury ion(1+)	Chemical Formula: CH_3Hg^+

REACTIVITY (4200, 4203)

Methylmercury decomposed to emit toxic fumes of Hg upon heating.

PHYSICO-CHEMICAL DATA (4200)

- Molecular Weight: 215.63
- Physical State: ND
- Color: ND
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: ND
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 62-38-4 NIOSH No.: OV6475000 EPA Hazardous Waste No.: P092
Phenylmercuric acetate Phenylmercury acetate (Acetato)phenylmercury Acetoxyphenylmercury Acetoxymercuribenzene Mercuriphenyl acetate PMA	**Chemical Formula:** $C_6H_5HgOOCCH_3$

REACTIVITY (4203, 4206)

Phenylmercuric ions precipitate in the presence of halides. Phenylmercury acetate is incompatible with strong oxidizing agents, strong reducing agents, and strong acids. It decomposes to emit carbon monoxide, carbon dioxide, and toxic fumes of Hg and HgO.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 336.75 (4201)
- Physical State: Crystalline powder, small prisms or leaflets (4203)
- Color: White to creamy white (4203)
- Odor: Odorless (4203)
- Odor Threshold: ND
- Density: ND
- Melting Point: 149°C (4201)
- Boiling Point: ND
- Flash Point: >100°F (4203)
- Flammable Limits: ND
- Autoignition Temperature: ND

PHYSICO-CHEMICAL DATA (Cont.)

- Vapor Pressure: 9E-06 mm Hg (35°C) (4203)
- Saturated Concentration in Air: ND
- Solubility in Water: Slightly soluble, 0.17 g/100 mL (4207)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

COMMON SYNONYMS:	CAS. Reg. No.: 100-56-1 NIOSH No.: OW1400000 EPA Hazardous Waste No.: D009
Phenylmercuric chloride Phenylmercury(II)chloride Phenylmercury chloride Chlorophenylmercury Mercuriphenyl chloride Phenyl chloromercury (Chloromercuri)benzene	Chemical Formula: C_6H_5HgCl

REACTIVITY (4206, 4200)

Phenylmercuric chloride is incompatible with strong oxidizing agents, strong reducing agents, and strong acids. It decomposes to emit carbon monoxide, carbon dioxide, hydrogen chloride gas, toxic fumes of Hg and HgO.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 313.18 (4201)
- Physical State: Solid, satiny leaflets (4201)
- Color: White (4201)
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: 250-252°C (4201)
- Boiling Point: Sublimes (4200)
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Practically insoluble; 1 in 20,000 parts (4201)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4208, 4209)

ELEMENTAL MERCURY:

* 0.5 mg/m^3: any chemical cartridge respirator with cartridge(s) providing protection against the compound of concern, any supplied-air respirator, any self-contained breathing apparatus * 1.25 mg/m^3: any supplied-air respirator operated in a continuous flow mode, any powered air-purifying respirator with cartridge(s) providing protection against the compound of concern * 2.5 mg/m^3: any supplied-air respirator with a full facepiece, any self-contained breathing apparatus with a full facepiece, any supplied-air respirator with a tight-fitting facepiece operated in a continuous flow mode, any chemical cartridge respirator with a full facepiece and cartridge(s) providing protection against the compound of concern, any air-purifying full facepiece respirator (gas mask) with a chin-style or front- or back-mounted canister providing protection against the compound of concern, any powered air-purifying respirator with a tight-fitting facepiece and cartridge(s) providing protection against the compound of concern * 28 mg/m^3: any supplied-air respirator with a half-mask and operated in a pressure-demand or other positive pressure mode * Unknown or IDLH conditions: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode, any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode * Escape: any air-purifying full facepiece respirator (gas mask) with a chin-style or front- or back-mounted canister providing protection against the compound of concern, any appropriate escape-type self-contained breathing apparatus.

INORGANIC MERCURY COMPOUNDS (mercuric chloride, mercuric nitrate, mercuric oxide, mercuric sulfate, mercurous nitrate, mercuric acetate, mercuric cyanide, mercury fulminate, mercuric thiocyanate):

* 0.5 mg/m^3: any air-purifying respirator with a high-efficiency particulate filter, any supplied-air respirator, any self-contained breathing apparatus * 1.25 mg/m^3: any supplied-air respirator operated in a continuous flow mode, any powered air-purifying respirator with a high-efficiency particulate filter * 2.5 mg/m^3: any supplied-air respirator with a full facepiece, any self-contained breathing apparatus with a full facepiece, any air-purifying full facepiece respirator with a high-efficiency particulate filter, any powered air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter, any supplied=air respirator with a tight-fitting facepiece operated in a continuous flow mode

HANDLING PRECAUTIONS (Cont.) (4208, 4209)

* 28 mg/m^3: any supplied-air respirator with a half-mask and operatedsupplied-air respirator with a half-mask and operated in a pressure-demand or other positive pressure mode * Unknown or IDLH conditions: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode, any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode * Escape: any air-purifying respirator with a high-efficiency particulate filter, any appropriate escape-type self-contained breathing apparatus.

MERCURY (ORGANO) ALKYL:

* 0.1 mg/m^3: any supplied-air respirator, any self-contained breathing apparatus * 0.25 mg/m^3: any supplied-air respirator operated in a continuous flow mode * 0.5 mg/m^3: any supplied-air respirator with a full facepiece, any aelf-contained breathing apparatus with a full facepiece, any supplied-air respirator with tight-fitting racepiece operated in a continuous flow mode * 10 mg/m^3: any supplied-air respirator with a half-mask and operated in a pressure-demand or other positive pressure mode * * Unknown or IDLH conditions: any self-contained breathing apparatus with full facepiece and operated in a pressure-demand or other positive pressure mode, any supplied-air respirator with a full facepiece and operated in pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive-pressure mode * Escape: any appropriate escape-type self-contained breathing apparatus.

PERSISTANCE IN THE SOIL-WATER SYSTEM

Mercury constantly cycles through the atmospheric, aquatic, and terrestrial environments. In the atmosphere, mercury is converted to soluble species that are transported to the earth's surface in rain; in soil, the movement of mercury is limited primarily by its sorption to sulfur and organic matter; in water, mercury may undergo various chemical and physical transformations, but biomethylation (aerobic and anaerobic) and bioaccumulation/bioconcentration are the most significant from the standpoint of human and environmental effects.

PATHWAYS OF EXPOSURE

There is evidence that mercury may be taken up from the soil by plants that are part of the human diet; however, primary sources of exposure include: contaminated fish, occupational activities (mining, smelting, refining), and dental amalgams. Groundwater/drinking water is not a significant source of exposure.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure:

Inhalation:

Mercury vapor causes coughing, rales, fever, constriction of the chest and acute pneumonitis.

Oral:

Elemental or metallic mercury is not a toxic hazard by the oral route. Inorganic mercuric salts are corrosive to the gastrointestinal tract and cause damage to the kidneys resulting in a decrease in renal function.

Dermal:

Elemental mercury can cause dermatitis in hypersensitive individuals.

Acute Toxicity Studies:

Inhalation:

TD_{Lo}	44.3 mg/m^3/8h	(mercury)	Human male	(4200)
LC_{Lo}	29 mg/m^3/30h	(mercury)	Rabbit	(4200)

Oral:

LD_{Lo}	29 mg/kg	(mercuric chloride)	Human	(4200)
LD_{Lo}	27 mg/kg	(mercuric cyanide)	Human	(4200)
TD_{Lo}	10 mg/kg	(mercuric cyanide)	Human female	(4200)
LD_{50}	40.9 mg/kg	(mercuric acetate)	Rat	(4200)
LD_{50}	76 mg/kg	(mercuric acetate)	Rat	(4210)
LD_{Lo}	25 mg/kg	(mercuric cyanide)	Rat	(4200)
LD_{50}	26 mg/kg	(mercuric cyanide)	Rat	(4210)
LD_{50}	26 mg/kg	(mercuric nitrate)	Rat	(4200)
LD_{50}	18 mg/kg	(mercuric oxide)	Rat	(4210, 4200)
LD_{50}	23.9 mg/kg	(mercuric acetate)	Mouse	(4200)
LD_{50}	62 mg/kg	(mercuric acetate)	Mouse	(4210)
LD_{50}	33 mg/kg	(mercuric cyanide)	Mouse	(4210)
LD_{50}	25 mg/kg	(mercuric nitrate)	Mouse	(4200)
LD_{50}	16-22 mg/kg	(mercuric oxide)	Mouse	(4210, 4200)

HEALTH HAZARD DATA (Cont.)

Oral (cont.)

LD_{50}	57 mg/kg	(mercuric sulfate)	Rat	(4210, 4200)
LD_{50}	170 mg/kg	(mercurous nitrate)	Rat	(4200)
LD_{50}	297 mg/kg	(mercurous nitrate)	Rat	(4210)
LD_{50}	25 mg/kg	(methoxyethyl mercuric acetate)	Rat	(4200)
LD_{50}	22 mg/kg	(phenylmercury acetate)	Rat	(4200)
LD_{50}	40 mg/kg	(phenylmercury acetate)	Rat	(4211)
LD_{50}	60 mg/kg	(phenylmercury acetate)	Rat	(4211)
LD_{50}	60 mg/kg	(phenylmercuric chloride)	Rat	(4200)
TD_{lo}	1.35 mg/kg	(methylmercury)	Rat	(4200)
LD_{50}	25 mg/kg	(mercuric sulfate)	Mouse	(4200)
LD_{50}	40 mg/kg	(mercuric sulfate)	Mouse	(4210)
LD_{50}	49.3 mg/kg	(mercurous nitrate)	Mouse	(4200)
LD_{50}	399 mg/kg	(mercurous nitrate)	Mouse	(4210)
LD_{50}	20 mg/kg	(methylmercuric dicyandiamide)	Mouse	(4200)
LD_{50}	13 mg/kg	(phenylmercuric acetate)	Mouse	(4211)
LD_{50}	43 mg/kg	(phenylmercury acetate)	Mouse	(4200)

Dermal:

TD_{Lo}	129 mg/kg/5 hr	(mercury)	Human	(4200)
LD_{50}	570 mg/kg	(mercuric acetate)	Rat	(4200)
LD_{50}	41 mg/kg	(mercuric chloride)	Rat	(4200)
LD_{50}	75 mg/kg	(mercuric nitrate)	Rat	(4200)
LD_{50}	315 mg/kg	(mercuric oxide)	Rat	(4200)
LD_{50}	625 mg/kg	(mercuric sulfate)	Rat	(4200)
LD_{50}	2330 mg/kg	(mercurous nitrate)	Rat	(4200)

HEALTH HAZARD DATA (Cont.)

Long-Term Effects:

Mercury: CNS and renal effects
Mercuric chloride, mercuric nitrate, mercuric oxide, mercuric sulfate, mercuric acetate: kidney effects
Methylmercury, methyl mercuric dicyandiamide: CNS effects
Ethylmercuric phosphate: CNS effects
Phenylmercury acetate, phenylmercury chloride, methoxyethyl mercuric acetate: probably kidney effects
Mercurous nitrate, mercuric cyanide, mercury fulminate, mercuric thiocyanate: ND

Pregnancy/Neonate Data:

Ethylmercuric phosphate, methylmercuric dicyandiamide: developmental toxicity
Mercury, mercuric chloride, mercuric nitrate, mercuric oxide, mercuric sulfate, mercurous nitrate, mercuric acetate, mercuric cyanide, mercury fulminate, mercuric thiocyanate, methoxyethyl mercuric acetate, phenylmercury acetate, phenylmercury chloride: ND

Genotoxicity Data:

Genotoxicity data are not sufficient for evaluation for mercury or mercury compounds.

Carcinogenicity Classification:

IARC — No evaluation
NTP — No data
EPA — Group D (not classifiable as to human carcinogenicity) for inorganic mercury (4212)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards

- OSHA (8-hr TWA): Mercury vapor: 0.05 mg/m^3 (as Hg) (skin); Organo mercury, alkyl compounds: 0.01 mg/m^3 (as Hg) (skin)
- OSHA CEILING: Aryl and inorganic mercury: 0.1 mg/m^3 (as Hg) (skin)
- STEL (15-min.): Organo mercury, alkyl compounds: 0.03 mg/m^3 (as Hg) (skin)
- AFOSH PEL (8-hr TWA): Mercury vapor: 0.05 mg/m^3 (as Hg) (skin); Organo mercury, alkyl compounds: 0.1 mg/m^3 (as Hg) (skin)
- AFOSH PEL (15-min. ceiling) Aryl and inorganic mercury (ceiling): 0.1 mg/m^3 (as Hg) (skin)

Criteria

- NIOSH IDLH (30-min): Elemental mercury and inorganic compounds: 28 mg/m^3 (as Hg); Organo and alkyl mercury compounds: 10 mg/m^3 (as Hg)
- NIOSH REL (10-hr TWA): Elemental mercury and inorganic compounds: 0.05 mg/m^3 (as Hg); Organo and alkyl mercury compounds: 0.01 mg/m^3 (as Hg)
- NIOSH STEL (15-min ceiling): Elemental mercury and inorganic compounds: 0.1 mg/m^3 (as Hg); Organo and alkyl mercury compounds: 0.01 mg/m^3 (as Hg)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- ACGIH TLV (8-hr TWA): Alkyl mercury compounds: 0.01 mg/m^3 (as Hg); All forms except alkyl mercury vapor: 0.05 mg/m^3 (as Hg); Aryl and inorganic mercury compounds: 0.1 mg/m^3 (as Hg);
- ACGIH STEL (15-min): Alkyl mercury compounds: 0.03 mg/m^3 (as Hg)

WATER EXPOSURE LIMITS:

Drinking Water Standards (4214)

- NIPDWR: 0.002 mg/L current MCL
- MCL: 0.002 mg/L (proposed)
- MCLG: 0.002 mg/L (proposed)

EPA Health Advisories and Cancer Risk Levels (4215)

- The EPA has developed nonregulatory concentrations of drinking water contaminants that would not result in adverse health effects over specified durations of exposure. The Health Advisories for mercury (as Hg) are as follows:

  — 1-day (child): ND
  — 10-day (child): ND
  — longer-term (child): ND
  — longer-term (adult): 0.002 mg/L
  — lifetime (adult): 0.002 mg/L
  — DWEL (adult): 10 mg/L
  — Cancer Group: D (oral route)

WHO Drinking Water Guideline (4216)

- A health-based guideline value of 0.001 mg/L (as Hg) is proposed for drinking water. A daily per capita consumption of two liters of water was assumed.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

EPA Ambient Water Quality Criteria (4217)

- Human Health
  - Based on ingestion of water and contaminated aquatic organisms, the ambient water quality criterion is 144 ng/L. Based on ingestion of contaminated aquatic organisms alone, the ambient water quality criterion is 146 ng/L

- **Aquatic Life**

  - **Freshwater species**

    Acute toxicity:
    No unacceptable effects if the 1-hr average mercury concentration (as Hg^{2+}) does not exceed 2.4 µg/L more than once every 3 years

    Chronic toxicity:
    No unacceptable effects if the 4-day average mercury concentration (as Hg^{2+}) does not exceed 0.012 µg/L more than once every 3 years

  - **Saltwater species**

    Acute toxicity:
    No unacceptable effects if the 1-hr average mercury concentration (as Hg^{2+}) does not exceed 2.1 µg/L more than once every 3 years

    Chronic toxicity:
    No unacceptable effects if the 4-day average mercury concentration (as Hg^{2+}) does not exceed 0.025 µg/L more than once every 3 years

REFERENCE DOSES:

- **Inhalation:**

  Mercury (inorganic): 3E-04mg/m^3 (4361)

- **Oral:**

  Methyl mercury: 3E-04 mg/kg/day (as Hg) (4218)
  Phenylmercuric acetate: 8E-05 mg/kg/day (4219)

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)
The following mercury compounds have been designated as hazardous substances under the CWA: mercuric cyanide, mercuric nitrate, mercuric sulfate, mercuric thiocyanate, and mercurous nitrate (7015). The reportable quantity (RQ) limit has been set at 0.454 kg (1 lb) for mercuric cyanide, and 4.54 kg (10 lbs) for the remaining mercury compounds (7016). Mercury and mercury compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (7017, 7018). Effluent limitations for effluent containing mercury exist in the following point source categories: inorganic chemicals manufacturing (7019), nonferrous metals manufacturing (7020), steam electric power generating (7021), ore mining and dressing (7023), and battery manufacturing (7027). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)
Mercury is on the list of 83 contaminants required to be regulated under the SDWA Amendments of 1986 (7050). Under the National Interim Primary Drinking Water Regulations, the maximum contaminant level (MCL) is set at 0.002 mg/L for mercury in drinking water. This applies to community water systems (7051). In states with an approved Underground Injection Control program, a permit is required for the injection of mercury-containing wastes designated as hazardous under RCRA (7054).

Resource Conservation and Recovery Act (RCRA)

The following mercury compounds are listed as acute hazardous wastes under RCRA: mercury fulminate (#P065), and phenylmercury acetate (#P092). Mercury is also identified as a toxic hazardous waste (7078). All of the above are also listed as hazardous waste constituents (7079). Brine purification muds (#K071) and wastewater treatment sludge (#K106) from the mercury cell process in chlorine production are listed as specific sources of mercury-containing hazardous waste (7076, 7077). Solid wastes containing mercury are listed as hazardous, in that they exhibit the characteristic defined as EP toxicity, when the TCLP extract concentration

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

of mercury is equal to or greater than 0.2 mg/L (7074). Mercury is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels. Effective August 8, 1990, mercury-containing hazardous waste stream #K071 is prohibited from land disposal or underground injection unless the designated treatment standard or the statutory no migration standard is met. Certain variances for waste stream numbers P092, P065, and K106 exist until May 8, 1990. EPA has proposed land disposal restrictions for these wastes and hopes to have them finalized by this date (see Proposed Regulations section). Site-specific variances can be obtained for soil and debris contaminated with hazardous waste (7068, 7084). Effective August 8, 1990, liquid wastes containing mercury in concentrations greater than or equal to 20 mg/L are prohibited from underground injection (7083). For groundwater protection, the maximum concentration of mercury-containing hazardous waste allowed in groundwater is 0.002 mg/L (7080). Mercury 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 (7082).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

Mercury compounds designated as hazardous substances under CERCLA, and their corresponding reportable quantity limits (RQs) include: mercuric nitrate, mercuric sulfate, mercuric thiocyanate, mercurous nitrate, and mercury fulminate, 4.54 kg (10 lbs); mercuric cyanide and mercury, 0.454 kg (1 lb); and phenylmercury acetate 45.4 kg (100 lbs). Reportable quantities have also been issued for RCRA hazardous waste streams containing mercury, but these depend on the concentration of the chemical in the waste stream (7064). Mercury compounds designated as extremely hazardous substances under SARA Title III Section 302 include: ethylmercuric phosphate, mercuric acetate, mercuric chloride, mercuric oxide, methoxyethylmercuric acetate, methylmercuric dicyanamide and phenylmercury acetate. Under Sections 311 and 312, any facility at which these compounds are present in an amount greater than or equal to 500 pounds or in excess of their threshold planning quantities, whichever is lower, must notify state and local emergency planning officials. The threshold planning quantities are set at 10,000 pounds for ethylmercuric phosphate and 500 pounds for the other mercury compounds. If any of these mercury compounds are released from a facility in excess of their reportable quantities (RQs), local emergency planning officials must be notified (7060). Under SARA Title III Section 313, manufacturers, processors, importers, and users of mercury compounds must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Occupational Safety and Health Act (OSHA)
Employee exposure to mercury aryl and inorganic compounds shall not exceed a ceiling level of 0.1 mg/m^3 at any time during an 8-hour workshift. Employee skin exposure to shall be prevented/reduced through the use of protective clothing and practices. Employee exposure to mercury (organo) alkyl compounds shall not exceed an 8-hour time-weighted average (TWA) of 0.01 mg/m^3, or a 15-minute short-term exposure limit (STEL) of 0.03 mg/m^3 at any time during an 8-hour work-day. Employee skin exposure shall be prevented/reduced through the use of protective clothing and practices. Enforcement of the limits for mercury alkyl compounds are indefinitely stayed until OSHA publishes in the Federal Register a notice that a sampling and analytical technique is available. Employee exposure to mercury vapor shall not exceed an 8-hour time-weighted average (TWA) of 0.05 mg/m^3. Employee skin exposure shall be prevented/ reduced through the use of protective clothing and practices (7000). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate, certain hazardous waste treatment, storage, and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

Clean Air Act (CAA)
Mercury has been designated a hazardous air pollutant under Section 112 of the Clean Air Act (7061). Detailed emission standards, and sampling, monitoring, reporting, and recordkeeping requirements are listed at 40CFR61.50-56. Emissions to the atmosphere from mercury ore processing facilities and mercury cell chlor-alkali plants shall not exceed 2300 grams of mercury per 24-hour period. Emissions to the atmosphere from sludge incineration plants, sludge drying plants, or a combination of these that process wastewater treatment plant sludges shall not exceed 3200 grams of mercury per 24-hour period (7062).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated the following mercury compounds as hazardous materials, subject to requirements for packaging, labeling and transportation: mercuric cyanide, mercuric nitrate, mercuric phenylmercuric acetate (7010).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds, mercury or cadmium compounds, as well as the dumping of oils or 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 (7009).

Food, Drug, and Cosmetic Act (FDCA)
The level for mercury in bottled drinking water is 0.002 mg/L. This level is identical to the maximum contaminant level (MCL) given under the Safe Drinking Water Act (7070).

- **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:

DISTRICT OF COLUMBIA
The District of Columbia has set a human health criterion of 0.0001 mg/L for total recoverable mercury in class D (public water supply) surface waters (7121).

FLORIDA
Florida has set the following water quality criteria for mercury in surface waters: 0.2 μg/L for class I (potable water supply), class III (recreation, fish and wildlife), class IV (agriculture) and class V (navigation, industry) fresh waters; 0.1 μg/L for class II (shellfish) and class III marine waters (7112).

VERMONT
Vermont has a preventive action limit of 1.0 μg/L for mercury in groundwater. The enforcement standard, however, is 2.0 μg/L, the same as the federal MCL (7114).

VIRGINIA
Virginia has a water quality criterion of 0.00005 mg/L for mercury in groundwater (7115).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

WEST VIRGINIA
West Virginia has set a water quality criterion of 0.2 μg/L total mercury concentration in any unfiltered water sample in classes B1 and B3 (warmwater), B2 (troutwater), C (recreation), and A (public water supply) surface waters (7123).

WISCONSIN
Wisconsin has set an acute toxicity criterion of 1.53 μg/L mercury for the protection of aquatic life in surface waters. Wisconsin also has a "wild and domestic animal" criterion of 2.0 ng/L for surface waters to protect animals from adverse effects from ingestion of surface water or aquatic organisms taken from surface water (7124). In addition, Wisconsin has set a preventive action limit of 0.2 μg/L for mercury in groundwater (7116).

WYOMING
Wyoming has a water quality criterion of 0.00005 mg/L for mercury in class III (livestock) groundwater (7120).

Proposed Regulations

- **Federal Programs**

Safe Drinking Water Act (SDWA)
The Environmental Protection Agency (EPA) has proposed a maximum contaminant level (MCL) and a maximum contaminant level goal (MCLG) of 0.002 mg/L for mercury in drinking water. This would apply to community water systems and non-community non-transient (NTNC) water systems. Final action on this proposal is expected by January, 1991 (7049).

Resource Conservation and Recovery Act (RCRA)
EPA has proposed that mercury-containing hazardous wastes #P065 and #P092 and wastewater treatment sludge from the mercury cell process in chlorine production (#K106) be prohibited from land disposal and underground injection, effective May 8, 1990, unless designated treatment standards or the statutory no migration standards are met. Final action on this rule is expected by May, 1990 (7085). EPA has proposed emission rate screening limits for mercury in the burning of hazardous waste in boilers and industrial furnaces. Limits vary as a function of device type and thermal capacity. Final action on this rule is expected by December, 1990 (7110).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
EPA has proposed that the following mercury compounds, listed as an extremely hazardous substances under SARA, be listed as CERCLA hazardous substances: mercuric acetate, mercuric chloride, mercuric oxide, methoxyethyl mercuric acetate, and methylmercuric dicyanamide. Reportable quantities would be set at 4.54 kg (10 lbs) for methylmercuric dicyanamide, and 45.4 kg (100 lbs) for the remaining mercury compounds (7065, 7066).

- **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 1990-91 (7058).

MISSISSIPPI
Mississippi has proposed a water quality criterion of 0.000144 mg/L for mercury in public water supply (PWS) surface waters (7122).

EEC Directives

Directive on Drinking Water (7086)
The mandatory values for mercury in surface water treatment categories A1, A2 and A3 used or intended for abstraction in drinking water are 0.001 mg/L. Guideline values for categories A1, A2, and A3 are 0.0005 mg/L.

Directive on Bathing Water Quality (7087)
There are no mandatory values for mercury or guidelines values. When inspection of the bathing area shows that concentrations of mercury may be present or that the quality of the water has deteriorated, concentrations should be checked by competent authorities.

Directive on Discharge of Dangerous Substances (7088)
Mercury 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 the substances into ground water.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for mercury specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of mercury in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive on Ground Water (7091)
To ensure the effective protection of groundwater in the Community it is necessary to limit the discharge of mercury in groundwater. The purpose of this directive is to prevent pollution of groundwater substances belonging to substances listed in the Annex of this directive. Mercury shall be subject to prior review so as to limit discharge into groundwater. Member states may grant authorization, provided that all technical precautions for preventing groundwater pollution by mercury has been observed.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
The maximum admissible concentration for mercury is 0.5μg/L. No guide level is given.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive on Toxic and Dangerous Wastes (7093)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including mercury and mercury compounds shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such wastes, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Mercury is classified as a toxic substance and is subject to packaging and labeling regulations. Mercury may contain a stabilizer. If the stabilizer changes the dangerous properties of this substance, substance should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

Directive on Plant Protection Products (7096)
Plant protection products containing mercuric oxide and mercurous chloride (calomel), inorganic mercury compounds, alkyl mercury compounds, alkoxyalkyl and aryl mercury compounds may be placed on the market only in cases permitted in accordance with Article 4 of this directive. If it appears necessary, because of an unforeseeable danger threatening plant production which cannot be controlled by other means, such products may be permitted to be marketed and/or used for a maximum period of 120 days.

Directive on Major Accident Hazards of Certain Industrial Activities (7100)
Mercury Fulminate manufacturers are required to notify competent authorities if it is stored or processed in quantities in excess of 10 tons. If a major accident occurs, authorities must be provided with the circumstances of the accident, substances involved, emergency measures taken, and the data available for assessing the effects on man and the environment.

Directive on the Combating of Air Pollution From Industrial Plants (7104)
Mercury and mercury compounds are considered heavy metals and are classified as polluting substances in Annex II of this directive. This directive requires member states to ensure that the types of industrial plans listed in Annex I receive authorization before operation or substantial alteration. Industrial plants which produce or use cadmium or cadmium compounds for its operation must require prior authorization by the competent authorities. An authorization may be issued only when competent authority is satisfied that: (1) all appropriate preventive measures against air pollution have been taken; (2) the use of the plant should not cause significant air pollution, particularly from the emission of substances in Annex II; and all air quality limit values applicable taken into account.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

EEC Directive on Limit Values and Quality Objectives For Mercury Discharges by the Chlor-Alkali Electrolysis Industry (7107)
This directive lays down limit values of emission standards on mercury discharged from industrial plants which produce chlorine by electrolysis alkali chlorides. Member states may only authorize discharges of mercury and its compounds from these plants if they conform to the limit values or quality objectives specified in Annexes I and II of this directive. Authorization must be reviewed every four years. New plants may only receive authorization if the authorizations contains a reference to the standards corresponding to the best technical means available for preventing discharges of mercury.

EEC Directive On Limit Values and Quality Objectives For Mercury Discharges by Sectors Other Than The Chlor-alkali Electrolysis Industry (7109)
This directive regulates mercury from other kinds of industrial processes that the chlor-alkali process. It requires member states to authorize industrial plants to discharge mercury in conformity, at the minimum, with the limit values or quality objectives outlined in Annexes I and II. For multiple sources which are not industrial plants and for which limit values cannot be applied in practice, member states must implement programs to avoid or eliminate mercury pollution as of July 1, 1989. The program must include the most appropriate measures and techniques to be used for the replacement, retention and recycling of mercury.

EEC Directive-Proposed

Proposal for a Council Directive on the Dumping of Waste at the Sea (7099)
EEC has proposed that dumping of mercury and mercury compounds at the sea may be prohibited.

Proposal for a Council Regulation Concerning Export From and Import Into the Community of Certain Dangerous Chemicals (7101)
EEC has proposed that any export of mercuric oxide, mercurous chloride (calomel), other inorganic mercury compounds, alkyl mercury compounds, alkoxyalkyl and aryl mercury compounds on its own or in preparations must be reported by the exporter to a designated authority in the state of export and the state of import. The product must be packaged and labeled in accordance with the Directive on Classification, Packaging, and Labeling of Dangerous Substances.

EEC Directives-Decisions

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7105)
The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials must be eliminated; Part II substances, includes mercury and its compounds which seem less noxious or are more readily rendered harmless by natural processes. Discharges must be subject to approval by representatives of the contracting party.

EEC Council Decision on Marine Pollution By Mercury and Cadmium (7106)
This decision mandates the EEC Community to comply with programs of emission standards, limit values, quality objectives, reference methods of measurement, monitoring procedures and time limits laid down in the PARCOM Decisions by directives 76/464/EEC, 83/513/EEC and 814/156 EEC. It applies to mercury and cadmium discharges by sectors other than the chlor-alkali electrolysis industry.

73.1 MAJOR USES

Mercury is produced in the liquid elemental form and is used predominately in that form and in a variety of amalgams with other metals (4220). In 1989, approximately 49% of the mercury consumed in the U.S. was used (as mercury metal, Zn-Hg and Cd-Hg amalgams, and HgO) in electrical apparatus such as lighting, wiring, and batteries; and about 21% was used (in liquid elemental form) in the manufacture of caustic soda and chlorine by the mercury cell process (4222, 4220). Mercury has been used in paint manufacturing (phenylmercuric acetate), and is used in dental preparations (Sn-Hg and Ag-Hg amalgams), in industrial control instruments (liquid form), and in the production of pharmaceuticals (such as diuretics, antiseptics, and skin preparations), catalysts, bactericides, and fungicides (4220, 4238). The U.S. mine production of mercury, which has been declining, was approximately 1.26×10^6 pounds in 1985 and worldwide production (minus U.S. production) was 13.59×10^6 pounds in 1986 (4222). In 1986 approximately 1.53×10^6 pounds were imported to the U.S. and in 1987 1.40×10^6 pounds were imported (4222).

73.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

Because mercury tends to concentrate in sulfides, it is considered to be a chalcophilic element (4223). Cinnabar (α-HgS), which is 86.2% mercury, is its principal and most common ore (4224). Mercury is also commonly found as metacinnabar (β-HgS), in the uncombined state, and, in small amounts, in other sulfides.

Mercury metal and amalgams, phenyl mercury compounds, HgO, and methylated forms of the metal are of potential environmental significance. The complex environmental chemistry of mercury is attributed to its various oxidation states (0, +1, +2), its propensity to undergo biotic and abiotic methylation, and the volatility of several forms of mercury (4221). Hg^0 (elemental or metallic mercury) exists in a liquid state at ambient temperatures and has a tendency to vaporize; Hg^+ is the mercurous state; Hg_2^{++}, is the intermediate oxidation state consisting of two atoms that have each lost one electron (forms salts such as mercurous chloride or calomel); and Hg^{++}, divalent inorganic or mercuric mercury, forms an array of salts and organic compounds (4225, 4226). Upon release to the environment, most species of mercury can be converted to Hg^{++} (4221). Organic mercury compounds are those in which the mercury atom is covalently linked to at least one carbon atom (4226). The forms, Hg^0, Hg^{++}, and CH_3Hg^+, are responsible for most human exposure to mercury (4226).

Mercury is released into the environment from both natural and manmade sources. Natural sources of mercury consist of the degassing of the earth's crust, volcanic emissions, and evaporation from the oceans (4226). Of these, degassing is the main source, resulting in the release of 25,000-125,000 metric tons a year (4227). An additional 800 metric tons of mercury are released into natural waters from weathering (4228). Some of this may be deposited as sediment, some is probably taken up by the soil. In fresh waters, levels of methylmercury are about 30% of the total mercury (4229, 4230). Anthropogenic sources include industries that use mercury in

manufacturing electrical equipment; facilities that produce chlorine, caustic soda, or biocides; crematoria; dentistry (amalgams); and the burning of fossil fuels (4226).

Using emissions factors and statistics on global production or consumption of industrial goods, Nriagu and Pacyna (4233) calculated the world wide anthropogenic emissions of trace metals to the atmosphere and to water and soil. Total atmospheric emissions of mercury were estimated to be 0.91-6.20 x 10^6 kg/yr mainly from coal combustion and municipal refuse incineration. Total emissions into aquatic ecosystems were estimated to be 0.3-8.8 x 10^6 kg/yr, with major contributions coming from steam electric, chemical manufacturing processes, and atmospheric fallout. Total emissions into soils were estimated to be 1.6-15 x 10^6 kg/yr, with a large part coming from coal and bottom fly ash and atmospheric fallout (4233).

Mercury is transported primarily in the atmospheric environment, where it may persist mainly as Hg^0; however, although both Hg++ and MeHg have been found in the atmosphere. It is converted in the atmosphere to soluble species that are transported to the earth's surface in rain (4226). The "final" deposition of approximately two-thirds of emitted mercury occurs within 200-2000 km of the source (4232). Less than 20% is permanently deposited and the remainder is re-emitted into the atmosphere (4234, 4235).

Andren and Nriagu (4236) calculated the residence times of mercury for the various environmental compartments to be: soils, 1000 years; atmosphere, 11 days; oceans, 2100 years; and sediments, 2.5 x 10^8 years. The atmospheric residence time is apparently lower than previous calculations by other investigators [0.3-2.0 years (4237)]. Figure 1 depicts the cycling of mercury in the environment.

73.2.1 Transport in Soil/Ground-water Systems

73.2.1.1 Overview

Background levels of mercury in the soil are difficult to determine because of widespread pollution (4240). It has been estimated, however, that the mercury content of magmatic rocks is fairly low while levels in sedimentary rocks, argillaceous sediments and in particular, organic rich shales are much higher (40-400 ppb) (4240). These concentrations are generally reflected in the concentrations of mercury in the corresponding soil and aquatic environments. The factors that are most significant in controlling the fate of mercury in the environment are sorption to soils and sediments, biotransformation and methylation/demethylation, and volatilization and photolysis (4221).

73.2.1.2 Sorption on Soils

Mercury, not very mobile during weathering, is strongly sorbed onto soils and sediments, particularly when added to the soil as elemental mercury or as cationic or anionic complexes (4241, 4242, 4243). The processes that are most important to the sorption of mercury are the formation of organomercury compounds that are relatively stable and only slightly mobile in aqueous media (4240, 4221) and the affinity to form

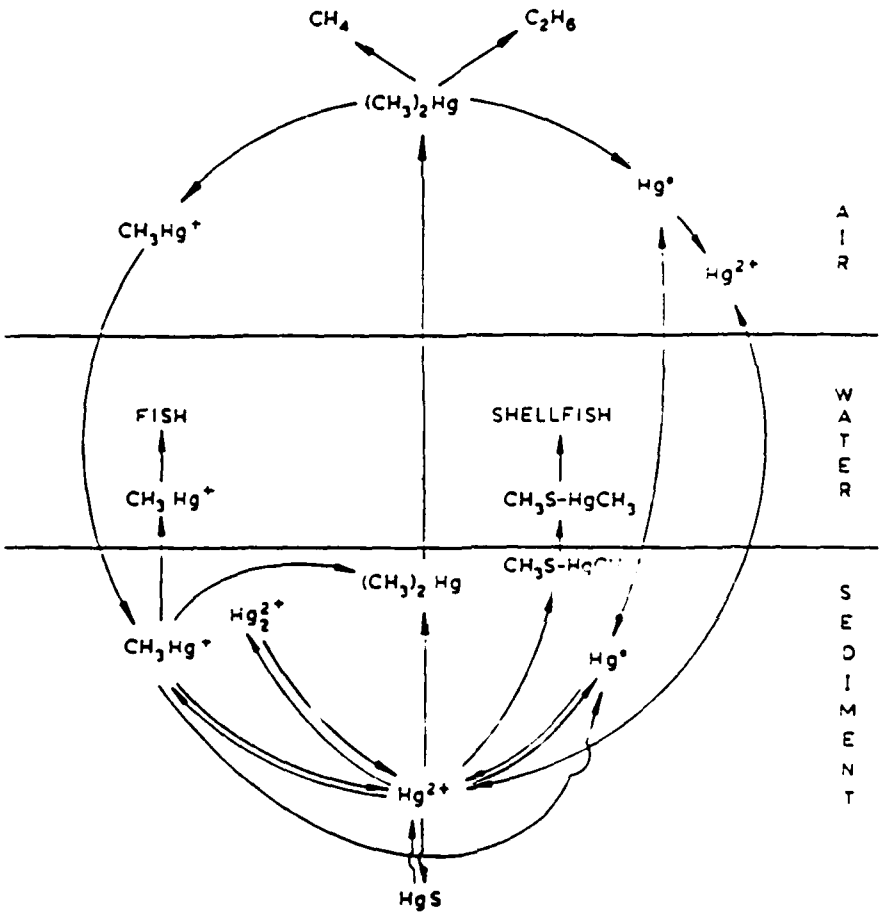


Figure 73-1

The Cycling of Mercury in the Environment

Source: (4232)

strong bonds with sulfur that could result in coprecipitation, with iron sulfides, for example (4240, 4221). Although mercury has an affinity for the sulfhydryl groups in clay as well as those in organic matter, some studies indicate that the sorption of mercury by clays in soil is relatively limited (4240). For methylmercury, the sequence of sorption is as follows: organics>>illite>>montmorillonite>>sand (4244). The results of experimental studies have suggested that $Hg(OH)_2$ is the predominant aqueous species at neutral or higher soil pH (4245) and, according to some sources, is the preferred sorbed species (4246, 4247). The highly stable Hg-Cl appears to be poorly sorbed (4248).

The sorption of mercury is influenced by pH, Cl^-, and dissolved oxygen. Although the effect of pH is not consistent, it appears that the optimal sorption of $HgCl_2$ on organics occurs at pH <5 (4249). The presence of Cl^- apparently decreases sorption on sediments (4244, 4250), peat (4251), and Mn oxides (4246). Increasing dissolved oxygen reduces the sorption of Hg(II) and methylmercury (4251).

Once sorption has occurred, the desorption of mercury is negligible (4252). In an experimental study, 70 hours of agitation with distilled water, resulted in the desorption of less than 1% of Hg^{++} (4252). The process of sorption is rapid and, for inorganic Hg, is 10^3-10^5 times greater than the rate of desorption.

Langmuir constants determined for mercury demonstrate that (a) as the percent of organic carbon and percent of clay in soil increase, the maximum sorption capacity (A_m) also increases (A_m values are 1.6 µmol/g for Asquith soil and 12.3 µmol/g for Oxbow soil); and (b) as the percent of organic matter in sediments increases (0.57-10.78%), the maximum sorption capacity (219.4-463.6 µmol/g) (4253) and the sorption constant (4.3-5.9 log K_L), which is related to the binding energy of the sorbate, increase (4247).

73.2.1.3 Volatilization from Soils

Metallic mercury has a uniquely high vapor pressure, relative to other metals (4225) and there is considerable evidence to demonstrate that mercury is volatilized from soil, water and biota (4254). Sources of atmospheric mercury include vascular plants; non-vascular plants, such as lichens and moss, algae, phytoplankton; the oceanic surface, especially in biologically productive up-welling equatorial locations; various types of mercuriferous and non-mercuriferous soils; and mercury-containing solid waste deposits (4254). In preliminary studies in Canada and Sweden, environmental measurements of vapor phase mercury concentrations over lakes and over nearby land, using a modified concentration gradient technique, revealed consistently and significantly higher concentrations in air over water (3.2-12.0 ng emitted/m^2/hour) than in air over land (0.9-1.4 ng emitted/m^2/hour) (4254). Based on experimental evidence and theoretical considerations that include Henry's Law coefficients, Schroeder and Lindqvist (4254) concluded that elemental mercury and dimethyl mercury [insoluble in water and having a high vapor pressure (4220)] are the principal candidates for volatilization (emission and/or re-emission) into the atmosphere from soil surfaces and from natural waters.

Liquid mercury [vapor pressure 0.0018 mm Hg at 25°C (4255)] is converted in soils to more volatile species making volatilization an even more significant transport mechanism. This occurs more quickly for the soluble species such as $HgCl_2$ and $Hg(NO_3)_2$, than for the less soluble ones such as HgO and HgS (4221), and more quickly in sand and loam than in clay (4256). Callahan et al. (4225) suggest that the methylation of mercury would enhance its volatilization, even though the monomethyl compounds, rather than the non-ionizable dimethyl compounds, are the principal products of biological methylation (4257).

The Henry's law constant for Hg^0 (aq.) has been estimated to be 8.5 atm M^{-1} (4258); the metal is readily lost from aqueous systems at normal temperature. The ratio of the mass transfer coefficient of mercury to that of oxygen is 0.94±0.08 between 0° and 30°C, a value that is higher than that of many common volatiles such as trichloroethylene (0.57), propane (0.72), and ethylene (0.87) (4259).

73.2.2 Transformation Processes in Soil/Ground-water Systems

Once mercury is deposited in soil or water it may undergo a variety of chemical and biological transformations. From the standpoint of human exposure, one of the most important of these transformations is the methylation of mercury by microorganisms, possibly via methylcobalamin (4226, 4232). The transformed mercury is soluble and mobile and is readily bioaccumulated and bioconcentrated by aquatic organisms, increasing in concentration as it rises through the food chain. The highest concentrations can be found in muscle of the most predatory species of fish (4226). Bioconcentration factors, based on the concentration of mercury in the aquatic organism (in ppm of wet weight) divided by the concentration of the element in water (in ppm) have been calculated for the following organisms: marine plants (1000), marine invertebrates (100,000), marine fish (1670), freshwater plants (1000), freshwater invertebrates (100,000), and freshwater fish (1000) (4225).

The biological methylation of mercury can proceed in soil solution and water under aerobic, and to a lesser extent, anaerobic conditions. In the anaerobic environment, mercury is rarely present without the simultaneous presence of hydrogen sulfide, favoring the formation of HgS (4260, 4261). Methylation can result in the remobilization of sorbed mercury (4221). Hg^{++} is the form that is methylated; however, Hg(liquid), phenylmercury, and most other species are available for methylation, because they can be converted to Hg^{++} upon release to the environment (4221). Even HgS, which is least available to methylation because of its insolubility (4220), can be solubilized by certain microbes and eventually methylated (4221).

The rate of biomethylation depends on the concentration of Hg^{++}, the metabolic activity of the bacteria, pH, temperature, redox potential, and organic substrate (4262). The proportions of monomethyl- and dimethylmercury formed are influenced by Hg^{++} concentration and pH. For example, low initial Hg^{++} concentrations and pH $\geq$7 result in dimethyl mercury, while higher initial Hg^{++} concentrations and acidic pH favor monomethylmercury (4285). A pH of approximately 4.5 is ideal for the formation of monomethyl mercury in the laboratory or in sediments (4263).

In addition to microbial methylation, chemical-mediated (abiotic) methylation is also possible (4221, 4231). For example, methyl groups from other compounds (e.g., water-soluble methyl silicon compounds and methyl groups present as contaminants in ethyl-lead compounds) react with Hg^{++} to produce methylmercury. These types of reactions are directly proportional to temperature and Hg^{++} concentration and inversely proportional to pH (where pH is >5) (4256).

A proposed kinetic model has shown that: (a) near neutral pH, monomethylmercury is the main product of methylation; (b) the rate of methylation is higher in aerobic than in anaerobic systems for a given inorganic mercury concentration and microbial growth rate; (c) a higher microbial growth rate produces higher methylation rate under aerobic as well as anaerobic conditions; (d) methylation rates can be reduced by the addition of sulfide to certain anaerobic systems; and (e) temperature influences methylation rate through its effects on the metabolic rate of the organisms (4264).

Biological methylation has been observed in sediments (4257), in the water column in freshwater (4265), in fish intestines (4266), and on fish skin (4267).

Demethylation of methylated mercury compounds has been observed (4268, 4269), complicating the interpretation of methylation data. The process is considered to be fairly widespread and frequent and has been shown to occur in polluted sediments, in marine mammals, and in birds, mink, otter and fish (4232). Compared with methylation, demethylation is a much slower process, occurring only at elevated levels of methylmercury (4260).

Another process, photolysis, appears to be important to the chemical speciation of mercury in the atmosphere and perhaps in the aquatic environment (4225). Various investigators have suggested that dimethylmercury undergoes photolysis to form monomethylmercury (4270, 4271, 4272), and others have suggested the photodecomposition of phenylmercury compounds in the atmosphere and natural waters (4273). Wood (4274) reported that once in the atmosphere, dimethylmercury is photolyzed by UV light to Hg^0 and methyl radicals which can react with hydrogen atoms to form methane or couple to form ethane.

In water, Hg^{++} behaves as an acid and theoretically is hydrolyzed, mainly to $HgOH^+$ at pH 2.2 to 3.8 and to $Hg(OH)_2^0$ at higher pH values (4351). Mercury(I), a weaker acid than Hg^{++}, hydrolyzes to produce small amounts of $Hg_2(OH)^+$ (4275). Hg^{++} forms relatively strong complexes with Cl^- and CO_3^{-2} (4221); this in combination with its strong hydrolysis suggests that the Cl^- complexes and hydrolyzed species are likely to predominate in water under aerobic environmental conditions (4221). Mercury also forms complexes with sulfur (to form HgS) and organics (via sulfhydryl groups and amino groups). Methylmercury forms highly stable complexes with S^{-2} and S-containing ligands.

The three oxidation states of mercury undergo redox reactions with the following equilibrium constants:

REACTION	Log K (25°C)	Source
$Hg^{++} + 2e^- \rightleftarrows Hg_2^{++}$	30.68	4276
$Hg_2^{++} + 2e^- \rightleftarrows 2Hg(liq)$	26.79	4276
$Hg^{++} + Hg(liq) \rightleftarrows Hg_2^{++}$	1.94	4276
$Hg^{++} + 2e^- \rightleftarrows Hg(liq)$	28.86	4277
$\frac{1}{2}Hg_2^{++} + e^- \rightleftarrows Hg^0$	6.93	4277
$Hg^{++} + 2e^- \rightleftarrows Hg^0$	22.34	4277

73.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

There is evidence to support the possibility that mercury, taken up from the soil by edible plants, could be directly ingested by humans or could enter the food chain, undergoing bioconcentration. Experimental studies have shown that plants readily take up and translocate mercury from solution and soil (4240). In plants for which the soil was the only source of mercury, the rate of mercury accumulation was highest for roots, and then leaves and grains (4253, 4278, 4279). In addition, plants directly absorb mercury vapor (4240).

Background levels of mercury in vegetables and fruits vary from 2.6 to 86 ppm dry weight (DW) and from 0.6 to 70 ppm fresh weight (FW) (4240). Food plants in which mercury levels were measured include alfalfa (39 ppb, FW); grass and feed legumes (100 ppb or less, DW); cereals (0.9 to 21 ppb, DW); grains from land where mercuric compound dressings of seeds were used (up to 170 ppb, DW) (4240). Mercury levels in plants may vary with location (plants grown in contaminated sites may accumulate higher than normal levels), species (lichens, carrots, lettuce, and mushrooms tend to take up more mercury than other plants grown at the same site), and parts of plant (apple flesh and apple pips absorb more mercury than other parts) (4240). Mercury also accumulates in lichens and moss, and more than 10 μg Hg/g was measured in edible fungi in the vicinity of chloralkali plants (4280) and in a city center (4282).

Mercury levels are biomagnified within terrestrial food chains, where carnivores>omnivores>herbivores, with fish-eating animals generally having the highest levels (4283). However, documented incidents of mercury poisoning in wild mammals are rare, either because it doesn't occur or because we just haven't observed it. In a

review of the literature on mercury levels in wild animals, levels of mercury detected in mammalian species were less than 100 µg/g wet weight, and most were even less than 1.0 µg/g (4283). Consistently high levels were observed among otters, ranging from less than 1 to 98 µg/g, depending on tissue sampled and location of the animals. Deer, the only animals studied that could be included in the human diet exhibited very low tissue levels of mercury. Bennett et al. (4284) estimated that the mean concentration of mercury in food other than fish is 0.004 µg/g.

Magos (4281) reviewed the literature on mercury exposure and toxicity and concluded that, except for the misuse of seeds dressed with mercurial fungicides, the daily intake of mercury from terrestrial food is negligible. In Sweden, for example, only about 5 µg Hg/day was attributed to terrestrial sources compared with 0-800 µg/day attributed to fish and marine products (4355). Bennett et al. (4284) also estimated the daily intake of mercury in foods other than fish to be 5 µg.

The mobility of mercury in soils is minimal and leaching of the metal through the soil to groundwater in not likely, except in soils where the mobility of mercury may be enhanced by leachates from municipal landfills (4286). In groundwater surveys, mercury levels of greater than 0.5 µg/L were found in 15-30% of wells tested (4288). In another survey, monitoring data revealed that 204,490 individuals were exposed to mercury in drinking water at concentrations of >2 µg/L (the current MCL), and of these 836 were exposed from a groundwater supply which contained 100 µg Hg/L (4239). Generally, however, drinking water is generally considered to be a minimal source of exposure to mercury (4239).

73.2.4 Other Sources of Human Exposure

The major pathway of mercury to man is through the ingestion of aquatic organisms, especially fish (4231). Fish, depending on size, can contain 10-1500 ng of Hg/g, as methylmercury (4289). Even higher levels of the metal have been observed in fish from lakes into which chloroalkali plants have released mercury (4290).

Specific examples for the concentrations of mercury measured in various fish are as follows: (a) white suckers (Catostomus commersoni), dorsal muscle, 1.2 µg/g dry weight (4291); (b) brown bullheads, 1.3 µg/g dry weight (4291) [fish from (a) and (b) were from two lakes known to have elevated surface concentrations of mercury in their sediments]; (c) eel liver, 6.25 to 25.57 µg/g dry weight (the eels were from a typical Dutch Polder Lake) (4292).

The estimated average intake rate for mercury via the ingestion of fish is approximately 10-12 µg/day (4284, 4293).

Mercury contamination of human milk has been associated with the ingestion of contaminated fish in instances of mercury poisoning in Japan in 1953 and 1970 and in Iran in 1971-1972 (4294). Levels in human breast milk of people living in Minimata, Japan, averaged 63 µg/L in 1968 and 500-540 in 1973 (4295), while levels in the milk of women in Iran averaged 29 µg/L (4296). In contrast, "unexposed" women in the U.S. had breast milk levels of 0.9±0.2 µg/liter (4297) and Japanese women had levels of 3.6

µg/L (4295). The higher levels in the milk of the Japanese women was attributed to their higher rate of fish consumption. These data indicate that women in the United States have safe levels of mercury in breast milk (levels >4 µg/L are thought to exceed the safe intake level for an infant) (4294).

Additional estimates have been made relating dietary intake of mercury and fish consumption in other high-risk locations: United Kingdom fishing community, 4-443 µg Hg/70 kg man/week (fish consumption, 10-225 g/day); Australia, 140 µg Hg/person (assumed)/week (fish consumption, 140 g/day); and Greenland, high exposure area, 2.39 mg/week (high rate of seal consumption).

The inadvertent consumption of bread made from alkylmercury-contaminated grain or by eating the meat of farm animals accidentally fed on such grains are recognized sources of exposure (4299, 4300). However, the use of mercury for agricultural purposes (particularly in seed dressings) and the direct industrial discharges of mercury into the environment have been reduced in North America and parts of Europe (4231, 4283).

In a monitoring study, background levels of mercury were measured in tissues from the carcasses of livestock (4301). Mercury concentrations in bovine muscle (7.8-16 µg/kg) did not change significantly with age over ~6 years; likewise, there were no age-related increases in kidney levels (18-28 µg/kg). In porcine carcasses, levels of 6.5 and 13 µg/kg, for muscle and kidney, respectively, were detected. Levels of mercury were measured in poultry carcasses obtained from several locations in Ontario. Muscle concentrations were 16 µg/kg in chickens both under and over 14 week old chickens, while liver concentrations were 21 and 20 µg Hg/kg
for chickens under and over 14 week old, respectively,

There is no evidence that excessive exposure to mercury would occur during the use of surface waters for drinking or recreational purposes (4293; 4239). Drinking water from several Canadian provinces contained approximately 0.0002 mg/liter (median) (4302). It is possible that mercury cocentrations in ambient waters may be signficantly reduced by conventional treatment processes with further losses occurring during the preparation of beverages. WHO (4227) estimated that the daily intake of mercury from drinking-water would not normally exceed 0.1 µg.

Occupational exposures are currently almost completely restricted to inorganic mercury, of which mercury vapor is the most important. The legal limit in the U.S. is 100 µg/m^3, but lower levels have been recommended (4226). The major occupational sources of exposure are mining, smelting, and refining and the use of liquid mercury (4281). The manufacture and repair of various mercury-containing products and on-job broken instruments are sources of exposure to high concentrations of mercury vapor (4281). Jewelers, dentists, and laboratory workers are generally exposed to elemental mercury, but exposure to organomercurials can occur during laboratory synthesis of various chemicals (4281). Exposure to inorganic and organic mercurials can occur during the manufacture of fungicides, explosives, pigments, catalysts, and pharmaceuticals. The use of mercury in the production of mirrors is now limited to

some fine optical equipment, and the use of mercuric nitrate in the felt-hat industry has declined considerably (4359, 4224).

Other sources of human exposure include medical and medicinal uses [many of which are declining; however, dental amalgams are thought to be a major source (4226)]; domestic use (broken thermometers, baromerter, old mirrors, etc. are sources of mercury vapor exposure); and foods other than fish (concentrations are usually less than 50 ng/g) (4281).

The approximate mean concentrations of mercury in ambient air has been estimated to be 7 ng/m^3 and the intake rate for the inhalation of mercury is an estimated 0.14 µg/d (4284). Levels in urban and industrial areas are higher than in rural areas (4239). The U.S. EPA (4237) indicated that atmospheric concentrations are unlikely to exceed average values of 50 ng/m^3.

73.2.5 Biological Monitoring

Mercury is not a nutritional element; therefore, its presence in the body does not serve a beneficial purpose. Blood mercury levels may be 6 µg/L in individuals with low consumption of fish, 50 µg/L in individuals with moderate consumption of tunafish and 200 µg/L in individuals consuming large quantities of predatory marine fish (4317). About 95% of mercury in whole blood is found in RBCs, almost all of which is methylmercury (4360). Mercury in hair correlates well with exposure to methylmercury, because the concentration in in hair reflects the blood concentration at the time the hair was formed and it remains stable in hair for may years (4227, 4226). Consequently, hair could be an ideal means of monitoring exposure to methylmercury (4226). Fecal excretion is the primary route for eliminating methylmercury (4227); therefore, urinary mercury is not an effective means for monitoring exposure to methylmercury. The concentration of total mercury (or a specific derivative) in whole blood is used monitor exposure to methylmercury and other organo mercury compounds (4317). For measuring exposure to mercury vapor or inorganic mercury compounds, the urinary or blood mercury level is considered to be an good means for monitoring exposure (4317). ATSDR (4238) summarized methods for analyzing mercury in blood and urine.

73.3 HUMAN HEALTH CONSIDERATIONS

73.3.1 Animal Studies

Numerous studies are available on the effects of mercury and mercury compounds in humans. These studies focus on the routes of exposure that cause effects by the different compounds. For example, studies regarding elemental mercury focus on the inhalation route, inorganic and organic (alkyl) mercuric salts focused on the oral route. Because these studies are available and are sufficient for evaluating the health effects of mercury and mercury compounds in humans, studies in laboratory animals are not emphasized in this report.

Numerous reviews on the health effects of mercury and mercury compounds can be found in the literature. Some additional information may be found in the following sources: 4227, 4238, 4239, 4287, 4304, 4348.

73.3.1.1 Carcinogenicity

A 2-year study conducted by Fitzhugh et al. (4305) did not show neoplastic lesions in rats administered phenylmercuric acetate or mercuric acetate. Other long-term studies are not available for evaluating the carcinogenicity of mercury and mercury compounds in laboratory animals.

73.3.1.2 Genotoxicity

No data are available regarding the mutagenicity of mercury and mercury compounds in bacteria. A significant increase in chromosome abnormalities was observed in cats exposed to methylmercury (4306). A positive correlation was observed in the frequency of chromosome breaks and methylmercury concentration in blood of Swedish subjects on a fish diet (4307).

73.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Mercuric chloride administered orally to pregnant Syrian hamsters at 4-100 mg/kg as a single dose caused increased resorptions at 35 mg/kg, but no teratogenic effects (4308). Methylmercury compounds have been shown to be fetotoxic in mice. In rats, methylmercury administered to the dams during pregnancy causes CNS toxicity in the offspring manifested by behavioral abnormalities and defects in learning ability (4238).

73.2.1.4.1 Short-term Toxicologic Effects

Elemental mercury is very poorly absorbed from the gastrointestinal tract; therefore, it should not be toxic by this route in laboratory animals. According to WHO (4227) the LD_{50}s for laboratory animals lie between 10 and 40 mg/kg. According to WHO (4227), any form of mercury compound in high acute doses can cause damage in tissues, because mercury denatures proteins and, therefore inactivate enzymes causing disruption of cellular processes in any tissue which mercury comes in contact in sufficiently concentrations.

The effects of acute exposure to mercury compounds are shock, cardiovascular collapse, acute renal failure, and severe gastrointestinal damage (4227). Inorganic mercuric salts do not efficiently cross the blood-brain barrier and are not considered neurotoxicants. The nervous system is the main target for alkylmercury compounds. Both inorganic and organic mercury compounds can cause damage to the kidney. Rats are more sensitive to induction of kidney damage than to induction of nervous tissue damage; methylmercury has been shown to induce morphological and functional kidney damage at doses causing no signs of neurological dysfunction (4227, 4239).

Mercury vapors are absorbed by the respiratory tract in laboratory animals. Nervous system effects are seen; rabbits exposed to 4 mg Hg/m^3 for 6 hr/day, 4 days/week for 13 weeks develop fine tremors and clonus in the fore- and hind limbs, but morphological damage was not observed (4309).

73.3.1.4.2 Subchronic and Chronic Toxicity

Phenylmercuric acetate and mercuric acetate were administered orally to rats for 2 years (4305). Doses of phenylmercuric acetate ranged from 0.005-8.0 mg/kg/day. Phenylmercuric acetate caused kidney damage in females at 0.025 mg/kg and in males at 0.125 mg/kg. Mercuric acetate caused kidney damage at 2 mg/kg.

Prolonged exposure to methylmercury at doses of 0.01 mg/kg/day for 11 months (cats), 0.45 mg/kg/day for 83 days (cats), 0.6-2.4 mg/kg/day for 8 weeks (rats), or 1 mg/kg/day for 11 weeks (rats) caused both behavioral and pathological changes in nervous tissue (4310, 4311, 4312, 4313, 4314). Methylmercury (0.05 mg/kg/day) fed to newborn cynamologous monkeys for 3-4 years caused impaired spatial vision at high and low luminescence (4315).

73.3.2 Human and Epidemiologic Studies

73.3.2.1 Short-term Toxicologic Effects

The acute toxic effects of mercury depends on the type of mercury compound and the route of exposure.

73.3.2.1.1 Oral Exposure

Elemental mercury is very poorly absorbed from the gastrointestinal tract (about 0.01%) and is eliminated almost entirely in the feces (4281, 4304, 4316). Therefore, ingestion of elemental mercury is of extremely low toxicologic significance (4211, 4304). A 200-g dose caused no adverse effects in a 2-year old child and large amounts ingested by adults were without significant effects (4211).

Inorganic mercuric salts are absorbed more efficiently from the gastrointestinal tract than elemental mercury. Absorption depends upon the solubility of the compound and has been estimated to be 2-20% of the ingested dose (4281, 4303, 4304, 4316). About 2% of ingested mercuric chloride is absorbed, but absorption may be higher at larger doses due to the corrosive action of the compound (4304). After absorption, inorganic mercuric compounds are converted to mercuric ions; consequently, all have similar distribution patterns, being taken up by kidney, liver, spleen, skin, testes, and some parts of the brain. These compounds are predominately taken up by the kidneys and accumulated in the proximal convoluted tubules of the renal cortex and excreted primarily into urine and feces (4316, 4304).

Acute lethal doses range from 1-4 g for inorganic mercuric salts (4304) and 0.2-1.0 g for mercuric chloride, specifically (4323). Inorganic mercuric salts cause corrosion of the gastrointestinal tract (mouth, esophagus, and stomach) resulting in pharyngitis,

dysphagia, abdominal pain, nausea, vomiting, bloody diarrhea due to the corrosive action of the compounds on the intestinal mucosa. After ingesting high doses, shock and peripheral vascular collapse followed by death occur as a result of loss of fluids and electrolytes. In less severe cases, a second phase of toxicity is manifested by delayed effects that include swelling of the salivary glands, stomatitis, gingivitis, inflammation of the gastrointestinal tract, and distended and tender abdomen. The kidneys are the primary target for inorganic mercuric salts in those surviving gastrointestinal damage. Effects on renal function are manifested by the occurrence of oliguria, anuria and uremia due to necrosis of the proximal tubular epithelium (4316, 4224, 4304, 4303). Stokinger (4224) also stated that hepatitis is a consequence of ingesting inorganic mercury salts (4224).

Samuels et al. (4323) reported that a 19-month old boy ingested an unknown amount of mercuric chloride powder and showed early symptoms of vomiting followed by blistering of the lips and tongue. Two days after ingestion, the patient became anuric; this condition persisted for 10 days. The blood mercury level was 1920 ng/mL day 2 after ingestion and 505 ng/mL on day 8. After blood mercury levels started to decrease, the urinary mercury level increased to 2349 ng/mL. Nineteen months after ingestion the mercury levels were 5 ng/mL in blood, 7 ng/mL in urine, and 500-900 ng/g in hair. Stack et al. (4318) reported very little renal damage, but extensive local ulceration in a 23-month old child who ingested mercuric chloride powder. The initial blood and urine mercury levels were 4.5 and 30.4 mg/L, (4500 and 30,400 ng/mL) respectively. This patient received very early medical treatment. In addition, intraperitoneal lavage with mercuric chloride solutions after some surgical procedures has resulted in acute renal failure and even to death in some patients (4319, 4320).

Inorganic mercurous salts are less soluble than mercuric salts and are less corrosive and less toxic. Absorption from the gastrointestinal tract is very low and as a result, systemic toxicity is rare (4316, 4303).

Short-chain alkyl mercury compounds (methylmercury or ethylmercury) are absorbed by >90% from the gastrointestinal tract. Methylmercury is retained for long periods after ingestion. Miettinen (4321) reported that only about 6% of radiolabeled methylmercury bound to fish protein was excreted during the first 4 days after being ingested by human volunteers. Urinary excretion was very slow with only 20% appearing in urine 100 days after ingestion. The biological half-time was 76 days. Two weeks after ingestion, about 7% of the body burden was in the red blood cells, and the half-time for elimination from this fraction was about 50 days. Methylmercury is secreted into bile and eliminated primarily in feces. Part of the methylmercury can be reabsorbed from the intestines and the remainder is converted to inorganic mercury by bacteria before elimination (4226). Because it easily crosses membranes, tissue distribution of methylmercury is fairly uniform (4239). However, approximately 10% of an ingested dose of radiolabeled methylmercury appear in the head region (4354), probably taken up by the brain and accounting for the CNS being the principal target for methylmercury. Methylmercury can also be converted to inorganic mercury in various organs in the body, but not in the brain, where 95% remains unconverted (4304). According to Inskip and Piotrowski (4322) between 3-5% of the body burden

of methylmercury is in the brain. Methylmercury is also incorporated into hair, where it remains for years (4226).

According to Berlin (4304) there are no differences due to effects of acute and chronic exposure to methylmercury compounds; poisoning occurs after a toxic dose has been accumulated. The CNS is the main target of methylmercury causing blindness, deafness, impaired levels of consciousness and convulsions in more severe cases; the symptoms, however, may be delayed for weeks or months after initial exposure (4239). Ethylmercury produces renal effects and neurological effects similar to methylmercury. These effects will be discussed in more detail in Section 1.3.2.2.

Phenylmercuric compounds at doses up to 100 mg have been reported to cause only slight gastrointestinal symptoms and ingestion of 1250 mg of mercury as phenylmercuric did not affect the kidney (4239). Because the phenol group is rapidly removed, phenylmercuric compounds have similar toxic effects, which, in turn, are similar to those of inorganic mercury compounds (4239). Alkoxyalkyl mercury compounds (methoxyethylmercuric acetate) are of low toxicity, because the mercury in these compounds is readily liberated and excreted (4324). No effects due to methoxyethylmercuric chloride were reported in workers who packaged this compound for 6 weeks, although blood levels ranged from 0.34-1.09 mg Hg/L (4325).

73.3.2.1.2 Inhalation Exposure

Approximately 80% of inhaled mercury vapor (elemental mercury) is retained in the lung and absorbed into the blood of humans (4227, 4287, 4316). The high efficiency of absorption is due to the lipid solubility and diffusible nature of metallic mercury favoring its partitioning into body tissues (4227). At air concentrations ranging from 0.05-0.35 mg/m^3, 75-85% of the mercury is retained in humans (4326). Elemental mercury is transformed to ionic mercury (Hg^{2+}) by a catalase in the blood (4281), but some elemental mercury is transformed to ionic mercury after is transported to the brain (4303). The biological half-time of mercury is 3.3 days for the blood, and 21 days for the head region, 58 days for the whole body, and 64 days for the kidney (4327). Stokinger (4224) reported that a brief single exposure to 62-100 mg/m^3 for 14-24 min may take up to 2 months for half-time clearance. Elemental mercury is distributed to numerous tissues, but it accumulates in the cerebral cortex, especially the occipital and parietal cortical areas of the brain of occupationally-exposed individuals (4304).

The lungs are the primary target for acute inhalation exposure to high concentrations of mercury vapor (4304). According to Gerstner and Huff (4316), symptoms may be delayed and resemble the acute onset of influenza, with symptoms of fever, chills, nausea, general malaise, shortness of breath, pain and tightness in the chest, and paroxysmal coughing. Gross and microscopic effects are seen as diffuse interstitial pneumonitis with profuse fibrinous exudation into the alveoli and erosion of the lining of the bronchi and bronchioli. Exposure to high concentrations of mercury vapor also cause a metallic taste and the symptoms similar to those seen after acute ingestion of inorganic mercuric compounds (nausea, abdominal pain, vomiting, diarrhea, headache, albuminuria, swelling of salivary glands, stomatitis, and gingivitis) (4224). Berlin (4303) reported that signs of CNS effects (tremors or increased excitability) may

also appear after acute intoxication. Magos (4281) reported that acute pneumonitis, tightness of the chest, dyspnea, and paroxysmal cough are seen very early after exposure to concentrations exceeding 2 mg/m^3, and Stokinger (4224) stated that acute intoxication resulted from concentrations of 1.2-8.5 mg/m^3. The lowest toxic dose for an 8-hour exposure in human males was reported as 44.3 mg/m^3 and 0.15 mg/m^3 for a 46-day exposure in human females (4200).

Goldwater (4211) reviewed several case study of intoxication occurring after a single exposure to mercury vapors in the home. An infant who inhaled a fatal dose showed symptoms within 2 hours and died of acute pulmonary edema. Autopsy findings included generalized body edema, dilatation of the right ventricle, necrosis on the gastric mucosa and degenerative changes in the renal tubules. Three children exposed to mercury vapors developed pneumonitis and autopsy findings included showed exudative pulmonary edema and necrotizing bronchiolitis. Coughing, rales, chills, fever, and constriction of the chest followed by pneumonitis are common features of acute intoxication due to mercury vapor.

Sexton et al. (4356) described a case of short-term repeated exposure to mercury vapor with different effects from those described by Goldwater (4211). Three teenage girls from two families along with other family members were exposed to mercury vapors after 100-300 mL of mercury was spilled onto the carpets of their homes. Approximately 2 weeks after the mercury was spilled, the girls suffered from anorexia, painful mouth, intermittent abdominal cramps, mild diarrhea, bleeding gingiva, red and painful eyes, insomnia, vague sense of restlessness, and generalized erythematous and pruritic skin rashes. About a month later inattentiveness in school and changes in handwriting and personalities were noted by the girls' teacher. The girls were exposed to the vapors for 51-61 days.

Inorganic mercuric compounds do not vaporize under normal conditions, but they could be suspended as dust or aerosols. Therefore, their disposition in the respiratory tract would depend on particle size and solubility. Some organic mercury compounds can vaporize and others can be suspended as dust or aerosols (4316). No data were found on acute inhalation of inorganic mercuric or mercurous compound.

Acute inhalation exposure to alkylmercury compounds cause effects similar to those of mercury vapor. The Study Group on Mercury Hazards (4328) described a case reported in 1865 in which two investigators accidentally inhaled the very volatile diethylmercury; one died within 11 days, and the other suffered very serious effects (blindness, deafness, and dementia) and died within a year .

73.3.2.1.3 Dermal Exposure

Elemental mercury is probably absorbed through the skin and into the blood; systemic effects have not been reported. Dermal contact with elemental mercury can cause dermatitis in hypersensitive persons. Inorganic and organic mercury compounds are probably absorbed from the skin of humans (4304, 4316); documentation of systemic toxic effects have not been reported.

73.3.2.2 Chronic Toxicologic Effects

73.3.2.2.1. ORAL

Metallic mercury is poorly absorbed from the gastrointestinal tract, and is of low order of toxicity by this route.

Data regarding chronic ingestion of inorganic mercury salts are very few. According to Goyer (4303) chronic low-dose exposure to mercuric salts can induce immunologic glomerular disease. This disease is also associated with chronic exposure to mercury vapor.

Acrodynia ("pink disease") is a disease seen in infants and children and is associated with repeated ingestion or contact with mercury compounds. This disease is rarely seen, but, at one time, it was relatively common. Mercury exposure resulted from the use of mercurial teething powders and lotions and the use of calomel, mercurial ointments, diaper rinses, paints, and wallpaper. The name "pink disease" comes from the pinkish colored rash that first appears on the fingertips, toes and nose and later involve the hands and feet. Progression of the disease is manifested by enlargement of the sweat glands, profuse perspiration, which causes dehydration and extreme thirst, anorexia, desquamation of the soles and palms, edematous fingers and toes due to hyperplasia and hyperkeratosis of the skin, constant pruritus and severe pain in the hands and feet, and gangrene of the toes and fingers. Photophobia, necrosis of the jaw bones, inflamed and swollen gums, profuse salivation are seen. The children suffer from mental apathy (appear dejected and melancholic) irritability, restlessness, and soft flabby musculature (4329). Bilderback and Anderson (4329) stated that the disease may be due to a hypersensitivity to mercury compounds.

For the most part, chronic oral exposure to mercury occurs when members of the general population ingest foodstuffs contaminated with alkylmercury compounds. Fish, which take up alkylmercury compounds from water or grain on which alkylmercury compounds have been sprayed as a fumigant have resulted in outbreaks of alkylmercury poisoning in different parts of the world.

Several outbreaks of alkylmercury poisoning have been reported in the literature. These have occurred in Iraq in 1956, 1960, and 1971-72, Guatemala in 1963, 1964, and 1965, Pakistan in 1969, and Minamata and Niigata, Japan from 1953-60, to name a few (4227, 4330, 4331). The most serious epidemics occurred in Iraq in 1971-72 and in Minamata and Niigata. Over 6000 individuals were hospitalized and 459 individuals died during the epidemic in Iraq (4330). This epidemic was attributed to consumption of bread prepared with grain (wheat and barley) treated with a methylmercurial fungicide. Methylmercury was detected in wheat flour at concentrations of 4.8-14.6 μg/g of flour (mean=9.1 μg/g); the ethylmercury content was very low. In addition, to methylmercury, some wheat may have been treated with ethylmercury-p-toluenesulfonanilide, N-dimethylmercury-p-toluenesulfonamide, or phenylmercuric compounds, but these were not detected. The barley was treated with a variety of mercury compounds, including phenylmercuric acetate, methylmercury dicyandiamide, methylmercury-2,3-dihydroxypropyl mercaptide, and methylmercury

acetate. Methylmercury was the predominant form found in barley and in the blood, hair, and autopsy samples of affected individuals. Phenylmercuric was detected in some barley samples (4330).

The epidemic in Minamata and Niigata was attributed to the consumption of fish contaminated with methylmercury and other mercury compounds as a result of industrial releases of these compounds into Minamata Bay and the Agano River (4227). By 1960 121 cases and 46 deaths were reported for Minamata, and 47 cases and 6 deaths in Niigata by 1970 (4330). By 1971 269 cases and 55 deaths were reported for Mimamata, and by 1974 a total of 700 cases were reported for Minamata and 500 for Niigata (4227). The mercury content was 11 and 10 mg/kg fresh weight of fish from Minamata Bay and the Agano River, respectively (4303).

The clinical symptoms of methylmercury poisoning as seen in the Iraqi epidemic were paresthesia (loss of sensation in the extremities and around the mouth, ataxia (ranging from slight unsteadiness to gross incoordination in gait), visual effects (ranging from blurred vision to constriction of the visual field and blindness in severe cases), dysarthria (slurred speech), and deafness; these symptoms occurred in this order. The most severe cases resulted in coma and death due to failure of the CNS. Only occasionally were effects seen on the gastrointestinal tract, urinary system, and cardiovascular system. Shahristani et al. (4353) rated the signs and symptoms as mild, moderate, and severe. Mild symptoms consisted of paresthesia, slight tremor and mild ataxia, and moderate symptoms consisted of partial hearing loss, tunnel vision, and partial paralysis. Severe symptoms consist of some combination of the following: complete paralysis, loss of vision, loss of hearing, loss of speech, and coma.

A study of a subset of 93 cases in the Iraqi study showed that the frequency and severity of symptoms showed a dose-response relationship with blood mercury levels ranging from <10 µg/dL up to 400-500 µg/dL. The milder symptoms occurred at the low blood levels, the deaths occurred at levels >300 µg/dL. The correlation coefficients between ingested mercury and blood mercury levels were 0.89 for children 10-15 years old and 0.85 for adults >16 years old; 1 mg of ingested mercury correlated with 1.7 µg/dL for the children and 0.9 µg/dL for the adults (4330).

The onset of symptoms methylmercury poisoning may be delayed for weeks or even months and is probably related to total body accumulation of mercury. The threshold body burden (amount of methylmercury in the body at the onset of a symptom) for mild paresthesia was estimated to be 25-40 mg of mercury corresponding to 0.5-0.8 mg/kg for a 50-kg person (standard weight used for the Iraqi population) (4330); the corresponding blood mercury levels are 24-48 µg/dL after correcting for a half-time clearance of 65 days (4227). Mufti et al. (4332) estimated a threshold body burden for paresthesia of 0.7 mg/kg, based on ingested dose and body weight, for a subpopulation of 1163 persons. Shahristani et al. (4353) calculated a threshold body burden of 0.8 mg/kg based on the average concentration of mercury in hair (120 mg/kg of hair) and the daily intake of methylmercury. The threshold calculated by the Swedish Expert Group (4355) was 20-40 µg/dL of blood for individuals affected during the Niigata epidemic. Bakir et al. (4330) reported a threshold body burden for the

onset of other symptoms as 55 mg of mercury for ataxia, 90 mg for dysarthria, 170 for deafness, and 200 mg for death.

WHO (4227) established three categories of exposure based on intensity and duration. The first category are those whose daily consumption of mercury is high for short periods (eg. 200 µg/kg for 1-2 months for the 1971 Iraq epidemic), the second are those who consume 5-100 µg/kg (median=30 µg/kg) (Minamata and Niigata epidemics), and third are those who consume levels up to 5 µg/kg for years. Populations in third category do not show signs and symptoms of methylmercury poisoning as a result of their chronic exposure. Gerstner and Huff (4316) concluded that severity and clinical course of methylmercury poisoning depend on daily intake and duration, age, and individual sensitivity.

The effects of exposure of pregnant women to alkyl mercury compounds were very striking in the Iraqi epidemic. Thirty-one pregnant women suffering from methylmercury poisoning were admitted to hospitals; 45% of these died, compared with 7% fatalities for the general population.

Infants were affected by exposure to alkyl mercury compounds in utero or via mother's milk during nursing. The concentration of methylmercury in milk of mothers exposed during the Iraqi epidemic was 3-6% of that in maternal blood, and the concentration in the blood of nursing infants was equal to or lower than that of maternal blood. Eight nursing Iraqi infants had blood mercury concentrations of 50 µg/dL and three had blood concentrations of 100 µg/dL; none of these showed signs of methylmercury poisoning (4330). Infants born during or after the epidemic were exposed in utero. The blood concentration in three infants ranged up to >250 µg/dL, and all three suffered severe brain damage.

Amin-Zaki et al. (4333) studied a group of 15 mother and infant pairs in which the infants received in utero exposure during the Iraqi epidemic and showed that methylmercury caused severe developmental toxic effects in humans. The infants were born during or not long after maternal consumption of bread contaminated with methylmercury. A total of six mothers showed clinical manifestations of methylmercury poisoning, and the most frequent maternal symptoms were headache and malaise, joint and muscle pain, paraesthesia, motor weakness, visual changes, and ataxia. Speech and hearing loss were not frequently seen. Five of the infants were severely affected, showing signs of gross impairment of motor and mental development; four of these also had cerebral palsy (severe generalized paralysis), severe hearing loss, and blindness; and three infants were microcephalic. These effects were seen by two months of age in four infants. No malformations were reported (microcephaly was not considered a malformation); therefore, methylmercury is not teratogenic. The three most severely affected infants had blood mercury levels of 3190 ppb (319 µg Hg/dL) to 4220 ppb (422 µg Hg/dL). The other two affected infant had blood levels of 564 and 1053 ppb. One infant with a blood level of 636 ppb was not affected; the remaining infants had blood mercury levels <564 and showed no signs of mercury poisoning. The infants of mothers with the three highest blood mercury levels also had the highest blood levels. In 14 pairs, the blood levels in infants were considerably higher than the maternal level.

In the Minamata Bay area, 220 infants were born between 1955 and 1958; they followed up for 15 years (4334). Thirteen showed evidence of severe poisoning. In contrast to the Iraqi infants, the Japanese infants (Minamata) appeared normal at birth and did not show signs of methylmercury poisoning until they were about 6 months of age (4334). The effects of prenatal exposure to methylmercury in the Japanese infants included instability of the neck, convulsions, failure of the eyes to follow and clinical manifestations of severe neurological and mental impairment. Signs of neurological and mental impairment in the 13 infants were intelligence disturbance, cerebellar symptoms, disturbance of body growth and nutrition, dysarthria, and deformed limbs (100%); hyperkinesia (95%), hypersalivation (95%), paroxysmal symptom (82%), strabismus (77%), and pyramidal symptom (75%).

The pathological effect of methylmercury on the developing brain is seen as derangement of the cytoarchitecture of most areas accomplished by abnormal migration of neurons to the cerebellar and cerebral cortices and by abnormal cell division (4322, 4226). Gerstner and Huff (4316) described the pathological effects as destruction of nerve cells in the granular layer of the cerebellum and the calcarine area of the cerebral cortex, with mild lesion occurring in the basal ganglia,hypothalamus, midbrain, and spinal cord. In more severe cases, the neuronal destruction occurs over larger regions of the brain, finally involving the entire cortex.

73.3.2.2.1. INHALATION

The critical targets for exposure to elemental mercury vapor is the CNS. Two epidemiology studies have been conducted on exposure to elemental mercury. Cragle et al. (4335) conducted a study on 2133 white male workers exposed to mercury vapors from 1953-1963 at the Y-12 plant in Oak Ridge, Tennessee and followed up until 1978. The Y-12 plant was built in 1943 as part of the Manhattan Project and used in the lithium isotope separation process, which required elemental mercury, from 1953-1963. A nonexposed group consisted of 3260 white male workers, and another group of 270 workers whose exposure was unknown was also included. Among the three cohorts, 378 exposed workers died, 710 unexposed and 52 unknown exposed workers died. Standard mortality ratios (SMR) were calculated using the U.S. white male population as referents. Excess deaths due to nonneoplastic diseases to target organs (liver, lung, kidney and CNS) were not found in any group. In the nonexposed group, the mortality rates were elevated for all malignant neoplasms (SMR=1.10; not significant), lung cancer (SMR = 1.34; $p<0.05$), and cancer of the brain and other CNS tissues (SMR=2.30; $p<0.05$). In the mercury exposed group, mortality rates were not significantly elevated (all malignant neoplasms, SMR=0.94; lung cancer, SMR=1.34; brain cancers, SMR=1.22).

Barregard et al. (4336) studied a cohort of 1190 Swedish chloroalkali workers for whom urinary or blood mercury levels were monitored for at least one year until 1984. The reference group consisted of the general Swedish male population. Mean urinary mercury excretion was 0.2 mg/L during the 1950s, 0.15 mg/L during the 1960s and the current urinary value is <0.05 mg/L. The number of deaths due to lung cancer was elevated (Obs/Exp=2.0; $p<0.05$) in the exposed group, but no dose-response relationship was noted when the incidence was related to accumulated mercury

exposure. The workers were exposed to asbestos and this may have contributed to the excess deaths due to lung cancer. The number of deaths due to ischemic heart disease (Obs/Exp=1.3; $p<0.05$) and cerebrovascular diseases (Obs/Exp=1.3; not significant) were increased, but the increase was not dose related. No excess deaths due to malignant or nonmalignant diseases of the brain or kidney were observed.

The CNS is the primary target for prolonged exposure to mercury vapors. The kidney is affected at exposure concentrations higher than those causing CNS effects. Signs and symptoms of prolonged exposure to mercury vapor are unspecific asthenic-vegetative syndrome characterized by weakness, fatigue, anorexia, loss of weight, and gastrointestinal disturbances. At higher concentrations, tremors begin in the fingers, eyelids, and lips and progress to fine trembling of the muscles interrupted by coarse body trembling every few minutes. In more severe cases, generalized tremors involving the whole body and chronic spasms of the extremities may develop along with mercurial erethism. Erethism is characterized by psychic disturbances such as, severe behavioral and personality changes, shyness, increased excitability, irritability, loss of memory, insomnia, and depression. Delirium and hallucination may occur in extreme cases (4304). Cognitive deficits, immunological effects, mild proteinuria, and nonspecific effects (such as insomnia) also occur at lower exposures (4226).

Numerous morbidity studies have been conducted on mercury exposure of workers in various industries. Abnormalities in electroencephalogram (EEG) were detected in 10/41 of chloroalkali workers exposed to 25 $\mu g/m^3$ of mercury vapor for a mean duration of 15.7 years (4337). The abnormal findings were significant for the occipital region of the brain. Albers er al. (4338) evaluated neurological functions in 138 workers who had urinary mercury concentrations ranging from 0-0.5 mg/L over 3-36 months (avg.=0.09 mg/L). Eighteen workers showed evidence of mild sensorimotor polyneuropathy, eight of these had abnormal electromyograms, and 5/8 showed 3 or more abnormalities in nerve conduction. The authors reported that polyneuropathy was most likely to occur in workers with the higher urinary mercury values (>0.25 mg/L) for 24 months. Similar data were presented by Levine et al. (4339).

Schuckman (4340) compared preclinical psychomotor functions (tremor measurements, bimanual coordination, color determination, and reaction time) in 39 male chloroalkali workers (at two plants) exposed to mercury vapor for 7 or more years with a matched unexposed control group and found no differences between the two groups. The ambient air concentration of mercury was 75.1 $\mu g/m^3$; two-thirds of the measurements ranged from 30-90 $\mu g/m^3$, and seven peaks ranged from 300-500 $\mu g/m^3$. The OSHA standard in 1979 was 0.1 mg/m^3 for inorganic mercury. The averages from personal samplers were 48.2 $\mu g/m^3$ at one plant and 35.1 $\mu g/m^3$ at the other.

Verberk et al. (4341) reported that workers making fluorescent lamp and having urinary mercury values ranging from 9-52 $\mu mol/mol$ creatine showed an increase in tremors in the fingers measured by two methods. Soleo et al. (4342) evaluated three groups of workers in a fluorescent lamp factory for preclinical signs of CNS impairment. The tests consisted of the WHO test battery (Santa Ana dexterity test, simple reaction time, Benton visual recognition test, and the Wechsler digit span and digit symbol tests), the Gordon personal profile, and the clinical depression test.

Group 1 consisted of 8 workers chronically exposed for 10.3 years (mean) and had mean urinary mercury levels ranging from 9.5-43.2 µg/L over a 9-year period; Group 2 consisted of 20 workers occasionally exposed to mercury for 12.4 years (mean) and had urinary levels ranging from 11.2-20.7 µg/L over a 9-year period; Group 3 (controls) were employed in the same factory, had no known exposure to mercury, and had urinary mercury levels ranging from 5.6-10.5 µg/L over a 9-year period. Short-term memory was severely impaired in Group 1 and less severely impaired in Group 2. Group 1 workers were also more depressed and had severe personality changes. Smith et al. (4349) found no effects on short-term memory measured by the Wechler digit span forward test among chloroalkali workers. The 50% threshold for serial digit recall, however, was significantly decreased in workers whose 12- and 24-month average urinary mercury value was 0.2 mg/L

Shapiro et al. (4343) reported that dentist with head and wrist mercury levels >20 µg/g of tissue (measured by X-ray fluorescence), showed evidence of preclinical polyneuropathy and mild visiographic impairment. De Rosis et al. (4344) reported that female workers exposed to mercury vapors in a lamp factory did not experience an increase in reproductive abnormalities. Endpoints examined were menstrual cycle disorders, fecundity, and adverse pregnancy outcomes.

Rosenman et al. (4345) studied a group of workers involved in the manufacture of mercury compounds, mercuric oxides, mercurial chlorides, and phenylmercuric acetate. Of the 42 workers evaluated, 32 had worked ≥2 years. The workers were subjected to a number of tests to assess the effect of exposure to mercury compounds on neuropsychological performance, renal function, and visual acuity. No tremor or peripheral neuropathy was found in these workers. The number of neuropsychological symptoms reported by the workers, urinary N-acetyl-ß-D-glucosaminidase (NAG) activity, and slowing of motor nerve conduction velocity were positively associated with increased urinary mercury levels. The neuropsychological symptoms were nonspecific and consisted of headaches, insomnia, fatigue, and nervousness. Lenticular opacities were found in all the mercury workers, and abnormal saccadic eye movements were also seen, but these could not be correlated with mercury levels.

A group of workers exposed to mercuric oxide, mercuric acetate, and probably mercury vapor for 4 months to 2 years had urinary mercury levels ranging from 1-1.5 mg/L and showed evidence of renal damage (4352). Urinary protein levels were high, hyaline casts were seen in urinary sediments, and renal biopsy showed lipid accumulation and vacuolization in the proximal tubular epithelium.

Mercuric nitrate is used in the making of felt hats. Inhaling the dust or vapors released from the fur results in mercury toxicity (4287, 4239, 4226). Symptoms of emotional and psychological disturbances were manifested by the "Mad Hatter" in *Alice in Wonderland* by Lewis Carrol (4226).

Occupational exposure to alkylmercury compounds can occur as a result of producing the alkylmercury fungicides, applying the compounds to seeds and grains, working in pulp and saw mills (4227). The workers either inhale the dust or vapor or absorb liquid preparations through the skin. Effects are primarily on the CNS. Signs

and symptoms include paresthesia of the extremities, mouth and lips, constriction of the visual field sometimes leading to blindness, deafness, unsteady gait, loss of coordination, and reflex changes. In more severe cases, the loss of the ability to speak and mental deterioration is seen (4346). Pathologic findings in a patient who died were cerebellar cortical atrophy, involving the granular-cell layer of the neocerebellum and cortical atrophy of the calcarine fissure-visual cortical area of the occipital lobe (4347).

Goldwater (4325) reported that the numerous observations conducted on workers who have been exposed for many years to phenylmercuric compounds at concentrations exceeding 0.1 mg/m^3 and excrete milligrams of mercury in their urine each day showed no adverse effects.

No data were found on the effects of inhalation exposure to other organic mercurials, including methylmercury.

73.3.3. Levels of Concern

The ambient water quality criteria for mercury are 144 ng/L for ingestion of water and contaminated aquatic organisms and 146 ng/L for ingestion of contaminated aquatic organisms only (4217). Two RfDs have been verified, 3E-04 mg/kg/day (as Hg) for methyl mercury and 8E-05 mg/kg/day for phenylmercury (4218, 4219). Inorganic mercury (CAS No. 7439-97-6) is placed in Group D ("not classifiable as to human carcinogenicity") (4212). The lifetime health advisory for mercury is 0.002 mg/L, which is the same as the MCLG and MCL (4214, 4215).

The OSHA standards are 0.05 mg/m^3 for mercury vapor and 0.1 mg/m^3 for organo and alkyl mercury compounds for an 8-hr work shift and 0.01 mg/m^3 for aryl and inorganic mercury for a ceiling. The 15-min STEL for organo and alkyl mercury compounds is 0.03 mg/m^3.

The NIOSH (4209) recommendations are 0.05 mg/m^3 for elemental mercury and inorganic compounds and 0.01 mg/m^3 for organo and alkyl mercury compounds for a 10-hr TWA. The 15-min STELs are 0.1 mg/m^3 for elemental mercury and inorganic compounds and 0.01 mg/m^3 for organo and alkyl mercury compounds.

73.3.4. Hazard Assessment

The toxicity of mercury and mercury compounds can be placed into five categories based on their toxicity, which include elemental mercury (mercury vapor), inorganic mercuric salts, inorganic mercurous salts, short-chain alkyl mercury compounds, and organomercurials with more than two carbon atoms (eg. phenylmercury) (4281).

Elemental mercury vaporized in air and the vapor is toxic via the inhalation route. The vapor is efficiently absorbed from the respiratory tract into the blood and distributed to the cerebral cortex of the brain, especially the occipital and parietal cortical areas. The respiratory tract, however, is the primary target for acute exposure to very high concentrations of mercury vapor, but CNS effects have also been reported.

The CNS is the primary target for prolonged or chronic exposure to mercury vapor. Ingested elemental mercury is very poorly absorbed from the gastrointestinal tract, and consequently has a very low toxicity by the oral route.

Inorganic mercuric salts are toxic primarily via the oral route. They are absorbed at a rate of 2-20% from the gastrointestinal tract, distributed to the various organs, but primarily taken up by the proximal convoluted tubules in the kidney. The kidney is the primary target for inorganic mercuric salts. Acrodynia ("pink disease) is a disease seen in children exposed to mercurials in teething remedies, diaper rinses, and ointments. The inhalation route is usually not a major concern for inorganic mercuric salts, unless they are suspended as dust or aerosols. Exposure of this type would more likely occur in an occupational environment where these compounds are produced or used. Occupation exposure to mercuric oxide, mercuric acetate, and probably mercury vapor has been associated with lipid accumulation and vacuolization in the proximal tubular epithelium (4352). Mercuric nitrate is used in the felt hat industry, and inhaling the dust and vapor released from the fur causes mercury toxicity.

Short-chain alkyl mercury compounds (ethyl- and methylmercury compounds) are efficiently absorbed from the gastrointestinal tract. These compounds accumulate in the brain, where they may remain for years due to a very long half-life. The brain is the primary target for short-chain alkyl mercury compounds. Placental transfer of short-chain alkyl mercury compounds results in exposed to the fetus and uptake of the compounds in the milk results in exposure to nursing infants. Severe CNS effects are seen in both adults and infants (whether exposed in utero or via nursing); ethyl- and methylmercury compounds cause developmental toxicity, but are not teratogenic. Symptoms may be delayed for weeks or months after ingestion, and it is believed that effects are delayed until a toxic dose has accumulated in the body.

The epidemiology studies in humans and the long-term studies in animals do not show evidence of carcinogenicity. No data regarding mutagenicity are available, and data regarding clastogenicity are inadequate.

73.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of mercury concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following sequence of reagents to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is

required for solid samples other than storage at 4°C until sample analysis. All samples should be analyzed within 28 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (4358).

The analytical method available for analyzing inorganic mercury in water, soils and waste is the cold-vapor atomic absorption (Methods 245.1 and 245.2) technique. In this procedure, mercury is reduced to its elemental form and aerated into a closed system. The mercury vapor passes into an optical cell located in the light path of an atomic absorption spectrometer. The absorption of radiation at 253.7 nm is proportional to mercury concentration. If this procedure is to be used for the purpose of measuring total mercury (inorganic plus organic), all organically bound mercury must be first converted to the inorganic form prior to the analytical determination. Potassium permanganate, in the presence of nitric and sulfuric acids, is used to oxidize the organo-mercury compounds. The technique has a detection limit of 0.2 µg/L mercury and a detection range of 2-20 µg/L. The reproducibility of the manual cold-vapor technique (Method 245.1) for measuring total mercury has been documented in a joint EPA/ASTM interlaboratory study. The standard deviation in results among the laboratories ranged from 40-79%. Results from samples containing less than 3.4 µg Hg/L showed a positive bias; results for samples containing greater quantities of mercury exhibited a negative bias from the true value. In a single EPA study of the automated procedure (Method 245.2), sample results were reproducible to within 4-8% for water samples spiked with 0.5 to 20 µg Hg/L. The recovery of organic mercurials spiked at the 10 µg/L level into surface water samples ranged from 87 to 117% (4357, 4358).

Detection Limit	Method
2 µg/L (aqueous & nonaqueous)	245.1
2 µg/L (aqueous & nonaqueous)	245.2

73.5 REFERENCES

Note: The numbering sequence of the references reflects the order of references as they appear in the master bibliography.

4200. Sax, N.I.; Lewis, Sr., R.J., Eds. 1989. Dangerous Properties of Industrial Materials. 7th ed. New York:Van Nostrand Reinhold.

4201. Windholz, M.; Budavari, S.; Blumetti, R.F.; Otterbein, E.S., Eds. 1983. The Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals, 10th ed. New Jersey: Merck and Co., Inc.

4202. Drake, H.G. 1978. Mercury. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Vol. 6, M. Grayson and D. Eckroth, Ed., New York: John Wiley and Sons. pp. 143-156.

4203. Hazardous Substances Data Bank(HSDB). 1989. National Library of Medicine, Bethesda, MD.

4204. Weast, R.C.; Astle, M.J.; Beyer, W.H., Eds. 1988. CRC Handbook of Chemistry and Physics, 69th ed., Boca Raton, FL: CRC Press, Inc.

4205. Singer, W; Nowak, M. 1978. Mercury compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Vol. 6, M. Grayson and D. Eckroth, Ed., New York: John Wiley and Sons. pp. 157-171.

4206. Lenga, R.E. 1985. The Sigma-Aldrich Library of Chemical Safety Data. First Edition. Sigma-Aldrich Corporation.

4207. Dean, J.A. 1987. Handbook of Organic Chemistry. New York:McGraw-Hill.

4208. Mackison, F.W.; Stricoff, R.S.; Partridge, Jr., L.J. 1981. NIOSH/OSHA Occupational Health Guideline for Inorganic Mercury. U.S. Department of Health and Human Services and U.S. Department of Labor, Washington, D.C. DHHS (NIOSH) Publication No. 81-123.

4209. National Institute for Occupational Safety and Health (NIOSH). 1985. NIOSH Pocket Guide to Chemical Hazards. Washington, D.C.: U.S. Government Printing Office. DHHS (NIOSH) Publ. No. 85-114.

4210. Vernot, E.H.; MacEwen, J.D.; Haun, C.C.; Kinkead, E.R. 1977. Acute toxicity and skin corrosion data for some organic and inorganic compounds and aqueous solutions. Toxicol. Appl. Pharmacol. 42:417-423.

4211. Goldwater, L.J. 1972. Mercury: A History of Quicksilver. Baltimore:York Press.

4212. U.S. Environmental Protection Agency (U.S. EPA). 1989. EPA Cover Sheet for Mercury (Inorganic). IRIS (Integrated Risk Assessment Information System), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH.

4213. American Conference of Governmental Industrial Hygienists (ACGIH). 1989. Threshold Limit Values and Biological Exposure Indices for 1989-1990. Cincinnati, Ohio.

4214. U.S. Environmental Protection Agency (U.S. EPA). 1989. National Primary and Secondary Drinking Water Standards. Proposed Rule. May 22, 1989. Office of Drinking Water, Office for Water and Waste Management. Federal Register 54:22062.

4215. U.S. Environmental Protection Agency (U.S. EPA). 1989. Drinking Water Regulations and Health Advisors. Office of Drinking Water, Office for Water and Waste Management, Washington, D.C.

4216. World Health Organization (WHO). 1984. Guidelines for Drinking-Water Quality: Recommendations. Vol. 1, Geneva. pp. 47-58.

4217. U.S. Environmental Protection Agency (U.S. EPA). 1987. Quality Criteria for Water 1986. Office of Water Regulations and Standards, Washington, D.C. EPA-440/5-86-001.

4218. U.S. Environmental Protection Agency (U.S. EPA). 1988. EPA Cover Sheet for Methyl Mercury. IRIS (Integrated Risk Assessment Information System), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH.

4219. U.S. Environmental Protection Agency (U.S. EPA). 1989. EPA Cover Sheet for Phenylmercuric acetate. IRIS (Integrated Risk Assessment Information System), Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH.

4220. Perwak, J.; Goyer, M.; Nelken, L.; Scow, K.; Wald, M.; Wallace, D. 1980. An Exposure and Risk Assessment for Mercury, Final Draft Report to U.S. Environmental Protection Agency, EPa Contracts 68-01-3857 and 68-01-5949, Monitoring and Data Support Division, Office of Water REgulations and Standards, Washington, DC. (Cited in 4221)

4221. McComish, M.F.; Ong, J.H. 1988. Trace metals. In: Environmental Inorganic Chemistry. Properties, Processes, and Estimation Methods. Bodek, I. et al., Eds. New York: Pergamon Press, pp. 7.10-1 - 7.10-17.

4222. Carrico, L.C. 1989. mercury. In: Minerals Yearbook 1987, vol. 1. Metals and Minerals. Washington, DC: Department of the Interior, pp. 617-623.

4223. Fleisher, J. 1970. Summary of the literature on the inorganic geochemistry of mercury. In: Mercury in the Environment, Professional Paper 713. Washington, DC: U.S. Geological Survey, pp. 6-13. (Cited in 4221)

4224. Stokinger, H.E. 1981. The metals. In: Patty's Industrial Hygiene and Toxicology. 3rd ed., Vol. 2A, Toxicology, G.D. Clayton and F.E. Clayton, Eds. New York: John Wiley and Sons. pp. 1769-1792.

4225. Callahan, M.A.; Slimak, M.W.; Gabel, N.W. et al. 1979. Mercury. In: Water-Related Environmental Fate of 129 Priority Pollutants, Vol. 1. Washington, DC: Office of Water and Waste Management, U.S. Environmental Protection Agency, pp. 14-1-14-15.

4226. Clarkson, T.W. 1989. Mercury. J. Am. Coll. Toxicol. 8:1291-1295.

4227. World Health Organization (WHO). 1976. Environmental Health Criteria 1. Mercury. Published under the joint sponsorship of the United Nations Environment Programme and the World Health Organization, Geneva. 131 p.

4228. Gavis, J.; Ferguson, J.F. 1972. The cycling of mercury through the environment. Water Res. 6: 989-1008.

4229. Kudo, A.; Nagase, H.; Ose, Y. 1982. Proportional methylmercury to toal amount of mercury in river waters in Canada and Japan Water Res. 16:1011-1015. (Cited in 4231)

4230. Brosset, C. 1981. The mercury cycle (preliminary communication). Water, Air, Soil Poll. 16:253-255. (Cited in 4231)

4231. Lindberg, S.; Stokes, P.M.; Goldberg, E.; Wren, C. 1987. Group report: mercury. In: Lead, Mercury, Cadmium and Arsenic in the Environment. Hutchinson, T.C.; Meema, K.M., Eds. New York: John Wiley & Sons, Ltd., pp. 17-33.

4232. Beijer, K.; Jernelöv, A. 1986. Sources, transport and transformation of metals in the environment. In: Handbook on the Toxicology of Metals, 2nd ed. Friberg, L.; Norkberg, G.F.; Vouk, V., Eds. Amsterdam: Elsevier Science Publishers, pp. 68-84.

4233. Nriagu, J.O.; Pacyna, J.M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333:134-139.

4234. Hogstrom; Enger (initials not given). 1986. Unpublished data. (Cited in 4232)

4235. Svedung, I. 1977. Unpublished report. Swedish Water and Air Pollution Research Institute, Stockholm. (Cited in 4232)

4236. Andren, A.W.; Nriagu, J.O. 1979. The global cycle of mercury. In: The Biogeochemistry of Mercury in the Environment. Nriagu, J.O., Ed. New York: Elsevier/North-Holland Biomedical Press, 1-21.

4237. U.S. Environmental Protection Agency (U.S. EPA). 1984. Mercury Health Effects Update. Final Report. Office of Health and Environmental Assessment, U.S. EPA. EPA 600/8-019F. (Cited in 4239 and 4238)

4238. Agency for Toxic Substances and Disease Registry (ATSDR). 1989. Toxicological Profile for Mercury (Draft). U.S. Public Health Service, Chamblee, GA.

4239. U.S. Environmental Protection Agency (U.S. EPA). 1985. Drinking Water Criteria Document for Mercury. Prepared by Environmental Criteria and Assessment Office, Cincinnati, OH. Prepared for the Office of Drinking Water, Washington, D.C.

4240. Kabata-Pendias, A.; Pendias H. 1984. Mercury. In: Trace Elements in Soils and Plants. Boca Raton, FL: CRC Press, pp. 116-125, 261-292.

4241. Jonasson, I.R. 1970. Mercury in the natural environment: a review of recent work. Geol. Surv. Can. 70/57:37. (Cited in 4240)

4242. Shcherbakov, V.P.; Dvornikov, A.T.; Zakrenichnya, G.L. 1970. New data on occurrence and forms of mercury in the Donbas coals. Dopov. ANUR 2b:126. (Cited in 4240)

4243. Landa, E.R. The retention of metallic mercury vapor by soils. Geodhim. Cosmochim. Acta 42:1407. (Cited in 4240)

4244. Reimers, R.S.; Krenkel, P.A. 1974. Kinetics of mercury adsorption and desorption in sediments. J. Water Pollut. Control Fed. 46;352-365. (Cited in 4221)

4245. Hem, J.D. 1978. Chemical behavior of mercury in aqueous media. U.S. Geol. Surv. Prof. Pap. 713:19. (Cited in 4240)

4246. Lockwood, R.A.; Chen, K.Y. 1973. Adsorption of Hg(II) by hydrous manganese oxides. Environ. Sci. Technol. 11:1028-1034. (Cited in 4221)

4247. Rai, D.; Zachara, J.; Schwab, A.; Schmidt, R.; Girvin, D.; Rogers, J.; 1984. Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration. Vol. I: A Critical Review. Report EA-03356 to EPRI by Pacific Northwest Laboratories (Battelle Institute), Richland, WA. (Cited in 4221)

4248. Kinniburgh, D.G.; Jackson, M.l. 1978. Adsorption of mercury(II) by iron hydrous oxide gel. Soil Sci. Soc. Am. J. 42:45-47. (Cited in 4221)

4249. Anderson, A. 1970. Mercury in soil. Grundforbattring 20:95. (Cited in 4221)

4250. DeGroot, A.J.; DeGoeij, J.J.M.; Zegers, C. 1971. Contents and behavior of mercury as compared with other heavy metals in sediments from the Rivers Rhine and Ems. Geol. Mijnbouw 50:393. (Cited in 4221)

4251. Feick, G; Johanson, E.E.; Yeaple, D.S. 1972. Control of Mercury Contamination in Fresh Water Sediments. Environmental Protection Technology Series, EPA-R2-72-077. (Cited in 4221)

4252. Ramamoorthy, S.; Rust, B.R. 1976. Mercury sorption and desorption characteristics of some Ottawa River Sediments. Can. J. Earth Sci. 13:530-536. (Cited in 4221)

4253. Hogg, T.J.; Stewart, J.W.B.; Bettany, J.R. 1978. Influence of the chemical form of mercury on its adsorption and ability to leach through soils. J. Environ. Qual. 7:440-445. (Cited in 4240 and 4221)

4254. Schroeder, W.H.; Lindqvist, J.M. 1989. Cycling of mercury between water, air, and soil compartments of the environment. Water, Air, Soil Pollut. 48:337-347.

4255. Sienko, M.J.; Plane, R.A. 1966. Chemistry: Principles and Properties. New York: McGraw-Hill Book Co. (Cited in 4221)

4256. Rogers, R.D. 1978. Volatility of Mercury from Soils Amended with Various Mercury Compounds. Office of Research and Development, U.S. EPA. EPA-600/3-78-046. (Cited in 4221)

4257. Jensen, S.; Jernelov, A. 1969. Biological methylation of mercury in aquatic organisms. Nature 223:753-754. (Cited in 4231 and 4225)

4258. Stumm, W.; Morgan, J.J. 1981. Aquatic Chemistry, 2nd ed. New York; John Wiley & Sons. (Cited in 4221)

4259. Okouchi, S.; Sasaki,S. 1984. Volatility of mercury in water. J. Hazard Mater. 8:341-348. (Cited in 4221)

4260. Fagerstrom, T; Jernelov, A. 1972. Some aspects of the quantitative ecology of mercury. Water Res. 6:1193-1202. (Cited in 4221)

4261. Rissanen (initial not given). 1974. Personal communication. (Cited in 4232)

4262. Beijer, K.; Jernelov, A. 1979. Methylation of mercury in aquatic environments. In: The Biogeochemistry of Mercury in the Environment, Iriagu, J.O., Ed. Amsterdam: Elsevier/North-Holland Biomedical Press, pp. 203-211. (Cited in 4231)

4263. Wood, J.M.; Lien, E.L. 1971. Report to the Government of Ontario. (Cited in 4221)

4264. Bisogni, J.J.; Lawrence, A.W. 1973. Cornell Univ. Tech. Rep. No. 63. Cornell University, Ithaca, N.Y. (Cited in 4232)

4265. Furutani and Rudd. 1980. Bibliographic information not given. (Cited in 4231)

4266. Rudd, J.W.; Furutani, A.; Tuner, M.A. 1980. Mercury methylation by fish intestinal contents. Appl. Environ. Microbiol. 40:777-782. (Cited in 4231)

4267. Rudd, J.W. Personal communication. 1984. Freshwater Institute, Winnipeg, Manitoba. (Cited in 4231)

4268. Furakawa, K; Suzuki, T; Tonomura, K. 1969. Title not given. Agric. Biol. Chem. 33:128-130. (Cited in 4232)

4269. Kitamura, S.; Sumino, K.; Taina, M. 1969. Title not given. Jpn. J. Hyg. 24:76-77. (Cited in 4232)

4270. Williston, S.H. 1968. Mercury in the atmosphere. J. Geophysical Res. 73:7051-7055. (Cited in 4225)

4271. Holm, H.W.; Cox, M.F. 1974. Mercury in aquatic systems: methylation, oxidation-reduction, and bioaccumulation. Washington, DC: U.S. EPA. EPA 660/3-74-021. (Cited in 4225)

4272. Johnson, D.L.; Bramen, R.S. 1974. Distribution of atmospheric mercury near ground. Environ. Sci. Technol. 8:1003-1009. (Cited in 4225)

4273. Zepp, R.G.; Wolfe, N.L.; Gordon, J.A. 1973. Photodecomposition of phenylmercury compounds in sunlight. Chemosphere 3:93-99. (Cited in 4225)

4274. Wood, J.M. 1975. Metabolic cycles for toxic elements in the environment. In: Heavy Metals in the Aquatic Environment. Krenkel, P.A., Ed. Oxford, England: Pergamon Press, 105-112. (Cited in 4221)

4275. Baes, C.F.; Mesmer, R.E. 1976. The Hydrolysis of Cations. New York: John Wiley & Sons. (Cited in 4221)

4276. Sillen, L.G.; Martell, A.E. 1964. Stability Constants of Metal-Ion Complexes, Special Publication No. 7. London: The Chemical Society. (Cited in 4221)

4277. Lindsay, W.L. 1979. Chemical Equilibria in Soils. New York: John Wiley & Sons. (Cited in 4221)

4278. Sorterberg, A. 1980. The effect of some heavy metals on oats in pot experiments with three different soil types. In: Geomedical Aspects in Present and Future Research Tag, J., Ed. Oslo: Universitetsforlaget, p. 209. (Cited in 4240)

4279. Lipsey, R.L. 1975. Accumulation and physiological effects of methyl mercury hydroxide on maize seedlings. Environ. Pollut. 8:149. (Cited in 4240)

4280. Lodenius, M.; Herranen, M. 1981. Title not given. Chemosphere 19:313. (Cited in 4281)

4281. Magos, L. 1988. Mercury. In: Handbook on Toxicity of Inorganic Compounds. H.G. Seiler, H.Sigel, and A. Sigel, Eds., New York: Marcel Dekker, Inc. pp. 419-436.

4282. Laaksovirta, K.; Lodenius, M. 1979. Title not given. Ann. Bot. Fenn. 16:208. (Cited in 4281)

4283. Wren, C.D. 1986. A review of metal accumulation and toxicity in wild mammals. Environ. Res. 40:210-244.

4284. Bennett, B.G. 1986. Exposure assessment for metals involved in carcinogenesis. In: IARC Sci. Publ. 71, Environmental Carcinogens Selected Methods of Analysis 8:115-28

4285. D'Itri, F.M. The Environmental Mercury Problem. Cleveland: CRC Press. (Cited in 4221)

4286. U.S Environmental Protection Agency (U.S. EPA). 1980. Ambient Water Quality Criteria for Mercury. Environmental Criteria and Assessment Office. EPA 440/5-80-058. NTIS BP 81-117699. (Cited in 4287)

4287. U.S. Environmental Protection Agency (U.S. EPA). 1984. Health Effects Assessment for Mercury. Prepared by the Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH. Prepared for the Office of Emergency and Remedial Response, Washington, D.C. EPA-540-1-86-042.

4288. U.S. Environmental Protection Agency (U.S. EPA). 1985. Health Advisory on Mercury--Draft. Washington, DC: Office of Drinking Water, U.S. EPA. (Cited in 4238)

4289. Bennett, B.G. 1981. Exposure Commitment Assessments of Environmental Pollutants, Vol. 1, No. 2. London: Monitoring and Assessment Research Center. (Cited in 4281)

4290. Saha, J.G. 1972. Title not given. Residue Rev. 42:103. (Cited in 4281)

4291. Heit, M.; Klusek, C.S. 1985. Trace element concentrations in the dorsal muscle of white suckers and brown bullheads from two acidic Adirondack lakes. Water, Air, Soil Pollut. 25:87-96.

4292. Badsha, K.S.; Goldspink, C.R. 1988. Heavy metal levels in three species of fish in Tjeukemeer, a Dutch polder lake. Chemosphere 17:459-63.

4293. World Health Organization (WHO). 1984. Mercury. In: Guidelines for Drinking-Water Quality, vol. 2. Geneva: WHO, pp. 120-123.

4294. Wolff, M.S. 1983. Occupationally derived chemicals in breast milk. Am. J. Ind. Med. 4:259-281.

4295. Fugita, M.; Takabatake, E. 1977. Mercury levels in human and neonatal blood, hair and milk. Bull. Enviornl. contam. Toxicol. 18:205-209. (Cited in 4294)

4296. Bakir (initial not given) et al. 1973. Estimated from data reported by Wilson, J.T.; Brown, R.D.; Cherek, D.R. et al. 1980. Drug excretion in human breast milk. Clin. Pharmacokinet. 5:1-55. (Cited in 4294)

4297. Pitkin, R.M.; Bahns, J.A.; Filer, L.J.; Reynolds, W.A. 1976. Mercury in human maternal and cord blood, placenta, and milk. Proc. Soc. Exp. Biol. Med. 151:565-567. (Cited in 4294)

4299. Clarkson, T.W.; Amin-Zaki, L.; Al-Tikriti, A. 1976. Title not given. Fed. Proc. Am. Soc. Exp. Biol. 35:2395. (Cited in 4281)

4300. Gerstner, H.E.; Huff, J.E. 1977. Title not given. Clin. Toxicol. 11:131. (Cited in 4281)

4301. Frank, R.; Stonefield, K.I.; Luyken, H.; Suda, P. 1986. Survey of elemental contents in two organs of slaughtered bovine, porcine and avian specimens. Environ. Monit. Assess. 6:259-265.

4302. Ministry of Supply and Services (MSS). 1979. Guidelines for Canadian Drinking Water Quality, 1978. Quebec: MSS. (Cited in 4293)

4303. Goyer, R.A. 1986. Toxic Effects of Metals. In: Casarett and Doull's Toxicology: The Basic Science of Poisons. 3rd ed., New York:Macmillan Publ. Co. pp. 582-635.

4304. Berlin, M. 1986. Mercury. In: Handbook on the Toxicology of Metals. Volume II: Specific Metals. 2nd ed., L. Friberg, G.F. Nordberg, and V.B. Vouk, Eds. New York:Elsevier. pp. 387-445.

4305. Fitzhugh, O.B.; Nelson, A.A.; Laug, E.P.; et al. 1950. Chronic oral toxicities of mercuriphenyl and mercuric salts. Arch. Ind. Hyg. Occup. Med. 2:433-442. (Cited in 4238 and 4239).

4306. Miller, C.T.; Zawidska, Z.; Nagy, E.; et al. 1979. Indicators of genetic toxicity in leukocytes and granulocytic precursors after chronic methylmercury ingestion by cats. Bull. Environ. Contam. toxicol. 21:296-303. (Cited in 4238)

4307. Skerfving, S.; Hansson, K.; Mangs, C.; Lindsten, J.; Ryman, N. 1974. Methyl mercury-induced chromosome damage in man. Environ. Res. 7:83-102. (Cited in 4239).

4308. Gale, T.F. 1974. Embryopathic effects of different routes of administration of mercuric acetate on the hamster. Environ. Res. 8:207-213. (Cited in 4238).

4309. Fukuda, K. 1971. Metallic mercury induced tremor in rabbits and mercury content of the central nervous system. Br. J. Ind. med. 28:308-311. (Cited in 4350).

4310. Magos, L.; Butler, W.H. 1972. Cumulative effects of methyl mercury dicyandiamide given orally to rats. Fd. Cosmet. Toxicol. 10:513-517. (Cited in 4239)

4311. Chang, L.; Hartmann, H.A. 1972. Blood-brain barrier dysfunction in experimental mercury intoxication. Acta Neuropathol. 21:179-184. (Cited in 4239).

4312. Albanus, L.; Frankenberg, L.; Grant, C.; et al. 1972. Toxicity for cats of methyl mercury in contaminated fish from Swedish lakes and of methyl mercury hydroxide added to fish. Environ. Res. 5:425-442. (Cited in 4239).

4313. Grant, C.A. 1973. Pathology of experimental methyl mercury intoxication: Some problems of exposure and response. In: Mercury, Mercurials and Mercaptans, M.W. Miller and T.W. Clarkson, Eds. Charles C. Thomas, Springfield, IL. pp. 294-312. (Cited in 4239).

4314. Chang, L.W.; Yamaguchi, S.; Dudley, Jr., A.W. 1974. Neurological changes in cats following long-term diet of mercury contaminated tuna. Acta Neuropathol. (Berl.) 27:171-176. (Cited in 4239)

4315. Rice, D.C.; Gilbert, S.G. 1982. Early chronic low-level methyl mercury poisoning in monkeys impairs spatial vision. Science. 216:759-761. (Cited in 4239)

4316. Gerstner, H.B.; Huff, J.E. 1977. Clinical toxicology of mercury. J. Toxicol. Environ. Health 2:491-526.

4317. Baselt, R.C. 1988. Mercury. In: Biological Monitoring Methods for Industrial Chemicals, 2nd ed. Littleton, MA: PSG Publishing Co., Inc., pp. 198-204.

4318. Stack, T.; Bissenden, J.G.; Hoffman, G.; Yeoman, W.B. 1983. Mercuric chloride poisoning in a 23 month old child. Br. Med. J. 287:1513.

4319. Lai, K.-N.; Pugsley, D.J.; Black, R.B. 1983. Acute renal failure after peritoneal lavage with mercuric chloride. Med. J. Aust. 1:37-38.

4320. Laundy, T.; Adam, A.E.; Kershaw, J.B.; Rainford, D.J. 1984. Deaths after peritoneal lavage with mercuric chloride solutions: A case report and review of the literature. Br. Med. J. 289:96-98.

4321. Miettinen, J.K. 1973. Absorption and elimination of dietary mercury (Hg^{2+}) and methylmercury in man. In:Mercury, Mercurials and Mercaptans. M.W. Miller and T.W. Clarkson, Eds. Springfield, IL: Charles C. Thomas Publisher. pp. 233-243.

4322. Inskip, M.J.; Piotrowski, J.K. 1985. Review of the health effects of methylmercury. J. Appl. Toxicol. 5:113-133.

4323. Samuels, E.R.; Heick, H.M.C.; McLaine, P.N.; Farant, J.-P. 1982. A case of accidental mercury poisoning. J. Anal. Toxicol. 6:120-122.

4324. Baer, J.E.; Beyer, K.H. 1986. Renal pharmacology. ann. Rev. Pharmacol. 6:261-292. (Cited in 4239).

4325. Goldwater, L.J. 1973. Aryl- and Alkoxyalkylmercurials. In: Mercury, Mercurials and Mercaptans. M.W. Miller and T.W. Clarkson, Eds. Springfield, IL: Charles C. Thomas Publishers. pp. 56-67.

4326. Teisinger, J.; Fierova-Bergerova, V. 1965. No title given. Ind. Med. Surg. 34:580. (Cited in 4227).

4327. Hursh, J.B.; Clarkson, T.W.; Cherian, M.G.; Vostal, J.J.; Mallie, R.V. 1979. No title given. Arch. Environ. Health 31:302. (Cited in 4281)

4328. Study Group on Mercury Hazards. 1971. Hazards of mercury. Special report to the Secretary's Pesticide Advisory Committee, Department of Health, Education, and Welfare, November 1970. Environ. Res. 4:1-69.

4329. Bilderback, J.B.; Anderson, J.A. 1975. Acrodynia (pink disease; Swift's disease; Feer's disease; erythredema; dermatopolyneuritis). In: Nelson Textbook of Pediatrics. 10th ed., V.C. Vaughan, III, R.J. McKay, W.E. Nelson, Eds. Philadelphia:W.B.Saunders Co. pp. 1682-1684.

4330. Bakir, F.; Kamluji, S.F.; Amin-Zaki, L.; et al. 1973. Methylmercury poisoning in Iraq. Science 181:230-241.

4331. Elhassani, S.B. 1982-83. the many faces of methylmercury poisoning. J. Toxicol.-Clin. Toxicol. 19:875-906.

4332. Mufti, A.W. Copplestone, J.F.; Kantzis, G.; Mahmoud, R.M.; Majid, M.A. 1976. Epidemiology of organomercury poisoning in Iraq. 1. Incidence in a defined area and relationship to the eating of contaminated bread. In: WHO Conference on Intoxication Due to Alkyl Mercury Treated Seed, Baghdad 9-13 November 1974, WHO, Geneva, Vol. 53 (Suppl. to Bull. WHO), pp. 23-63. (Cited in 4227).

4333. Amin-Zaki, L.; Elhassani, S.; Majeed, M.A.; Clarkson, T.W.; Doherty, R.A.; Greenwood, M. 1974. Intra-uterine methylmercury poisoning in Iraq. Pediatrics 54:587-595.

4334. Harada, M. 1978. Congenital Minamata disease: Intrauterine methylmercury poisoning. Teratology 18:285-288.

4335. Cragle, D.L.; Hollis, D.R.; Qualters, J.R.; Tankersley, W.G.; Fry, S.A. 1984. A mortality study of men exposed to elemental mercury. J. Occup. Med. 26:817-821.

4336. Barregard, L.; Sallsten, G.; Jarvholm B. 1990. Mortality and cancer incidence in chloralkali workers exposed to inorganic mercury. Br. J. Ind. Med. 47:99-104.

4337. Piikivi, L.; Tolonen, U. 1989. EEG findings in chlor-alkali workers subjected to low long term exposure to mercury vapour. Br. J. Ind. Med. 46:370-375.

4338. Albers, J.W.; Cavender, D.; Levine, S.P.; Langolf, G.D. 1982. Asymptomatic sensorimotor polyneuropathy in workers exposed to elemental mercury. Neurology 32:1168-1174.

4339. Levine, S.P.; Cavender, G.D.; Langolf, G.D.; Albers, J.W. 1982. Elemental mercury exposure: peripheral neurotoxicity. Br. J. Ind. Med. 39:136-139.

4340. Schuckmann, F. 1979. Study of preclinical changes in workers exposed to inorganic mercury in chloralkali plants. Int. Arch. Occup. Environ. Health. 44:193-200.

4341. Verberk, M.M.; Salle, H.J.A.; Kemper, C.H. 1986. Tremor in workers with low exposure to metallic mercury. Am. Ind. Hyg. Assoc. 47:559-562.

4342. Soleo, L.; Urbano, M.L.; Petrera, V.; Ambrosi, L. 1990. Effects of low exposure to inorganic mercury on psychological performance. Br. J. Ind. Med. 47:105-109.

4343. Shapiro, I.M.; Sumner, A.J.; Spitz, L.K.; et al. 1982. Neurophysiological and neuropsychological function in mercury-exposed dentists. Lancet (pt.2; Sept. 25, 1982):1147-1150.

4344. De Rosis, F.; Anastasio, S.P.; Selvaggi, L.; Beltrame, A.; Moriani, G. 1985. Female reproductive health in two lamp factories: effects of exposure to inorganic mercury vapour and stress factors. Br. J. Ind. Med. 42:488-494.

4345. Rosenman, K.D.; Valciukas, J.A.; Glickman, L.; Meyers, B.R.; Cinotti, A. 1986. Sensitive indicators of inorganic mercury toxicity. Arch. Environ. Health 41:208-215.

4346. Hunter, D.; Bomford, R.R.; Russell, D.S. 1940. Poisoning by methyl mercury compounds. Quart. J. Med. 9:193-213. (Cited in 4328)

4347. Hunter, D.; Russell, D.S. 1954. Focal cerebral and cerebellar atrophy in a human subject due to organic mercury compounds. J. Neurol. Neurosurg. Psychiat. 17:235-241. (Cited in 4328).

4348. Nriagu, J.O., Ed. 1979. The Biogeochemistry of Mercury in the Environment. New York: Elsevier/North-Holland.

4349. Smith, P.J.; Langolf, G.D.; Goldberg, J. 1983. Effects of occupational exposure to elemental mercury on short term memory. Br. J. Ind. Med. 40:413-419.

4350. Suzuki, T. 1979. Dose-effect and dose-response relationships of mercury and its derivatives. In: The Biogeochemistry of Mercury in the Environment, J. O. Nriagu, Ed. New York: Elsevier/North-Holland Biomed. Press. pp. 399-431.

4351. Hahne, H.C.H.; Kroontje, W. 1973. Significance of pH and chloride concentration on behavior of heavy metal pollutants - mercury(II), cadmium(II), zinc(II), and lead(II). J. Environ. Qual. 2:444-450. (Cited in 4221)

4352. Kazantzis, G.; Schiller, K.F.R.; Asscher, A.W.; Drew, R.G. 1962. Albuminuria and nephrotic syndrome following exposure to mercury and its compounds. Q. J. Med. 31:403-419. (Cited in 4239).

4353. Shahristani, H. et al. 1976. In: World Health Organization conference on Intoxication Due to Alkyl Mercury Treated Seed, Baghdad 9-13 November 1974, Geneva, World Health Organization, pp. 105. (Suppl. to Bull. World Health Organ., Vol. 53). (Cited in 4227).

4354. Aberg, B.; Ekman, L.; Falk, R.; Greitz, U. Persson, g.; Snihs, J. 1969. Metabolism of methyl mercury(^{203}Hg) compounds in man. Excretion and distribution. Arch. Environ. Health. 19:478-484. (Cited in 4239).

4355. Swedish Expert Group. 1971. Methyl Mercury in Fish. Toxicological-Epidemiological Evaluation of Risks. Report From an Expert Group. Norw. Hyg. Tidschr., Suppl 4. (Cited in 4281 and 4227).

4356. Sexton, D.J.; Powell, K.E.; Liddle, J.; Smrek, A.; Smith, J.C.; Clarkson, T.W. 1978. A nonoccupational outbreak of inorganic mercury vapor poisoning. Arch. Environ. Health 33:186-191.

4357. U.S. Environmental Protection Agency (U.S. EPA). 1986. Test Methods for Evaluation of Solid Waste, U.S. EPA SW-846, 3rd ed.

4358. U.S. Environmental Protection Agency (U.S. EPA). 1983. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020.

4359. Nriagu, J.O. 1979. Production and uses of mercury. In: the Biogeochemistry of Mercury in the Environment. Nriagu, J.O., Ed. Amsterdam: Elsevier/North-Holland, p. 23-40.

4360. Clarkson, T.W. 1979. Mercury poisoning. In: Clinical Chemistry and Chemical Toxicology of Metals. Brown, S.S., Ed. New York: Elsevier/North Holland, pp. 189-200. (Cited in 4317)

4361. U.S. Environmental Protection Agency (U.S. EPA). 1990.Environmental Criteria and Assessment Office. Research Triangle Park, NC. (Personal Communication, September, 1990).

7000. Occupational Safety and Health Administration (OSHA). 1989. Air contaminants: final rule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7003. Occupational Safety and Health Administration (OSHA). 1989. Hazardous waste operations and emergency response; final rule. 29CFR1910.120, Fed. Regist., 3/6/89, 54:9294-9336.

7009. U.S. Environmental Protection Agency (U.S. EPA). 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT). 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7015. U.S. Environmental Protection Agency (U.S. EPA). 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. U.S. Environmental Protection Agency (U.S. EPA). 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. U.S. Environmental Protection Agency (U.S. EPA). 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. U.S. Environmental Protection Agency (U.S. EPA). 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. U.S. Environmental Protection Agency (U.S. EPA). 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020. U.S. Environmental Protection Agency (U.S. EPA). 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. U.S. Environmental Protection Agency (U.S. EPA). 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7023. U.S. Environmental Protection Agency (U.S. EPA). 1982. Ore mining and dressing point source category. 40CFR440, Fed. Regist., 12/3/82, 47:54609, as amended 1988, 53:18788.

7025. U.S. Environmental Protection Agency (U.S. EPA). 1981. Electroplating point source category. 40CFR413, Fed. Regist., 1/28/81, 46:9467, as revised 1983, 48:43681 and 32483.

7027. U.S. Environmental Protection Agency (U.S. EPA). 1984. Battery manufacturing point source category. 40CFR461, Fed. Regist., 3/9/84, 49:9134 and 13879, as revised 1986, 51:30816.

7049. U.S. Environmental Protection Agency (U.S. EPA). 1989. National primary and secondary drinking water regulations; proposed rule. 40CFR141-143, Fed. Regist., 5/22/89, 54:22062-22160.

7050. U.S. Environmental Protection Agency (U.S. EPA). 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7051. U.S. Environmental Protection Agency (U.S. EPA). 1975. Maximum contaminant levels for inorganic contaminants. 40CFR141.11, 12/24/75, 40:59570, as amended 1980, 45:57342 and 1982, 47:10998 and 1986, 51:11410.

7054. U.S. Environmental Protection Agency (U.S. EPA). 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. U.S. Environmental Protection Agency (U.S. EPA). 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7060. U.S. Environmental Protection Agency (U.S. EPA). 1987. Extremely hazardous substance list and threshold planning quantities. 40CFR355 (SARA Title III Section 302), Fed. Regist., 4/22/87, 52:13395, as revised 1987, 52:48073 and 1988, 53:5574.

7061. U.S. Environmental Protection Agency (U.S. EPA). 1971. Lists of pollutants and applicability of part 61; mercury. 40CFR61.01, Fed. Regist., 3/31/71, 36:5931.

7062. U.S. Environmental Protection Agency (U.S. EPA). 1975. National emission standard for mercury.40CFR61.51, 4/6/73, 38:8826, as amended 1975, 40:48302; 1982, 47:24704; 1985, 50:46294, 1987, 52:8726; and 1988, 53:36972.

7064. U.S. Environmental Protection Agency (U.S. EPA). 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7065. U.S. Environmental Protection Agency (U.S. EPA). 1989. Designation of extremely hazardous substances as CERCLA hazardous substances; proposed rule. 40CFR302, Fed. Regist., 1/23/89, 54:3388.

7066. U.S. Environmental Protection Agency (U.S. EPA). 1989. Reportable quantity adjustments; proposed rule. 40CFR302 and 355, Fed. Regist., 8/30/89, 54:35988.

7068. U.S. Environmental Protection Agency (U.S. EPA). 1989. Waste specific prohibitions - second third wastes. 40CFR268.34, Fed. Regist., 6/23/89, 54:26594.

7070. Food and Drug Administration (FDA). 1977. Bottled drinking water standards. 21CFR103.35, Fed. Regist., 3/15/77, 42:14325, as last amended 1984, 49:10090.

7074. U.S. Environmental Protection Agency (U.S. EPA). 1980. Characteristic of EP toxicity. 40CFR261.24, Fed. Regist., 5/19/80, 45:33119, as amended 1981, 46:35247.

7076. U.S. Environmental Protection Agency (U.S. EPA). 1981. Hazardous wastes from specific sources. 40CFR261.32, Fed. Regist., 1/16/81, 46:4618, as last amended 1988, 53:35420.

7077. U.S. Environmental Protection Agency (U.S. EPA). 1981. Basis for listing hazardous waste. 40CFR261 Appendix VII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:35421.

7078. U.S. Environmental Protection Agency (U.S. EPA). 1980. Discarded commercial chemical products and their hazardous waste numbers. 40CFR261.33, Fed. Regist., 11/25/80, 45:78529 and 78541, as last amended 1988, 53:43881 and 43884.

7079. U.S. Environmental Protection Agency (U.S. EPA). 1981. Hazardous constituents. 40CFR261 Appendix VIII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:43881.

7080. U.S. Environmental Protection Agency (U.S. EPA). 1982. Groundwater protection: concentration limits. 40CFR264.94, Fed. Regist., 7/26/82, 47:32350, as amended 1983, 48:14294.

7082. U.S. Environmental Protection Agency (U.S. EPA). 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7083. U.S. Environmental Protection Agency (U.S. EPA). 1988. Hazardous waste injection restrictions: waste specific prohibitions. 40CFR148.10-16, Fed. Regist., 8/16/88, 53:30908, as amended 1988, 53:41602 and 1989, 54:25422 and 26647.

7084. U.S. Environmental Protection Agency (U.S. EPA). 1988. Waste specific prohibitions - first third wastes. 40CFR268.33, Fed. Regist., 8/17/88, 53:31217.

7085. U.S. Environemntal Protection Agency (U.S. EPA). 1989. Land disposal restrictions for third third scheduled wastes; proposed rule. 40CFR 148,261,264-5,268,271, Fed. Regist., 11/22/89, 54:48372.

7086. Council of European Communities Directive on Drinking Water, 16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7087. Council of European Communities Directive on Bathing Water Quality, 8 December 1975 (76/160/EEC-OJ L31, 5 February 1976, amended by 1851).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7091. Council of European Communities Directive on Groundwater, 17 December 1979 (80/68/EEC-OJ L20, 26 January 1980).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7093. Council of European Communities Directive on Toxic and Dangerous Waste, 20 March 1978, amended by 1851.

7095. Council of European Communities Directive on Classification, Packaging and Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7096. Council of European Communities Directive on Plant Products, 21 December 1978 (79/117/EEC-OJL53, 8 February 1979, amended by 83/131/EEC, 14 March 1983, amended by 85/298/EEEC, 22 May 1985).

7099. Proposal or a Council Directive on the Dumping of Waste at Sea, Comm (85) 373 Final, 4 July 1985.

7100. Council Directive on Major Accident Hazards of Certain Industrial Accidents.June 24, 1982; 82/501/EEC.Official Journal No. L 230/1, 87/21/216/EEC, OJ L 85, 28 March 1987, p. 36, amended by 87/216/EEC of 19 March 1987).

7101. Council of European Communities Directive.Proposal for a Council Regulation Concerning Export from and Import Into the Community of Certain Dangerous Chemicals, amended 22 June 1988, OJ L 155).

7104. Council Directive on the Combating of Air Pollution from Industrial Plants, 84/360/EEC, 228 June 1984.

7105. Council Decision Concluding the Convention for the Prevention of Marine Pollution From Land-Based Sources, 75/437/EEC, 3 March 1975.

7106. Council Decision - Marine Pollution by Mercury and Cadmium, 85/613/EEC, 1985.

7107. Council Directive on Limit Values and Quality Objectives for Mercury Discharges by the Chlor-Alkali Electrolysis Industry, 82/176/EEC, 22 March 1982.

7109. Council Directive on Limit Values and Quality Objectives for Mercury Discharges by Sectors Other than the chlor-Alkali Electrolysis Industry.

7110. U.S. Environmental Protection Agency (U.S. EPA). 1989. Burning of hazardous waste in boilers and industrial furnaces; proposed rule. 40CFR260-1,264-6,270-1, Fed. Regist., 10/26/89, 54:43718.

7112. Florida Department of Environmental Regulation. 1989. Florida Water Quality Standards, Chapter 17-3, effective 12/20/89.

7114. Vermont Department of Water Resources. 1988. State of Vermont Ground Water Protection Rule and Strategy, Chapter 12:101-710, effective 9/29/88.

7115. Virginia Water Control Board. 1988.Commonwealth of Virginia Water Quality Standards, VR 680-21-00, effective 11/1/88.

7116. Wisconsin Department of Natural Resources. 1988. Wisconsin Chapter NR140, Groundwater Quality, effective 10/88.

7120. Wyoming Department of Environmental Quality. 1980. Chapter VIII, Quality Standards for Wyoming Groundwaters, effective 9/4/80.

7121. District of Columbia Department of Consumer and Regulatory Affairs. 1985. Water Quality Standards of the District of Columbia, Chapter II, Title 21 DCMR, effective 12/27/85.

7122. Mississippi Department of Environmental Quality. 1989. State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters; proposed amendments, 12/22/89.

7123. West Virginia Water Resources Board. 1989. State of West Virginia Water Quality Standards, effective 4/28/89.

7124. Wisconsin Department of Natural Resources. 1989. Wisconsin Chapter NR105, Surface Water Quality Criteria for Toxic Substances, effective 3/1/89.

COMMON SYNONYMS:	CAS. REG. NO.: 7440-66-6 NIOSH NO.: ZG8600000 EPA HAZARDOUS WASTE NO.: ND
Zinc (dust, powder) ASARCO L 15 Blue Powder Emanay Zinc Dust Granular Zinc Jasad Merrillite	CHEMICAL SYMBOL: Zn

REACTIVITY (5604)

Zn + Hydrogen → no reaction
Zn + Oxygen, Ozone (dry, 25°C) → rapid formation of thin oxide film
Zn + Air (moist, 25°C) → basic carbonate
Zn + Air (heated) → ZnO, metal burns with bright blue-green flame
Zn + Water (gas) → no or very slow reaction below 400°C
Zn + Water (liquid) → slow formation of ZnO, Beta-Zn hydroxide coating
Zn + Sulfur dioxide (moist air, 25°C) → Zinc sulfate, oxide, carbonate, etc.
Zn + Dilute mineral acids, organic acids → hydrogen, Zn^{2+}
Zn + Aq. NaOH → hydrogen, soluble hydroxo anionic species
Zn + Metal oxides (heated) → ZnO + metal (e.g. Cd, Ni, Fe, Cu, Pb)
Zn + Metal halides (heated) → Zn halide + metal (e.g., Cd, Hg, Sn, Pb)

PHYSICO-CHEMICAL DATA

• Atomic Weight: 65.38	(5603)
• Atomic Number: 30	(5600)
• Physical State: Solid (at 20°C)	(5640)
• Color: Lustrous, blue-white	(5640)
• Odor: NA	
• Odor Threshold: NA	
• Density: 7.133 g/cm^3 (at 25°C)	(5640)
• Melting Point: 419.5°C	(5640)
• Boiling Point: 907°C	(5640)
• Flash Point: ND	
• Flammable Limits: Powdered form can burn when damp	(5603)
• Autoignition Temperature: ND	
• Vapor Pressure: 1 mm Hg (at 487°C)	(5645)
• Saturated Concentration in Air: NA	
• Solubility in Water: Insoluble	(5645)
• Viscosity: NA	
• Surface Tension: NA	

PHYSICO-CHEMICAL DATA (Cont.)

- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: Range 0.1-8000 mL/g (5612)
  Average 40 mL/g (5612)
  Sandy loam, 939 mL/g (5612)
  Sandy soil, 12.2 mL/g (5646)
- Henry's Law Constant: NA
- Bioconcentration Factor: 400-1400 (5600)

HANDLING PRECAUTIONS

Zinc powder may form an explosive mixture when mixed with air. The pyrophoric form should be handled without exposure to air. It should be stored separately from acids, alkalis, and halogenated hydrocarbons and protected from moisture. Self-contained breathing apparatus should be used for handling zinc powder (5603).

Safety glasses, dust masks, and rubber gloves should be used for handling zinc chloride and zinc sulfate (5642, 5643).

COMMON SYNONYMS:	CAS. REG. NO.: 557-34-6 NIOSH NO.: AK1500000 EPA HAZARDOUS WASTE NO.: ND
Zinc acetate Acetic acid, zinc salt Dicarbomethoxyzinc Zinc diacetate	CHEMICAL FORMULA: $C_4H_8O_4.Zn$

REACTIVITY

No data.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 183.46
- Physical State: Solid
- Color: White
- Odor: Faint vinegar
- Odor Threshold: ND
- Density: 1.735 g/cm^3
- Melting Point: 237°C
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Not flammable
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 434 g/L
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)

Dust irritating to eyes, nose, throat. Solid irritating to skin. Use of rubber gloves, goggles, and respirator recommended.

COMMON SYNONYMS:	CAS. REG. NO.: 7699-45-8 NIOSH NO.: ZH1150000 EPA HAZARDOUS WASTE NO.: ND
Zinc bromide Zinc dibromide	CHEMICAL FORMULA: $ZnBr_2$

REACTIVITY (5676)

Mixtures of sodium or potassium and zinc bromide produce strong explosion on impact.

PHYSICO-CHEMICAL DATA (5676)

- *Molecular Weight:* 225.21
- Physical State: Solid
- Color: Colorless
- Odor: Odorless
- Odor Threshold: NA
- Density: 4.201 g/cm^3 (at 25°C)
- Melting Point: 394°C
- Boiling Point: 650°C
- Flash Point: ND
- Flammable Limits: Non-combustible
- Autoignition Temperature: NA
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 4000 g/L
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)

Contact causes burns to skin and eyes. Inhalation may be harmful. Chemical goggles or face shield, rubber gloves, and NIOSH approved respirator are recommended.

COMMON SYNONYMS:	CAS. REG. NO.: 3486-35-9 NIOSH NO.: FG3375000 EPA HAZARDOUS WASTE NO.: ND
Zinc carbonate Calamine Natural Smithsonite	CHEMICAL FORMULA: $ZnCO_3$

REACTIVITY

No data.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 125.38
- Physical State: Solid
- Color: White
- Odor: Odorless
- Odor Threshold: NA
- Density: 4.398 g/cm^3
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 0.01 g/L
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS
No data.

COMMON SYNONYMS:	CAS. REG. NO.: 7646-85-7 NIOSH NO.: ZH1400000 EPA HAZARDOUS WASTE NO.: ND
Zinc chloride Butter of zinc Zinc dichloride AI3-04470 Caswell No. 910 EPA Pesticide #087801 Zintrace	CHEMICAL FORMULA: $ZnCl_2$

REACTIVITY

Reacts with water to form basic zinc chloride and hydrochloric acid (5641). When heated to decomposition it produces toxic fumes (5676). Soluble zinc salts are precipitated as zinc hydroxides by alkaline hydroxides. Mixtures of zinc chloride and potassium are explosive on impact (5676).

PHYSICO-CHEMICAL DATA (5643)

- Molecular Weight: 136.29
- Physical State: Solid
- Color: White
- Odor: Acrid (fume)
- Odor Threshold: ND
- Density: 2.907 g/cm^3 (at 25°C)
- Melting Point: 290°C
- Boiling Point: 732°C
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: 1 mm Hg (at 428°C)
- Saturated Concentration in Air: ND
- Solubility in Water: 432 g/100 g (at 25°C)
- Viscosity: ND
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS

Contact causes burns to skin or eyes (5676). Harmful if inhaled. Zinc chloride should be stored in a well-ventilated place with containers tightly closed. Safety glasses, dust masks, and rubber gloves should be worn during handling of zinc chloride powder (5642).

For exposures to zinc chloride OSHA (5675) has the following respirator requirements:

- 10 mg/m^3 — Any dust, mist and fume respirator with full facepiece, or any supplied-air respirator, or any self-contained breathing apparatus.
- 25 mg/m^3 — Any powered air-purifying respirator equipped with a dust, mist and fume filter or any supplied-air respirator operated in a continuous flow mode.
- 50 mg/m^3 — Any air-purifying full facepiece respirator with a high-efficiency particulate filter or any powered air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter or any self-contained breathing apparatus with a full facepiece or any supplied-air respirator with a full facepiece.
- 2000 mg/m^3 — Any supplied-air respirator with a full facepiece and operated in a pressure-demand or other positive pressure mode.
- Unknown — Any self-contained breathing apparatus with a full facepiece and operated in a pressure-demand or other positive pressure mode or any supplied-air respirator with a full facepiece and operated in a pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 7783-49-5 NIOSH NO.: ZH3500000 EPA HAZARDOUS WASTE NO.: ND
Zinc fluoride Zinc difluoride	CHEMICAL FORMULA: ZnF_2

REACTIVITY (5676)

Reacts violently with potassium. When heated to decomposition emits toxic fumes.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 103.38
- Physical State: Solid
- Color: Colorless
- Odor: ND
- Odor Threshold: ND
- Density: 4.95 g/cm^3 (at 25°C)
- Melting Point: 872°C
- Boiling Point: ND
- Flash Point: NA
- Flammable Limits: Non-combustible
- Autoignition Temperature: NA
- Vapor Pressure: 1 mm Hg (at 970°C)
- Saturated Concentration in Air: ND
- Solubility in Water: 16.2 g/L (at 20°C)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)
Irritating to the eyes and nose.

COMMON SYNONYMS:	CAS. REG. NO.: 557-41-5 NIOSH NO.: LR0550000 EPA HAZARDOUS WASTE NO.: ND
Zinc formate Formic acid, zinc salt Zinc diformate	CHEMICAL FORMULA: $C_2H_4O_4.Zn$

REACTIVITY

No data.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 155.42
- Physical State: Solid
- Color: Colorless
- Odor: ND
- Odor Threshold: ND
- Density: 2.368 g/cm^3
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 38 g/L
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)
Approved respirator, rubber gloves and safety goggles recommended.

COMMON SYNONYMS:	CAS. REG. NO.: 7779--86-4 NIOSH NO.: JP2105000 EPA HAZARDOUS WASTE NO.: ND
Zinc hydrosulfite Dithionous acid, zinc salt Zinc dithionate Zincate(4-), tetrakis (monthiosulfato(2-)) di-	CHEMICAL FORMULA: $H_2O_4S_2.Zn$

REACTIVITY (5676)

Contact with water liberates SO_2 gas.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 195.52
- Physical State: Solid
- Color: White
- Odor: Slight SO_2 odor
- Odor Threshold: ND
- Density: g/cm^3: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Not flammable
- Autoignition Temperature: NA
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 280 lb/100 lb (at 68° F)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)
Dust irritating to eyes, nose, and throat. Solid irritating to skin.

COMMON SYNONYMS:	CAS. REG. NO.: 1314-13-2 NIOSH NO.: ZH4772000 EPA HAZARDOUS WASTE NO.: ND
Zinc nitrate Nitric acid, zinc salt Zinc dinitrate Celloxan	CHEMICAL FORMULA: $Zn(NO_3)_2$

REACTIVITY (5676)

Dangerous fire and explosion hazard. Non-combustible, but will accelerate the burning of combustible materials. Can react violently with carbon, copper, metal sulfides, organic matter, sulfides, and sulfur. When heated to decomposition emits toxic fumes of nitrates and zinc oxide.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 189.38
- Physical State: Solid
- Color: Colorless
- Odor: ND
- Odor Threshold: ND
- Density: 2.065 g/cm^3 (at 14°C, hexahydrate)
- Melting Point: 45.5°C (trihydrate)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Soluble, 1840 g/L (at 20°C, hexahydrate)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)

Inhalation of dust may irritate nose and throat. Contact with eyes or may cause irritation. NIOSH approved respirator, goggles or face shield, and gloves are recommended for the hexahydrate.

COMMON SYNONYMS:	CAS. REG. NO.: 1314-13-2 NIOSH NO.: ZH4810000 EPA HAZARDOUS WASTE NO.: ND
Zinc oxide ACTOX 14 ACTOX 16 ACTOX 216 AMALOX AZODOX AZO 22 Chinese white Emanay zinc oxide EMAR Flowers of zinc	CHEMICAL FORMULA: ZnO

REACTIVITY (5604)

$ZnO + X_2$ (X = F, Cl) → ZnX_2
$ZnO + X_2$ (X = Br, I) → No reaction
$ZnO + H_2S$ (at 500°C) → ZnS
$ZnO + SO_2/H_2O$ (at 25°C) → $ZnSO_3$
$ZnO + NO_2$ (at <140°C) → $Zn(NO_3)_2$
$ZnO + NO_2$ (at >140°C) → $Zn(NO_3)_2 + Zn(NO_2)_2$
$ZnO + H_2O → Zn(OH)_2$
$ZnO + CO → Zn + CO_2$
$ZnO + M$ (+heat) (M = K, Al, Fe, Cl, Ni) → $MO_x + Zn$
$ZnO + MO$ (+heat) (M = Mg, Cd, Mn, Co, Ni) → solution

PHYSICO-CHEMICAL DATA (5643)

- Molecular Weight: 81.38 (5676)
- Physical State: Powder or crystals (5676)
- Color: White or yellowish white (5676)
- Odor: Odorless (5676)
- Odor Threshold: NA
- Density: 5.607 g/cm^3 (at 20°C) (5676)
- Melting Point: 1975°C (5604)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND

PHYSICO-CHEMICAL DATA (5643) (Cont.)

- Vapor Pressure: 12 mm Hg (at 1500°C) (5604)
- Saturated Concentration in Air: ND
- Solubility in Water: 0.16 mg/100 mL (at 29°C) (5604)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS

Respirators should be used during handling of zinc oxide powder (5642). Fumes of zinc oxide cause metal fume fever. For exposures to fumes OSHA (5675) has the following respirator requirements:

• 50 mg/m^3	Any dust, mist and fume respirator with full facepiece, or any supplied-air respirator, or any self-contained breathing apparatus.
• 125 mg/m^3	Any powered air-purifying respirator equipped with a dust, mist and fume filter or any supplied-air respirator operated in a continuous flow mode.
• 250 mg/m^3	Any air-purifying full facepiece respirator with a high-efficiency particulate filter or any powered air-purifying respirator with a tight-fitting facepiece and a high-efficiency particulate filter or any self-contained breathing apparatus with a full facepiece or any supplied-air respirator with a full facepiece or any supplied-air respirator with a tight-fitting facepiece operated in a continuous flow mode.
• 2500 mg/m^3	Any supplied-air respirator with a full facepiece and operated in a pressure-demand or other positive pressure mode.
• Unknown	Any self-contained breathing apparatus with a full facepiece and operated in a pressure-demand or other positive pressure mode or any supplied-air respirator with a full facepiece and operated in a pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 127-82-2 NIOSH NO.: DB7120000 EPA HAZARDOUS WASTE NO.: ND
Zinc phenolsulfonate 1-phenol-4-sulfonic acid, zinc salt Benzenesulfonic acid, 4-hydroxy-, zinc salt Benzenesulfonic acid, p-hydroxy-, zinc salt Zinc sulfophenate Zinc phenol sulfonate	CHEMICAL FORMULA: $C_{12}H_{12}O_8S_2.Zn$

REACTIVITY

No data.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 411.70
- Physical State: ND
- Color: Colorless or white (octahydrate)
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 625 g/L (octahydrate)
- Viscosity: ND
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS
No data.

COMMON SYNONYMS:	CAS. REG. NO.: 16871-71-9 NIOSH NO.: VV8754000 EPA HAZARDOUS WASTE NO.: ND
Zinc silicofluoride Zinc fluosilicate Zinc hexaflurosilicate Silicon zinc fluoride Fungol	CHEMICAL SYMBOL: ZnF_6Si

REACTIVITY (5676)

Hydrolyzed by alkali to fluoride ion. When heated to decomposition, emits toxic fumes of hydrogen fluoride, silicon tetrafluoride and zinc oxide.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 207.46
- Physical State: Solid
- Color: Colorless
- Odor: ND
- Odor Threshold: ND
- Density: 2.104 g/cm^3 (hexahydrate)
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Non-combustible
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 54.371 lb/100 lb (at 70° F);
  77 g/100 g (at 10° C)
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5676)

Flurosilicates are irritants. Poisonous if swallowed. Inhalation of dust poisonous. NIOSH approved respirator, chemical goggles or face shield, and protective gloves recommended (hexahydrate).

COMMON SYNONYMS:	CAS. REG. NO.: 557-05-1 NIOSH NO.: ZH5200000 EPA HAZARDOUS WASTE NO.: ND
Zinc stearate Zinc octadecanoate Zinc distearate	CHEMICAL FORMULA: $C_{36}H_{72}O_4.Zn$

REACTIVITY

Not reactive. Repels water. When heated to decomposition emits acrid smoke and fumes of zinc oxide.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 632.33
- Physical State: Solid
- Color: White
- Odor: Faint odor
- Odor Threshold: ND
- Density: 1.095 g/cm^3
- Melting Point: 130°C
- Boiling Point: ND
- Flash Point: 530°F (open cup)
- Flammable Limits: ND
- Autoignition Temperature: 420°C
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Insoluble
- Viscosity: ND
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS
No data.

COMMON SYNONYMS:	CAS. REG. NO.: 7733-02-0 NIOSH NO.: ZH5260000 EPA HAZARDOUS WASTE NO.: ND
Zinc sulfate MEDIZINC OP-THAL-ZIN OPTRAEX SOLVEZINK VERAZINC White viiriol Zinlosite A13-03967 CASWELL No. 927	CHEMICAL FORMULA: $ZnSO_4$

REACTIVITY

Zinc sulfate forms three stable hydrates; monohydrate, hexahydrate, and heptahydrate (5641). Its aqueous solution is acidic (pH 4.5) (5644).

PHYSICO-CHEMICAL DATA

• Molecular Weight: 161.44	(5676)
• Physical State: Crystalline	(5676)
• Odor Threshold: ND	
• Density: 3.54 g/cm^3 (at 25°C)	(5676)
1.96 g/cm^3 (25°C), hexahydrate	(5645)
• Melting Point: 100°C, heptahydrate	(5602)
• Boiling Point: ND	
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	
• Solubility in Water: Soluble	(5602)
• Viscosity: NA	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Log K (Stability Constant for Humic Acid): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS
Contact with dust may cause burns to skin and eyes; inhalation may irritate nose and throat. NIOSH approved respirator and protective clothing recommended (5676).

COMMON SYNONYMS:	CAS. REG. NO.: 1314-98-3 NIOSH NO.: ND EPA HAZARDOUS WASTE NO.: ND
Zinc sulfide Zinc monosulfide CI Pigment white 7 Albalith Irtran 2	CHEMICAL SYMBOL: ZnS

REACTIVITY (5676)

When containing water, it slowly oxidizes in air to sulfate.

PHYSICO-CHEMICAL DATA (5676)

- Molecular Weight: 97.45
- Physical State: Crystalline (alpha form hexagonal; beta form cubic)
- Color: Colorless
- Odor: ND
- Odor Threshold: ND
- Density: 3.98 g/cm^3 (at 25°C, alpha);
  4.102 g/cm^3 (at 25°C, beta)
- Melting Point: 1700 ±20°C (at 50 atm., alpha)
- Boiling Point: 1185°C (at 1 atm., alpha)
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 6.9 mg/L (at 18°C, alpha)
  6.5 mg/L (at 18°C, beta)
- Viscosity: ND
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS
No data.

PERSISTENCE IN THE SOIL-WATER SYSTEM

Although highly soluble forms of zinc such as zinc chloride may be mobile in soil-water systems, under most conditions zinc is usually bound to soil, adsorbed to hydrated metal oxides (manganese and iron), clays, or organics, or present as insoluble precipitates. In general, desorption and increased zinc mobility are favored by low pH levels, reduced cation exchange capacity, light soil texture, and high salinity of soil water. Under such conditions leaching of zinc into groundwater may occur.

PATHWAYS OF EXPOSURE

Major pathways of exposure to the general population are through drinking water and food. Inhalation of airborne particles containing zinc may also be a significant route in certain areas close to industrial sources.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure:

Ingestion of high doses of zinc compounds can cause gastrointestinal disturbances including nausea, vomiting, and abdominal pain.

Inhalation of zinc oxide fume, formed as a result of oxidation of zinc vapor in air, can cause metal fume fever. The symptoms include chills, fever, aching, nausea, dry throat, cough, weakness and lassitude. Recovery is usually rapid without any sequelae.

Contact with zinc chloride causes burns to skin and eyes and inhalation of zinc chloride vapor is damaging to the respiratory system (5642).

Acute Toxicity Studies (5634):

INHALATION:

TC_{Lo} 600 mg/m^3/10-12 min	(zinc oxide)	human
TC_{Lo} 4800 mg/m^3/30 min	(zinc chloride)	human

ORAL:

LD_{Lo} 500 mg/kg	(zinc oxide)	human
LD_{Lo} 40 mg/kg	(zinc phosphide)	human
TD_{Lo} 45 mg/kg/7d	(zinc sulfate)	human
TD_{Lo} 106 mg/kg	(zinc sulfate)	human
LD_{50} 2510 mg/kg	(zinc acetate)	rat
LD_{50} 350 mg/kg	(zinc chloride)	rat
LD_{50} 1800 mg/kg	(zinc phenolsulphonate)	rat
LD_{50} 2949 mg/kg	(zinc sulfate)	rat
LD_{50} 12 mg/kg	(zinc phosphide)	rat

DERMAL:

LD_{50} 2 gm/kg	(zinc phosphide)	rabbit

HEALTH HAZARD DATA (Cont.)

Long-Term Effects:

In animals chronic oral exposures to zinc sulfate have resulted in pancreatic lesions.

Pregnancy/Neonate Data:

Although i.v. and i.p. injections of some zinc compounds during gestation cause teratogenic effects in animals, there is no evidence that oral exposures are teratogenic; however, diminished reproduction and reduced fetal growth have been reported at high doses. Zinc deficiencies can also result in embryo malformations.

Genotoxicity Data:

Zinc was not found to be mutagenic in microbial assays and in a dominant lethal test in mice; however, chromosomal aberrations have been reported in animal and human studies.

Carcinogenicity Classification:

IARC — No data
NTP — No data
EPA — No data

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards

• OSHA PEL (8-hr TWA):	Zinc chloride (fume) 1 mg/m^3 Zinc oxide (fume) 5 mg/m^3 Zinc oxide (total dust) 10 mg/m^3 Zinc oxide (respirable fraction) 5 mg/m^3 Zinc stearate (total dust) 10 mg/m^3 Zinc stearate (respirable fraction) 5 mg/m^3
• OSHA STEL (15-min):	Zinc chloride (fume) 2 mg/m^3 Zinc oxide (fume) 10 mg/m^3
• OSHA CL (ceiling value):	Zinc chromate 0.1 mg/m^3
• AFOSH PEL (8-hr TWA):	Zinc chloride (fume) 1 mg/m^3 Zinc oxide (fume) 5 mg/m^3 Zinc oxide (total dust) 10 mg/m^3 Zinc oxide (respirable fraction) 5 mg/m^3 Zinc stearate (total dust) 10 mg/m^3 Zinc stearate (respirable fraction) 5 mg/m^3
• AFOSH CL (15-min.):	Zinc chromate 0.1 mg/m^3

Criteria

• NIOSH IDLH (30-min):	Zinc chloride 2000 mg/m^3
• NIOSH REL (10-hr TWA):	Zinc oxide 5 mg/m^3
• NIOSH STEL (15-min ceiling):	Zinc oxide 15 mg/m^3
• ACGIH TLV● (8-hr TWA):	Zinc chloride (fume) 1 mg/m^3 Zinc oxide (fume) 5 mg/m^3 Zinc oxide (total dust) 10 mg/m^3
• ACGIH STEL (15-min):	Zinc chloride (fume) 2 mg/m^3 Zinc oxide (fume) 10 mg/m^3

WATER EXPOSURE LIMITS:

Drinking Water Standards

• MCLG:	None established
• MCL:	None established
• Secondary standard:	5 mg/L (7056)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

EPA Health Advisories and Cancer Risk Levels (5680)

- Health advisories (draft):

— 1-day (child):	4 mg/L
— 10-day (child):	4 mg/L
— longer term (child):	4 mg/L
— longer term (adult):	4 mg/L
— lifetime (adult):	4 mg/L
— DWEL:	4 mg/L

- Cancer risk levels: None established

WHO Drinking Water Guideline

No data

EPA Ambient Water Quality Criteria

- **Human Health**
  - None established
- **Aquatic Life**
  - **Freshwater species**
    Acute toxicity: acute toxicity generally decreases with increasing hardness and increases with rise in temperature. At a hardness of 50 mg/L, sensitivities range from 50.7 to 88,960 µg/L for 43 species of fish investigated.

    Chronic toxicity: chronic toxicity values for 7 fish species ranged from 46.73 µg/L for the flagfish, Jordanella floridae, to 854.7 µg/L for the brook trout, Salvelinus fontinalis.

    Freshwater organisms and their uses should not be affected adversely if the four-day average concentrations of zinc do not exceed 59, 110, and 190 µg/L and the one-hour average concentrations do not exceed 65, 120, and 210 µg/L at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$, respectively.
  - **Saltwater species**
    Acute toxicity: LC_{50}s range from 191.5 µg/L for cabezon, Scorpanichthys marmoratus, to 320,400 µg/L for adults of another clam, Macoma balthica.

    Chronic toxicity: no data available.
    Saltwater organisms and their use should not be affected adversely if the four-day average concentration of zinc does not exceed 86 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 95 µg/L more than once every three years on the average.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

REFERENCE DOSES:

- Inhalation: No data
- Oral: 100 µg/kg/day (zinc) (5680)
  0.3 µg/kg/day (zinc phosphide) (5648)
  0.05 mg/kg/day (zinc cyanide) (5648)

RECOMMENDED DIETARY ALLOWANCE (RDA) (5677):

- Adults, male, 15 mg/day
- Adults, female, 12 mg/day
- Pregnant women, 15 mg/day
- Nursing mothers, 1st six months, 19 mg/day
- Nursing mothers, 2nd six months, 16 mg/day
- Children, 1 + yr old, 10 mg/day
- Children, <1 yr old, 5 mg/day

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- Federal Programs

Clean Water Act (CWA)

The following zinc compounds have been designated as hazardous substances under the CWA: zinc acetate, zinc ammonium chloride, zinc borate, zinc bromide, zinc carbonate, zinc chloride, zinc cyanide, zinc fluoride, zinc formate, zinc hydrosulfite, zinc nitrate, zinc phenolsulfonate, zinc phosphide, zinc silicofluoride, and zinc sulfate (7015). Reportable quantity (RQ) limits have been set at 4.54 kg (10 lbs) for zinc cyanide, 45.4 kg (100 lbs) for zinc phosphide, 2270 kg (5000 lbs) for zinc phenolsulfonate and zinc silicofluoride, and 454 kg (1000 lbs) for the remaining zinc compounds (7015, 7016). Zinc and zinc compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and to effluent standards and guidelines (7017, 7018). Effluent limitations for zinc have been set in the following point source categories: electroplating (7025), organic chemicals, plastics and synthetic fibers (7030), inorganic chemicals manufacturing (7019), iron and steel manufacturing (7032), nonferrous metals manufacturing (7020), steam electric power generating (7021), rubber manufacturing (7035), pulp, paper and paperboard (7042), metal finishing (7026), ore mining and dressing (7023), battery manufacturing (7027), metal molding and casting (7040), coil coating (7036), porcelain enameling (7037), aluminum forming (7038), copper forming (7039), electrical and electronic components (7024), and nonferrous metals forming and metal powders (7028). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)

Zinc was on the original list of 83 contaminants required to be regulated under the SDWA Amendments of 1986, but was subsequently removed and placed on the first priority list of additional drinking water contaminants which may require regulation (7050).

Although it is being considered for regulation eventually, it is not included in any of the Environmental Protection Agency's (EPA's) Phase I through Phase V proposals scheduled for action by 1991 (7057). EPA has set a secondary maximum contaminant level (SMCL) of 5 mg/L for zinc in drinking water (7056). In states with an approved Underground Injection Control program, a permit is required for the injection of zinc-containing wastes designated as hazardous under RCRA (7054).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Resource Conservation and Recovery Act (RCRA)
Zinc cyanide (#P121), and zinc phosphide when present at concentrations greater than 10% (#P122), are identified as RCRA acute hazardous wastes. Zinc phosphide when present at concentrations of 10% or less (#U249) is identified as a RCRA toxic hazardous waste (7078). All three of the above zinc compounds are also listed as hazardous waste constituents (7079). Zinc is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels. Effective June 8, 1989, hazardous wastes containing zinc cyanide (#P121) are prohibited from land disposal and underground injection unless the designated treatment standard or the statutory no migration standard is met. Variances exist until May 8, 1990, for zinc-containing hazardous waste numbers P122 and U249 since designated treatment standards have not yet been promulgated. Site-specific variances can be obtained for soil and debris contaminated with hazardous waste (7068, 7080). Zinc 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 (7082).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Zinc compounds designated as hazardous substances under CERCLA include: zinc, zinc acetate, zinc ammonium chloride, zinc borate, zinc bromide, zinc carbonate, zinc chloride, zinc cyanide, zinc fluoride, zinc formate, zinc hydrosulfite, zinc nitrate, zinc phenolsulfonate, zinc phosphide, zinc silicofluoride,and zinc sulfate. Reportable quantity (RQ) limits are set at 4.54 kg (10 lbs) for zinc cyanide, 45.4 kg (100 lbs) for zinc phosphide, 2270 kg (5000 lbs) for zinc silicofluoride and zinc phenolsulfonate, and 454 kg (1000 lbs) for the rest of these zinc compounds (7064). Zinc phosphide and zinc, dichloro(4,4-dimethyl-5(methylamino) carbonyl)oxy)lmino) entanenitrile)-, T-4)- are designated as extremely hazardous substances under SARA Title III Section 302. Under Sections 311 and 312, any facility at which these compounds are present in excess of their threshold planning quantities of 500 pounds and 100 pounds, respectively, must notify state and local emergency planning officials. If either of these compounds is released from a facility in excess of their RQ, local emergency planning officials must be notified (7060). Under SARA Title III Section 313, manufacturers, processors, importers, and users of zinc must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
Pesticide registration standards for zinc phosphide have been issued by EPA (7004). The following zinc compounds are exempt from the requirement of a tolerance when used as ingredients in pesticide formulations applied to growing crops, to raw agricultural commodities after harvest, or when applied to animals: zinc oxide, zinc stearate, and zinc sulfate. Zinc orthophosphate is exempt from a requirement of a tolerance also, but only when applied to growing crops (7006). Pesticide products containing zinc phosphide are classified for restricted use and are limited to use by or under the direct supervision of a certified applicator (7007). Tolerances are established for residues of a fungicide which is a coordination product of zinc ion and maneb containing 20% manganese, 2.5% zinc, and 77.5% ethylenebis-dithiocarbamate in or on foods designated in 40CFR185.6300 when present therein as a result of the application of this fungicide to growing crops (7008). Tolerances for residues of phosphine from the use of zinc phosphide in or on raw agricultural commodities are as follows: 0.1 ppm in or on grasses, 0.01 ppm in or on grapes and sugarcane. A tolerance of 30 ppm is established for residues of the fungicide basic zinc sulfate, calculated as elemental zinc, in or on the raw agricultural commodity peaches (7005).

Occupational Safety and Health Act (OSHA)
Employee exposure to zinc chloride fume shall not exceed an 8-hour time-weighted average (TWA) of 1 mg/m^3 or a 15-minute short-term exposure limit (STEL) of 2 mg/m^3. Employee exposure to zinc oxide fume shall not exceed an 8-hour time-weighted average (TWA) of 5.0 mg/m^3 or a 15-minute short-term exposure limit (STEL) of 10 mg/m^3. Employee exposure to zinc oxide dust shall not exceed an 8-hour time-weighted average (TWA) of 10 mg/m^3 for total dust or 5 mg/m^3 for the respirable fraction. Employee exposure to zinc stearate dust shall not exceed an 8-hour time-weighted average (TWA) of 10 mg/m^3 for total dust or 5 mg/m^3 for the respirable fraction. Employee exposure to zinc chromate (as CrO_3) shall not exceed a ceiling level of 0.1 mg/m^3 at any time during an 8-hour work-shift (7000). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate, certain hazardous waste treatment, storage, and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Clean Air Act (CAA)
After consideration of the data regarding serious health effects from ambient air exposure to zinc and zinc oxide, EPA has decided not to regulate them as hazardous air pollutants (7044).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated the following zinc compounds as hazardous materials, subject to requirements for packaging, labeling and transportation: zinc, zinc acetate, zinc ammonium chloride, zinc borate, zinc bromide, zinc carbonate, zinc chloride, zinc cyanide, zinc fluoride, zinc formate, zinc hydrosulfite, zinc nitrate, zinc phenolsulfonate, zinc phosphide, zinc silicofluoride, and zinc sulfate. Reportable quantity (RQ) limits have been set at 4.54 kg (10 lbs) for zinc cyanide, 45.4 kg (100 lbs) for zinc phosphide, 2270 kg (5000 lbs) for zinc phenolsulfonate and zinc silicofluoride, and 454 kg (1000 lbs) for the remaining zinc compounds (7010).

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of oils or 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 (7009).

Food, Drug, and Cosmetic Act (FDCA)
The level for zinc in bottled drinking water is 5.0 mg/L. This level is identical to the secondary maximum contaminant level (SMCL) given under the Safe Drinking Water Act (7070). Zinc methionine sulfate is approved for use as a direct food additive when used in compliance with the conditions set forth in 21CFR172.399. A number of other zinc compounds, listed under 21CFR175 and 178, are approved for use as indirect food additives as components of adhesives, coatings, and packaging materials (7072, 7073).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

- **State Water Programs**

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. The following states have promulgated additional or more stringent criteria:

DISTRICT OF COLUMBIA
The District of Columbia has set an aquatic life criterion of 0.05 mg/L for total recoverable zinc in class C surface waters (7121).

FLORIDA
Florida has set the following water quality criteria: a general criterion of 1.0 mg/L for zinc for all surface waters; and 0.03 mg/L for zinc in class I (potable water supply) and class III (fish and wildlife, recreation) fresh surface waters (7112).

ILLINOIS
Illinois has set a primary MCL of 5.0 mg/L for zinc in drinking water (7129).

MASSACHUSETTS
Massachusetts has a water quality criterion of 5 mg/L for class I and II groundwaters (7125).

NEW YORK
New York has established the following ambient water quality criteria: 300 μg/L for zinc in fresh surface water classed for drinking water supply (A,A-S,AA,AA-S), 5000 μg/L for groundwater classed for drinking water supply, 30 μg/L for zinc in fresh surface waters classed for fishing and fish propagation (A,A-S,AA,AA-S,B,C); 58 μg/L for zinc in marine surface waters classed for fishing and fish propagation (SA, SB, SC), and 170 μg/L for marine surface water classed for fishing and fish survival (SD) (7119).

NORTH CAROLINA
North Carolina has set an action level of 50 μg/L for all fresh surface waters (7113).

VIRGINIA
Virginia has set the following water quality chronic criteria for the protection of aquatic life: 47 μg/L zinc in fresh surface waters, 58 μg/L zinc in saltwater surface waters. Virginia also has a water quality standard of 0.05 mg/L for zinc in groundwater (7115).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

WEST VIRGINIA
West Virginia has a water quality criterion of 47 μg/L for zinc in surface waters classed troutwater B2 (7123).

WISCONSIN
Wisconsin has set a preventive action limit of 2.5 mg/L for zinc in groundwater. The enforceable standard, however, is 5.0 mg/L zinc which is the same as the federal MCL (7116).

WYOMING
Wyoming has a water quality criterion of 2.0 mg/L for zinc in class II (agriculture) groundwaters (7120).

Proposed Regulations

- **Federal Programs**

Resource Conservation and Recovery Act (RCRA)
The Environmental Protection Agency (EPA) has proposed that zinc-containing wastes numbers P122 and U249 be prohibited from land disposal and underground injection, effective May 8, 1990, unless designated treatment standards or statutory no migration standards are met. Final action is expected on this proposal by May, 1990 (7085).

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
EPA has proposed that the following zinc compound, listed as an extremely hazardous substance under SARA, be listed as a CERCLA hazardous substance, with a reportable quantity (RQ) of 45.4 kg (100 lbs): zinc,dichloro(4,4-dimethyl-5((((methylamino)carbonyl) oxy)lmino)pentanenitrile)-,(T-4)-. Final action on this rule is expected by September, 1990 (7065, 7066).

- **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 1990-91 (7058).

ILLINOIS
Illinois has proposed a general use water quality criterion of 1.0 mg/L for zinc in all state waters (7130).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

EEC Directives

Directive on Drinking Water (7086)
The mandatory values for zinc in surface water treatment categories A1, A2 or A3 used or intended for abstraction of drinking water are 3 mg/L, 5 mg/L and 5 mg/L respectively. Guideline levels for categories A2 and A3 are 1 mg/L and for A1, 0.5 mg/L.

Directive on Discharge of Dangerous Substances (7088)
Zinc 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 the substances into ground water.

Directive on Fishing Water Quality (7089)
Zinc products must not be present in salmonid and cyprinid waters in such quantifies that they: (1) from a visible film on the surface of the water or form coatings on the beds of water-courses and lakes, (2) impart a detectable "hydrocarbon" taste to fish and, (3) produce harmful effects in fish.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for zinc specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of zinc in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive on Ground Water (7091)
To ensure the effective protection of groundwater in the Community it is necessary to limit the discharge of zinc in groundwater. The purpose of this directive is to prevent pollution of groundwater substances belonging to substances listed in the Annex of this directive. Zinc shall be subject to prior review so as to limit discharge into groundwater. Member states may grant authorization, provided that all technical precautions for preventing groundwater pollution by zinc has been observed.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
No maximum admissible concentration is given for zinc. A guide level of 100 µg/L is given for outlets of pumping and/or treatment works and their substations and 5000 µg/L after the water has been standing for 12 hours in the piping and at the point where the water is made available to the consumer. Above 5000 µg/L astringent taste, opalescence and -like deposits may occur.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Zinc alkyls, zinc chloride, zinc chromates, zinc dimethyldithiocarbamate, zinc dust, zinc phosphide and zinc powder are classified as flammable and corrosive substances and are subject to packaging and labeling regulations. Hydrogen cyanide may contain a stabilizer. If the stabilizer changes the dangerous properties of this substance, substance should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

EEC Directives-Decisions

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7105)
The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials must be eliminated; Part II substances, includes zinc and zinc compounds and its compounds which seem less noxious or are more readily rendered harmless by natural processes. Discharges must be subject to approval by representatives of the contracting party.

74.1 MAJOR USES

Of the 816,000 tons of zinc used in the United States in 1980, 42.3% was used in galvanizing metal, 25.5% in zinc-base alloys, 12% in brass and bronze, 2.6% in rolled zinc, 3.4% in zinc oxide, and 14.2% in other miscellaneous products (5640).

The most widely used compounds of zinc are zinc oxide, zinc sulfate, and zinc chloride. In 1980, U.S. production and importation totaled 175,352 metric tons for zinc oxide, 39,030 metric tons for zinc sulfate, and 12,684 metric tons for zinc chloride. The largest user of zinc oxide is the rubber industry which uses the compound as a vulcanization activator and accelerator and to slow down the aging of rubber by neutralizing sulfur and organic acids formed by oxidation. Zinc oxide also has applications as a reinforcing agent, a heat conductor, a pigment, and a UV stabilizer. It has also been used as a supplement in animal feeds and fertilizers, as a catalyst and chemical intermediate, and in mildew inhibitors and ceramics. Zinc sulfate is used in rayon manufacture, in agriculture, in zinc plating, in flotation processes, and as a chemical intermediate and mordant. Zinc chloride is used in textiles, adhesives, flux, and as a wood preservative, antiseptic, and astringent (5641).

74.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

Zinc is released into the environment from both natural and anthropogenic sources. Anthropogenic sources of atmospheric zinc are: mining and milling operations, metallurgical operations, secondary zinc production, and combustion of fossil fuels and solid wastes (5612, 5620). Refuse incineration, coal combustion, smelter operations, and some metallurgic industries are the primary sources of atmospheric zinc (5623). Atmospheric particulate matter containing zinc settles out onto water and land. Major sources of zinc in surface water are leaching from exposed zinc ore (primarily sphalerite or zinc sulfide), erosion of agricultural soils, road surface runoff of zinc oxide derived from automobile tire erosion, and corrosion of zinc alloys and galvanized surfaces.

Most of the zinc released to the environment partitions to water, soil and sediments (5617). Ocean sediments are considered to be the ultimate environmental sink for zinc. About 700,000 metric tons of zinc are estimated to be transported to the sea annually (5600). Sedimentation occurs chiefly in association with clay minerals, but also with manganese oxide nodules and phosphorites. In anoxic waters zinc may precipitate in the form of sulfide.

Zinc is essential for all living organisms and bioconcentration and transport of zinc occur through the food chain (5600).

74.2.1 Transport in Soil/Groundwater System

74.2.1.1 Overview

Transport of zinc in soil-groundwater systems will generally be determined by compound solubility, soil type, cation exchange capacity, pH, and salinity (5661). In general, mobility is favored by low pH levels, reduced cation exchange capacity, increased salinity, and light soil texture. Under aerobic conditions, mobility decreases with increasing pH due to adsorption of zinc onto hydrous iron and manganese oxides and clay minerals. However, for soils high in organic matter, zinc mobility may increase as pH increases above 7 due to dispersion and chelation of more water soluble organic complexes. In calcareous soils and at high pH levels zinc will form complexes/precipitates with carbonates, hydroxides, sulfides and organic ligands (5619). In reducing environments mobility may be limited by precipitation reactions, primarily involving zinc sulfide; however, in saturated and submerged soils, production of organic chelates and dissolution of Zn-containing metal oxides may predominant (7136).

74.2.1.2 Sorption on Soils

The mobility of zinc in soil-groundwater systems is strongly affected by compound solubility, pH, cation exchange capacity, soil type, and salinity (5661). Zinc compounds of high solubility, such as zinc sulfate, will be fairly mobile in soils. Zinc deposition in soil occurs by complexation/adsorption on hydrated metal oxides (manganese and iron), clays, and organics and by precipitation reactions. Deposition depends on the character of the soil and tends to increase in the order: gravel < sands < muddy sands < muds.

In general, zinc adsorption onto soil particles decreases with decreasing pH and decreasing cation exchange capacity (CEC) (7139). At low pH levels there are fewer negative charges on soil surfaces and consequently, fewer adsorption sites (5663). The lowering of soil pH by one unit will increase metal solubility by a factor of about 10 (5660). The relationship between pH and zinc mobility is shown in Figure 74.1.

Field studies indicate that soil acidification can result in increases in fluxes of many heavy metals to deeper soil horizons as well as increased uptake of metals into plants (7138).

Zinc mobility will also be affected by soil texture. Verloo et al. (7139) reported that zinc was 1000 times more soluble in sandy soil than in heavy clay soil. The relationship between pH, soil texture and zinc mobility is shown in Figure 74.2.

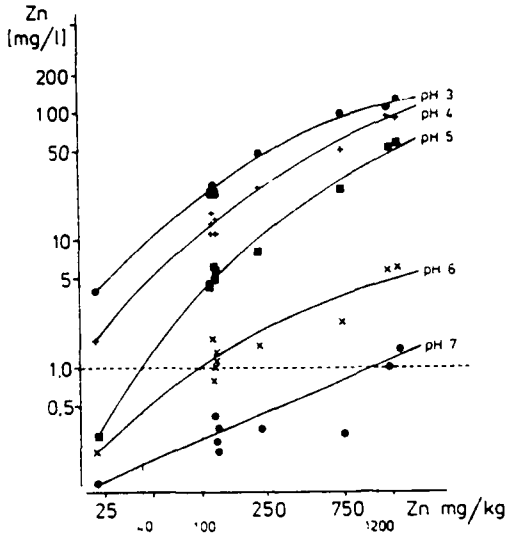


FIGURE 74-1

RELATIONSHIP BETWEEN SOIL PH AND ZINC MOBILITY.

Source: (5678)

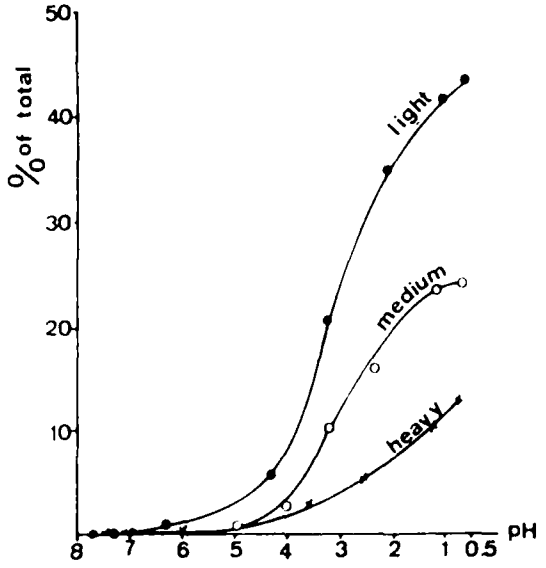


FIGURE 74-2

PERCENTAGE OF TOTAL ZINC SOLUBILIZED AS A FUNCTION OF PH IN THREE DIFFERENT TEXTURED SOILS.

Source: (5679)

For soils rich in organic matter adsorption of zinc may decrease at pH levels above 7 due to dispersion and chelation of water soluble organic complexes (5600). Organic complexes accounted for 28-99% of the total soluble zinc in displaced soil solutions of less than 0.2 mg/L (7136). Desorption from organic complexes may be enhanced in the presence of Cu^{2+}, Al^{3+}, and Fe^{3+} which form more stable and less soluble bonds with humic acids. At estuarine sites desorption increases as salinity increases, probably due to the displacement of zinc ions by alkali and alkaline earth cations (5619).

The distribution of zinc between soil and soil-water can also be expressed in terms of the distribution coefficient, K_d, which is defined as the ratio of the concentration of an element in soil (µg/100 g) to that in water (µg/100 mL). In soil-water systems at equilibrium, K_d varies considerably depending on the nature of the soil. Reported K_d values for zinc range from 0.1 to 8000 mL/g (5615). In one study a K_d value of 12.2 mL/g was determined for a sandy soil and one of 939 mL/g for a sandy loam soil (5646).

A computer model (code name TERRA) has been developed to predict the leaching of metals from the soil (5616). Although the model was originally developed for radionuclides, it is applicable to non-radioactive metal ions. It is based on the following relationship:

$$\delta_l = \frac{P + I - E}{\Phi d[1 + (\sigma/\Phi.K_d)]}$$

where:

δ_l = leaching constant
P = annual average total precipitation (cm)
I = annual average irrigation (cm)
E = annual average evapotranspiration (cm)
Φ = volumetric water content of the soil [mL/cm^3]
d = depth of soil layer from which leaching occurs (cm)
σ = soil bulk density (g/cm^3)
K_d = the distribution coefficient (mL/g)

The default estimate of K_d used in the TERRA code for zinc is 40 (5616).

74.2.1.3 Volatilization from Soils

Volatilization of zinc compounds from soil through the formation of volatile zinc alkyls by bioalkylation is unlikely. In aquatic systems such compounds are unstable in the presence of water and oxygen (5619).

74.2.2 Transformation Processes in Soil/Groundwater Systems

Little information is available on transformation pathways of zinc in soil/groundwater systems. Soil chemistry is controlled primarily by pH which affects cation exchange processes (dominant at low pH levels) and interactions with organic ligands (dominant at high pH levels), and precipitation processes. Free ionic Zn occurs as the hexaquo ion, $Zn(H_2O)_6^{2+}$ and forms coordination complexes or ion pairs by ligand substitution of the H_2O groups (7136). The free ionic form predominants below pH 7.7; $ZnOH^+$ is the major species at pH 7.7-9.1, and $Zn(OH)_2^0$ or $Zn(OH)_4^{2-}$ are the major species above pH 9.1 (7136). The ion pairs $ZnSO_4^0$, $ZnHCO_3^+$, $ZnHCO_3^0$, or $Zn(HCO_3)_2^0$, and $ZnHPO_4^0$ may also be formed depending on pH and solution composition.

In aqueous solutions, where zinc also exists primarily as the $Zn(H_2O)_6^{2+}$ ion, water soluble zinc salts such as zinc chloride may hydrolyze to form zinc hydroxide or zinc carbonate in the presence of excess bicarbonate. Under alkaline conditions, zinc hydroxide readily precipitates (solubility 0.2 mg Zn/L) but zinc carbonate stays in solution (solubility 107 mg Zn/L) (5600). The equilibrium constant for precipitation reactions, termed the solubility product (K_{sp}), for zinc hydroxide [$Zn(OH)_2$], and zinc carbonate ($ZnCO_3$) are 15.5 and 10.8 (expressed as negative logs), respectively (5650). The $-\log K_{sp}$ for zinc sulfide (sphalerite, ZnS) is 23.6.

Precipitation reactions may be important under anaerobic, reducing conditions. In studies in which soil was irrigated with raw wastewater, it was found that zinc deposition occurred primarily in the form of inorganic precipitates (5662).

For surface waters it has been demonstrated that under acidic conditions, and without other geochemical controls, zinc concentration (Y_1) decreases very gradually with distance (in kilometers) from the source (Y_2):

$$Y_1 = aY_2^{-0.17 \pm 0.01}$$

where a is the zinc concentration 1 km from the source.

According to this equation, zinc contamination will persist throughout the course of the water systems. However, with a rise in pH (ca. 6.5) and in absence of significant iron levels, zinc will presumably be adsorbed onto suspended solids, and zinc levels should decrease rapidly with distance downstream according to the following equation:

$$Y_1 = aY_2^{-1.6}$$

Under these conditions there should not be a significant concentration of zinc in the surface waters 4 km from the source (5612).

74.2.3 Primary Routes of Exposure From Soil/Groundwater Systems

Zinc has been found in groundwater at approximately 97% of 2,783 hazardous waste sites (5647). The geometric mean zinc concentration for these samples was 0.010 mg/L. Data on the concentrations of zinc in drinking water derived from groundwater were not located.

Data on the concentration of zinc in soil indicate that zinc may be present at concentrations ranging between 10 and 300 mg/kg with a mean of approximately 50 mg/kg (5623). Zinc has been detected in soil at all of 2763 hazardous waste sites sampled (5647). The geometric mean concentration was 376 mg/kg. The agricultural use of fertilizers containing zinc and metal-rich sewage sludge may result in increased zinc concentrations in soil.

The soil/plant transfer coefficient for zinc has been reported to be 1-10 (5660) and the bioconcentration factor for plants 0.4 (5624). Bioconcentration factors for zinc uptake by terrestrial invertebrates and mammals are 8, and 0.6, respectively (5624), indicating limited potential for bioaccumulation. Zinc content of grains, vegetables, and fruits is usually less than 10 mg/kg, and that of meats, fish and poultry averages 24.5 mg/kg (5664).

74.2.4 Other Sources of Exposure

Zinc is released into the atmosphere as dust and fumes associated with zinc production facilities, smelters, automobile emissions, fossil fuel combustion, and waste incineration. The average concentration of zinc in particulate matter in the air of six U.S. cities over a 10-day period was reported to be 500 ng/m^3 (5620). Atmospheric zinc is not expected to be a significant source of exposure for the general public. However, inhalation exposures may occur in locations close to the sources of emission. The major primary zinc production areas in the U.S. are Tennessee, Missouri, Colorado, New York, and New Jersey (5600). Inhalation exposures may be significant in industrial situations. Occupational exposures have occurred in metallurgical industries where zinc and zinc alloys are heated and zinc vapors are oxidized in air to zinc oxide. Inhalation of zinc oxide fumes is thought to be a cause of so-called "metal fume fever".

The zinc concentration in fresh waters is variable but usually averages 10 µg/L (5600). Zinc has been detected in surface water at 68% of 2,783 hazardous waste sites, the geometric mean concentration being 0.016 mg/L (5647). Zinc has also been detected in 77% of 380 finished drinking waters in the United States. The average concentration of zinc in drinking water is 79.2 µg/L (minimum 3, maximum 2,010 µg/L) (5622).

Bioconcentration factors for twelve aquatic species capable of utilizing zinc from both food and water, range from 4 to 24,000 (5625). The zinc content of marine organisms, oysters in particular, can be relatively high (10-50 mg/kg wet weight) (5624).

Other possible sources of exposure to zinc include accidental poisonings occurring when inadvertently large doses of zinc salts are taken for therapeutic purposes or when acidic brews or drinks are made in galvanized vessels (5603).

74.2.5 Biological Monitoring

Biological monitoring methods for zinc have been reviewed by ATSDR (5617). Atomic absorption spectrometry is the method of choice for determining levels of zinc in bone, liver, hair, blood, and urine. Sample detection limits of 0.01 μg/100 mL for blood and 0.2 μg/g for tissue have been reported. Neutron activation analysis has also been used to detect zinc in blood and urine. Limits of detection for blood samples is 5×10^{-5} μg/100 mL.

74.3 HUMAN HEALTH CONSIDERATIONS

Zinc is an essential element in human and animal nutrition and is present in high concentrations in prostate, bone, muscle, and liver (7133). The minimum daily recommended dietary intakes are: 15 mg for adult males, 12 mg for adult females, 15 mg for pregnant women, 19 mg for nursing mothers during the first six months and 16 mg during the second six months, 10 mg for children older than 1 yr, and 5 mg for infants 0-12 months old (5677). Zinc deficiency has been linked to teratogenic effects.

Absorption of zinc into the body is highly variable (10-90%) and is dependent on a number of factors. Homeostatic mechanisms exist for gastrointestinal absorption and excretion. The biological half-life of retained ^{65}Zn is about 1 yr in humans.

Some zinc salts are toxic due to the characteristic of the anions, e.g., zinc cyanide, zinc chromate, and zinc phosphide (5600). Information on the health effects of cyanide can be found in the Air Force Toxicology Guide, Chapter 56. Information on the health effects of chromates can be found in Chapter 54 of the Tox Guide. Zinc phosphide is a rodenticide whose toxicity results from the formation of phosphine gas under aqueous acidic conditions. Cases of accidental ingestion of zinc phosphide have been reported. Adverse clinical symptoms in such poisonings include vomiting, anorexia, abdominal pain, and lethargy. In acute cases hypotension, cardiac arrhythmias, circulatory collapse, pulmonary edema, seizures, renal damage, leukopenia, and coma and death in days to weeks have occurred (5654). These effects have been attributed to the release of phosphine gas under the acidic conditions in the stomach.

The discussion in the following sections will focus on those compounds in which the reported toxic effects are likely to be due to the zinc component of the compounds.

74.3.1 Animal Studies

74.3.1.1 Carcinogenicity

The potential carcinogenicity of zinc has been evaluated in very few studies. Walters and Roe (5606) maintained mice on diets containing zinc oleate for a period of 3 (dietary level 2,500 and 5,000 ppm) or 6 months (1,250 ppm) and examined the animals for tumors at 45 weeks of age. There was no statistically significant increase in incidence of hepatomas, lymphomas, or lung adenoma when compared to controls. Addition of zinc chloride to drinking water at concentrations of 5,000 ppm and 1,000 ppm for the same time period did not materially alter the results. In another study, Marrs et al. (5667) evaluated the carcinogenic effects of a zinc oxide/hexachloroethane smoke mixture on several species of animals and found a statistically significant increase in the frequency of alveologenic carcinomas in female mice exposed to 123 mg Zn/m^3, 1 hr/day, 5 days/week, for 18 months. Similar exposures to rats and guinea pigs did not produce a carcinogenic response. Evaluation of this study is complicated by the presence of several compounds in the smoke mixture that may have contributed to the carcinogenic effects. No other experimental evidence for any other carcinogenic effect of zinc in laboratory animals is available. On the other hand, there is some evidence that zinc may act antagonistically towards the carcinogenic effects of other compounds. For example, administration of zinc sulfate in drinking water reduced the incidence of 9,10-dimethyl-1,2-benzanthracene-induced tumors in the cheek pouches of golden hamsters (5607).

74.3.1.2 Genotoxicity

Zinc chloride and zinc sulfate were found to be non-mutagenic when tested in microbial assays using Escherichia coli, Salmonella typhimurium TA102, and in the mouse lymphoma cell assay (5626, 5627, 5628). An in vivo dominant lethal assay with mice was also negative (5629). However, chromosomal aberrations have been observed in bone marrow cells in mice receiving 650 mg/kg/day of zinc chloride in their diet (5630) and in mice exposed to zinc oxide dust by inhalation (5631).

74.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Intravenous and intraperitoneal injections of zinc compounds in rodents during gestation have resulted in teratogenic effects. The offspring of pregnant golden hamsters injected intravenously with a single dose of 2 mg zinc sulfate/kg on the eighth day of gestation, showed mild teratogenic effects such as congenital malformations (exencephaly and rib fusions) (5657). Similar skeletal anomalies including delayed ossification and ripple ribs were observed in the offspring of mice injected intraperitoneally with single doses of 12.5, 20.5, and 25 mg zinc chloride/kg on day 8, 9, 10, or 11 of gestation (5658).

Animal studies have not shown a correlation between oral exposure to zinc salts during pregnancy and teratogenic effects; however, high oral doses can affect reproduction and fetal growth. In one study demonstrating such effects, albino rats were maintained on a diet containing 250 mg Zn/kg/day (as ZnO) during gestation and

470 mg Zn/kg/day (as ZnO) during lactation, respectively. The fetal growth was reduced and the whole body burden of Zn and the liver concentration of Zn were increased in both the dams and pups. The concentrations of iron and copper in the liver and the whole body were reduced in both the dams and pups (5656). In another study, female rats ingesting dietary levels of 500 mg/kg/day as zinc carbonate ceased to reproduce after 5 months on the ration. It was reported that these effects may have been associated with a zinc-induced anemia indicated by reduced hemoglobin and RBC levels (5632).

74.3.1.4 Other Toxicological Effects

74.3.1.4.1 Short-term Toxicologic Effects

Respiratory system effects.-Rats exposed to zinc oxide at 15 mg/m^3 for 8 hr daily for up to 84 days showed only minor histological changes in the lung, but pulmonary function tests were indicative of chronic pulmonary inflammation (5624). Histological examination of lungs from rats exposed to zinc stearate at 5 mg/m^3 for 3-5 months showed no signs of fibrosis (5624).

Gastrointestinal effects.-Zinc-induced gastrointestinal effects have been reported in a number of animal studies. Ferrets exposed to 850 mg Zn/kg/day (as zinc oxide) for 6 months developed gastrointestinal hemorrhages (5608). Similar results as well as degenerative changes in the pancreas, were observed in rats and mice ingesting zinc sulfate (1,500 mg/kg/day and 3,900 mg/kg/day, respectively) for 13 weeks (5609). Inflammation of the gastrointestinal tract and stunted growth occurred in weanling pigs kept on 1000 mg Zn/kg for more than a month (5633). Severe enteritis was observed in cows that accidentally ingested 20,000 ppm of zinc oxide (5611). Pancreatic abnormalities have also been reported for cats receiving 333.3 mg zinc oxide/kg/day (5674), and in sheep receiving 33 mg Zn/kg/day (5665).

Hematological effects.-Anemia has been observed in mice, ferrets, and sheep following oral exposures to zinc oxide or zinc oleate (5617, 7137). Rats and mice given oral doses of zinc sulfate (1,500 mg/kg/day, and 3,900 mg/kg/day, respectively) for 13 weeks developed low levels of hemoglobin, low hematocrit, decreased numbers of leukocytes, and morphological changes in red blood cells (5609).

Kidney and liver effects.-Pathological changes in the kidney have been observed in sheep following 49 or 72 day oral exposures to 13-20 mg/kg/day (5665). Diffuse nephrosis was observed in ferrets dosed with 850 mg zinc oxide/kg/day for 9-13 days (5608), Renal lesions were seen in mice given 3,900 mg/kg/day of zinc sulfate in their diet for 13 weeks (5609).

Hepatic necrosis has been observed in sheep receiving 33 mg Zn/kg/day (5665).

Adrenal effects.-Increased adrenal and thymus weights and decreased plasma levels of 11-hydroxysteroids occurred in rats receiving zinc in their drinking water at a level corresponding to 10 mg $ZnSO_4$/day (7135).

74.3.1.4.2 Chronic Toxicologic Effects

Very few long-term animal toxicity studies have been conducted on zinc compounds. Pancreatic lesions have been reported in mice ingesting 95 mg zinc sufate/kg/day in drinking water for 14 months (5666).

74.3.2 Human and Epidemiological Studies

74.3.2.1 Short-term Toxicologic Effects

Respiratory system effects.-Inhalation exposure to high concentrations of some zinc compounds, such as zinc chloride and zinc oxide, can result in toxic effects to the respiratory system (5617). Inhalation of zinc oxide fumes has been associated with metal fume fever (7133). Exposure to 600 mg Zn/m^3 for 10 min or more can result in acute toxic effects. Symptoms, including nasal passage irritation, cough, rales, headache, fever, hyperpnea, leukocytosis, sweating, and pains in the legs and chest, usually occur within a few hours after the exposure and last 6-48 hr. Respiratory changes include reduced lung volume and decreased diffusing capacity of carbon monoxide. Exposed individuals usually recover within 2 days (5624).

Inhalation exposure to zinc chloride produces more severe toxic effects than those due to exposure to zinc oxide. Acute exposures can result in dyspnea, cough, chest pain, bilateral diffuse infiltrations, pneumothorax, and acute pneumonitis from respiratory tract infections (5617). More severe effects include ulcerative and edematous changes in mucous membranes, subpleural hemorrhage, advanced pulmonary fibrosis, and respiratory distress syndrome. Fatalities have occurred in some accidental exposures (5624).

Gastrointestinal effects.-Gastrointestinal disturbances are a common symptom of acute oral exposure to zinc, particularly to zinc sulfate (5617). Accidental poisonings have occurred as a result of the therapeutic use of zinc supplements and from food contamination caused by the use of zinc galvanized containers. Symptoms develop within 24 hr and include nausea, vomiting, diarrhea, and abdominal cramps (5624). Gastrointestinal bleeding may occur and result in hematological signs of anemia.

In one case study, ingestion of zinc chloride reportedly resulted in pharyngitis, esophagitis, hypocalcemia, and elevated levels of amylase; the latter two changes being indicative of acute pancreatitis (5673). Elevated serum amylase levels were also reported in a case of ingestion of elemental zinc (12 g over a 2-day period) (5600).

Hematological effects.-Acute inhalation of zinc oxide has also been associated with moderate leukocytosis (5672). Some individuals ingesting large doses of zinc have developed anemia, possibly due to gastrointestinal bleeding (5617).

Neurological effects.-Ingestion of 12 g of elemental zinc over a 2-day period by a 16 year-old boy resulted in lethargy, a slightly staggering gait, and difficulty in writing (5600).

Dermatological effects.-Exposure to zinc-chromium compounds from galvanized steel was considered to be a partially responsible for an outbreak of irritant hand dermatitis which affected 24 of 41 employees working on a new assembly line of an electronics factory (5655).

Adrenal effects.-In a clinical study on 13 normal individuals, it was found that oral doses of 25, 37.5 or 50 mg of zinc (administered as hexahydrate zinc sulfate) resulted in a significant transitory decrease in adrenal cortisol levels in the plasma.

74.3.2.2 Chronic Toxicologic Effects

Several epidemiological studies have examined cancer mortality rates in occupationally exposed workers and in residents in areas with potentially high zinc contamination (5668-5671). No association between cancer mortality and zinc exposure could be established for workers employed in electrolytic zinc and copper refining plants; however, analysis of the data was limited by the small number of deaths in workers exposed to zinc (5668). Lung cancer mortality was reported to be elevated in residents living in an old lead/zinc mining and smelting area, but there was no association with environmental levels of zinc (5669). Because many confounding factors (i.e., smoking, occupation and duration of residence) were not considered, it is unlikely that the study could have detected zinc-related effects (5617). An excess rate of gastric cancer was reported for a region of Great Britain having high zinc to copper ratios in home garden soil (5670); however, in another study significantly lower gastric cancer rates were reported for areas having high soil zinc to copper ratios (5671).

Non-cancer health effects have been reported in occupationally exposed workers. Zinc-exposed workers have exhibited gastrointestinal symptoms including anorexia, nausea, vomiting, epigastric discomfort, and weight loss (5600). Levels of exposure to airborne zinc and gastrointestinal disturbances in occupationally exposed workers have been correlated with changes in serum enzyme actives indicative of liver dysfunction (7132). Although concomitant exposure to other toxic substances may have contributed to these effects, similar effects have been documented in laboratory animals exposed to zinc compounds. Such health effects may be indicative of an acute toxic response to transient elevations in exposure levels rather than to chronic low level exposures.

Some workers exposed to zinc have shown a higher than normal prevalence of chromosome anomalies in leukocytes (7131), and zinc chloride has been shown to induce chromosome aberrations in human lymphocytes in vitro (5624). The health implications of these findings have not been established.

74.3.3 Levels of Concern

Zinc is an essential element. The recommended dietary allowance for adults has been set at 15 mg/day for men and 12 mg/day for women (5677). The currently established USPHS "recommended" or secondary drinking water standard for zinc is 5 mg/L (5622). The EPA secondary drinking water quality criterion is also set at 5 mg/L (7605).

The oral reference dose for zinc is 100 µg/kg/day (5680). The U.S. EPA Health Advisories for zinc (1-day, 10-day, and longer term for children and longer term and lifetime for adults) are 4 mg/L. The DWEL is also 4 mg/L (5680). The oral reference dose for zinc cyanide is 0.05 mg/kg/day (5648). The oral reference dose for zinc phosphide is 0.0003 mg/kg/day (5648).

No federal air quality standards for zinc have been promulgated. Air concentrations are generally low (average 500 ng/m^3), and exposure of the general public is likely to be minimal except near sources of industrial emissions.

Significant levels of exposure to zinc are most likely to occur only in occupational exposure situations. The major occupational exposure route to zinc is inhalation. OSHA has set the time-weighted average (TWA) permissible exposure limits (PEL) at 1 mg/m^3 for zinc chloride fume, 5 mg/m^3 for zinc oxide fume, 10 mg/m^3 for zinc oxide, or zinc stearate, total dust, and 5 mg/m^3 for zinc oxide or zinc stearate, respirable fraction (5635). Employee exposure to zinc chromate (as CrO_3) shall not exceed a ceiling level of 0.1 mg/m^3 at any time during an 8-hour work-shift (7000). NIOSH has recommended an exposure limit of 5 mg/m^3 (10-hr TWA) for zinc oxide fume and dust (5637). The recommended 15-min short-term exposure limit is 15 mg/m^3. ACGIH has recommended an 8-hr threshold limit value and short-term exposure limit of 1 mg/m^3 and 2 mg/m^3, respectively, for zinc chloride fumes. The corresponding values for zinc oxide (dust and fume) are set at 5 and 10 mg/m^3 (5636).

74.3.4 Hazard Assessment

The major effects of zinc deficiency are decreased food intake, cessation of growth, and interference of the growth and function of the reproductive organs. Zinc deficiency may be caused by insufficient intake of zinc in food and/or by the presence of excess phytate in food which interferes with the absorption of zinc in the gastrointestinal tract. Zinc deficiency has been shown to enhance the toxicity of cadmium and excess of zinc intake may inhibit the absorption of copper (5601).

Zinc occurs in most foods at low concentrations, but it does not bioaccumulate through the food chain. Most surface waters in the United States have very low concentrations of non-filtrable zinc (5600). Although the potential exists for zinc to be released from industrial sources such as mining and metallurgical operations, or from leaching at waste sites, the environmental data suggest that much of the zinc will become bound to sediments and soil, and therefore will be less likely to become a groundwater or drinking water contaminant. However, under certain environmental conditions, such as in acidic sandy soils, zinc mobility may be sufficiently enhanced to allow for significant transport to groundwater. Zinc levels in drinking may also become elevated as a result of leaching from galvanized pipes used in distribution systems.

Exposure to toxic amounts of zinc is unlikely except in occupational exposure situations and in cases of accidental poisoning (5624). Toxic effects in humans have been observed following acute and short-term exposures. Inhalation of zinc oxide fumes is associated with so-called "metal fume fever" (7133). The symptoms are influenza-like: headache, fever, hyperpnea, leukocytosis, sweating, and pains in the legs

and chest. No fatalities have resulted from such exposures and normal recovery takes place within days. Ingestion of high concentrations of zinc compounds by humans and animals can result in gastrointestinal disturbances (5617). Renal and hepatic effects have also been observed in animals (5608, 5609, 5665). Toxic effects resulting from chronic low level exposures to zinc have not been documented in humans; however, in animals chronic adverse effects involve the gastrointestinal system and pancreas (5666).

The only carcinogenic effect of zinc reported in the literature involves the development of alveologenic carcinomas in female mice exposed to zinc oxide/hexachloroethane smoke mixtures (5605, 5667). The relevance of this study to human health has not been established.

There is no evidence that zinc is mutagenic in standard microbial assays; however, chromosomal aberrations have been observed in bone marrow cells of exposed animals, in human lymphocytes exposed in vitro, and in leukocytes of occupationally exposed workers (5626-5631, 7131).

74.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of zinc concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following sequence of reagents to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is required for solid samples other than storage at 4°C until sample analysis. All samples should be analyzed within 180 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (5651).

Analytical methods available for analyzing inorganic zinc in water, soils and waste include atomic absorption (Methods 289.1 and 289.2) and inductively coupled plasma atomic emission spectrometry (Method 200.7) techniques. Depending upon the analytical method, treatment with acid or a combination of acid with hydrogen peroxide is used to digest the samples. Sample preparation procedures specific to each analytical technique are described in Methods 200.0, and 200.7 for aqueous samples (5651) and Methods 3005, 3010, 3020, 3040, and 3050 for solid or waste samples. Quality control samples should be processed with the samples to determine whether analyte losses have occurred during the sample dissolution procedure (5652).

The atomic absorption techniques are probably the most common procedures for determining the concentration of zinc in water, soil and waste samples. Following the appropriate digestion of the sample, a representative aliquot of the digestate is atomized by either directly aspirating it into a flame or by charring it in a graphite tube furnace. The absorption of hollow cathode or electrodeless discharge lamp radiation at 213.9 nm will be proportional to the zinc concentration. The detection ranges are 0.05-1 mg/L and 0.2-4 µg/L for the flame and the furnace atomic absorption techniques, respectively. Precision and accuracy data for the graphite furnace technique are not available at this time. However, an EPA interlaboratory study has been performed to document the precision and accuracy of the flame atomic absorption procedure. In the analysis of six synthetic samples containing 7-310 µg Zn/L, the relative standard deviation of results among the laboratories ranged from 34 to 118%. The results tended to exhibit a positive bias, particularly in the samples containing lower concentrations of zinc (5651).

EPA has recently approved the use of the inductively coupled plasma (ICP) atomic emission method for determining compliance with existing National Primary (and Secondary) Drinking Water Regulations (5653). The technique is based upon the simultaneous or sequential multi-element measurement of atomic emission of trace metals. A preserved and/or digested sample is nebulized to form an aerosol that is introduced into a high temperature plasma where atomic excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma and are dispersed by a grating spectrometer. The line intensities, which are a measurement of elemental concentrations, are monitored by photomultiplier tubes. Optical compensation techniques are used to correct for spectral interferences. In an EPA evaluation of the reproducibility and accuracy of the ICP method, the mean percent relative standard deviation for triplicate analysis of 22 elements was found to be 9%. The mean percent recovery of spiked elements for all waste samples was 93% (5651).

Aqueous Detection Limit	Non-Aqueous Detection Limit
2 µg/L (Method 200.7)	2 µg/L (Method 200.7)
5 µg/L (Method 289.1)	5 µg/L (Method 289.1)
0.05 µg/L (Method 289.2)	0.05 µg/L (Method 289.2)

74.5 REFERENCES

Note: The numbering sequence of the references reflects the order of references as they appear in the master bibliography.

5600. National Research Council (NRC) 1979. Zinc. Baltimore, MD: University Park Press.

5601. Martin, R.B. 1988. Bioinorganic chemistry of toxicity. In: Handbook on toxicity of inorganic compounds, Sigel, H.; Seiler, H.G, eds. New York: Marcel Dekker, Inc. p. 15.

5602. Windholtz, M. 1983. The Merck Index. Rahway, NJ: Merck and Co., Inc. p. 1455.

5603. Clayton, G.D.; Clayton, F.E., eds. 1981. Patty's Industrial Hygiene and Toxicology, Vol. 2A. New York: John Wiley & Sons. pp. 2033-2049.

5604. Aylett B.J. 1973. Group IIB. In: Comprehensive Inorganic Chemistry, Bailar Jr., J.C.; Emeleus, H.J.; Nyholm, R., eds. Oxford: Pergamon Press.

5605. Michalowsky, I. 1930. Das 10. Experimentalle zink-teratoma. Virchows Arch. Path. Anat. Physiol. Klin. Med. 254:319-325.

5606. Walters, M.; Roe, F.J.C. 1965. A study of the effects of zinc and tin administered orally to mice over a prolonged period. Food Cosmet. Toxicol. 3:271-276.

5607. Poswillo, D.E.; Cohen, B. 1971. Inhibition of carcinogenesis by dietary zinc. Nature 231:447.

5608. Straube, E.F.; Schuster, N.H.; Sinclair, A.J. 1980. Zinc toxicity in the ferret. J. Comp. Pathol. 90:355-361.

5609. Maita, K.; Hirano, M.; Mitsumori, K.; et al. 1981. Subacute toxicity with zinc sulfate in mice and rats. J. Pest. Sci. 6:327-336.

5610. Stake, P.E.; Miller, W.J.; Gentry, R.P.; Neathery, M.W. 1975. Zinc metabolic adaptations in calves fed a high but nontoxic zinc level for varying time periods. J. Anim. Sci. 40:132-137.

5611. Allen, G.S. 1968. An outbreak of zinc poisoning in cattle. Vet. Rec. 83:8-9.

5612. Spear, P.A. 1981. Zinc in the aquatic environment: chemistry, distribution, and toxicology. Environmental Secretariat, NRCC.

5613. Browning, E. 1969. Toxicity of industrial metals. London: Appleton-Century-Crofts.

5614. United States Environmental Protection Agency (U.S. EPA). 1987. Quality Criteria for Water, updated May 1, 1987. EPA Report No. 440/5-86-001. Washington, DC.

5615. Baes, C.F.; Sharp, R.D. 1983. A proposal for estimation of soil leaching and leaching constants for use in assessment models. J. Environ. Qual. 12:17-28.

5616. Baes, C.F.; Sharp, R.D.; Sjoreen, A.L.; et al. 1984. A review and analysis of parameters for assessing transport of environmentally released radionuclides through agriculture. ORNL Report No. 5786. Oak Ridge, TN: Oak Ridge National Laboratory.

5617. Agency for Toxic Substances and Disease Registry (ATSDR) 1989. Toxicological profile for zinc. Atlanta, GA: Agency for Toxic Substances and Disease Registry.

5618. Beijer, K.; Jernelov, A. 1986. Sources, transport and transformation of metals in the environment. In: Handbook on the toxicology of metals, vol. 1, Friberg, L.; Nordberg, G.F.; Vouk, V.B., eds. New York: Elsevier.

5619. Callahan, M.A.; Slimak, M.W.; Gabel, N.W.; et al. 1979. Water-related environmental fate of 129 priority pollutants. EPA Report No. 440/4-79 029a. Washington, DC: U.S. Environmental Protection Agency, Office of Water Planning and Standards.

5620. Goyer, R.A. 1986. Toxic effects of metals. In: Casarett and Doull's Toxicology, Klaassen, C.D.; Amdur, M.O.; Doull, J., eds. New York: MacMillan, pp. 582-635.

5621. Camner, P.; Clarkson, T.W.; Nordberg, G.F. 1986. Routes of exposure, dose and metabolism of metals. In: Handbook on the toxicology of metals, vol. 1, Friberg, L.; Nordberg, G.F.; Vouk, V.B., eds. New York: Elsevier.

5622. National Academy of Sciences (NAS). 1977. Drinking water and health. Washington, D.C.: National Academy of Science.

5623. United States Environmental Protection Agency (U.S. EPA) 1980. Exposure and risk assessment for zinc. EPA Report No. 440/4-81-016. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards.

5624. Elinder, C.-G. 1986. Zinc. In: Handbook on the Toxicology of Metals, Second Edition, vol. II: Specific Metals, Friberg, L.; Nordberg, G.F.; Vouk, V.B., eds. New York: Elsevier.

5625. United States Environmental Protection Agency (U.S. EPA) 1987. Ambient water quality criteria for zinc. EPA Report No. 440/5-87-003. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards.

5626. Nishioka, H. 1975. Mutagenic activity of metal compounds in bacteria. Mutat. Res. 31:185-189.

5627. Marzin, D.R.; Vo Phi, H. 1985. Study on the mutagenicity of metal derivatives with Salmonella typhimurium TA102. Mutat. Res. 155:49-51.

5628. Amacher, D.I.; Paillet, S.C. 1980. Induction of trifluorothymidene-resistant mutants by metal ions in L5178y/TK^{+} cells. Mutat. Res. 78:279-298.

5629. Vilkina, G.A.; Pmerantzeva, M.D.; Ramaya, L.K. 1988. Lack of mutagenic activity of cadmium and zinc salts in somatic and germ mouse cells. Genetika (Moscow) 14:2212-2214.

5630. Deknudt, G.H. 1982. Clastogenic effects of zinc in mammals. CR. Soc. Biol. 176:563-567.

5631. Voroshilin, S.I.; Plotko, E.G.; Fink, T.V.; et al. 1978. Cytogenetic effects of inorganic and acetate compounds of tungsten, zinc, cadmium, and cobalt in animal and human somatic cells. Tsitol. Genet. 12:241-243.

5632. Sutton, W.R.; Nelson, V.E. 1937. Studies on zinc. Proc. Soc. Exp. Biol. Med. 36:211-213.

5633. Brink, M.F.; Becker, D.E.; Terrill, S.W.; et al. 1959. Zinc Toxicity in the weanling pig. J. Anim. Sci. 18:836-842.

5634. Registry of Toxic Effects of Chemical Substances (RTECS) 1985-1986. Washington, DC: U.S. Department of Health and Human Services.

5635. Occupational Safety and Health Administration (OSHA) 1974. Occupational safety and health standards. Fed. Reg. 39:23541-23543.

5636. American Conference of Governmental Industrial Hygienists (ACGIH) 1989. Documentation of the threshold limit values and biological exposure indices, 5th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

5637. National Institute for Occupational Safety and Health (NIOSH) 1975. Criteria for a recommended standard - occupational exposure to zinc oxide. NIOSH Rept. No. 76-104. Cincinnati, OH: U.S. Department of Health Education and Welfare.

5638. U.S Environmental Protection Agency (U.S. EPA) 1989. Health effects assessment summary tables, second quarter. EPA Report No. OS-230. Washington, DC: U.S Environmental Protection Agency, Office of Solid Waste and Emergency Response.

5639. National Air Toxics Information Clearinghouse (NATICH) 1987. NATICH Data Base Report on State, Local, and EPA Air Toxics Activities.

5640. Lloyd, T.B.; Showak, W. 1984. Zinc and zinc alloys. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Mark, H.F.; Othmer, D.F.; Overberger, C.G.; Seaborg, G.T., eds. New York: John Wiley & Sons. pp. 807-851.

5641. Lloyd, T.B. 1984. Zinc compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, 3rd ed., Mark, H.F.; Othmer, D.F.; Overberger, C.G.; Seaborg, G.T., eds. New York: John Wiley & Sons. pp. 851-863.

5642. International Technical Information Institute 1986. Toxic and Hazardous Industrial Chemicals Safety Manual.

5643. Association of American Railroads 1987. Emergency Handling of Hazardous Materials in Surface Transportation. Washington, DC.

5644. U.S. Environmental Protection Agency (U.S. EPA) 1989. National primary and secondary drinking water regulations: Proposed rule. Fed. Reg. 54:22062-22160, May 22, 1989. 40 CFR Parts 141, 142 and 143.

5645. Weast, R.C. 1988-89. Handbook of Chemistry and Physics, 68th ed. Boca Raton, FL: The Chemical Rubber Company.

5646. Gerritse, R.G.; Vriesema, R.; Dalenberg, J.W.; et al. 1982. Effect of sewage sludge on trace element mobility in soils. J. Environ. Qual. 11:359-363.

5647. United States Environmental Protection Agency (U.S. EPA). 1988. Contract Laboratory Program Statistical Data Base. Washington, DC: U.S. Environmental Protection Agency. As reported in 5617.

5648. United States Environmental Protection Agency (U.S. EPA). 1990. Integrated Risk Information System (IRIS). Cincinnati, OH: U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office.

5649. Pagenkopf, L. 1986. Metal speciation and toxicity in aquatic systems. In: Metal Ions in Biological Systems, Sigel, H.,ed. New York: Marcel Dekker, Inc. p. 111-118.

5650. Jørgensen, S.E.; Jensen, A. 1984. Processes of metal ions in the environment. In: Metal Ions in Biological Systems, Sigel, H., ed. New York: Marcel and Dekker. pp. 61-103.

5651. United States Environmental Protection Agency (U.S. EPA). 1983. Methods for chemical analysis of water and wastes. EPA Report No. 600/4-79-020, revised March 1983. Washington, DC: U.S. Environmental Protection Agency.

5652. United States Environmental Protection Agency (U.S. EPA). 1986. Test methods for evaluation of solid waste. EPA Report No. SW-846. Washington, DC: U.S. Environmental Protection Agency.

5653. United States Environmental Protection Agency (U.S. EPA). 1988. National primary drinking water regulations: Analytical techniques. Fed. Regist. 53 (33): 5142-5147. 40 CFR Parts 141 and 143.

5654. Mack, R.B. 1989. A hard day's knight, zinc phosphide poisoning. N.C. Med. J. 50:17-18.

5655. Bruynzeel, D.P.; Hennipman, G.; van Ketel, W.G. 1988. Irritant contact dermatitis and chrome-passivated metal. Contact Dermatitis 19:175-179.

5656. Ketcheson, M.R.; Barron, G.P.; Cox, D.H. 1969. Relationship of maternal dietary zinc during gestation and lactation to development and zinc, iron, and copper content of the postnatal rat. J. Nutr. 98:303-311.

5657. Ferm, V.H.; Carpenter, S.J. 1968. Teratogenic effect of cadmium and its inhibition by zinc. Nature 216:1123.

5658. Chang, D.; Mann, D.J.; Gautieri, R. 1977. Teratogenicity of zinc chloride, 1,10-phenanthroline and zinc-1,10-phenanthroline complex in mice. J. Pharm. Sci. 66:1755-1758.

5659. World Health Organization (WHO). 1984. Guidelines for drinking water quality, vol. 1, Recommendations. Geneva: World Health Organization.

5660. Förstner, U. 1988. Analysis and prognosis of metal mobility in soils and wastes. In: Contaminated Soil, vol. 1. Wolf, K.; van den Brink, W.J; Colon, F.J., eds. Boston: Kluwer Academic Publishers. pp. 1-10.

5661. Clement Associates 1985. Chemical, physical, and biological properties of compounds present at hazardous waste sites. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. As reported in 5617.

5662. Schalscha, E.B.; Morales, M.; Vergara, I.; et al. 1982. Chemical fractionation of heavy metals in wastewater-affected soils. J. Water Pollut. Control Fed. 54:175-180. As reported in 5617.

5663. Saeed, M.: Fox, R.L. 1977. Relations between suspension pH and zinc solubility in acid and calcareous soils. Soil Sci. 124:199-224. As reported in 5617.

5664. Mahaffey, K.R.; Corneliussen, P.E.; Jelinek, C.F.; et al. 1975. Heavy metal exposure from foods. Environ. Health Perspect. 12:63-69. As reported in 5617.

5665. Allen, J.G.; Master, H.G.; Peet, R.L.; et al. 1983. Zinc toxicity in ruminants. J. Compar. Pathol. 93:363-377. As reported in 5617.

5666. Aughey, E.; Grant, L.; Furman, B.L.; et al. 1977. The effects of oral zinc supplementation in the mouse. J. Comp. Pathol. 87:1-14. As reported in 5617.

5667. Marrs, T.C.; Colgrave, H.F.; Edginton, J.A.G.; et al. 1988. The repeated dose toxicity of a zinc oxide/hexachloroethane smoke. Arch. Toxicol. 62:123-132. As reported in 5617.

5668. Logue, J.; Koontz, M.; Hattwick, A. 1982. A historical perspective mortality study of workers in copper and zinc refineries. J. Occup. Med. 24:398-408. As reported in 5617.

5669. Neuberger, J.; Hollowell, J. 1982. Lung cancer excess in an abandoned lead-zinc mining and smeltering area. Sci. Total Environ. 25:287-294. As reported in 5617.

5670. Stocks, P.; Davies, R. 1964. Zinc and copper content of soils associated with the incidence of cancer of the stomach and other organs. Brit. J. Cancer 18:14. As reported in 5617.

5671. Phillip, R.; Hughes, A.; Robertson, M. 1982. Stomach cancer and soil metal content. Brit. J. Cancer 45:482. As reported in 5617.

5672. Sturgis, C.C.; Drinker, P.; Sinclair, A.J. 1927. Metal fume fever: I. Clinical observations on the effect of the experimental inhalation of zinc oxide by two apparently normal persons. J. Ind. Hyg. 9:88-97. As reported in 5617.

5673. Chobanian, S.J. 1981. Accidental ingestion of liquid zinc chloride: local and systemic effects. Ann. Emerg. Med. 10:91-93. As reported in 5617.

5674. Drinker, K.R.; Thompson, P.K.; Marsh, M. 1927. An investigation of the effect of long-continued ingestion of zinc, in the form of zinc oxide, by cats and dogs, together with observations upon the excretion and storage of zinc. Am. J. Physiol. 80:31-64. As reported in 5617.

5675. National Institute for Occupational Safety and Health (NIOSH). 1985. NIOSH Pocket Guide to Chemical Hazards.

5676. Hazardous Substance Data Bank (HSDB). 1990. National Library of Medicine. Bethesda, MD.

5677. National Reseach Council. 1989. Recommended Dietary Allowances. 10th ed. National Academy Press, Washington, DC.

5678 Herms, U.; Brummer, G. 1980. Einfluss der Bodenreaktion auf Loslichkeit und tolerierbare Gesamtgehalte an Nickel, Kupfer, Zink, Cadmium, und Blei, in Boden und komposotierbaren Siedlungsarbfallen. Landwirtschaftliche Forschung 33:408-423.

5679 Kiekens, L.; Cottenie, A. 1985. Principles of investigations on the mobility and plant uptake of heavy metals. In: Chemical Methods for Assessing Bio-Available Metals in Sludges and Soils, R. Leschber et al., eds., Elsevier Applied Science Publ., London. pp 32-47.

5680 United State Environmental Protection Agency (U. S. EPA). 1990. Drinkine water regulations and health advisories. Office of Drinkine Water, Washington, D.C.

7000. Occupational Safety and Health Administration (OSHA). 1989. Air contaminants: final rule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7003. Occupational Safety and Health Administration (OSHA). 1989. Hazardous waste operations and emergency response; final rule. 29CFR1910.120, Fed. Regist., 3/6/89, 54:9294-9336.

7004. United States Environmental Protection Agency (U.S. EPA). 1989. Notice of issuance of pesticide registration standards. Fed. Regist., 2/22/89, 54:7740.

7005. United States Environmental Protection Agency (U.S. EPA). 1971. Tolerances and exemptions from tolerances for pesticide chemicals in or on raw agricultural commodities. 40CFR180, Fed. Regist. 11/25/71, 36:22540, as revised 1976, 41:4537.

7006. United States Environmental Protection Agency (U.S. EPA). 1971. Exemptions from the requirement of a tolerance for pesticide chemicals. 40CFR180.1001, Fed. Regist. 11/25/71, 36:22540, as revised 1976, 41:4537.

7007. United States Environmental Protection Agency (U.S. EPA). 1978. Pesticides classified for restricted use. 40CFR152.175, Fed. Regist. 2/9/78, 43:5790, as last amended 1988, 53:15988.

7008. United States Environmental Protection Agency (U.S. EPA). 1988. Tolerances for pesticides in food and animal feeds; zinc ion and maneb coordination byproduct. 40CFR185.6300, Fed. Regist., 6/29/88, 53:24666.

7009. United States Environmental Protection Agency (U.S. EPA). 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT). 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7015. United States Environmental Protection Agency (U.S. EPA). 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. United States Environmental Protection Agency (U.S. EPA). 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. United States Environmental Protection Agency (U.S. EPA). 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. United States Environmental Protection Agency (U.S. EPA). 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. United States Environmental Protection Agency (U.S. EPA). 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020. United States Environmental Protection Agency (U.S. EPA). 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. United States Environmental Protection Agency (U.S. EPA). 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7023. United States Environmental Protection Agency (U.S. EPA). 1982. Ore mining and dressing point source category. 40CFR440, Fed. Regist., 12/3/82, 47:54609, as amended 1988, 53:18788.

7024. United States Environmental Protection Agency (U.S. EPA). 1983. Electrical and electronic components point source category. 40CFR469, Fed. Regist., 4/8/83, as revised 1983, 48:45250.

7025. United States Environmental Protection Agency (U.S. EPA). 1981. Electroplating point source category. 40CFR413, Fed. Regist., 1/28/81, 46:9467, as revised 1983, 48:43681 and 32483.

7026. United States Environmental Protection Agency (U.S. EPA). 1983. Metal finishing point source category. 40CFR433, Fed. Regist., 7/15/83, 48:32485 as revised 1983, 48:41410 and 43682.

7027. United States Environmental Protection Agency (U.S. EPA). 1984. Battery manufacturing point source category. 40CFR461, Fed. Regist., 3/9/84, 49:9134 and 13879, as revised 1986, 51:30816.

7028. United States Environmental Protection Agency (U.S. EPA). 1985. Nonferrous metals forming and metal powders point source category. 40CFR471, Fed. Regist., 8/23/85, 50:34290, as revised 1986, 51:2884.

7030. United States Environmental Protection Agency (U.S. EPA). 1987. Organic chemicals, plastics, and synthetic fibers point source category. 40CFR414, Fed. Regist., 11/5/87, 52:42568, as amended 1989, 54:27351.

7035. United States Environmental Protection Agency (U.S. EPA). 1974. Rubber manufacturing point source category. 40CFR428, Fed. Regist., 2/21/74, 39:6662 as revised 1975, 40:2344.

7036. United States Environmental Protection Agency (U.S. EPA). 1982. Coil coating point source category. 40CFR465, Fed. Regist., 12/1/82, 47:54244, as revised 1984, 49:33648.

7037. United States Environmental Protection Agency (U.S. EPA). 1982. Porcelain enameling point source category. 40CFR466, Fed. Regist., 11/24/82, 47:53184, as revised 1985, 50:36543.

7038. United States Environmental Protection Agency (U.S. EPA). 1983. Aluminum forming point source category. 40CFR467, Fed. Regist., 10/24/83, 48:49149, as revised 1984, 49:11631.

7039. United States Environmental Protection Agency (U.S. EPA). 1983. Copper forming point source category. 40CFR468, Fed. Regist., 8/15/83, 48:36957 and 50719, as revised 1986, 51:22521.

7040. United States Environmental Protection Agency (U.S. EPA). 1985. Metal molding and casting point source category. 40CFR464, Fed. Regist., 10/30/85, 50:45247, as revised 1986, 51:21760.

7042. United States Environmental Protection Agency (U.S. EPA). 1982. Pulp, paper and paperboard point source category. 40CFR430, Fed. Regist., 11/18/82, 47:52019, as revised 1983, 48:13177 and 31404.

7044. United States Environmental Protection Agency (U.S. EPA). 1987. Assessment of zinc and zinc oxide as potentially toxic air pollutants. 40CFR61.01, Fed. Regist., 8/28/87, 52:32597.

7050. United States Environmental Protection Agency (U.S. EPA). 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7054. United States Environmental Protection Agency (U.S. EPA). 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7056. United States Environmental Protection Agency (U.S. EPA). 1979. Secondary maximum contaminant levels. 40CFR143, Fed. Regist., 7/19/79, 44:42198.

7057. Personal communication with national Safe Drinking Water Hotline, 10/18/89, 1-800-426-4791.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. United States Environmental Protection Agency (U.S. EPA). 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7060. United States Environmental Protection Agency (U.S. EPA). 1987. Extremely hazardous substance list and threshold planning quantities. 40CFR355 (SARA Title III Section 302), Fed. Regist., 4/22/87, 52:13395, as revised 1987, 52:48073 and 1988, 53:5574.

7064. United States Environmental Protection Agency (U.S. EPA). 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7065. United States Environmental Protection Agency (U.S. EPA). 1989. Designation of extremely hazardous substances as CERCLA hazardous substances; proposed rule. 40CFR302, Fed. Regist., 1/23/89, 54:3388.

7066. United States Environmental Protection Agency (U.S. EPA). 1989. Reportable quantity adjustments; proposed rule. 40CFR302 and 355, Fed. Regist., 8/30/89, 54:35988.

7068. United States Environmental Protection Agency (U.S. EPA). 1989. Waste specific prohibitions - second third wastes. 40CFR268.34, Fed. Regist., 6/23/89, 54:26594.

7070. Food and Drug Administration (FDA). 1977. Bottled drinking water standards. 21CFR103.35, Fed. Regist., 3/15/77, 42:14325, as last amended 1984, 49:10090.

7072 Food and Drug Administration (FDA). 1977. Indirect food additives; adhesives and components of coatings. 21CFR175, Fed. Regist., 3/15/77, 42:14534, as revised 42:56728.

7073. Food and Drug Administration (FDA). 1977. Indirect food additives; substances approved for use as antioxidants and/or stabilizers for polymers used in the manufacture of articles for use in food packaging. 21CFR178, Fed. Regist., 3/15/77, 42:14609.

7078. United States Environmental Protection Agency (U.S. EPA). 1980. Discarded commercial chemical products and their hazardous waste numbers. 40CFR261.33, Fed. Regist., 11/25/80, 45:78529 and 78541, as last amended 1988, 53:43881 and 43884.

7079. United States Environmental Protection Agency (U.S. EPA). 1981. Hazardous constituents. 40CFR261 Appendix VIII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:43881.

7080. United States Environmental Protection Agency (U.S. EPA). 1982. Groundwater protection: concentration limits. 40CFR264.94, Fed. Regist., 7/26/82, 47:32350, as amended 1983, 48:14294.

7082. United States Environmental Protection Agency (U.S. EPA). 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7085. United States Environmental Protection Agency (U.S. EPA). 1989. Land disposal restrictions for third scheduled wastes; proposed rule. 40CFR 148,261,264-5,268,271, Fed. Regist., 11/22/89, 54:48372.

7086. Council of European Communities Directive on Drinking Water, 16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7089. Council of European Communities Directive on Fishing Water Quality, 18 July 1978 (76/659/EEC-OJ L222, 14 August 1978, amended by 1851).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7091. Council of European Communities Directive on Groundwater, 17 December 1979 (80/68/EEC-OJ L20, 26 January 1980).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7095. Council of European Communities Directive on Classification, Packaging and Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7105. Council Decision Concluding the Convention for the Prevention of Marine Pollution From Land-Based Sources, 75/437/EEC, 3 March 1975.

7112. Florida Department of Environmental Regulation. *1989.* Florida Water *Quality* Standards, Chapter 17-3, effective 12/20/89.

7113. North Carolina Department of Natural Resources and Community Development. 1989. Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina, 15NCAC 2B.0200-0218, effective 10/1/89.

7115. Virginia Water Control Board. 1988. Commonwealth of Virginia Water Quality Standards, VR 680-21-00, effective 11/1/88.

7116. Wisconsin Department of Natural Resources. 1988. Wisconsin Chapter NR140, Groundwater Quality, effective 10/88.

7119. New York State Department of Environmental Conservation. 1987. Memorandum: New York Ambient Water Quality Standards and Guidance Values, 4/1/87.

7120. Wyoming Department of Environmental Quality. 1980. Chapter VIII, Quality Standards for Wyoming Groundwaters, effective 9/4/80.

7121. District of Columbia Department of Consumer and Regulatory Affairs. 1985. Water Quality Standards of the District of Columbia, Chapter II, Title 21 DCMR, effective 12/27/85.

7123. West Virginia Water Resources Board. 1989. State of West Virginia Water Quality Standards, effective 4/28/89.

7125. Massachusetts Division of Water Pollution Control. 1983. Massachusetts Ground Water Quality Standards, 314CMR6.00, effective 12/31/83.

7129. Illinois Environmental Protection Agency. 1986. Title 35: Environmental Protection, Subtitle F: Public Water Supplies, Chapter I: Pollution Control Board, effective 4/22/86.

7130. Illinois Environmental Protection Agency. 1989. Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter I: Pollution Control Board, proposed rule, 12/6/89.

7131. Badawy, N.B.A.; El Salam, M.A.; Eissa, S.M.; et al. 1987. Chromosomal aberrations in peripheral lymphocytes of zinc workers. In: Heavy Metals in the Environment, 6th International Conference, New Orleans, September 1987. vol. 1, Lindberg, S.E.; Hutchinson, T.C., eds. Edinburgh: CEP Consultants. pp. 343-345.

7132. Badawy, N.B.A.; El Salam, M.A.; Eissa, S.M.; et al. 1987. Studies on some enzymatic activities among zinc workers. In: Heavy Metals in the Environment, 6th International Conference, New Orleans, September 1987. vol. 2, Lindberg, S.E.; Hutchinson, T.C., eds. Edinburgh: CEP Consultants. pp. 77-79.

7133. Bertholf, R.L. 1988. Zinc. In: Handbook on toxicity of inorganic compounds, Sigel, H.; Seiler, H.G, eds. New York: Marcel Dekker, Inc. pp. 787-800.

7134. Brandao-Neto, J.; de Mendonca, B.B.; Shuhama, T.; et al. 1990. Zinc acutely and temporarily inhibits adrenal cortisol secretion in humans. Biol Trace Element Res. 24:83-89.

7135. Quarterman, J. 1974. The effects of zinc deficiency or excess on the adrenals and the thymus in the rat. In: Trace Element Metabolism in Animals - 2. Hoekstra, W.G.; Suttie, J.W.; Ganther, H.E.; Mertz, W., eds. Baltimore: University Park Press. pp. 742-744.

7136. Bingham, F.T.; Peryea, F.J.; Jarrell, W.M. 1986. Metal toxicity to agricultural crops. In: Metal Ions in Biological Systems, Sigel, H.,ed. New York: Marcel Dekker, Inc. pp. 119-156.

7137. Fox, M.R.S.; Jacobs, R.M. 1986. Zinc: essentiality, function, effects of deficiency, and requirementsy. In: Metal Ions in Biological Systems, Sigel, H.,ed. New York: Marcel Dekker, Inc. pp. 214-248.

7138. Mayer, R.; Schultz, R. 1987. Effect of soil acidification on heavy metal cycling in forest ecosystems. In: Heavy Metals in the Environment, 6th International Conference, New Orleans, September 1987. vol. 2, Lindberg, S.E.; Hutchinson, T.C., eds. Edinburgh: CEP Consultants. pp. 402-406.

7139. Verloo, M.; Willaert, G.; Eeckhout, M.; et al. 1987. Chemical and biological implications of metal speciation in contaminated soils. In: Heavy Metals in the Environment, 6th International Conference, New Orleans, September 1987. vol. 1, Lindberg, S.E.; Hutchinson, T.C., eds. Edinburgh: CEP Consultants. pp. 253-255.

COMMON SYNONYMS:	CAS. REG. NO.: 7440-38-2 NIOSH NO.: CG0525000 EPA Hazardous Waste No.: 0D004 K084 K101 K102
Arsenic-75 Metallic arsenic Arsenic black Colloidal arsenic	CHEMICAL SYMBOL: As

REACTIVITY (4000-4003)

Dust flammable when exposed to heat or flame. Mixtures of arsenic with some bromates, chlorates, iodates, fluorides, nitrates, permanganates, carbides, and peroxides may ignite or explode on contact or with heat, percussion, or sometimes light friction. Incompatible with bromine azide, rubidium acetylide, bromine trifluoride, chlorine, bromine pentafluoride, chlorine trifluoride, nitrogen trichloride, nitrogen tribromide, and dichlorine oxide. When aqueous solutions of arsenicals come in contact with active metals such as arsenic, iron, aluminum, or zinc, toxic fumes including arsine may be released.

PHYSICO-CHEMICAL DATA (4000)

- Atomic Weight: 74.92
- Atomic Number: 33
- Physical State: Solid
- Color: Silver-gray
- Odor: Odorless
- Odor Threshold: NA
- Density: 5.727 g/cm^3 at 14°C
- Melting Point: 817°C (28 atm)
- Boiling Point: 613°C (sublimes)
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: 1 mm Hg at 372°C

PHYSICO-CHEMICAL DATA (4000) (Cont.)

- Saturated Concentration in Air: NA
- Solubility in Water: Insoluble
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: Freshwater: 20,000 (algae); 9.9-219 (invertebrates); 7-17 (fish). Marine: 600-86,000 (algae); 64,000 (crustaceans); 5000 (fish).

HANDLING PRECAUTIONS

Avoid breathing dust or fumes from fires. Avoid eye or skin contact. Use goggles, rubber gloves, long sleeve coveralls, and respirator. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- $\leq 100\ \mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- $\leq 500\ \mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- $\leq 10\ mg/m^3$ — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- $\leq 20\ mg/m^3$ — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- $\geq 20\ mg/m^3$ (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 98-50-0 NIOSH NO.: CF7875000 EPA Hazardous Waste No.: ND
Arsanilic acid *p*-Arsanilic acid 4-Arsanilic acid Aminophenylarsine acid Aminophenylarsonic acid *p*-Aminophenylarsonic acid 4-Aminophenylarsonic acid *p*-Anilinearsonic acid	CHEMICAL FORMULA: $C_6H_8AsNO_3$

REACTIVITY (4000)

When heated to decomposition or when in contact with acids or acid fumes, it emits highly toxic fumes of aniline and arsenic.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 217.04
- Physical State: Crystals
- Color: White
- Odor: Odorless
- Odor Threshold: NA
- Density: 1.9571 g/cm^3 at 20°C
- Melting Point: 232°C
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Flammable vapors above 232°C
- Autoignition Temperature: ND
- Vapor Pressure: NA
- Saturated Concentration in Air: ND
- Solubility in Water: Slightly sol. in cold water
- Viscosity: ND
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
No data.

COMMON SYNONYMS:	CAS. REG. NO.: 7778-39-4 NIOSH NO.: CG0700000 EPA HAZARDOUS WASTE NO.: P010 D004
Arsenic acid Orthoarsenic acid	CHEMICAL FORMULA: H_3AsO_4

REACTIVITY (4000-4002)

Will corrode metal and give off toxic arsine gas. Does not react with water. When aqueous solutions of arsenicals come in contact with active metals such as arsenic, iron, aluminum, and zinc, toxic gases, including arsine, may be released.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 141.93 (4000)
- Valence: +5 (4001)
- Physical State: Solid (4001)
- Color: White (4001)
- Odor: Odorless (4002)
- Odor Threshold: NA
- Density: 2.2 g/cm^3 at 20°C (4000)
- Melting Point: 35.5°C (4000)
- Boiling Point: 160°C (4000)
- Flash Point: NA
- Flammable Limits: Not combustible (4000)
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 302 g/100 cm^3 at 12.5°C (4001)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4002)

Avoid contact with solution, solid or dust or use calamine lotion and zinc oxide powder on hands and other skin areas, rubber gloves, dust respirator or NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- $\leq 100\ \mu g/m^3$ Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- $\leq 500\ \mu g/m^3$ Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- $\leq 10\ mg/m^3$ Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- $\leq 20\ mg/m^3$ Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- $\geq 20\ mg/m^3$ (firefighting) Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 1303-28-2 NIOSH NO.: CG2275000 EPA Hazardous Waste No.: P011
Arsenic pentoxide Arsenic (V) oxide Arsenic acid anhydride Diarsenic pentoxide	CHEMICAL FORMULA: As_2O_5

REACTIVITY (4000)

Thermally unstable with decomposition occurring near the melting point with the release of oxygen and arsenic trioxide. Reacts violently with bromine pentafluoride; liberates chlorine from hydrogen chloride. Combines very slowly with water to form H_3AsO_4. When aqueous solutions of arsenicals come in contact with active metals such as arsenic, iron, aluminum, and zinc, toxic gases, including arsine, may be released.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 229.84
- Valence: +5
- Physical State: Amorphous solid
- Color: White
- Odor: ND
- Odor Threshold: NA
- Density: 4.32 g/cm^3
- Melting Point: Decomposes at 315°C
- Boiling Point: NA
- Flash Point: ND
- Flammable Limits: Burns with difficulty
- Autoignition Temperature: ND
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 150 g/100 ml at 16°C
  76.7 g/100 ml at 100°C

PHYSICO-CHEMICAL DATA (4000) (Cont.)

- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS

Avoid inhalation and contact with eyes or skin or Use protective clothing, goggles, gloves, boots, and dust respirator or NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

• $\leq 100\ \mu g/m^3$	Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
• $\leq 500\ \mu g/m^3$	Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
• $\leq 10\ mg/m^3$	Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
• $\leq 20\ mg/m^3$	Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
• $\geq 20\ mg/m^3$ (firefighting)	Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 7784-34-1 NIOSH NO.: CG1750000 EPA Hazardous Waste No.: D004
Arsenic trichloride Arsenic chloride Arsenous trichloride Trichloroarsine	CHEMICAL FORMULA: $AsCl_3$

REACTIVITY (4015)

When in contact with active metals such as arsenic, iron, aluminum, or zinc, or when heated to decomposition, emits highly toxic fumes of arsenic. Decomposed by water to form arsenic hydroxide and hydrogen chloride.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 181.28	(4000)
• Valence: +3	(4000)
• Physical State: Liquid or solid	(4000)
• Color: Pale yellow needles	(4015)
• Odor: Acrid	(4000)
• Odor Threshold: ND	
• Density: 2.1497 g/cm^3 at 25°C	(4000)
• Melting Point: -16°C	(4000)
• Boiling Point: 130.21°C	(4000)
• Flash Point: NA	
• Flammable Limits: Noncombustible	(4015)
• Autoignition Temperature: NA	
• Vapor Pressure: 10 mm Hg at 23.5°C	(4000)
• Vapor density: 6.25 (air=1)	(4000)
• Saturated Concentration in Air: ND	
• Solubility in Water: 1 mole in 9 moles water.	(4000)
• Viscosity: ND	
• Surface Tension: ND	
• Log (Octanol-Water Partition Coeff.): ND	
• Log K (Stability Constant for Humic Acid): ND	
• Soil-Water Distribution Coeff.: ND	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS

May be fatal if inhaled, swallowed or absorbed through the skin. Can cause burns to the throat, eyes and skin. Use full protective clothing, rubber gloves and boots, and bands around legs and waist, and self-contained breathing apparatus. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to inorganic arsenic compounds having a significant vapor pressure and capable of being absorbed rapidly through the skin (i.e., arsenic trichloride), OSHA (4013) has the following respirator requirements:

- $\leq 100\ \mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter and acid gas cartridge or full facepiece mask supplied-air respirator.
- $\leq 500\ \mu g/m^3$ — Front or back mounted full facepiece gas mask equipped with high-efficiency filter and acid gas canister or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- $\leq 10\ mg/m^3$ — Full facepiece supplied-air respirator operated in positive pressure mode.
- $\leq 20\ mg/m^3$ — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- $\geq 20\ mg/m^3$ (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 1327-53-3 NIOSH NO.: CG3325000 EPA Hazardous Waste No.: PO12
Arsenic trioxide Arsenic oxide Arsenous acid anhydride Arsenous acid Arsenous oxide White arsenic Arsenolite Claudetite	CHEMICAL FORMULA: As_2O_3

REACTIVITY (4000-4002)

No reaction with common materials. No reaction with water. Poisonous gases may be produced when heated. A mixture of arsenic trioxide and zinc filings will explode on heating. Incompatible with tannic acid, infusion cinchona, other vegetable astringent infusions and decoctions. Forms a spontaneously flammable mixture with sodium chlorate. Reacts with incandescence with hydrogen fluoride. Forms toxic volatile halides in contact with halide acids. Forms volatile toxic arsine when reduced in acid solution. Reacts violently with oxygen difluoride, fluorine, and chlorine trifluoride. Aqueous solutions of arsenicals in contact with active metals such as arsenic, iron, aluminum, and zinc, release highly toxic fumes including arsine. Trivalent arsenic in aqueous solutions is rapidly oxidized at room temperature but not at 4°C. The rate of oxidation is determined by the pH of the solution. At pH levels of 7.0 and 9.6, 70-90% conversion occurred within one week; at pH 4.8 only 25% conversion occurred.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 197.82	(4000)
• Valence: +3	(4001)
• Physical State: Solid	(4000)
• Color: Colorless crystals, white crystalline powder	(4000)
• Odor: Odorless	(4000)
• Odor Threshold: NA	
• Density: 3.738 g/cm^3	(4000)
• Melting Point: 312.3°C	(4000)
• Boiling Point: 465°C	(4000)
• Flash Point: NA	
• Flammable Limits: Not flammable	(4000)

PHYSICO-CHEMICAL DATA (Cont.)

- Autoignition Temperature: NA
- Vapor Pressure: 66.1 mm Hg at 312°C (4000)
- Saturated Concentration in Air: NA
- Solubility in Water: 2.1 g/100 cc (4001)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000-4002)

Avoid contact with solid or dust. Use respirator, protective gloves, eye protection, and full protective overalls. May volatilize in fires. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit, and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 1303-33-9 NIOSH NO.: CG2638000 EPA Hazardous Waste No.: P038
Arsenic trisulfide Arsenic sulfide Arsenous sulfide Arsenic yellow Arsenic tersulfide Arsenic sesquisulfide Diarsenic trisulfide Orpiment	CHEMICAL FORMULA: As_2S_3

REACTIVITY (4000-4002)

Does not react with water. May ignite at high temperatures. When heated to decomposition produces arsine and hydrogen sulfide. Burns in air to release arsenic trioxide and sulfur dioxide. Reacts with chlorine to form arsenic trichloride and sulfur chloride. Yields flammable hydrogen sulfide on contact with strong acids. Reacts vigorously with strong oxidizing agents. When aqueous solutions of Arsenic trisulfide come in contact with active metals including arsenic, iron, zinc, and aluminum, toxic fumes, including arsine are released. Trivalent arsenic in aqueous solutions is rapidly oxidized at room temperature but not at 4°C. The rate of oxidation is determined by the pH of the solution. At pH levels of 7.0 and 9.6, 70-90% conversion occurred within one week; at pH 4.8 only 25% conversion occurred.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 246.00	(4001)
• Valence: +3	(4001)
• Physical State: Solid	(4001)
• Color: Yellow or orange	(4001)
• Odor: Odorless	(4000)
• Odor Threshold: NA	
• Density: 3.46 g/cm^3	(4000)
• Melting Point: 300-325°C	(4000)
• Boiling Point: 707°C	(4000)
• Flash Point: ND	
• Flammable Limits: Not flammable	(4000)
• Autoignition Temperature: ND	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: 0.00005 g/100 ml at 18°C	(4000)

PHYSICO-CHEMICAL DATA Cont.)

- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000-4002)

Poisonous if inhaled or swallowed. Skin, eye and respiratory tract irritant. Use protective clothing and respirator. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or Any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 7784-42-1 NIOSH NO.: CG6475000 EPA Hazardous Waste No.: ND
Arsine Arsenic hydride Arsenic trihydride	CHEMICAL FORMULA: AsH_3
	CONVERSION FACTORS: 1 mg/m^3 = 0.313 ppm 1 ppm = 3.2 mg/m^3

REACTIVITY (4000)

Can explode on contact with warm dry air. Burns with a bluish flame, releasing arsenic trioxide. Can react vigorously with oxidizing materials. Moderate explosion hazard when exposed to chloride, nitric acid, (potassium plus ammonia). Decomposes at 300°C. Hydrolyses rapidly in water to form arsenic acids and hydrides. On exposure to light, moist arsine decomposes quickly depositing shiny black arsenic.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 77.93
- Valence: -3
- Physical State: Gas
- Color: Colorless
- Odor: Disagreeable garlic odor
- Odor Threshold: ND
- Density: 2.695 g/cm^3
- Melting Point: -117°C
- Boiling Point: -55°C
- Flash Point: ND
- Flammable Limits: Extremely flammable
- Autoignition Temperature: ND
- Vapor Pressure: 11,000 mm Hg at 20°C
- Saturated Concentration in Air: ND
- Solubility in Water: 20 ml/100 g cold water at 20°C

PHYSICO-CHEMICAL DATA (Cont.)

- Viscosity: 101.325 kPa at 0° C
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)

May be fatal if inhaled, swallowed or absorbed through the skin. Contact results in burns to the eyes and skin. Must be stored in glass lined container. Use full protective clothing and respirator. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

COMMON SYNONYMS:	CAS. REG. NO.: 7778-44-1 NIOSH NO.: CG0830000 EPA Hazardous Waste No.: ND
Calcium arsenate Calcium orthoarsenate	CHEMICAL FORMULA: $Ca_3(AsO_4)_2$

REACTIVITY (4000-4002)

When heated, violent exothermic reactions occur with the release of ozone. Does not react with water, but moisture and carbon dioxide cause slow decomposition to calcium carbonate and dicalcium hydrogen arsenate. Slight corrosive action with metals. Arsenates are oxidizing agents which are reduced by strong acids such as hydrochloric acid. When aqueous solutions of arsenicals come in contact with active metals such as arsenic, iron, aluminum, and zinc, toxic gases, including arsine, may be released.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 398.08	(4000)
• Valence: +5	(4001)
• Physical State: Amorphous solid	(4001)
• Color: White	(4001)
• Odor: Odorless	(4000)
• Odor Threshold: NA	
• Density: 3.620 g/cm^3	(4000)
• Melting Point: 1455°C	(4001)
• Boiling Point: NA	
• Flash Point: NA	
• Flammable Limits: Not flammable	(4002)
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: 0.013 g/100 cm^3	(4000)

PHYSICO-CHEMICAL DATA (Cont.)

- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000-4002)

Avoid inhalation and skin or eye contact. Use dust mask, goggles or face mask, gloves, and protective clothing. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide, OSHA (4013 has the following respirator requirements:

• ≤100 $\mu g/m^3$	Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
• ≤500 $\mu g/m^3$	Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
• ≤10 mg/m^3	Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
• ≤20 mg/m^3	Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
• ≥20 mg/m^3 (firefighting)	Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 27152-57-4 NIOSH NO.: CG3380000 EPA Hazardous Waste No.: ND
Calcium arsenite Arsenous acid, calcium salt Arsonic acid, calcium salt	CHEMICAL FORMULA: $As_2O_6.Ca$

REACTIVITY (4000)

Inorganic arsenic compounds may react with hydrogen gas and produce arsine. Slowly converted to arsenate by atmospheric oxygen.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 366.08
- Valence: +3
- Physical State: Solid
- Color: White
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: NA
- Saturated Concentration in Air: ND
- Solubility in Water: Slightly soluble
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)

Avoid inhalation and skin or eye contact. Trivalent arsenic compounds cause burns to the skin and eyes. Use protective clothing, boots, gloves, face mask, and respirator.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- $\leq 100\ \mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- $\leq 500\ \mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- $\leq 10\ mg/m^3$ — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- $\leq 20\ mg/m^3$ — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- $\geq 20\ mg/m^3$ (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 12002-03-8 NIOSH NO.: GL6475000 EPA Hazardous Waste No.: D004
Cupric acetoarsenate Copper acetate arsenate Copper acetate metaarsenate Paris Green	CHEMICAL FORMULA: $Cu(C_2H_3O_2)_2 \cdot 3Cu(AsO_2)_2$ (approx.)

REACTIVITY (4000)

Unstable in acids, bases and towards hydrogen sulfide. Volatile arsenic oxide may be formed in fires. Decomposes on prolonged heating in water. Decomposes in the presence of water and carbon dioxide to give phytotoxic water soluble arsenical compound.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 1013.71
- Physical State: Crystalline powder
- Color: Green
- Odor: Odorless
- Odor Threshold: NA
- Density: >1.1 g/cm^3 at 20°C
- Melting Point: ND
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Not flammable
- Autoignition Temperature: ND
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: Insoluble
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)

Dusts may be poisonous if inhaled or swallowed. May irritate the skin or eyes. Fire may produce irritating or poisonous gases. Use protective clothing, goggles and respirator. For exposure to copper dusts, OSHA recommends dust and mist respirator (except single-use type) for level of 5.0 mg/m^3.

For exposures to copper aceto-arsenite and all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 692-42-2
Diethyl arsine Arsine, diethyl-	CHEMICAL FORMULA: $C_4H_{11}As$

REACTIVITY (4000)

Spontaneously flammable in air.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 134.05
- Physical State: ND
- Color: ND
- Odor: ND
- Odor Threshold: ND
- Density: 1.4709 g/cm^3
- Melting Point: 1.1338°C
- Boiling Point: 105°C
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: Slightly soluble
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS
No data.

COMMON SYNONYMS:	CAS. REG. NO.: 75-60-5 NIOSH NO.: CH7525000 EPA Hazardous Waste No.: ND
Dimethyl arsenic acid Arsine oxide, hydroxydimethyl- Dimethyl arsinic acid Hydroxydimethylarsine oxide Cacodylic acid ANSAR PHYTAR	CHEMICAL FORMULA: $C_2H_7AsO_2$

REACTIVITY (4000, 4026, 4216)

Aqueous solutions are mildly corrosive. Aqueous solutions incompatible with active metals such as iron, aluminum, and zinc. Reacts with hydrous oxides to form insoluble salts.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 138.01
- Physical State: Crystals
- Color: Colorless
- Odor: Odorless
- Odor Threshold: NA
- Density: 1.95 g/cm^3
- Melting Point: 195-196°C
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 66 g/100 g
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
Poisonous if inhaled or swallowed. Fire may produce irritating or poisonous gases. Use rubber gloves, goggles or face shield for eye protection, rubber apron.

COMMON SYNONYMS:	CAS. REG. NO.: 144-21-8 NIOSH NO.: PA2275000 EPA Hazardous Waste No.: KO84
Disodium methanearsonate Disodium methanearsenate Arsonic acid, methyl-, disodium salt	CHEMICAL FORMULA: $CH_3AsO_3.2Na$

REACTIVITY (4000)

Non-corrosive to iron, rubber, and most plastics. Dangerous when water solution is in contact with active metals such as iron, aluminum, or zinc.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 185.95
- Physical State: Crystalline hydrate
- Color: Colorless or white
- Odor: ND
- Odor Threshold: ND
- Density: 1.0 (hydrate)
- Melting Point: >355°C
- 132-139°C (hexahydrate)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Non-flammable
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: NA
- Solubility in Water: ~1 g/mL
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
Slightly irritating to the skin and eyes; avoid inhalation and skin contact; wear protective rubber or neoprene gloves, goggles, and rubber apron.

COMMON SYNONYMS:	CAS. REG. NO.: 7784-40-9 NIOSH NO.: CG0980000 EPA Hazardous Waste No.: D004 D008
Lead arsenate Acid lead arsenate Lead orthoarsenate, di	CHEMICAL FORMULA: $AsHO_4.Pb$

REACTIVITY (4000)

At about 280° C lead arsenate is converted into pyroarsenate. When subjected to intense fire conditions, will form arsenic and lead oxide. Lead salts will burn fiercely in contact with fluorine. When mixed with lime, lime sulfur, sulfur, or casein, arsenite is formed. When aqueous solutions of arsenicals come in contact with active metals, such as arsenic, iron, aluminum, zinc, highly toxic fumes such as arsine may be released.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 347.14	(4214)
• Valence: +5	(4001)
• Physical State: Solid, powder	(4000)
• Color: White	(4000)
• Odor: Odorless	(4000)
• Odor Threshold: NA	
• Density: 5.79 g/cm^3	(4000)
• Melting Point: 720° C (decomposes)	(4000)
• Boiling Point: ND	
• Flash Point: NA	
• Flammable Limits: Not flammable	(4000)
• Autoignition Temperature: NA	
• Vapor Pressure: ND	
• Saturated Concentration in Air: ND	

PHYSICO-CHEMICAL DATA (Cont.)

- Solubility in Water: Insol. in cold water; Slightly sol. in hot water (4000)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)

Avoid inhalation, and skin or eye contact. Can cause inflammation of the skin and mucous membranes. Use protective clothing, boots, and respirator. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 124-58-3 NIOSH NO.: PA1575000 EPA Hazardous Waste No.: K031
Methanearsonic acid Methylarsinic acid Methylarsenic acid Arsonic acid, methyl	CHEMICAL FORMULA: CH_5AsO_3

REACTIVITY (4000)

No data.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 139.98
- Physical State: Crystalline solid
- Color: White
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: 161°C
- Boiling Point: NA
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: NA
- Saturated Concentration in Air: ND
- Solubility in Water: Freely soluble
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
No data.

COMMON SYNONYMS:	CAS. REG. NO.: 696-28-6 NIOSH NO.: CH5425000 EPA Hazardous Waste No.: ND
Phenyldichloroarsine Dichlorophenylarsine Arsine, dichlorophenyl Arsonous dichloride, phenyl Phenyl dichloroarsine Phenylarsinedichloride	CHEMICAL FORMULA: $C_6H_5AsCl_2$

REACTIVITY (4000)

Decomposed by water.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 222.93
- Physical State: Liquid
- Color: ND
- Odor: ND
- Odor Threshold: ND
- Density: 1.6516 g/cm^3 at 19°C
- Freezing Point: -20°C
- Boiling Point: 254.4-257.6°C
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: 0.14 mm Hg at 15°C
- Saturated Concentration in Air: ND
- Solubility in Water: Insoluble
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
May be fatal if inhaled, swallowed, or absorbed through the skin. Contact may cause burns to the eyes and skin. Use chemical protective clothing and self-contained breathing apparatus.

COMMON SYNONYMS:	CAS. REG. NO.: 7784-41-0 NIOSH NO.: CG1100000 EPA Hazardous Waste No.: D004
Potassium arsenate Arsenic acid, monopotassium salt Monopotassium arsenate Potassium hydrogen arsenate Potassium dihydrogen arsenate Macquer's salt	CHEMICAL FORMULA: KH_2AsO_4

REACTIVITY (4000)

Dangerous when heated to decomposition; releases toxic fumes including arsine. Does not react with water. When aqueous solutions of arsenicals come in contact with active metals such as arsenic, iron, aluminum, and zinc, toxic gases, including arsine, may be released.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 180.03
- Valence: +5
- Physical State: Crystals or powder
- Color: colorless or white
- Odor: Odorless
- Odor Threshold: NA
- Density: 2.867 g/cm^3
- Melting Point: 288°C
- Boiling Point: ND
- Flash Point: NA
- Flammable Limits: Not flammable
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 19 g/100 cc
- Viscosity: NA

PHYSICO-CHEMICAL DATA (Cont.)

- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)

Avoid inhalation or skin and eye contact. Use protective clothing, goggles, boots, gloves, and dust respirator. NIOSH recommends a supplied-air or self-contained breathing apparatus with full face mask and high-efficiency particulate filter.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

• ≤100 $\mu g/m^3$	Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
• ≤500 $\mu g/m^3$	Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator. or any full facepiece self-contained breathing apparatus.
• ≤10 mg/m^3	Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
• ≤20 mg/m^3	Supplied-air respirator with full facepiece, hood, or helmet or suit, and operated in positive pressure mode.
• ≥20 mg/m^3 (firefighting)	Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 10124-50-2 NIOSH NO.: CG3800000 EPA Hazardous Waste No.: ND
Potassium arsenite Arsenous acid, potassium salt Arsonic acid, potassium salt Potassium metaarsenite	CHEMICAL FORMULA: $KAsO_2 \bullet HAsO_2$

REACTIVITY (4000)

Arsenites of alkali metals in solution are slowly converted to arsenates by atmospheric oxygen. Incompatible with alkaloidal salts, hypophosphites and sulfites in acid solution; salts of iron and most other heavy metals; tannic acid. Decomposes at 300° C.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 254.8
- Valence: +3
- Physical State: Solid
- Color: Colorless crystals, white powder
- Odor: ND
- Odor Threshold: NA
- Density: ND
- Melting Point: ND
- Boiling Point: ND
- Flash Point: NA
- Flammable Limits: ND
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air:
- Solubility in Water: Soluble
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)

Avoid inhalation and skin or eye contact. Trivalent arsenic compounds cause burns to the skin and eyes. Use protective clothing, boots, gloves, face mask, and respirator.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 7778-43-0 NIOSH NO.: CG0875000 EPA Hazardous Waste No.: ND
Sodium arsenate Disodium arsenate Sodium biarsenate	CHEMICAL FORMULA: Na_2HAsO_4

REACTIVITY

No reaction with water. When aqueous solutions of arsenicals come in contact with active metals such as arsenic, iron, aluminum, and zinc, toxic gases, including arsine, may be released.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 185.91
- Valence: +5
- Physical State: Solid
- Color: White
- Odor: Odorless
- Odor Threshold: NA
- Density: 1.87 g/cm^3
- Melting Point: 57°C
- Boiling Point: Decomposes at 180°C
- Flash Point: NA
- Flammable Limits: Not flammable
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: Very soluble
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS

Avoid contact with solid or dust. Use dust mask, goggles or face shield, and protective gloves (4002).

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator or any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit, and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 7784-46-5 NIOSH NO.: CG3675000 EPA Hazardous Waste No.: ND
Sodium arsenite Sodium metaarsenite Arsenious acid, sodium salt	CHEMICAL FORMULA: $NaAsO_2$

REACTIVITY (4002)

No reaction with water or common materials. Somewhat hygroscopic; absorbs carbon dioxide from the air. The arsenites of common alkali metals are slowly converted in solution to arsenates by atmospheric oxygen. Fire may produce irritating or poisonous gases.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 130.92	(4000)
• Valence: +3	(4001)
• Physical State: Solid	(4001)
• Color: White to gray	(4000)
• Odor: Odorless	(4002)
• Odor Threshold: NA	
• Density: 1.87 g/cm^3	(4000)
• Melting Point: 615°C	(4000)
• Boiling Point: ND	
• Flash Point: NA	
• Flammable Limits: Not flammable	(4002)
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: Freely soluble	(4000)
• Viscosity: NA	

PHYSICO-CHEMICAL DATA (Cont.)

- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS

Avoid inhalation and skin or eye contact. Trivalent arsenic compounds cause burns to the skin and eyes. Use protective clothing, boots, gloves, face mask, and respirator.

For exposures to all inorganic compounds containing arsenic except arsine and those having a significant vapor pressure (i.e., arsenic trichloride and arsenic phosphide), OSHA (4013) has the following respirator requirements:

- ≤100 $\mu g/m^3$ — Half-mask or air-purifying respirator equipped with high-efficiency filter or any half-mask supplied-air respirator.
- ≤500 $\mu g/m^3$ — Full facepiece air-purifying respirator equipped with high-efficiency filter or any full facepiece supplied-air respirator any full facepiece self-contained breathing apparatus.
- ≤10 mg/m^3 — Powered air-purifying respirators in all inlet face coverings with high-efficiency filters or half-mask supplied-air respirators operated in positive pressure mode.
- ≤20 mg/m^3 — Supplied-air respirator with full facepiece, hood, or helmet or suit and operated in positive pressure mode.
- ≥20 mg/m^3 (firefighting) — Any full facepiece self-contained breathing apparatus operated in positive pressure mode.

COMMON SYNONYMS:	CAS. REG. NO.: 124-65-2 NIOSH NO.: CH7700000 EPA Hazardous Waste No.: ND
Sodium cacodylate Sodium dimethylarsinate Sodium dimethy larsonate Arsinic acid, dimethyl-, sodium salt	CHEMICAL FORMULA: $C_2H_6AsO_2.Na$

REACTIVITY (4000)

No data.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 159.98
- Physical State: Crystals or powder
- Color: Colorless to light yellow
- Odor: None
- Odor Threshold: NA
- Density: ND
- Melting Point: 200°C
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 2000 g/L at 15-20°C
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
Irritating to skin and eyes; wear rubber gloves, goggles or face shield for eye protection, and rubber apron.

COMMON SYNONYMS:	CAS. REG. NO.: 2163-80-6 NIOSH NO.: PA2625000 EPA Hazardous Waste No.: ND
Sodium methanearsonate Methanearsonic acid, sodium salt	CHEMICAL FORMULA: $CH_4AsO_3.Na$

REACTIVITY (4000)

Non-corrosive to iron, rubber and most plastics. Decomposed by strong oxidizing and reducing agents. Toxic gases may be generated in fires.

PHYSICO-CHEMICAL DATA (4000)

- Molecular Weight: 161.96
- Physical State: Crystalline solid
- Color: White
- Odor: ND
- Odor Threshold: NA
- Density: 1.57 g/cm^3
- Melting Point: 119°C
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: Nonflammable
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 570 g/L (at 25°C)
- Viscosity: NA
- Surface Tension: NA
- Log K (Stability Constant for Humic Acid): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (4000)
Skin, eye, and respiratory tract irritant; use protective rubber or neoprene gloves, goggles or face shield for eye protection, and rubber apron.

PERSISTENCE IN THE SOIL-GROUNDWATER SYSTEM

Arsenic is strongly adsorbed to soils, particularly to soils rich in hydrous iron and aluminum oxides (4007). Heavy soils such as clays, with a high surface area and substantial hydrous oxide content, adsorb more arsenic than light sandy soils. Soils are generally considered a sink for arsenic; however, varying amounts may be lost to the atmosphere through biotransformation and volatilization. A small amount may also be lost through downward migration and transport to groundwaters. Estimates of soil half-lives for arsenic compounds are 6.0 yr for arsenite, 5.6 yr for methanearsonic acid, 5.2 yr for cacodylic acid, 6.5 yr for arsenic trioxide, and about 16 yr for lead arsenate.

PATHWAYS OF EXPOSURE

The low mobility of arsenic in soils generally limits transport to groundwater and thereby reduces the potential for exposure through the use of groundwater as a source of drinking water. The potential for arsenic to become a groundwater contaminant as a result of leaching from waste disposal sites may exist only under very specific conditions (i.e., sandy soils, moist, low oxygen, reducing conditions) favoring the formation of the more water soluble arsenic species with limited adsorption to soil particulate matter. Deep groundwaters are more likely to have a high arsenic content as a result of leaching from naturally occurring arsenic-rich geologic formations. The potential for arsenic exposure occurring through ingestion of foods grown on arsenic-contaminated soils is relatively low. Although plants take up arsenic, the amounts accumulated are generally only slightly higher than those for plants grown on noncontaminated soils. However, because of the ubiquitous distribution of arsenic in the environment, arsenic is present in most food products, although usually at very low levels, and usually in the form of organic arsenic compounds of relatively low toxicity. It has been estimated that the daily intake of arsenic through ingestion ranges from 30 to 370 μg/day and averages about 120 μg/day (4036).

The most likely sources of excessive exposure to arsenic compounds occur in association with mining, smeltering operations, chemical manufacturing, agricultural use of arsenic products, and with the combustion of arsenic-containing wastes. Direct atmospheric releases, or indirect releases following biotransformation into volatile organoarsenicals may result in inhalation exposures to workers and to residents living nearby. Improper use and/or disposal, and leaching from waste piles may also result in contamination of surface waters, and in some cases also groundwaters.

HEALTH HAZARD DATA

The most common immediate symptoms of inorganic arsenic poisoning include: nausea, anorexia, vomiting, epigastric and abdominal pain, and diarrhea. Other symptoms that have been reported are: constriction of the throat and difficulty in swallowing, edema of the face, headache, fatigue, upper respiratory distress (cough, sore throat, and rhinitis), dermatitis, and peripheral neuropathy (4110, 4112). Arsine poisoning may also produce fever, tachycardia, and tachypnea (4111). Organic arsenic compounds such as methanearsonates produce symptoms similar to those caused by inorganic arsenites and arsenates (4088). Phenylarsonates however, have more direct neurotoxic effects, and may cause loss of coordination, inability to control limb movements, ataxia, blindness, and paralysis (4001).

Acute Toxicity Studies:

ORAL:

LD_{lo}	≥0.6 mg/kg/day		Human	(4001)
LD_{lo}	1-2.5 mg As^{+3}/kg		Human	(4000)
LD_{lo}	5-50 mg/kg	(arsenic pentoxide)	Human	(4015)
LD_{50}	8 mg/kg	(arsenic pentoxide)	Rat	(4016)
LD_{50}	15-48 mg As/kg	(arsenic trioxide, gavage)	Rat	(4087)
LD_{50}	145-214 mg As/kg	(arsenic trioxide, diet)	Rat	(4087)
LD_{50}	185 mg/kg	(arsenic trisulfide)	Rat	(4000)
LD_{50}	700-830 mg/kg	(cacodylic acid)	Rat	(4083)
LD_{50}	298 mg/kg	(calcium arsenate)	Rat	(4000)
LD_{50}	>1000 mg/kg	(disodium methanearsonate)	Rat	(4019)
LD_{50}	80 mg/kg	(lead arsenate)	Rat	(4000)
LD_{50}	44-216 mg/kg	(phenylarsonates)	Rat	(4001)
LD_{50}	14 mg/kg	(potassium arsenate)	Rat	(4000)
LD_{50}	600-2600 mg/kg	(sodium cacodylate)	Rat	(4083)
LD_{50}	700 mg/kg	(sodium methanearsonate)	Rat	(4019)

DERMAL:

LD_{50}	52.5 µL/kg	(phenyldichloroarsine)	Rat	(4000)
LD_{50}	936 mg/kg	(arsenic trisulfide)	Rat	(4000)

HEALTH HAZARD DATA

Long-Term Effects:

Skin abnormalities (hyperpigmentation and hyperkeratosis), neurological disorders (peripheral neuropathy due to inorganic arsenic and encephalopathy and optic atrophy by some organoarsenicals), and vascular disorders (cardiovascular disease, Raynaud's phenomenon, and Blackfoot disease) have occurred in individuals exposed to arsenic for long periods. Other effects reported n some studies include pulmonary damage, liver damage, hematological changes, and reproductive abnormalities. Severe anemia is a characteristic feature of chronic exposure to arsine (4111). Phenyldichloroarsine may suppress the immune system (4000).

Pregnancy/Neonate Data:

Very limited human data suggest that arsenic may cause an increase in spontaneous abortions, reduced birth weights, and an increase in the male to female birth ratio. Inorganic arsenic compounds including sodium arsenate and sodium arsenite are known to be fetotoxic and to cause adverse reproductive and teratogenic effects in laboratory animals. Exposure to arsenic results in reabsorptions, reduced fetal weights, and malformations such as skeletal abnormalities, eye defects, and exencephaly.

Genotoxicity Data:

In vivo and in vitro studies indicate that arsenic causes increases in chromosomal aberrations and sister chromatid exchanges (SCE) in exposed individuals. Similar results have been reported in in vitro animal bioassays. However, in vitro animal tests for clastogenicity have been inconclusive. Arsenic compounds are generally nonmutagenic or only weakly mutagenic microbial test systems.

Carcinogenicity Classification:

IRAC — Group 1 (sufficient evidence in humans; limited evidence in animals) (4012)
NTP — ND
EPA — Group A (oral) (4008)
Group A (inhalation)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards

- OSHA PEL (8-hr TWA): Inorganic arsenic 10 µg As/m^3; Organic arsenic 500 µg As/m^3; Arsine 200 µg/m^3 (0.05 ppm)
- OSHA STEL (15-min): ND
- AFOSH PEL (8-hr TWA): Inorganic arsenic 10 µg As/m^3; Organic arsenic 500 µg As/m^3; Arsine 200 µg/m^3 (0.05 ppm)
- AFOSH CL (15-min): Arsine 0.15 ppm

Criteria

- NIOSH IDLH (30-min): ND
- NIOSH REL (10-hr TWA): ND
- NIOSH STEL (15-min ceiling): Inorganic arsenic 2 µg As/m^3; Arsine 2 µg As/m^3
- ACGIH TLV® (8-hr TWA): As and soluble compounds 0.2 mg As/m^3
- ACGIH STEL (15-min): ND

WATER EXPOSURE LIMITS:

Drinking Water Standards (4008, 4209)

- MCLG (proposed): 0
- MCL: ND

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 (4008).

- 1-day (child): ND
- 10-day (child): ND
- longer-term (child): ND
- longer-term (adult): ND
- lifetime (adult): ND
- 1 E-04 cancer risk level: 3 µg/L

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WHO Drinking Water Guideline

- A health-based guideline for drinking water of 0.05 mg/L is recommended for arsenic (4001).

EPA Ambient Water Quality Criteria

- **Human Health**
  - Based on the ingestion of contaminated water and aquatic organisms, (1E-05, 1E-06, 1E-07 cancer risk), 0.02 µg/L, 0.002 µg/L, and 0.0002 µg/L.
  - Based on the ingestion of contaminated water only, (1E-05, 1E-06, 1E-07 cancer risk), 0.25 µg/L, 0.025 µg/L, and 0.0025 µg/L.
- **Aquatic Life**
  - Freshwater species
    Acute toxicity: Trivalent As: 0.36 mg/L (maximum, 1-hr average)
    Chronic toxicity: Trivalent As: 0.19 mg/L (24-hr, 4-day average)
  - Saltwater species
    Acute toxicity: Trivalent As: 0.069 mg/L (maximum, 1-hr average)
    Pentavalent As: the lowest effect level at 2.3 mg/L.
  - Chronic toxicity: Trivalent As: 0.036 mg/L (24-hr, 4-day average)

REFERENCE DOSES: (4008)

- Inhalation: ND
- Oral: ND

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- **Federal Programs**

Clean Water Act (CWA)
The following arsenic compounds have been designated as hazardous substances and have a reportable quantity (RQ) limit of 2270 kg (5000 lbs): arsenic disulfide, arsenic pentoxide, arsenic trichloride, arsenic trioxide, arsenic trisulfide, and lead arsenate. The following arsenic compounds are also designated as hazardous substances and have an RQ limit of 454 kg (1000 lbs): calcium arsenate, calcium arsenite, potassium arsenate, potassium arsenite, sodium arsenate, and sodium arsenite. Finally, cupric acetoarsenite is designated a hazardous substance with an RQ limit of 0.454 kg (1 lb) (7015, 7016). Arsenic and arsenic compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and to effluent standards and guidelines (7017, 7018). Effluent limitations specific to arsenic have been set in the following point source categories: inorganic chemicals manufacturing (7019), nonferrous metals manufacturing (7020), steam electric power generating (7021), timber products manufacturing (7022), ore mining and dressing (7023), and electrical and electronic components (7024). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)
Arsenic is on the list of 83 contaminants required to be regulated under the SDWA Amendments of 1986 (7050). Under the National Interim Primary Drinking Water Regulations, the maximum contaminant level (MCL) is set at 0.05 mg/L for arsenic in drinking water. This applies to community water systems (7051). In states with an approved Underground Injection Control program, a permit is required for the injection of arsenic-containing wastes designated as hazardous under RCRA (7054).

Resource Conservation and Recovery Act (RCRA)
The following arsenic compounds are listed as acute hazardous wastes and hazardous waste constituents under RCRA: arsenic acid (#P010), arsenic pentoxide (#P011), arsenic trioxide (#P012), diethylarsine (#P038), and dichlorophenylarsine (#P036) (7078, 7079). Dimethylarsinic acid (#U136) is listed as a toxic hazardous waste (7078). Waste streams from the

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

following industries contain arsenic and are listed as specific sources of hazardous wastes: production of the pesticides MSMA and cacodylic acid (#K031), coking operations (#K060), wastewater treatment sludges and distillation tar residues from the production of veterinary pharmaceuticals from arsenic compounds (#K084, #K101), and residue from the use of activated carbon for decolorization in the production of arsenic-derived veterinary pharmaceuticals (#K102) (7076, 7077). Solid wastes containing arsenic are listed as hazardous, in that they exhibit the characteristic defined as EP toxicity, when the TCLP extract concentration of arsenic is equal to or greater than 5.0 mg/L (7074). Arsenic is subject to land disposal restrictions when its concentration as a hazardous constituent exceeds designated levels. Effective August 8, 1988, arsenic-containing waste streams from coking operations (#K060) are prohibited from land disposal unless respective treatment standards or the statutory no migration standards are met. Certain variances exist until May, 1990 for the other arsenic compounds and waste streams listed above as hazardous for which treatment standards have not yet been promulgated. Site-specific variances can be obtained for soil and debris contaminated with hazardous waste (7084). Effective August 8, 1990, liquid wastes containing arsenic at concentrations greater than or equal to 500 mg/L or having a pH greater than 2.0 are prohibited from underground injection (7083). For groundwater protection, the maximum concentration of arsenic-containing hazardous waste allowed in groundwater is 0.05 mg/L (7080). Arsenic 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 (7082). Used oil that is burned for energy recovery may not contain greater than 5 ppm arsenic (7067).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

Arsenic compounds designated as hazardous substances under CERCLA, with a reportable quantity (RQ) limit of 0.454 kg (1 lb) include: arsenic, arsenic acid, arsenic disulfide, arsenic trioxide, arsenic pentoxide, arsenic trichloride, arsenic trisulfide, diethylarsine, dimethylarsinic acid, dichlorophenylarsine, calcium arsenate, calcium arsenite, cupric acetoarsenite, lead arsenate, potassium arsenate, potassium arsenite, sodium arsenate, and sodium arsenite. Reportable quantities have also been issued for RCRA hazardous waste streams containing arsenic, but these depend on the concentration of the chemical in the waste stream (7064). Arsenic compounds designated as extremely hazardous substances under SARA Title III Section 302 include: arsenic pentoxide, arsenous oxide, arsenous trichloride, arsine, calcium arsenate, potassium arsenite, sodium arsenate,

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

and sodium arsenite. Under Sections 311 and 312, any facility at which these compounds are present in an amount greater than or equal to 500 pounds or in excess of their threshold planning quantities, whichever is lower, must notify state and local emergency planning officials. The threshold planning quantities for these arsenic compounds are: 100 pounds for arsenic pentoxide, arsenous oxide, and arsine; 500 pounds for arsenous trichloride, calcium arsenate, potassium arsenite, and sodium arsenite; and1000 pounds for sodium arsenate. If any of these arsenic compounds are released from a facility in excess of their Reportable Quantities (RQs), local emergency planning officials must be notified (7060). Under SARA Title III Section 313, manufacturers, processors, importers, and users of arsenic compounds must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

Toxic Substances Control Act (TSCA)
Manufacturers, processors, or importers who possess health and safety studies on diethylarsine or phenylarsonous dichloride must submit them to EPA (7045).

Federal Insecticide, Fungicide, and Rodenticide Act (TSCA)
Pesticide registration standards for arsenic acid and chromated arsenicals have been issued by EPA (7004). The following arsenic compounds have tolerances established, under 40CFR180, when they are used as pesticide chemicals in or on raw agricultural commodities: calcium arsenate, copper arsenate, lead arsenate, orthoarsenic acid, and sodium arsenite (7005).

Occupational Safety and Health Act (OSHA)
Employee exposure to organic arsenic shall not exceed an 8-hour time-weighted average (TWA) of 0.5 mg/m^3. Employee exposure to arsine shall not exceed an 8-hour time-weighted average (TWA) of 0.05 ppm or 0.2 mg/m^3 (7000). Employee exposure to inorganic arsenic shall not exceed an 8-hour time-weighted average (TWA) of 10 $\mu g/m^3$. Respirator use is required where employee exposure exceeds this permissible exposure limit. 29CFR1910.1018 lists extensive reporting, record keeping, compliance, training, and protective clothing/ work practice requirements for inorganic arsenic (7001). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate, certain hazardous waste treatment, storage,

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

Clean Air Act (CAA)
Inorganic arsenic has been designated a hazardous air pollutant under Section 112 of the Clean Air Act (7011). Detailed national emission standards for inorganic arsenic emissions, including emission limits and monitoring, reporting, and record keeping requirements, exist at 40CFR61.160-165 for glass manufacturing plants, at 40CFR61.170-177 for primary copper smelters, and at 40CFR61.180-186 for arsenic trioxide and metallic arsenic production facilities (7012, 7013, 7014).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated the following arsenic compounds as hazardous materials, subject to requirements for packaging, labeling and transportation: arsenic, arsenic acid, arsenic disulfide, arsenic pentoxide, arsenic trichloride, arsenic trioxide, arsenic trisulfide, diethylarsine, calcium arsenate, calcium arsenite, cupric acetoarsenite, dichlorophenylarsine, hydroxydimethylarsine oxide, lead arsenate, potassium arsenate, potassium arsenite, sodium arsenate, and sodium arsenite. All these compounds have a reportable quantity (RQ) limit of 0.454 kg (1 lb) (7010).

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of oils or 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 (7009).

Food, Drug, and Cosmetic Act (FDCA)
The level for arsenic in bottled drinking water is 0.05 mg/L. This level is identical to the maximum contaminant level (MCL) given under the Safe Drinking Water Act (7070).

- **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. The following states have promulgated additional or more stringent criteria:

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

DISTRICT OF COLUMBIA
The District of Columbia has set an aquatic life criterion of 0.09 mg/L for total recoverable arsenic in class C surface waters, and a human health criterion of 0.000002 mg/L for total recoverable arsenic in class D (public water supply) surface waters (7121).

Proposed Regulations

- **Federal Programs**

  Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
  EPA has proposed that arsine, listed as an extremely hazardous substance under SARA, be listed as a CERCLA hazardous substance, with a reportable quantity (RQ) of 0.454 kg (1 lb). Final action on this rule is expected by September, 1990 (7065,7066).

- **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 officer is advised. Changes are projected for 1990-91 (7058).

  MINNESOTA
  Minnesota has proposed a water quality criterion of 0.01 mg/L for class I surface waters (IA, IB, and IC) (7128).

  MISSISSIPPI
  Mississippi has proposed a water quality criterion of 0.0175 mg/L for trivalent arsenic in surface waters classed for public water supply (7122).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

EEC Directives

Directive on Drinking Water (7086)
The mandatory values for total arsenic in surface water treatment categories A1, A2 and A3 used or intended for abstraction if drinking water are 0.05 mg/L and 0.01 respectively. Guideline values for categories A1 and A3 are 0.01 mg/L and 0.05 mg/L, respectively. No guideline value is given for treatment category A2.

Directive on Bathing Water Quality (7087)
No mandatory value or guideline values are given for arsenic. When inspection of the bathing area shows that concentrations of arsenic may be present or that the quality of the water has deteriorated, concentrations should be checked by competent authorities.

Directive on Discharge of Dangerous Substances (7088)
Arsenic 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 the substances into ground water.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for arsenic specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of arsenic in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
No guide level is given for arsenic.

Directive on Toxic and Dangerous Wastes (7093)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including arsenic and arsenic compounds shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such wastes, and of the methods and sites used for disposing of such waste.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive on Drinking Water (7086)
The mandatory values for total arsenic in surface water treatment categories A1, A2 and A3 used or intended for abstraction if drinking water are 0.05 mg/L and 0.01 respectively. Guideline values for categories A1 and A3 are 0.01 mg/L and 0.05 mg/L, respectively. No guideline value is given for treatment category A2.

Directive on Bathing Water Quality (7087)
No mandatory value or guideline values are given for arsenic. When inspection of the bathing area shows that concentrations of arsenic may be present or that the quality of the water has deteriorated, concentrations should be checked by competent authorities.

Directive on Discharge of Dangerous Substances (7088)
Arsenic 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 the substances into ground water.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for arsenic specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of arsenic in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
No guide level is given for arsenic.

Directive on Toxic and Dangerous Wastes (7093)
Any installation, establishment, or undertaking which produces, holds and/or disposes of certain toxic and dangerous wastes including arsenic and arsenic compounds shall keep a record of the quantity, nature, physical and chemical characteristics and origin of such wastes, and of the methods and sites used for disposing of such waste.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Arsenic is classified as a toxic substance and is subject to packaging and labeling regulations. Arsenic may contain a stabilizer. If the stabilizer changes the dangerous properties of this substance, substance should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive on the Combating of Air Pollution From Industrial Plants (7104)
Arsenic and arsenic compounds are considered heavy metals and are classified as polluting substances in Annex II of this directive. This directive requires member states to ensure that the types of industrial plans listed in Annex I receive authorization before operation or substantial alteration. Industrial plants which produce or use cadmium or cadmium compounds for its operation must require prior authorization by the competent authorities. An authorization may be issued only when competent authority is satisfied that: (1) all appropriate preventive measures against air pollution have been taken; (2) the use of the plant should not cause significant air pollution, particularly from the emission of substances in Annex II; and all air quality limit values applicable taken into account.

Directive on Major Accident Hazards of Certain Industrial Activities (7100)
Arsenic pentoxide, arsenic trioxide and arsenic hydride manufacturers are required to notify competent authorities if it is stored or processed in quantities in excess of 599 kg for arsenic pentoxide; 100 kg for arsenic trioxide and 10 kg for arsenic hydride, respectively. If a major accident occurs, authorities must be provided with the circumstances of the accident, substances involved, emergency measures taken, and the data available for assessing the effects on man and the environment.

EEC Directives - Proposed

Proposal for a Council Directive on the Dumping of Waste at the Sea (7099)
EEC has proposed that dumping of arsenic and arsenic compounds at the sea shall be not be prohibited, without, in each case, prior issue of a special permit by the competent authorities.

EEC Directives - Decisions

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7105)
The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials must be eliminated; Part II substances, includes arsenic and its compounds which seem less noxious or are more readily rendered harmless by natural processes. Discharges must be subject to approval by representatives of the contracting party.

75.1 MAJOR USES

Arsenic compounds are important industrial and agricultural chemicals. Arsenic trioxide is used primarily in the manufacture of pressed and blown glass and in the synthesis of other commercially useful arsenic compounds. Monosodium methane arsenate and disodium methane arsenate are used as herbicides, and cacodylic acid (hydroxydimethylarsine oxide) has been used as a herbicide and defoliant. Chromated copper arsenate, ammoniacal copper arsenate, and fluor chrome arsenate phenol have been used as wood preservatives. Arsenic acid has been used as an agricultural desiccant. Sodium arsenite, lead arsenate, sodium arsenide, and calcium arsenate have been used as pesticides, but such use has declined in recent years. Arsenic compounds are also important in the electronics industry (particularly gallium arsenide and its alloys), as feed additives for poultry, as corrosion inhibitors and catalysts, and in the manufacture of pharmaceuticals. Chlorinated organic arsenic compounds such as mustard gas have been used as chemical weapons. As of 1983, total annual U.S. industrial and agricultural demand for arsenic was about 13,600 metric tons (4004).

75.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

Arsenic is released into the environment from both natural and anthropogenic sources. The most important natural sources include volcanic activity, weathering of the earth's crust, and releases from the terrestrial biosphere (4024; 4017). Major anthropogenic sources of arsenic include fossil fuel combustion, agricultural burning, waste incineration, mining and smelter operations, chemical manufacturing industries, and the use of pesticides and wood preservatives. Total atmospheric arsenic emissions from both natural and anthropogenic sources have been estimated to be 73,000 tons per year (4017).

Arsenic occurs primarily in three oxidation or valence states, -3, +3, and +5. The predominant form is pentavalent (+5) arsenic as exemplified by compounds such as arsenic acid (H_3AsO_4), arsenic pentoxide (As_2O_5), calcium arsenate ($Ca_3(AsO_4)_2$), and sodium arsenate (Na_2HAsO_4). The +3 form occurs in such compounds as arsenic trioxide (As_2O_3), arsenic trisulfide (As_2S_3), arsenic trichloride ($AsCl_3$), sodium arsenite ($NaAsO_2$), and potassium arsenite ($AsH_3O_3.xK$). The -3 valence state occurs in arsine (AsH_3).

In the environment arsenic cycles through different physicochemical forms as a result of various abiotic and biotic processes such as oxidation-reduction reactions, methylation-demethylation, and adsorption and precipitation (4025). Under aerobic conditions, oxidized species are favored. Under anaerobic conditions, reduced species predominate. The most common mobile forms of arsenic are complex anions AsO_2^-, AsO_4^{3-}, $HAsO_4^{2-}$, $H_2AsO_3^-$ (4018). In biological systems, both oxidation and reduction reactions may occur. In some microorganisms, inorganic arsenic is alkylated and reduced to volatile alkylarsine compounds which may then be released to the environment where they can be reoxidized. Methylation can occur under either aerobic or anaerobic conditions. Other microorganisms may be responsible for oxidation reactions and demethylation. In addition, some marine organisms, including algae,

invertebrates and fish, synthesize highly complex organoarsenic compounds. Adsorption and coprecipitation onto particulate matter and coprecipitation with metal-ion complexes are the major environmental transport processes operating in water and soils.

Because of the various physicochemical and biological processes which cycle arsenic through the environment, arsenic compounds are found in all environmental media and are also present in most species of plants and animals. In biological systems, arsenic usually occurs in organic compounds of relatively low toxicity. Background arsenic levels in humans average 0.3 ppm, with the highest levels occurring in the hair and nails (4006).

75.2.1 Transport in Soil/Ground-water Systems

75.2.1.1 Overview

Arsenic occurs in soils as a result of natural and man-made processes. Natural background levels of arsenic in soils range from 1 to 5 ppm, but may be as high as 40 ppm (4007). Anthropogenic activities, such as disposal of waste materials from mining operations, combustion of fossil fuels, smelting of ores, and application and disposal of arsenic-based pesticides may considerably enhance soil concentrations of arsenic in specific areas. Soil concentrations greater than 10,000 ppm have been reported near smelters, and concentrations greater than 1,000 ppm have been reported in areas where inorganic arsenic pesticides have been used (4007).

Although soils are generally considered a sink for arsenic, substantial amounts of arsenic can be lost to the atmosphere through biotransformation and volatilization. A small amount may also be lost through downward migration and transport to groundwaters.

75.2.1.2 Sorption on Soils

Inorganic arsenic is adsorbed strongly to soils, particularly those rich in hydrous iron and aluminum oxides (4007, 4026). Adsorption is also affected by soil pH, texture, organic carbon, and time of reaction (4210). Arsenic can also form insoluble precipitates with calcium, sulfur, aluminum, iron and barium, although these reactions are generally slow (4210). Heavy soils such as clays with a high surface area and substantial hydrous oxide content retain more arsenic than light sandy soils. Therefore, arsenic will be more mobile in sandy soils, particularly at higher pH levels (4025).

In tests with Na_2HAsO_4 and micaceous mineral colloids (muscovite and biotite), Huang (4212) measured adsorption levels of 408 and 432 µg/g. In both cases adsorption levels increased when the particle size was decreased from 2-5 µm to <0.08 µm.

The mobility of trivalent (As^{+3}) and pentavalent (As^{+5}) arsenic through sand columns was studied by Gulens et al. (4211). Elution water of different redox potentials was used in the tests. In an oxidizing environment (pH 5.7), As^{+3} was eluted 5 to 6 times faster and in greater quantities than As^{+5}. Under neutral oxidizing conditions

(pH 6.9), elution of both species was rapid, but recovery was low (i.e., 50% for As^{+3} and 5% for As^{+5}). Under reducing conditions at pH 8.3, elution of both species was rapid and recovery was very high (≥75%).

Studies on the adsorption of As^{+3} and As^{+5} on amorphous $Fe(OH)_3$ at different pH levels have shown that the adsorption of As^{+3} is not affected by pH, while adsorption of As^{+5} decreases as pH is increased (4210, 4213).

Organic arsenic compounds can also be adsorbed onto clay soils and form complexes with hydrous oxides, however, these complexes are generally more water soluble than the inorganic arsenic complexes. Adsorption onto clay soils varies with the type of mineral present and the particle size. Kaolinite removed more disodium methanearsonate from solution than did vermiculite, and smaller size particles of Augusta silt loam removed larger percentages of methanearsonic acid from solution than larger particles (4026). No leaching of disodium methanearsonate occurred in Decatur clay loam, but 52% was recovered from Norfolk loamy sand (4026).

Arsenic competes with phosphates for soil adsorption sites. Consequently, the application of phosphates to arsenic-containing soil will result in the release of soluble arsenic, and thus may allow for the downward transport of the arsenic into groundwaters (4005). In landfill leachate experiments, arsenic ($H_2AsO_2^{-1}$) was found to relatively immobile; less mobile than zinc or cadmium in acid soils and less mobile than chromium in neutral to alkaline soils (4005).

75.2.1.3 Volatilization from Soils

Arsenic present in or applied to soils can be lost through the volatilization of alkylarsine compounds produced through microbial activity. Dimethylarsine and trimethylarsine are two of the more common akylarsines released from soils. Such alkylarsines are not stable and would be subject to oxidation and recycling to the soil environment.

Woolson (4027) reviewed several field and laboratory studies to determine rates of transformation and loss of arsenic from soils. Daily loss rates averaged 0.030% for soils treated with arsenite, 0.032% for soils treated with methanearsonic acid, and 0.034% for soils treated with cacodylic acid. Woolson (4027) calculated a soil half-life of 6.0 yr for arsenite, 5.6 yr for methanearsonic acid, and 5.2 yr for cacodylic acid. The NRC of Canada (1978) reported soil half-lives ranging from 6.5 yr for arsenic trioxide to about 16 yr for lead arsenate ($Pb_3(AsO_4)_2$).

In a review of earlier studies, Sandberg and Allen (4028) reported that total arsenic losses in an agro-ecosystem could be as high as 17-35%/year (equivalent to 0.046-0.096%/day), but this estimation included losses due to leaching, wind-borne dust, runoff, and crop removal, as well as losses through volatilization.

75.2.2 Transformation Processes in Soil/Ground-water Systems

Arsenic can exist in soils in several chemical forms depending on oxygen levels, reducing conditions, and microbial activity (4005). Two competing reactions are involved; oxidation-reduction, and methylation-demethylation (4007). Photodecomposition is not likely to be a transformation pathway for either inorganic or organic arsenic (4014).

Pentavalent arsenates and trivalent arsenites are expected to be the major forms of arsenic in the soil environment. Arsenates are the predominant forms under aerobic conditions and arsenites occur under reduced conditions. Oxidation-reduction reactions of arsenic in soils are controlled by pH and iron content which affects the redox potential (Eh) of the soil (4025). High iron levels favor high Eh values which lead to the formation of arsenates. At Eh levels of less than 300 mV, such as may occur during flooding, the arsenate will be reduced back to arsenite. Under typical soil conditions, most arsenic compounds, inorganic and organic, are likely to be converted to arsenates (4007). In contrast, the formation of arsenites might be favored under anaerobic conditions such as those which might occur at landfills and waste disposal sites.

In soil water arsenates react in varying degrees with ions, such as Fe, Al, Ca, Mg, Mn, and Pb, to form relatively insoluble products. The extent of the reactions depends on the concentrations, solubility products and soil pH (4007). According to Woolson (4007), arsenic that has been in the soil for a long time, may form a non-extractable hydroxy apatite mineral.

Soil microorganisms are responsible for biotransformation reactions involving arsenic compounds. Studies have demonstrated increased decomposition of organic arsenic compounds relative to soil organic matter, indicating adaptation of soil microbial populations to metabolize the methyl carbon of methanearsonic acid (4026). Organoarsenic compounds such as the monosodium and disodium salts of methanearsonic acid can be metabolized to arsenates (4007). Conversely, inorganic arsenic compounds can be methylated to methanearsonate and cacodylic acid, and then reduced to alkylarsines. Oxidation reactions are favored under high temperature, low soil saturation conditions. Methylation and reduction are favored under low temperature, high soil saturation conditions (4007).

Under anaerobic conditions, microorganisms can convert arsenates to dimethylarsine [$(CH_3)_2AsH$] via the formation of arsenites, methanearsonic acid [$CH_2AsO(OH)_2$], and dimethylarsinic acid (cacodylic acid). Arsine and alkylarsines may be released to the air, oxidized to precursors such as dimethylarsinic acid, or demethylated and returned to the soil as arsenates. Dimethylarsinic acid is a very common form of arsenic in the environment and is resistant to oxidation (4005).

Arsenic that enters groundwater is generally present as arsenate or arsenite (4031). The dominant aqueous species under varying pH and redox conditions at equilibrium are shown in Figure 75-1. According to Welch et al. (4031), the major processes determining arsenic concentrations in groundwater include: mineral precipita-

tion/dissolution, adsorption/deadsorption, chemical transformations, ion exchange, and biological activity. Factors such as pH, Eh, solution composition, competing and complexing ions and reaction kinetics, and aquifer mineralogy and hydraulics, affect chemical speciation and concentration. In comparison with surface waters, deep groundwaters generally have higher pH levels which reduce the solubility of iron and thereby lower Eh values. These conditions favor the formation of reduced, more soluble, and more toxic arsenic compounds such as arsenites (4025). In contrast, in shallow groundwaters lower pH values and higher iron content favor the formation of the less soluble arsenates, and these are more likely to precipitate out or become adsorbed onto soil particles. Several studies have shown that arsenic levels are generally elevated in slightly alkaline nonthermal groundwaters.

Because of the underlying geologic formations, the deep groundwaters of the western United States have relatively high levels of arsenic. In one survey, arsenic concentrations in most locations were greater then 10 µg/L. Concentrations as high 1,000 µg/L occurred in areas affected by agricultural irrigation and levels up to 48,000 µg/L were found in mining areas (4031).

75.2.3 Primary Routes of Exposure from Soil/Groundwater Systems

The low mobility of arsenic in soils generally limits transport to groundwater and thereby reduces the potential for exposure through the use of groundwater as a source of drinking water. Under acidic and oxidizing conditions, arsenic compounds migrate to subsurface soil horizons where they may become adsorbed to iron hydrous oxides (4005). In monitoring studies conducted at 85 wells and springs near industrial waste disposal sites in 13 states, arsenic was found in only four samples (4005). The reported concentrations were 30 to 5,800 µg/L. These results suggest that the potential for arsenic to become a groundwater contaminant as a result of leaching from waste disposal sites may exist only under very specific conditions favoring the formation of water soluble arsenic species with limited adsorption to soil particulate matter. There are some locations, however, where groundwaters have a high arsenic content as a result of leaching from naturally occurring arsenic-rich geologic formations. High arsenic levels have been reported for well water samples from California (1,400 ppb), Oregon (2,150 ppb)), and Alaska (10,000 ppb) (4032, 4033, 4034). In some underdeveloped countries the use of such groundwater as a source of drinking water has been implicated in cases of mass arsenic poisonings.

Arsenic can be taken up by terrestrial plants, however, concentrations are generally only slightly higher than those for plants grown on noncontaminated soils. Uptake by plants is affected to a great deal by bioavailability, which in turn is controlled by the type of soil on which the plants are grown. Plants grown on sands and sandy loams have higher arsenic residues at equivalent soil arsenic levels than those grown on silty and clay soils. In the latter case, the arsenic is more tightly bound to

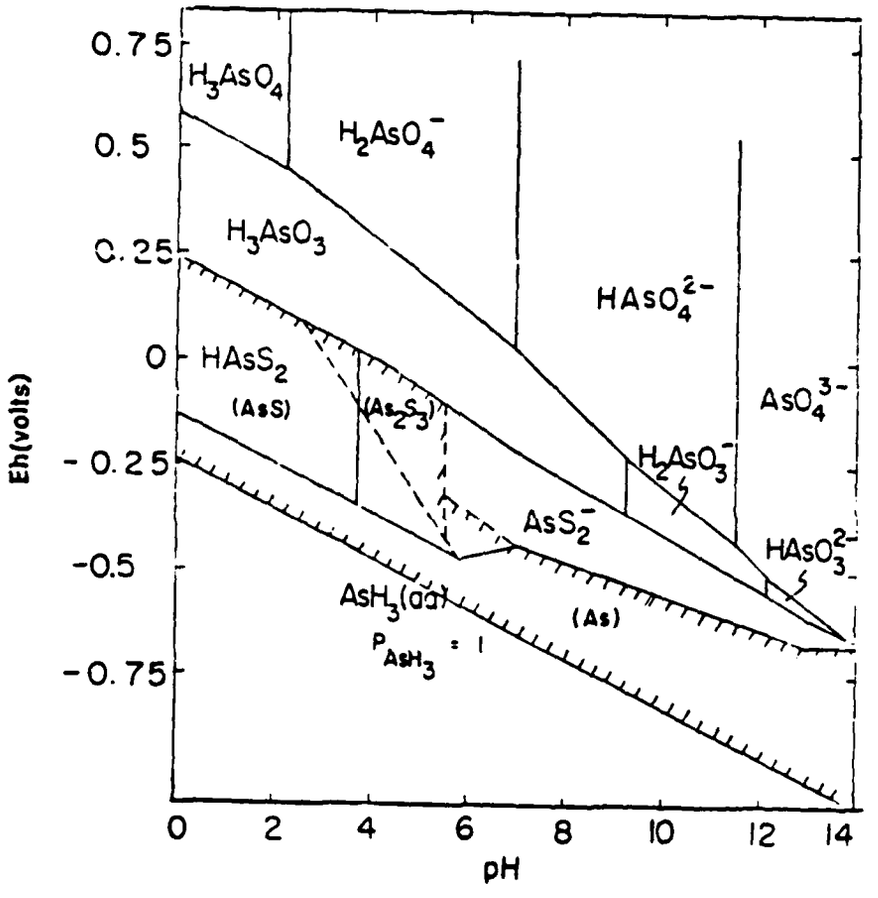


Figure 75.1. The Eh-Ph diagram for As at 25° C and one atmosphere with total arsenic 10^{-5} mol l^{-1}. Solid species are enclosed in parentheses in cross-hatched area.

Source: Ferguson and Gavis 1972 (4208)

the soil particles and thus unavailable to the plants. Thoresby and Thornton (4035) reported that arsenic levels in pasture grass were 0.26 to 9.6 ppm even though the soil arsenic levels were 28 to 1200 ppm. However, some studies have shown that soil As concentrations as low as 15-50 ppm (dry weight) can be phytotoxic (4018).

Field studies indicate that animals living in areas contaminated with arsenic may accumulate the metal. Small mammals living on arsenic-contaminated orchard soils had higher body burdens of arsenic (1.2-28 μg) than animals living in uncontaminated areas (0.0-0.8 μg)(4005).

Because of the ubiquitous distribution of arsenic in the environment, it is not surprising that arsenic is present in most food products, although usually at very low levels. Studies conducted in the 1970s demonstrated that arsenic levels ranged from 0 to 0.16 ppm in infant foods, 0 to 0.43 ppm in toddler foods, and 0 to 0.83 ppm in adult foods. In reviewing the available data on the occurrence of arsenic in foods, Arnold (4006) reported that arsenic levels of 0.007 to 0.26 mg/kg had been found in vegetables and vegetable products, 0.003 to 0.22 mg/kg in grains and cereals, 0.003 to 0.025 mg/kg in dairy products, 0.001 to 0.212 mg/kg in meats, and 0.01 to 0.5 mg/kg in eggs.

The presence of arsenic in well water and food products indicates that exposure to arsenic through ingestion occurs regularly. It has been estimated that the daily intake of arsenic through ingestion ranges from 30 to 370 μg/day and averages about 120 μg/day (4036). The rate of absorption through the gastrointestinal tract has been reported to range from 80 to 100% (4036). EPA estimated that the average daily intake of arsenic in food would be 50 μg of which 40 μg would be absorbed (4020).

75.2.4 Other Sources of Human Exposure

Arsenic present in the atmosphere occurs primarily in association with particulate matter. Arsenic trioxide is the major arsenic compound released from combustion sources and smelter operations. Gaseous species may also be present in the atmosphere, particularly in areas where total arsenic concentrations are high. The gaseous species may include As_4O_6, as well as arsine and alkylarsines. Concentrations of arsenic in the atmosphere are reported to average 0.002 $\mu g/m^3$ in rural areas, 0.02 $\mu g/m^3$ in urban areas, and 0.2 $\mu g/m^3$ in cities containing smelters (4007). Air concentrations adjacent to smelters may even be an order of magnitude higher. The residence time for arsenic in the troposphere is about 9 days (4024). These data indicate that inhalation of airborne arsenic may be a significant source of exposure particularly near point sources. Evidence of arsenic exposure has been found in adults and children living near smelters (4037, 4038, 4039). Estimates of the daily intake of arsenic through inhalation range from 0.1 to 4 μg/day with an average value of 0.4 μg/day (4036). The rate of absorption of arsenic through the lungs has been estimated to range from 20 to 40% (4036). Using a national average air concentration of 0.006 μg As/m^3, EPA estimated that the daily intake of arsenic through inhalation would be 0.12 μg of which 0.036 μg would be absorbed (4020).

Arsenic is removed from the atmosphere through wet and dry deposition. After deposition into surface waters, arsenic trioxide forms $As(OH)_3$ and other arsenites.

The chemical forms and concentrations of arsenic species present in aquatic environments vary with pH, dissolved oxygen, oxidation-reduction potential, and the type of minerals present. Most surface waters have Eh and pH levels that favor the formation of arsenates (4025). In oxygenated water with a pH of 8.16, thermodynamic calculations indicate that the ratio of arsenate to arsenite would be 10^{26}:1 (4040). Arsenites may be present in natural waters as a result of incomplete oxidation, locally high Eh levels or biological reduction of arsenates (4025).

Arsenic present in surface waters is subject to attenuation processes involving the formation of insoluble precipitates and/or adsorption onto stream and lake sediments (4025). Precipitation reactions can occur with calcium, sulfur, iron, aluminum, and barium. Conversely, arsenic may also bond with dissolved, low molecular weight organics to form complexes less susceptible to adsorption and precipitation reactions (4029, 4041). Coprecipitation and sorption of arsenic with hydrous oxides of iron is probably the most important removal mechanism (4014). In one field study, a 35% reduction in arsenic occurred over a 565-m reach of test stream following injection of 1 mmol of arsenic (as Na_2HAsO_4) for each liter per minute of flow rate (4042).

Arsenic compounds are generally not subject to photolysis in aquatic environments (4014). However, in the photic zone inorganic arsenic is subject to methylation by microorganisms, phytoplankton and higher organisms (4025). The methylated arsenic compounds are available for oxidation-reduction reactions and adsorption-precipitation. Methylated arsine compounds such as trimethylarsine may be formed in aquatic environments under both aerobic and anaerobic conditions (4219). These compounds are quite volatile and can be lost to the atmosphere where human exposure can occur, or they can be oxidized to more soluble products (4014).

The average concentration of arsenic in surface waters is 1.5-2.0 µg/L (4043). In a 1970 survey, 79% of 727 water samples had As levels of less than 10 µg/L; 21% had levels greater than 10 µg/L, and 2% had levels greater than 50 µg/L (4044). However, concentrations as high as 1000-5000 µg/L or more have been reported for thermal or mineral springs and for water bodies containing high dissolved solids, and/or receiving industrial waste or sewage inputs (4043).

The arsenic content of drinking water, particular that obtained from surface water supplies, is generally low. Of 969 community water supplies studied in 1969, fewer than 1% had arsenic levels greater than 30 µg/L (4045). Of 2595 tap water samples taken, only 0.2% had arsenic levels exceeding 50 µg/L, and the maximum reported concentration was 100 µg/l. Using a national average drinking water concentration of $\leq$ 10 µg As/L, EPA estimated that the average daily intake of arsenic in drinking water would be $\leq$ 20 µg all of which would be absorbed (4020). High arsenic levels occur in drinking water in some locations, particularly in cases where leaching into groundwater supplies occurs from arsenical pyrite geologic layers or where groundwater or surface water supplies are contaminated from mine waste piles or from the use of arsenical pesticides. In such cases the intake through drinking water considerably higher than the national average.

Arsenic has a potential for bioconcentration, particularly at the lower levels of the aquatic food chain (4014). In seawater containing 3 µg As/L, marine algae take up arsenic at rates corresponding to bioconcentration factors (BCF) of 600 to 86,000 (dry weight). Early studies on freshwater algae and weeds indicated BCFs up to 20,000 (4043). In contrast, BCFs for freshwater invertebrates and fish were less than 130. In more recent studies on freshwater invertebrates (stoneflies, snails, and Daphnia), Spehar et al. (4046) found that arsenic levels in tissues were 99 to 219 times greater than the water concentration (up to 1000 µg/L). However, at the higher levels of the aquatic food chain, the BCFs for arsenic are much lower. In tests of 21-28 days duration, freshwater species exhibited BCFs of 17 for arsenic trioxide, 7 for arsenic pentoxide, and 9 for other arsenic compounds (4005). The BCFs for marine fish are generally higher than those for freshwater species; values above 5000 have been reported (4043). Marine crustaceans also accumulate high levels of arsenic and BCFs up to 64,000 have been reported.

The concentration of arsenic in the tissues of marine animals generally falls in the range of 0.1 to 50 mg/kg, but in shrimp and lobster it may be as high as 200 mg/kg (4005). The primary organic arsenic compound in fish and shellfish is arsenobetaine which has a relatively low toxicity (i.e., i.p. doses of 500 mg/kg and oral doses as high as 10 g/kg caused no toxic effects in mice) (4001).

75.2.5 Biological Monitoring

Methods for analyzing for arsenic in biological samples have been summarized by ATSDR (4001). Total arsenic levels in blood and urine have been determined by atomic absorption spectrophotometry following conversion of the arsenic to the gaseous hydride form. The detection limit is 0.5 µg/L. The same method has been used to measure total arsenic levels as low as 5 ppb in adipose tissue. Furnace atomic absorption spectrophotometry and gas-liquid chromatography with electron capture detection have been used to measure arsenic in other mammalian soft tissues. Detection limits are 0.2-0.9 ppm or better.

75.3 HUMAN HEALTH CONSIDERATIONS

In evaluating the potential health effects of arsenic, consideration must be given to the fact that the metal occurs in many different types of inorganic and organic compounds of varying toxicity. With some exceptions, such as the halogenated organo-arsine vesicants, inorganic arsenic compounds are generally more toxic than organic arsenic compounds. Overall, toxicity of inorganic arsenic compounds can be correlated with the valence state of the arsenic. Arsine with a arsenic valence state of -3 is one of the most toxic inorganic arsenic compounds. Trivalent (+3) compounds such as arsenic trioxide (As_2O_3) and arsenites, are much more toxic than pentavalent (+5) compounds such as arsenic pentoxide (As_2O_5) and arsenates. However, the relative toxicity of the trivalent and pentavalent forms may be altered by other factors such as water solubility. Although the more soluble compounds are generally more toxic and more likely to have systemic effects, the less soluble compounds such as

calcium arsenate and lead arsenate may produce localized effects, particularly in the lungs following chronic inhalation exposures.

The physical state of the arsenic compound, the dose and exposure duration, and the route of exposure are other factors that can significantly alter the potential toxicity of arsenic compounds. The available data indicate that uptake of soluble inorganic arsenic in humans is very high through the digestive tract (>93%), particularly when the arsenic is administered in drinking water (4047, 4048). In contrast, rates of absorption following inhalation exposures have been reported to range from 20 to 60% (4049; 4036). Once absorbed, arsenic compounds are subject to metabolic transformation which may also alter their toxicity. In both humans and animals, pentavalent compounds may be reduced to more toxic trivalent compounds, or complexed with organics to form less toxic products. In higher organisms arsenic is excreted relatively rapidly and the potential for bioaccumulation is relatively low.

In contrast to the potential multiplicity of effects and levels of response caused by the many different chemical and physical states of arsenic, concentrations in environmental and biological media are usually measured in terms of total arsenic, or total inorganic arsenic. Consequently, quite different responses might be reported for the same exposure level, or similar responses reported for different exposure levels. Most of the currently available animal and human toxicity data for arsenic deal with oxides of arsenic or various arsenite or arsenate salts. It should be noted that extrapolation of these data to other types of arsenic compounds may not be appropriate.

75.3.1 Animal Studies

75.3.1.1 Carcinogenicity

There is limited evidence that inorganic arsenic is carcinogenic to several animal species; in mice, perinatal treatment with arsenic trioxide resulted in lung adenomas; in hamsters, intratracheal instillation of arsenic trioxide induced low incidences of respiratory tract carcinomas, adenomas, papillomas and adenomatoid lesions; and in rats, a single intratracheal instillation of a pesticide mixture containing calcium arsenate induced a high incidence of lung carcinomas (4050, 4051, 4052, 4053, 4054).

In studies utilizing Syrian hamster cells, DiPaolo and Casto (4056) found that sodium arsenate induced cell transformations. Casto et al. (4057) reported that inorganic arsenic also enhanced virus-induced transformation of Syrian hamster cells.

75.3.1.2 Genotoxicity

Trivalent and pentavalent arsenic have been tested for the potential to induce gene mutations in a number of biological systems. Most studies utilizing bacterial systems have yielded negative results (4058, 4059, 4060). Negative results have also been reported in tests using yeast (4061) and cultured mammalian cells (4060, 4062, 4063, 4064). Inorganic arsenic is therefore considered to be nonmutagenic or only very weakly mutagenic in in vitro assays (4065).

Both trivalent and pentavalent arsenic (arsenite and arsenate) have been shown to cause chromosome aberrations and increased sister chromatid exchanges (SEC) in cultured animal cells in vitro (4064, 4066, 4067, 4068, 4069). Trivalent arsenic is considered to be an order of magnitude more potent in inducing such clastogenic effects (4065). However, clastogenic effects have not been demonstrated in in vivo studies on experimental animals.

Several studies have demonstrated that inorganic water-soluble arsenic salts have the ability to inhibit the repair of DNA damage caused by UV radiation and crosslinking agents (4203-4205). Arsenic-induced skin cancers might be attributed to a systemic effect resulting from the lack of repair of DNA damage induced by UV light (4206).

75.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Various types of inorganic arsenic compounds including sodium arsenate and sodium arsenite have been shown to be fetotoxic and to cause adverse reproductive and teratogenic effects in laboratory animals, particularly when administered parenterally on the 8th day of gestation (4070-4080, 4215). Depending on chemical compound, dose, duration, and day of gestation when tested, arsenic causes reabsorptions, reduced fetal weights, and malformations, including skeletal abnormalities, eye defects, and exencephaly. Teratogenic and fetotoxic effects have been reported following parenteral doses of 10-45 mg/kg/day of sodium arsenate and 5-9 mg/kg/day of sodium arsenite. In contrast, oral doses as high as 120 mg/kg/day of sodium arsenate and 25-45 mg/kg/day of sodium arsenite have been reported to be fetotoxic but not teratogenic.

In a three-generation study conducted on mice, Schroeder and Mitchener (4081) found that an arsenic concentration of 5 ppm in drinking water resulted in an increase in the male to female ratio (0.93 to 1.71) and a significant decrease in litter size. There were no other observable effects on reproduction or development.

Studies on rodents indicate that methylated arsenic compounds may also be teratogenic but at dose levels much higher than those for inorganic arsenic compounds. Oral administration of high doses of dimethylarsinic acid (30-100 mg/kg/day), sodium dimethylarsinate (900-1000 mg/kg) and disodium dmethanearsonate (500-1500 mg/kg) resulted in fetotoxic effects and fetal malformations (4082-4086).

75.3.1.4 Other Toxicologic Effects

75.3.1.4.1 Short-term Toxicologic Effects

The acute toxicity of arsenic to laboratory animals is dependent on the chemical form of the arsenic, the dose, exposure route and duration, and the animal species tested. Median lethal oral doses to rodents for several of the more common inorganic and organic arsenic compounds are summarized in Table 75-1.

Symptoms of acute and subacute exposure to inorganic arsenic include: gastrointestinal disturbances and neurological effects. In studies on adolescent and infant Rhesus monkeys, oral doses of a complex inorganic arsenic compound [$2Na_3(PO_4AsO_4VO_4)NaF{\cdot}18H_2O$], containing the equivalent of 7.5 mg/kg/day of arsenic trioxide, induced toxic effects within 5 days (4089). The affected animals exhibited loss of condition, vomiting, diarrhea, salivation and uncontrolled shaking of the head. Methanearsonates produce gastrointestinal irritation, as well as listlessness and hematuria (4090). High doses may result in stupor, convulsions, paralysis and death (4001).

Studies involving the intratracheal instillation of inorganic arsenic into laboratory animals indicate that arsenic can have direct toxic effects on respiratory tissues. Trivalent arsenic oxide and gallium arsenide were shown to cause pulmonary inflammation and pneumocyte hyperplasia in rats (4091-4093). In hamsters, intratracheal instillation of calcium arsenate caused lung lesions but arsenic trioxide and arsenic trisulfide did not (4094). This difference was attributed to either differences in in vivo solubility, with the more highly soluble arsenic trioxide being cleared faster, or to the higher wetting capacity of the calcium arsenate which allowed more of the compound to reach the alveolar regions where clearance was slower.

75.3.1.4.2 Subchronic and Chronic Toxicity

The response of laboratory animals following subchronic and chronic exposure to arsenic differs from that of humans in that the critical effects appear to be immunosuppression and hepato-renal dysfunction, rather than dematological, neurotoxic, and vascular disorders. Long-term oral toxicity studies in rats have demonstrated a no-adverse-effect level for sodium arsenite at doses up to 1.4 mg As/kg/day for males and 1.6 mg As/kg/day for females and for sodium arsenate at doses up to 2 8 mg As/kg/day for males and 3.25 mg As/kg/day for females (4095). Similar studies on dogs revealed a no-adverse-effect level at 1.1 mg As/kg/day. A drinking water concentration of 5 ppm produced no toxic effects in rats when administered over an entire lifetime (4096).

Immunotoxicity - The immunosuppressive activity of arsenic has been documented in several animal studies. Dose-related effects, as measured by hemagglutination, radial immunodiffusion, and Cunningham plaque assay, were seen in mice exposed to sodium arsenite levels of 0.5 ppm in drinking water (4097). In mice, a significant reduction in the pulmonary immune response (as measured by increases in mortality due to infectious streptococcal challenge (4098, 4099) and decreases in pulmonary bactericidal activity to Klebsiella pneumonia) occurred following exposure to arsenic trioxide (4099). Alveolar macrophage dysfunction was reported to be the main effect of arsenic exposure.

TABLE 75-1
TOXICITY OF ARSENIC COMPOUNDS TO RODENTS

Compound	Oral LD_{50} (mg/kg)	Species	Reference
Arsenic trioxide (gavage)	15	rat	4087
	26-48	mouse	
Arsenic trioxide (diet)	191	rats	4087
Arsenic pentoxide	8	rat	4019
	55	mouse	
Arsenic acid	48	rat	4019
Potassium arsenate	14	rat	4000
Lead arsenate	80	rat	4000
	1000	mouse	4019
Arsenic trisulfide	185	rat	4000
	254	mouse	
Calcium arsenate	298	rat	4000
	794	mouse	
Cacodylic acid	700-830	rat	4083
Sodium cacodylate	600-2600	rat	4083
Methanearsonic acid	1800	rat	4000
Sodium methanearsonate	700	rat	4019
Disodium methanearsonate	1000	rat	4088
	8000	rat	4000
Arsanilic acid	216	rat	4019

Renal and hepatic effects — Studies using laboratory animals have demonstrated renal and hepatotoxic effects following exposure to arsenic (4100). Mild swelling of renal tubular cell mitochondria and decreases in liver-derived serum enzymes (AST and alkaline phosphatase) occurred in rats following 10 weeks of exposure to 50 ppm dietary arsenate (4101). Functional and ultrastructural changes occurred in the kidneys of rats exposed for 6 wk to arsenate in their drinking water at concentrations of 85 and 125 ppm (4102). Liver biosynthesis of heme and ALA synthetase activity were disrupted in mice and rats by arsenic levels of 40 and 85 ppm in their drinking water (4103, 4104). Hepatocyte mitochondrial structure and liver enzyme activity (monoamine oxidase, cytochrome oxidase) and respiratory function were altered in rats and mice exposed to 20-85 ppm sodium arsenate in drinking water (4217, 4218). Bile duct abnormalities have been observed in rats on a diet containing 125 and 250 ppm As as arsenite, 250 and 400 ppm As as arsenate (4095), or 399 ppm as lead arsenate (4105).

Hematotoxicity — Exposure to arsine gas results in severe hematological effects in laboratory animals. In studies on mice, arsine concentrations as low as 2.5 ppm caused significant decreases in red blood cells, hematocrit and hemoglobin, as well as significant increases in white blood cell counts, and mean corpuscular volume of RBC. Erythropoiesis in bone marrow cells was impaired and erythropoiesius of spleen was increased (4216).

Dematological effects — Laboratory animals seem to be less susceptible than humans to arsenic-induced skin abnormalities; however, mild hyperkeratosis has been reported in mice exposed for a lifetime to arsenic oxide in their drinking water at a concentration of 0.01% (4106), and eczema, hyperplasia, and hyperkeratosis were seen in 2-wk-old rats dosed (by stomach intubation) with 2 mg/kg/day or 10 mg/kg/day arsenic trioxide for 40 days (4107).

Neurotoxicity — Chronic exposure to 10 mg/kg/day of arsenic by injection (once per day for 18 months) did not result in any signs of neuropathy in rats (4108).

75.3.2 Human and Epidemiologic Studies

In humans the toxicity of arsenic compounds can be manifested in adverse effects on various organ systems including the skin, lungs, nervous system, vascular system, liver, kidneys, blood and reproductive system. Because of the nature of the studies from which this information was obtained (i.e., accidental poisonings and occupational exposures) quantitative data indicating dose/response levels were rarely available.

75.3.2.1 Short-term Toxicologic Effects

Lethality — Acute arsenic poisoning can result in stupor, convulsions, paralysis, coma and death. Oral doses of 50 to 300 mg may be fatal to adults (4001). Subchronic doses of 3 mg/day were reported to be fatal to infants (4109). The acute lethal dose to humans has been estimated to be about 0.6 mg/kg/day (4001). Physiologically, acutely

toxic doses of arsenic cause vasodilation and increased permeability of the capillaries (4110). If death occurs within 1 or 2 days, it is usually caused by relative hypovolemic shock. If death is delayed from 3 to 14 days, it is caused by dehydration, electrolyte imbalance, and a more gradual drop in blood pressure (4110). In arsine poisonings, acute oliguric renal failure is often the cause of death (4111).

General symptoms of toxicity — The most common immediate symptoms of inorganic arsenic poisoning involve the gastrointestinal system and include nausea, anorexia, vomiting, epigastric and abdominal pain, and diarrhea. Other symptoms that have been reported are: constriction of the throat and difficulty in swallowing, edema of the face, headache, fatigue, upper respiratory distress (cough, sorethroat, and rhinitis), dermatitis, and peripheral neuropathy (4112, 4110). The lowest dose or exposure level producing such effects is not clearly defined. In some individuals short-term oral doses of 20-60 µg/kg/day have been reported to cause symptoms of toxicity, whereas in others, doses as high as 150 µg/kg have been without effect (4001).

Organic arsenic compounds used as herbicides and pesticides (i.e., cacodylic acid, sodium dimethyl arsenate, methanearsonic acid, and sodium and disodium methanearsonates) produce symptoms of acute toxicity similar to those caused by inorganic arsenic, but these are generally not as severe (4088). Nausea, vomiting, diarrhea, abdominal pain, eye irritation, dermatitis, and allergic rash have been reported in agricultural workers exposed to these compounds. Exposure to arsine gas is unique among arsenic compounds in causing fever, tachycardia, tachypnea, and severe hemolytic anemia (4111).

Dematological effects — Acute exposures to arsenic often result in dermatitis, particularly in the palms, soles, and other areas subject to pressure (4110). Skin eruptions may develop into exfoliative dermatitis. In arsine poisonings, the skin developes a bronze jaundice-like hue (4111). Transverse white lines across the nails (Mee's lines) often appear several weeks after exposures to arsenic (4113).

Respiratory system effects — Exposure to high levels of arsenic in the air can result in damage to mucous membranes, laryngitis, and bronchitis (4113). Within a few weeks of exposure nasal septum perforation may occur. Quantitative data on minimum effect levels were not reported.

Neurotoxicity — Very high oral doses of arsenic can affect the central nervous system and produce encephalopathy (4114, 4115, 4116). Children exposed to high levels of arsenic may develop mental retardation, hearing loss, and abnormal electroencephalograms (4109, 4020). Nonlethal acute exposures often lead to polyneuropathy characterized by numbness, tingling, "pins and needles" sensation in the extremities, pain, burning, and tenderness in the limbs (4117, 4110). Loss of proprioception, other sensory functions, and motor functions may occur in some individuals (4117, 4110). Arsenic-induced peripheral neuropathy may be indicated by electromyographic changes. Single exposures to arsenic reportedly resulted in a reduction in motor conduction velocity and abnormalities of sensory nerve action potential (4118, 4119). Other studies have indicated decreased nerve conduction amplitude with little change in nerve

conduction velocity (4120). Peripheral neuropathy may not appear until 1-3 weeks after the initial exposure to arsenic (4112, 4110).

Cardiovascular effects — Acute and subchronic exposure to arsenic may cause electrocardiographic abnormalities including prolongation of the Q-T interval and abnormal T waves (4112, 4121, 4122, 4123). Individuals severely poisoned by arsenic may be subject to ventricular fibrillation and cardiac arrest during anesthesia (4125). The effects of arsenic on the capillaries may result in peripheral circulatory problems resulting in blanching or flushing of the skin.

Hematological effects — Acute exposures to inorganic and organic arsenic can result in hematological abnormalities including anemia and leukocytosis (4126). Clinical characteristics of arsenic toxicity include Coomb's negative hemolytic anemia, sideroblastic anemia, megaloblastic anemia, thrombocytopenia, eosinophilia, and aplastic anemia (4126). Kyle and Pease (4127) examined six patients poisoned with arsenic and found that leukopenia (neutropenia) and anemia was present in all patients and thrombocytopenia was present in three. Anemia and thrombocytopenia have been reported in several cases of acute arsenism in which exposures were high enough to produce symptoms of severe poisoning (4020).

The early use of arsphenamine as an anti-syphilis drug was also associated with hematological findings including anemias and thrombocytopenia (4126).

Clinical features of arsine toxicity include hemolytic anemia with Heinz bodies and leukocytosis (4111). Severe hemolysis, resulting in hemoglobinuria, jaundice, and hemolytical anemia were found in workers occupationally exposed to arsine gas (AsH_3) (4128).

Renal and hepatic effects — Renal and hepatic effects have been observed in a number of clinical cases of severe arsenic poisoning. Oliguria with urine containing blood and albumen and anuria leading to renal sufficiency or renal failure have been reported (4129). Necrosis of the renal tubules is a characteristic feature of acute arsine poisoning (4111). The effects of arsenic on the liver include fatty infiltration and enlargement, cortical necrosis, central necrosis, and cirrhosis (4109, 4130).

75.3.2.2 Chronic Toxicologic Effects

In humans, general symptoms of chronic arsenic poisoning are weakness, general debility and lassitude, loss of appetite and energy, loss of hair, hoarseness of the voice, loss of weight, and mental abnormalities (4025). Specific toxic effects that have been identified in individuals following chronic long-term exposures include tumors, neurological changes, and skin and vascular disorders. Other effects seen in some studies include pulmonary damage, genotoxicity, liver damage, hematological changes, and reproductive abnormalities. Severe anemia is a characteristic feature of chronic exposure to arsine (4111).

Carcinogenicity — Chronic exposure to arsenic has been associated with increased incidences of several types of cancer. Epidemiological studies have revealed a

close correlation between chronic oral exposures resulting from contaminated drinking water and increased incidences of skin cancers including squamous cell carcinomas and multiple basal cell carcinomas. Tseng et al. (4131) studied a Taiwanese population that had been exposed to arsenic in drinking water (average As concentration 0.4-0.6 ppm; maximum level of 1.0 ppm or more), and found that the incidence of skin cancer was 10.6 per 1000, compared to no cases in a control population of 7500 whose drinking water contained less than 0.017 mg As/L. The exposed population also had higher levels of other skin abnormalities such as Blackfoot disease, hyperpigmentation and hyperkeratosis. In a study of residents of a Mexican town exposed to 0.4 mg/L of arsenic in their drinking water, Cebrian et al. (4132) found a 3.6-fold elevation in ulcerative skin lesions considered to be compatible with a diagnosis of epidermoid or basal cell carcinomas (4001). In contrast to the studies of Tseng (4131) and Cebrian (4132), a number of epidemiological studies conducted in the U.S. have found no correlation between increased risk of skin cancer and arsenic levels of 0.1 to 0.2 ppm in drinking water (4032, 4034, 4133, 4134).

Chronic oral exposure to arsenic has also been linked to various types of internal cancers (4135). Sommers and McManus (4136) reported that 10 of 27 arsenic-exposed patients with skin cancer also had internal cancers; Reyman et al. (4137) reported increased incidences of internal cancers in patients with arsenical keratoses, and Dobson et al. (4138) reported that palmar keratoses were common in patients with internal cancers. Hepatic angiosarcomas reportedly occur with a high frequency in individuals exposed to Fowler's solution or to arsenical pesticides (4001). Higher standardized mortality ratios for several types of cancers including bladder and liver cancer were found in populations exposed to 0.35-1.14 mg/L of arsenic in their drinking water (4139, 4140). High rates of respiratory and gastrointestinal tract cancer have been reported for a population in Argentina whose drinking water contained elevated levels of arsenic.

Inhalation exposure to arsenic has been found to be associated with an elevated risk of lung cancer, particularly in occupational exposure situations (4142-4150, 4158, 4207). Exposure of smelter workers to arsenic trioxide has been associated with elevated rates of lung cancer (4016). A dose- and duration-dependent increased frequency of respiratory tract cancers was found in copper smelter workers exposed to air-borne arsenic levels averaging 0.4, 7, and 62 mg/m^3, for low, medium, and high exposure groups (4145, 4151-4157). The standardized mortality ratios (SMR) ranged from 111 to 832. In another study, lung cancer mortality rates were correlated with cumulative arsenic exposure as measured by urinary arsenic excretion values (4158, 4159). Cumulative arsenic exposure levels of 10 mg/m^3 were linked to a SMR greater than 200 (4160). Similarly, in a study of Swedish smelter workers, a clear positive dose-response relationship was found between cumulative arsenic exposure and lung cancer mortality (4161). The overall SMR was reported to be 372.

An increased risk of lung cancer may also occur in non-occupationally exposed populations living in areas with high atmospheric levels of arsenic resulting from industrial emissions. Higher lung cancer rates have been reported in residents living near smelters (4162, 4163) and near a arsenic pesticide manufacturing plant (4164).

Dermatological effects — Skin abnormalities, particularly hyperpigmentation and hyperkeratosis have been observed in populations exposed to arsenic (4131, 4132, 4165, 4166, 4167, 4150). Individuals suffering from chronic exposures may also develop white transverse lines, 1-2 mm in width, on the nails (4025). Skin abnormalities have been seen in patients consuming Fowler's solution (containing potassium arsenite) as a treatment for asthma, and in populations whose drinking water was contaminated with arsenic. Similar effects were also reported in several early studies of workers occupationally exposed to arsenic (4168, 4169). Tseng et al. (4131 reported that in a Taiwanese population exposed to arsenic in drinking water (average concentration 0.4-0.6 ppm, but up to 1.0 ppm or more), there was a high incidence of skin disorders including Blackfoot disease (0.89%), hyperpigmentation (18%), and keratosis (7%). Hyperpigmentation first appeared in children after 5 years exposure; keratosis after about 15 years exposure. High rates of hyperkeratosis and/or hyperpigmentation have also been reported in several South American populations whose drinking water contained high levels of arsenic (4023; 4170, 4171).

Neurotoxicity — Arsenic-induced neurotoxicity is often manifested as peripheral neuropathy, involving both sensory and motor nerves (4020, 4172). Sensory defects are more common than motor defects and the legs are more likely to be affected than the arms. Typical features are numbness and paresthesia, diminished sensation of touch, pain, heat and cold, and reduced muscle power (4025). As measured by electromyographic techniques, peripheral neuropathy has been observed in populations exposed to arsenic in their drinking water at concentrations of 0.1 mg/L or higher (4173, 4174). However, in other studies no clinical or subclinical evidence of peripheral neuropathy was seen in populations whose drinking water contained arsenic at levels of 0.2-4 mg/L (4134, 4175).

Polyneuropathy has also been observed in individuals consuming arsenic-contaminated foods, and in those taking arsenic-based drugs (4112, 4176). The estimated dose levels were 3 mg As/day for a soy sauce contaminated with calcium arsenate, 3 mg As/day for an anti-asthmatic drug containing arsenic trioxide, and about 10 mg As/day for an anti-asthmatic drug containing arsenic sulfide.

Neurological disorders have also been documented in workers exposed to high atmospheric arsenic levels as indicated by on-site air sampling or urinary As measurements (4177, 4178, 4179).

Several organic compounds used in drugs are known to produce adverse side effects on the central nervous system; both glycobiarsol and tryparsamide cause encephalopathy and the latter compound is also associated with optic atrophy (4113). Arsphenamine and neoarsphenamine have also been reported to cause serious neurological effects (4113).

Cardiovascular effects — Increased rates of cardiovascular disease has been reported in some arsenic-exposed workers (4145, 4143, 4180). Chronic exposure to low levels of arsenic may result in subtle changes in the peripheral vascular system, as indicated by increased incidence of Raynaud's phenomenon (white fingers) and increased vasospastic reactivity in fingers exposed to low temperatures (4181). Such

effects were attributed to functional alterations in blood vessels caused by inhalation of arsenic. A severe vascular disorder, called Blackfoot disease, which is characterized by gangrene of the lower extremities, was reported for a population whose drinking water contained high levels of arsenic (mean level about 0.5 mg/L, maximum greater than 1 mg/L) (4131). Recent studies have demonstrated that the arsenic occurring in the drinking water was bound to organic fluorescent substances which may have enhanced the toxic effects. It has also been suggested that zinc and selenium dietary deficiencies may have increased the toxic effects (4182).

Genotoxicity — A number of in vivo and in vitro studies have demonstrated that arsenic causes increases in chromosomal aberrations and sister chromatid exchanges (SCE) in exposed individuals (4183-4189). The types of chromosomal aberrations induced by arsenic include breaks and gaps. A considerable amount of individual and population variation in response occurs even for similar exposures and in some epidemiological studies genotoxic effects have not been seen. For example, in a study of a population exposed to 0.1 mg/L of arsenic in drinking water, Vig et al. (4190) reported no increased incidence of chromosome aberrations or SECs.

Respiratory effects — Rhinopharyngolaryngitis, nasal septal perforation, tracheobronchitis, and pulmonary insufficiency, as well as high incidences of bronchiectasis and recurrent bronchopneumonia have been observed in individuals exposed to arsenic-contaminated drinking water (4020). Rhinitis, pharyngitis and laryngitis have also be observed in workers exposed to inorganic arsenic in the work place air (4113).

Hematological effects — Chronic exposure to arsenic may also cause hematological abnormalities. In early studies, leukopenia was the most common hematological finding; white cell counts as low as 600 were reported (4127). In one occupational exposure study, a 23% incidence of relative neutropenia occurred in 130 smelter workers exposed to arsenic at levels that were reported to average less than 0.5 mg/m^3 (4124). Total white cell counts were not significantly reduced, and no other hematological abnormalities were reported. Chronic exposure to very low levels of arsine gas may have a cumulative effect in causing an anemic condition (4111).

Reproductive effects — Limited data are available suggesting that arsenic may cause adverse reproductive effects in humans. A significantly higher frequency of spontaneous abortions (11% vs 7.6%) and significantly reduced birth weights occurred in a population living near a copper smelter as compared to more distantly located populations (4191-4194). No exposure estimates were given, and it was also noted that the smelter emissions also included other toxic substances such as lead and sulfur dioxide. In another study, a high male to female birth ratio (157 to 100) was seen in a population that may have been exposed to elevated arsenic levels in their drinking water 10 to 11 months earlier (4195). Exposure levels were not estimated.

Hepatic effects — Chronic oral exposures to arsenic reportedly resulted in hepatic cirrhosis and portal hypertension (4150, 4196-4198). Organic arsenic drugs, such as arsphenamine and neoarsphenamine have also been reported to cause liver damage (4113).

Immunotoxicity — There are very limited data linking arsenic with immunosuppressive effects in humans. Zaldivar (4199) suggested that the occurrence of bronchiectasis (11%) and recurrent bronchopneumonia in children whose drinking water contained 0.6 ppm arsenic was due to the immunosuppressive action of arsenic in the lungs.

75.3.3 Levels of Concern

Based on evidence that inorganic arsenic is a human carcinogen, USEPA has specified that the ambient water quality criterion and the drinking water MCLG be set at zero. In that the attainment of a zero concentration level may not be feasible in some cases, the concentrations of inorganic arsenic calculated to result in incremental lifetime cancer risks of 10^{-5}, 10^{-6}, and 10^{-7} from ingestion of both water and contaminated aquatic organisms was estimated to be 0.02 µg/L, 0.002 µg/L, and 0.0002 µg/L, respectively. Based on the ingestion of contaminated water only, the corresponding levels were estimated to be 0.25 µg/L, 0.025 µg/L, and 0.0025 µg/L, respectively. Risk estimates are expressed as the probability of cancer after a lifetime consumption of two liters of drinking water and 6.5 g of contaminated fish per day. Thus a risk of 10^{-5} implies that a lifetime daily consumption of two liters of drinking water and 6.5 g of contaminated fish at the criterion level of 0.02 µg/L would be expected to produce one excess case of cancer above the normal background incidence for every 100,000 people exposed. The oral unit risk value (the increased risk of developing skin cancer after lifetime ingestion of water containing 1 µg As/L) was estimated by the EPA to be 5×10^{-5} (4022).

USEPA Health Advisories have not been issued for arsenic. There is some evidence seen in individuals consuming arsenic compounds as a tonic, that a daily dose equivalent to 20-60 µg/kg can lead to mild symptoms of poisoning (4110).

The World Health Organization recommends a health-based drinking water guideline of 0.05 mg/L for arsenic (4021).

IARC (4012) lists arsenic in Category 1 (sufficient evidence of human carcinogenicity and limited evidence of animal carcinogenicity) in its weight-of-evidence ranking of potential carcinogens. The EPA lists inorganic arsenic in Group A (sufficient evidence of human carcinogenicity) (4008).

For inhalation exposures, EPA has calculated a carcinogenic slope factor (95% upper bound limit on linearized multistage model) of 50 $(mg/kg/day)^{-1}$ (4020). The inhalation unit risk (the excess cancer risk associated with lifetime exposure to 1 µg/m^3) was estimated by EPA to be 4.29×10^{-3} (4020).

The OSHA standards for inorganic arsenic, organic arsenic and arsine are 10 µg As/m^3, 500 µg As/m^3, and 200 µg As/m^3, for an 8-hr time-weighted average exposure (4009, 4011). The ACGIH TLV® (8-hr TWA) for inorganic arsenic (As and soluble compounds) is 0.2 mg As/m^3 (4010). NIOSH recommends a 15-min ceiling STEL of 2 µg As/m^3 for inorganic arsenic (4009).

75.3.4 Hazard Assessment

Inorganic arsenic is a human carcinogen. Chronic oral exposures have been associated with increased incidences of skin cancers (squamous cell carcinomas and multiple basal cell carcinomas), and chronic inhalation exposures have been associated with an elevated risk of lung cancer, particularly in occupationally exposed workers.

The major noncarcinogenic toxic effects that have been identified in individuals chronically exposed to arsenic include skin abnormalities, neurological changes, and vascular disorders. Other effects seen in some studies are pulmonary damage, chromosomal abnormalities, liver damage, hematological changes, and reproductive abnormalities. Some effects, such as peripheral neuropathy may persist for several years after the exposure is discontinued.

75.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of arsenic concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following sequence of reagents to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is required for solid samples other than storage at 4°C until sample analysis. All samples should be analyzed within 180 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (4200).

Analytical methods available for analyzing inorganic arsenic in water, soils and waste include furnace atomic absorption (Method 206.2), gaseous hydride (Method 206.3), and inductively coupled plasma atomic emission spectrometry (Method 200.7) techniques. If these procedures are to be used for the purpose of measuring total arsenic (inorganic plus organic), all organically bound arsenic must be first converted to the inorganic form prior to the analytical determination. Depending upon the analytical method, acid or a combination of acid with hydrogen peroxide is used to digest the samples. Sample preparation procedures specific to each analytical technique are described in Methods 200.0, 200.7, and 206.5 for aqueous samples (4200) and Methods 3005, 3010, 3020, 3040, and 3050 for solid or waste samples. Because arsenic and many of its compounds are volatile, quality control samples should be processed with the samples to determine whether analyte losses have occurred during the sample dissolution procedure (4201).

The atomic absorption techniques are probably the most common procedures for determining the concentration of arsenic in water, soil and waste samples. In the graphite furnace technique, a representative aliquot of the sample digestate is spiked with nickel nitrate solution and placed into a graphite tube furnace. The sample aliquot is then slowly evaporated to dryness, charred, and atomized. The absorption of hollow cathode or electrodeless discharge lamp radiation at 193.7 nm will be proportional to the arsenic concentration. The technique has a detection limit of 1 µg/L arsenic and a detection range of 5-100 µg/L. In a single EPA study, sample results using this technique were reproducible to within 2% for water and within 9% for waste effluent. Arsenic recovery in the water samples ranged from 101-105% and 85-90% in the waste effluent (4200).

The gaseous hydride method determines inorganic arsenic when present in concentrations at or above 2 µg/L. The method is applicable to drinking water, fresh and saline waters, and acid-digested solid samples in the absence of high concentrations of chromium, cobalt, copper, mercury, molybdenum, nickel and silver. Arsenic in the sample is first reduced to the trivalent state using stannous chloride, followed by conversion to arsine using zinc metal. The gaseous hydride is swept into an argon-hydrogen flame of an atomic absorption spectrometer. Arsenic spectral absorption is observed at a wavelength of 193.7 nm; correction for spectral interferences are made by observing optical absorbance at a background wavelength. The working range of the method is 2-20 µg/L and the detection limit is 2 µg/L. The reproducibility at 10 µg/L is approximately ± 1 µg/L; the recovery is 93% (4200).

EPA has recently approved the use of the inductively coupled plasma (ICP) atomic emission method for determining compliance with existing National Primary Drinking Water Regulations (4202). The technique is based upon the simultaneous or sequential multi-element measurement of atomic emission of trace elements. A preserved and/or digested sample is nebulized to form an aerosol that is introduced into a high temperature plasma where atomic excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma and are dispersed by a grating spectrometer. The line intensities, which are a measurement of elemental concentrations, are monitored by photomultiplier tubes. Optical compensation techniques are used to correct for spectral interferences. The ICP detection limit for arsenic is 53 µg/L. To meet the regulation requirements for the determination of arsenic in drinking water, samples are concentrated prior to ICP analysis. The concentration procedure is described in the Appendix to Method 200.7. In an EPA evaluation of the reproducibility and accuracy of the ICP method, the mean percent relative standard deviation for triplicate analysis of 22 elements was found to be 9%. The mean percent recovery of spiked elements for all waste samples was 93%.

Detection Limit	Method
53 µg/L (aqueous & nonaqueous)*	200.7
1 µg/L (aqueous & nonaqueous)	206.2
2 µg/L (aqueous & nonaqueous)	206.3

*This detection limit does not include any preconcentration factor.

75.5 REFERENCES

Note: The numbering sequence of the references reflect the order of references as they appear in the master bibliography.

4000. Hazardous Substance Data Bank (HSDB) 1989. National Library of Medicine. Bethesda, MD.

4001. Agency for Toxic Substances and Disease Registry (ASTDR) 1989. Toxicological Profile for Arsenic. Prepared by Life Systems, Inc. for Agency for Toxic Substances and Disease Registry, in collaboration with U.S. Environmental Protection Agency. ATSDR/TP-88/02.

4002. Weiss, G., ed. 1980. Hazardous Chemicals Data Book. Park Ridge, NJ: Noyes Data Corporation.

4003. Oak Ridge National Laboratory (ORNL) 1980. Material Safety Data Sheets. In: Hazardous Chemicals Data Book, G. Weiss, ed., . Park Ridge, NJ: Noyes Data Corporation.

4004. Edelstein, D.L. 1985. Arsenic. In: Mineral Facts and Problems. Bureau of Mines, Bull. 675. Washington, DC: U.S. Department of the Interior.

4005. Oil and Hazardous Materials/Technical Assistance Data System (OHMTADS) 1989. Online file. Baltimore, MD: Chemical Information Systems, Inc.

4006. Arnold, W. 1988. Arsenic. In: Handbook on Toxicity of Inorganic Compounds, H.G. Seiler and H. Sigel, eds. New York: Marcel Dekker, Inc. pp. 79-93.

4007. Woolson, E.A. 1983. Man's perturbation of the arsenic cycle. In; Arsenic, Industrial, Biomedical, Environmental Perspectives. New York: van Nostrand Reinhold Co. pp. 393-408.

4008. U.S. Environmental Protection Agency (U.S. EPA) 1989. Drinking water regulations and health advisories. C fice of Drinking Water, Washington, D.C., November, 1990.

4009. National Institute for Occupational Safety and Health (NIOSH) 1988. NIOSH recommendations for occupational safety and health standards, August 1988. (Suppl. to Morbidity and Mortality Weekly, vol. 37, no. S-7, Aug. 26, 1988). Atlanta, GA: National Institute for Occupational Safety and Health.

4010. American Conference of Governmental Industrial Hygienists (ACGIH). 1988-89. Threshold limit values and biological exposure indices for 1988-1989. Cincinnati, OH.

4011. Occupational Safety and Health Administration (OSHA) 1989. Air contaminants; final rule. Fed. Regist. 54(12):2332.

4012. International Agency for Research on Cancer (IARC) 1987. Overall evaluation of carcinogenicity: an updating of IARC Monographs, volumes 1-47. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Supplement 7. Geneva: International Agency for Research on Cancer.

4013. Occupational Safety and Health Administration (OSHA) 1988. Code of Federal Reg. 1910.1018.

4014. Callahan, M.A.; Slimak, M.W.; Gabel, N.W., et al. 1979. Water-related fate of 129 priority pollutants. vol. 1, Introduction and technical background, metals and inorganics, pesticides and PCBs. Washington, DC: U.S. Environmental Protection Agency. EPA-440/4-79-029a.

4015. U.S. Environmental Protection Agency (U.S. EPA) 1989. Extremely Hazardous Substances, Superfund Chemical Profiles. Park Ridge, NJ: Noyes Data Corp.

4016. International Agency for Research on Cancer (IARC) 1980. Some metals and metallic compounds. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. volume 23. Geneva: International Agency for Research on Cancer.

4017. Chilvers, D.C.; Peterson, P.J. 1987. Global cycling of arsenic. In: Lead, Mercury, Cadmium and Arsenic in the Environment, T.C. Hutchinson and K.M. Meems, eds. New York: John Wiley & Sons Inc. pp. 279-301.

4018. Kabata-Pendias, A.; Pendias, H. 1984. Trace Elements in Soils and Plants. Boca Raton, FL: CRC Press.

4019. Sax, N.I.; Lewis, R.J., Jr. 1989. Dangerous Properties of Industrial Materials. 7th ed., vol. 3. New York: van Nostrand Reinhold.

4020. U.S. Environmental Protection Agency 1984. Health Assessment Document for Inorganic Arsenic. Research Triangle Park, NC: U.S. Environmental Protection Agency. EPA 600/8-83-021F.

4021. World Health Organization (WHO) 1984. Guidelines for Drinking-water Quality. vol. 1 and 2. Geneva: World Health Organization.

4022. U.S. Environmental Protection Agency (U.S. EPA) 1988. Recommended Agency policy on the carcinogenic risk associated with the ingestion of inorganic arsenic. Memorandum from the Administrator to Assistant Administrators. June 21, 1988. Washington, DC. U.S. Environmental Protection Agency.

4023. Zaldivar, R. 1974. Arsenic contamination of drinking water and foodstuffs causing endemic chronic poisoning. Beitr. Path. 151:384-400.

4024. Walsh, P.R.; Duce, R.A.; Fasching, J.L. 1979. Considerations of the enrichment, sources, and flux of arsenic in the troposphere. J. Geophys. Res. 84(C4):1719-1726.

4025. Hindmarsh, J.T.; McCurdy, R.F. 1986. Clinical and environmental aspects of arsenic toxicity. CRC Crit. Rev. Clin. Lab. Sci. 23:315-347.

4026. Kearney, P.C.; Kaufman, D.D., eds. 1976. Herbicides, Chemistry, Degradation, and Mode of Action. 2nd ed. 2 volumes. New York: Marcel Dekker.

4027. Woolson, E.A. 1977. Fate of arsenicals in different environmental substrates. Environ. Health Perspect. 19;73-81.

4028. Sandberg, G.R.; Allen, I.K. 1975. A proposed arsenic cycle in an agronomic ecosystem. In: Arsenical Pesticides, E. Woolson, ed., ACS Symp., Series No. 7. Washington, DC: American Chemical Society. pp. 124-147.

4029. Waslenchuk, D.G.; Windom, H.L. 1978. Factors controlling the asterion chemistry of arsenic. Asterion Coastal Mar. Sci. 7:455-464.

4030. Weed Science Society of America. 1983. Herbicide Handbook, 5th ed. Weed Science Society of America, Champaign, IL.

4031. Welch, A.H.; Lico, M.S.; Hughes, J.L. 1988. Arsenic in groundwater of the western USA. Groundwater 26(3):333-347.

4032. Goldsmith, J.R.; Dean, M.; Thom, J.; Gentry, G. 1972. Evaluation of health implications of elevated arsenic in well water. Water Res. 6:1133-1136.

4033. Whanger, P.D.; Weswig, P.H.; Stoner, J.C. 1977. Arsenic levels in Oregon waters. Environ. Health Perspect. 19:139-143.

4034. Harrington, J.M.; Middaugh, J.P.; Morse, D.L.; Housworth, J. 1978. A survey of a population exposed to high arsenic in well water in Fairbanks, Alaska. Am. J. Epidemiol. 108:377-385.

4035. Thoresby, P.; Thornton, I. 1979. Heavy metals and arsenic in soil, pasture herbage and barley in some mineralized areas in Britan: Significance to animal and human health. Trace Substances in Environmental Health - XIII. Proceedings of the University of Missouri's 13th Annual Conference on Trace Substances in Environmental Health, June 4-7, Columbia Missouri, pp. 93-103.

4036. Fishbein, L. 1984. Overview of analysis of carcinogenic and/or mutagenic metals in biological and environmental samples. I. Arsenic, beryllium, cadmium, chromium and selenium. Int. J. Environ. Anal. Chem. 17:113-170.

4037. Beckman, L. 1978. The Ronnskar smelter - Occupational and environmental effects in and around a polluting industry in northern Sweden. Ambio 7:226-231.

4038. Buchet, J.P.; Roels, H.; Lauwerys, R.; Bruaux, P.; Claeys-Thoreau, F.; LaFontaine, A.; Verduyn, G. 1978. Repeated surveillance of exposure to cadmium, manganese and arsenic in school-age children living in rural, urban and nonferrous smelter areas in Belgium. Environ. Res. 22:95-108.

4039. Binder, S.; Kaye, W.; Forney, D.; Paschal, D. 1985. Arsenic exposure in children living near the former copper smelter at Anaconda, Montana. Proceedings of the Sixth National Conference on Management of Uncontrolled Hazardous Waste Sites. Washington, DC. pp. 409-411.

4040. Johnson, D.L. 1972. Bacterial reduction of arsenate in seawater. Nature (London) 240:40. As reported in 4025.

4041. Waslenchuk, D.G. 1979. The geochemical controls on arsenic concentrations in southeastern United States rivers. Chem. Geol. 24:315-325.

4042. Chapman, B.M.; Jones, D.R.; Jung, R.F. 1988. Heavy metal transport in streams - Field release experiments. In: Chemistry and Biology of Solid Waste; Dredged Material and Mine Tailings, W. Salomons and U. Foerstner, eds. New York: Springer-Verlag. pp. 275-300.

4043. Woolson, E.A. 1975. Bioaccumulation of arsenic. In: Arsenical Pesticides. E.A. Woolson, ed. ACS Symp. Series No. 7. Washington, DC. American Chemical Society. pp, 97-107.

4044. Durum, W.H.; Hem, J.D.; Heidel, S.G. 1971. Reconnaissance of selected minor elements in surface waters of the United States. October 1970. U.S. Geological Survey Circular 643. 49 pp.

4045. McCabe, L.J.; Symons, J.M.; Lee, R.D.; Robeck, G.G. 1970. Survey of community water supply systems. J. Am. Water Works Assoc. 62:670-687.

4046. Spehar, R.L.; Fiandt, J.T.; Anderson, R.L.; DeFoe, D.L. 1980. Comparative toxicity of arsenic compounds and their accumulation in invertebrates and fish. Arch. Environ. Contam. Toxicol. 96:63-63.

4047. Bettley, F.R.; O'Shea, J.A. 1975. The absorption of arsenic and its relation to carcinoma. Br. J. Dermatol. 92:563. As reported in 4025.

4048. Pomroy, C.; Charbonneau, S.M.; McCullough, R.S.; Tam, G.K.H. 1980. Human retention studies with ^{74}As. Toxicol. Appl. Pharmacol. 53:550. As reported in 4025.

4049. Holland, R.H.; McCall, M.S.; Lanz, H.C. 1959. A study of inhaled arsenic-74 in man. Cancer Res. 19:1154-1156.

4050. Ivankovic, S.; Eisenbrand, G.; Preussmann, R. 1979. Lung carcinoma induction in BD rats after a single intratracheal instillation of an arsenic-containing pesticide mixture formerly used in vineyards. Int. J. Cancer 24:786-788. As reported in 4016.

4051. Rudnay, P.; Borzsonyi, M. 1981. The tumorigenic effect of treatment with arsenic trioxide. (Hung.) Magyar Onkol. 25:73-77. As reported in 4012.

4052. Ishinishi, N.; Yamamoto, A.; Hisanaga, A.; Inamasu, T. 1983. Tumorigenicity of arsenic trioxide to the lung in Syrian golden hamsters by intermittent instillations. Cancer Lett. 21:141-147. As reported in 4016.

4053. Pershagen, G.; Nordberg, G.; Bjorkland, N.E. 1984a. Carcinomas of the respiratory tract in hamsters given arsenic trioxide and/or benzo-a-pyrene by the pulmonary route. Environ Res. 37:425-432. As reported in 4016.

4054. Pershagen, G.; Nordberg, G.; Bjorkland, N.E. 1984b. Experimental evidence on the pulmonary carcinogenicity of arsenic trioxide. Arch. Toxicol., Suppl, ISS., Dis. Metab. Reprod. Toxic Response Drugs Other Chem. 7:403-404. As reported in 4016.

4055. Nelson, W.C.; Lykins, M.H.; Mackey, J.: Newill, V.A.; Finklea, J.F.; Hammer, D.I. 1973. Mortality among orchard workers exposed to lead arsenate spray: a cohort study. J. Chron. Dis. 26:105-118. As reported in 4016.

4056. DiPaolo, J.A.; Castro, B.C. 1979. Quantitative studies of in vitro morphological transformation of Syrian hamster cells by inorganic metal salts. Cancer Res. 39:1008-1013.

4057. Casto, B.C.; Meyers, J.; DiPaolo, J.A. 1979. Enhancement of viral transformation for evaluation of the carcinogenic or mutagenic potential of inorganic metal salts. Cancer Res. 39:193-198.

4058. Lofroth, G.; Ames, B.N. 1978. Mutagenicity of inorganic compounds in Salmonella typhimurium: Arsenic, chromium, and selenium. Mutat. Res. 54:65-66.

4059. Leonard, A.; Lauwerys, R.R. 1980. Carcinogenicity, teratogenicity, and mutagenicity of arsenic. Mutat. Res. 75:49-62.

4060. Rossman, T.G.; Stone, D.; Molina, M.; Troll, W. 1980. Absence of arsenite mutagenicity in E. coli and Chinese hamster cells. Environ. Mutagenesis 2:371-379.

4061. Singh, I. 1983. Induction of reverse mutation and mitotic gene conversion by some metal compounds in Saccharomyces cerevisiae. Mutat. Res. 117:149-152.

4062. Amacher, D.E.; Paillet, S.C. 1980. Induction of trifluorothymidine-resistant mutants by metal in L5178Y/TK cells. Mutat. Res. 78:279-288.

4063. Oberly, T.J.; Piper, C.E.; McDonald, D.S. 1982. Mutagenicity of metal salts in the L5178Y mouse lymphoma assay. Toxicol. Environ. Health 9:367-376.

4064. Lee, T.-C.; Oshimura, M.; Barrett, J.C. 1985. Comparison of arsenic-induced cell transformation, cytotoxicity, mutation, and cytogenetic effects in Syrian hamster embryo cells in culture. Carcinogenesis (London) 6:1421-1426.

4065. Jacobson-Kram, D,; Montalbano, D. 1985. The reproductive effects assessment group's report on the mutagenicity of inorganic arsenic. Environ. Mutagenesis 7:787-804.

4066. Larramendy, M.L.; Popescu, N.C.; DiPaolo, J. 1981. Induction by inorganic metal salts of sister chromatid exchanges and chromosome aberrations in human and Syrian hamster strains. Environ. Mutagenesis 3:597-606.

4067. Nakamuro, M.; Sayato, Y. 1981. Comparative studies of chromosomal aberrations induced by trivalent and pentavalent arsenic. Mutat. Res. 88:73-80.

4068. Nordenson, I.; Sweins, A.; Beckman, L. 1981. Chromosome aberrations in cultured human lymphocytes exposed to trivalent and pentavalent arsenic. Scand. J. Work Environ. Health 7:277-281.

4069. Wan, B.; Christian, R.T.; Soukup, S.W. 1982. Studies of cytogenetic effects of sodium arsenicals on mammalian cells in vitro. Environ. Mutagenesis 4:493-498.

4070. Ferm, V.H.; Carpenter, S. 1968. Malformations induced by sodium arsenate. J. Reprod. Fertil. 17:199-201.

4071. Hood, R.D.; Bishop, S.L. 1972. Teratogenic effects of sodium arsenate in mice. Arch. Environ. Health 24:62-65.

4072. Beaudoin, A. R. 1974. Teratogenicity of sodium arsenate in rats. Teratology 10:153-158.

4073. Hood, R.D.; Thacker, G.T.; Patterson, B.L. 1977. Effects in the mouse and rat of prenatal exposure to arsenic. Environ. Health Perspect. 19:219-222.

4074. Nagymajtenyi, L.; Selypes, A.; Berencsi, G. 1985. Chromosomal aberrations and fetotoxic effects of atmospheric arsenic exposure in mice. J. Appl. Toxicol. 5:61-63.

4075. Willhite, C.C. 1981. Arsenic-induced axial skeletal (dysraphic) disorders. Exp. Mol. Pathol. 34:145-158.

4076. Baxley, M.N.; Hood, R.D.; Vedel, G.C.; Harrison, W.P.; Szczech, G.M. 1981. Prenatal toxicity or orally administered sodium arsenite in mice. Bull. Environ. Contam. Toxicol. 26:749-756.

4077. Hood, R.D. 1972. Effects of sodium arsenite on fetal development. Bull. Environ. Contam. Toxicol. 7:216-222.

4078. Hood, R.D.; Harrison, W.P. 1982. Effects of prenatal arsenite exposure in hamster. Bull. Environ. Contam. Toxicol. 29:671-678.

4079. Ferm, V.H.; Hanlon, D.P. 1985. Constant rate exposure of pregnant hamsters to arsenate during early gestation. Environ. Res. 37:425-432.

4080. Ferm, V.H.; Saxon, A.; Smith, B.M. 1971. The teratogenic profile of sodium arsenate in the golden hamster. Arch. Environ. Health 22:557-560.

4081. Schroeder, H.A.; Mitchener, M. 1971. Toxic effects of trace elements on the reproduction of mice and rats. Arch. Environ. Health 23:102-106.

4082. Hood, R.D.; Harrison, W.P.; Vedel, G.C. 1982. Evaluation of arsenic metabolites for prenatal effects in the hamster. Bull. Environ. Contam. Toxicol. 29:679-687.

4083. Hood, R.D. 1985. Cacodylic Acid: Agricultural Uses, Biological Effects, and Environmental Fate. Washington, D.C.: Veterans Administration Central Office.

4084. Harrison, W.P.; Frazier, J.C.; Mazzanti, E.M.; Hood, R.D. 1980. Teratogenicity of disodium methanearsonate and sodium dimethylarsinate (sodium cacodylate) in mice. Teratology 21:43A.

4085. Chernoff, N.; Rogers, E.H. 1975. Effects of cacodylic acid on the prenatal development of rats and mice. Substitute chemical program; the first year of progress. Proceedings of a symposium. Vol. II. Toxicological Methods and Genetic Effects Workshop. Environmental Protection Agency, pp. 197-204.

4086. Rogers, E,H.; Chernoff, N.; Kaylock, R.J. 1981. The teratogenic potential of cacodylic acid in the rat and mouse. Drug. Chem. Toxicol. 4:49-61.

4087. Harrison, J.W.; Packman, E.W.; Abbott, D.D. 1958. Acute oral toxicity and chemical and physical properties of arsenic trioxides. Arch. Ind. Health 17:118-123.

4088. Peoples, S.A. et al. 1979. Occupational exposures to pesticides containing organoarsenicals in California. Vet. Hum. Toxicol. 21:417-421.

4089. Heywood, R.; Sortwell, R.J. 1979. Arsenic intoxication in the rhesus monkey. Toxicol. Lett. 3:137-144.

4090. Palmer, J.S. 1972. Toxicity of 45 organic herbicides to cattle, sheep, and chickens. USDA Production Research Report 137.

4091. Webb, D.R.; Sipes, I.G.; Carter, D.E. 1984. In vitro solubility and in vivo toxicity of gallium arsenide. *Toxicol. Appl. Pharmacol. 76:96-104.*

4092. Webb, D.R.; Wilson, S.E.; Carter, D.E. 1986. Comparative pulmonary toxicity of gallium arsenide, gallium (III) oxide, or arsenic (III) oxide intratracheally instilled into rats. Toxicol. Appl. Pharmacol. 82:405-416.

4093. Webb, D.R.; Wilson, S.E.; Carter, D.E. 1987. Pulmonary clearance and toxicity of respirable gallium arsenide particulates intratracheally instilled into rats. Am. Ind. Hyg. Assoc. J. 48(7):660-667.

4094. Pershagen, G.; Lind, B.; Bjorklund, N.E. 1982. Lung retention and toxicity of some inorganic arsenic compounds. Environ. Res. 29:425-434.

4095. Byron, W.R.; Bierbower, G.W.; Brouwer, J.B.; Hansen, W.H. 1967. Pathological changes in rats and dogs from two-year feeding of sodium arsenite or sodium arsenate. Toxicol. Appl. Pharmacol. 10:132-147.

4096. Schroeder, H.A.; Kanisawa, M.; Frost, D.V.; Mitchener, M. 1968. Germanium, tin and arsenic in rats: effects on growth, survival and tissue levels. J. Nutr. 96:37-45.

4097. Blakley, B. R.; Sisodia, C.S.; Mukkur, T.K. 1980. The effect of methylmercury, tetrethyl lead, and sodium arsenite on the humoral immune response in mice. Toxicol. Appl. Pharmacol. 52:245-254.

4098. Hatch, G.E.; Boykin, E.; Graham, J.A.; Lewtas, J.; Pott, F.; Loud, K.; Mumford, J.L. 1985. Inhalable particles and pulmonary host defense: in vivo and in vitro effects of ambient air and combustion particles. Environ. Res. 36:67-80.

4099. Aranyi, C.; Bradof, J.N.; O'Shea, W.J.; Graham, J.A.; Miller, F.J. 1985. Effects of arsenic trioxide inhalation exposure on pulmonary antibacterial defenses in mice. J. Toxicol. Environ. Health 15:163-172.

4100. Squibb, K.S.; Fowler, B.A. 1983. The toxicity of arsenic and its compounds. In: Biological and Environmental Effects of Arsenic, K.A. Fowler, ed. New York: Elsevier Science Publishers B.V. pp. 233-269.

4101. Mahaffey, K.R.; Capar, S.G.; Gladen, B.C.; Fowler, B.A. 1981. Concurrent exposure to lead, cadmium, and arsenic. Effects on toxicity and tissue metal concentrations in the rat. J. Lab. Clin. Med. 98:463-481.

4102. Brown, M.M.; Rhyne, B.C.; Goyer, R.A.; Fowler, B.A. 1976. Intracellular effects of chronic arsenic administration on renal proximal tubule cells. J. Toxicol. Environ. Health 1:505-514.

4103. Woods, J.S.; Fowler, B.A. 1977. Effects of chronic arsenic exposure on hematopoietic function in adult mammalian liver. Environ. Health Perspect. 19:209-213.

4104. Woods, J.S.; Fowler, B.A. 1978. Altered regulation of mammalian hepatic heme biosynthesis and urinary porphyrin excretion during prolonged exposure to sodium arsenate. Toxicol. Appl. Pharmacol. 43:361-371.

4105. Kroes, R.; Van Logten, M.J.; Berkvins, J.M.; deVries, I.; van Esch, G.J. 1974. Study on the carcinogenicity of lead arsenate and sodium arsenate and the possible synergistic effect of diethylnitrosamine. Food Cosmet. Toxicol. 12:671-679.

4106. Baroni, C.; van Esch, G.J.; Saffiotti, U. 1963. Carcinogensis tests of two inorganic arsenicals. Arch. Environ. Health 7:668-674.

4107. Ishinishi, N.; Osato, K.; Kodama, Y.; Kunitake, E. 1976. Skin effects and carcinogenicity of arsenic trioxide; a preliminary experimental study in rats. In: Effects and Dose-Response Relationships of Toxic Metals, G.F. Nordberg, ed. Amsterdam:Elsevier. pp. 471-479.

4108. Schaumburg, H.A. 1980. Failure to produce arsenic neurotoxicity in the rat - an experimental study. Washington, DC: Environmental Protection Agency, Office of Toxic Substances. EPA 560/11-80-022. PB 80-209505.

4109. Hamamoto, E. 1955. Infant arsenic poisoning by powdered milk. Jap. Med. J. 1649:2-12.

4110. Hayes, W.J., Jr. 1982. Pesticides Studies in Man. Baltimore, MD: Williams and Wilkins. pp. 41-50.

4111. Fowler, B.A.; Weissberg, J.B. 1974. Arsine poisoning. New Eng. J. Med. 291:1171-1174.

4112. Mizuta, N.; Mizuta, M.; Ita, F.; Ito, T.; Uchida, H.; Watanabe, Y.; Akama, H.; Murakami, T.; Hayashi, F.; Nakamura, K.; Yamaguchi, T.; Mizuia, W.; Oishi, S.; Matsumura, H. 1956. An outbreak of acute arsenic poisoning caused by arsenic-contaminated soy sauce (shoye). A clinical report of 220 cases. Bull. Yamaguchi Med. Sch. 4:131-150.

4113. Pershagen, G. 1983. The epidemiology of human arsenic exposure. Topics in Environ. Health 6:199-232.

4114. Armstrong, C.W.; Stroube, R.B.; Rubio, T.; et al. 1984. Outbreak of fatal arsenic poisoning caused by contaminated drinking water. Arch. Environ. Health 39:276-279.

4115. Danan, M.; Dally, S.; Conso, F. 1984. Arsenic-induced encephalopathy (letter to the editor). Neurology 34:1524.

4116. Beckett, W.S.; Moore, J.L.; Keogh, J.P.; Bleecker, M.L. 1986. Acute encephalopathy due to occupational exposure to arsenic. Br. J. Ind. Med. 43:66-67.

4117. Jenkins, R.B. 1966. Inorganic arsenic and the nervous system. Brain 89:479-498.

4118. LeQuesne, P.M.; McLeod, J.G. 1977. Peripheral neuropathy following a single exposure to arsenic. J. Neurol. Sci. 32:437-451.

4119. Murphy, M.J.; Lyon, I.W.; Taylor, J.W. 1981. Subacute arsenic neuropathy: clinical and electrophysiological observations. J. Neurol. Neurosurg. Psychiatry 44:896-900.

4120. Donofrio, P.D.; Wilbourn, A.J. 1985. Subacute arsenic toxicity presenting on clinical and electromyographic examination as Guillain-Barre syndrome. 110th Annual Meeting of the American Neurological Association, Chicago, IL, October 2-5, 1985. Ann Neurol 18:156-157.

4121. Glazener, F.S.; Ellis, J.G.; Johnson, P.K. 1968. Electrocardiographic findings with arsenic poisoning. Calif. Med. 109:159-162.

4122. Zettel, H. 1943. The effect of chronic arsenic damage on heart and blood vessels. Z. Klin. Med. 142:689-703. As reported in 4124.

4123. Butzengeiger, K.H. 1949. Chronic arsenic poisoning. - 1. EKG alterations and other cardiovascular manifestations. Dtsch. Arch. Klin. Med. 194:1-16. As reported in 4124.

4124. Hine, C.H.; Pinto, S.S.; Nelson, K.W. 1977. Medical problems associated with arsenic exposure. J. Occup.. Med. 19:391-396.

4125. Wang, B.C.; Mazzia, V.D.B. 1969 Arsenic poisoning as an anesthetic risk. N.Y. State J. Med.69:2911-2912. As reported in 4110.

4126. Ringenberg, Q.S.; Doll, D.C.; Patterson, W.P.; Perry, M.C. Yarbro, J.W. 1988. Hematologic effects of heavy metal poisoning. South. Med. J. 81:1132-1139.

4127. Kyle, R.A.; Pease, G.L. 1965. Hematologic aspects of arsenic intoxication. New Eng. J. Med. 273(1):18-23.

4128. American Conference of Governmental Industrial Hygienists (ACGIH). 1986. Documentation of TLVs. Arsine. American Conference of Governmental Industrial Hygienists, Cincinnati, OH. pp. 39.

4129. Haley, T.J. 1984. Arsenic. Dangerous Prop. Indust. Mat. Rep. 4:9-17.

4130. Franklin, M.; Bean, W.; Harden, R.C. 1950. Fowler's solution as an etiologic agent in cirrhosis. Am. J. Med. Sci. 219:589-596.

4131. Tseng, W.P.; Chu, H.M.; How, S.W.; Fong, J.M.; Lin, C.S.; Yeh, S. 1968. Prevalence of skin cancer in an endemic area of chronic arsenium in Taiwan. J. Natl. Cancer Inst. 40:453-463.

4132. Cebrian, M.E.; Albores, A.; Aguilar, M.; Blakely, E. 1983. Chronic arsenic poisoning in the north of Mexico. Hum. Toxicol. 2:121-133.

4133. Morton, W.; Starr, G.; Pohl, D.; Stoner, J.; Wagner, S.; Weswig, P. 1976. Skin cancer and water arsenic in Lane County, Oregon. Cancer 37:2523-2532.

4134. Southwick, J.W.; Western, A.E.; Beck, M.M. et al. 1981. Community health associated with arsenic in drinking water in Millard County, Utah. Health Effects Research Laboratory, Cincinnati, OH: U.S. Environmental Protection Agency. EPA-600/1-81-064. NTIS PB82-108374.

4135. U.S. Environmental Protection Agency. 1987. Risk Assessment Forum. Special Report on Ingested Inorganic Arsenic: Skin Cancer; Nutritional Essentiality. Draft report dated November 1987. EPA/625/3-87/013.

4136. Sommers, S.C.; McManus, R.G. 1953. Multiple arsenical cancers of the skin and internal organs. Cancer 6:347-359. As reported in 4001.

4137. Reymann, F.; Moller, R.; Nielsen, A. 1978. Relationship between arsenic intake and internal malignant neoplasms. Arch. Dermatol. 114:378-381.

4138. Dobson, R.L.; Young, M.R.; Pinto, J.S. 1965. Palmar keratoses and cancer. Arch. Dermatol. 92:553-556.

4139. Chen, C.J.; Chuang, Y.C.; Lin, T.M.; Wu, H.Y. 1985. Malignant neoplasms among residents of a Blackfoot disease-endemic area in Taiwan: High-arsenic artisan well water and cancers. Cancer Res. 45:5895-5899.

4140. Chen, C.J.; Chuang, Y.C.; You, S.L.; Lin, T.M.; Wu, H.Y. 1986. A retrospective study on malignant neoplasms of bladder, lung, and liver in a Blackfoot disease-endemic area in Taiwan. Br. J. Cancer 53:399-405.

4141. Knoth, W. 1966. Arsenbehandlung. Arch. Klin. Exp. Derm. 227:228-234. As reported in 4001.

4142. Ott, M.G.; Holder, B.B.; Gordon, H.I. 1974. Respiratory cancer and occupational exposure to arsenicals. Arch. Environ. Health 29:250-255. As reported in 4001.

4143. Axelson, O.; Dahlgren, E.; Jasson, C.-D.; Rehnlund, S.O. 1978. Arsenic exposure and mortality: a case-referent study from a Swedish copper smelter. Br. J. Ind. Med. 35:8-15. As reported in 4001.

4144. Hill, A.B.; Fanning, E.L. 1948. Studies on the incidence of cancer in a factory handling inorganic compounds of arsenic. I. Mortality experience in the factory. Br. J. Ind. Med. 5:1-6.

4145. Lee, A.M.; Fraumeni, J.F., Jr. 1969. Arsenic and respiratory cancer in man: An occupational study. J. Natl. Cancer Inst. 42:1045-1052.

4146. Rencher, A.C.; Carter, M.W.; McKee, D.W. 1977. A retrospective epidemiological study of mortality at a large western copper smelter. J. Occup. Med. 19:754-758.

4147. Blejer, H.P.; Wagner, W. 1976. Case study 4: Inorganic arsenic-ambient level approach to the control of occupational cancerigenic exposures. In: Occupational Carcinogenesis, Proceedings of a Conference, New York Academy of Sciences, New York, March 24-27, 1975. Ann N Y Acad Sci 271:179-186.

4148. Mabuchi, K.; Lilienfeld, A.; Snell, L. 1979. Lung cancer among pesticide workers exposed to inorganic arsenicals. Arch. Environ. Health 34:312-320.

4149. Baetjer, A.M.; Lilienfeld, A.M.; Levin, M.L. 1975. Cancer and occupational exposure to inorganic arsenic. In: Abstracts, 18th International Congress on Occupational Health, Brighton, England, September 14-19, 1975. Organizing Committee, Brighton, England, p. 393.

4150. Roth, F. 1958. The sequelae of chronic arsenic poisoning in Moselle Vintners. Ger. Med. Mon. 2:172-175.

4151. Lubin, J.H.; Pottern, L.M.; Blot, W.J.; et al. 1981. Respiratory cancer among copper smelter workers: Recent mortality statistics. J. Met. 23:779-784.

4152. Higgins, I.; Welch, K.; Burchfiel, C. 1982. Mortality of Anaconda smelter workers in relation to arsenic and other exposures. Ann Arbor, MI: Department of Epidemiology, University of Michigan.

4153. Welch, K.; Higgins, I.; Oh, M.; Burchfiel, C. 1982. Arsenic exposure, smoking, and respiratory cancer in copper smelter workers. Arch. Environ. Health 37:325-335.

4154. Lee-Feldstein A. 1983. Arsenic and respiratory cancer in man: Follow-up of an occupational study. In: Arsenic: Industrial, Biomedical, and Environmental Perspectives. W. Lederer and R. Fensterheim R, eds. New York: Van Nostrand Reinhold.

4155. Brown, C.C.; Chu, K.C. 1983. Implications of the multistage theory of carcinogenesis applied to occupational arsenic exposure. J. Natl. Cancer Inst. 70:455-463.

4156. Lee-Feldstein A. 1986. Cumulative exposure to arsenic and its relationship to respiratory cancer among copper smelter employees. J. Occup. Med. 28:296-302.

4157. Lee-Feldstein A. 1989. A comparison of several measures of exposure to arsenic: matched case-control study of copper smelter employees. Am. J. Epidemiol. 129:112-124.

4158. Pinto, S.S.; Enterline, P.E.; Henderson, V.; Varner, M.O. 1977. Mortality experience in relation to a measured arsenic trioxide exposure. Environ. Health Perspect. 19:127-130.

4159. Enterline, P.E.; Marsh, G.M. 1982. Mortality among workers exposed to arsenic and other substances in a copper smelter. Am. J. Epidemiol. 116:895-910.

4160. Enterline, P.E.; Henderson, V.L.; Marsh, G.M. 1987. Exposure to arsenic and respiratory cancer. A reanalysis. Am. J. Epidemiol. 125(6):929-938.

4161. Järup, L.; Pershagen, G.; Wall, S. 1989. Cumulative arsenic exposure and lung cancer in smelter workers: a dose-response study. Am. J. Ind. Med. 15:31-42.

4162. Brown, L.M.; Pottern, L.M.; Blot, W.J. 1984. Lung cancer in relation to environmental pollutants emitted from industrial sources. Environ. Res. 34:250-261.

4163. Pershagen, G. 1985. Lung cancer mortality among men living near an arsenic-emitting smelter. Am. J. Epidemiol. 122:684-696.

4164. Matanoski, G.; Landau, E.; Towascia, J.; et al. 1981. Lung Cancer Mortality in Proximity to a Pesticide Plant. Washington, DC: American Public Health Association, Environmental Protection Agency, Office of Toxic Substances. PB80-207376.

4165. Pascher, F.; Wolf, J. 1952 Cutaneous sequelae following treatment of bronchial asthma with inorganic arsenic. J. Am. Med. Assoc. 148;734-736.

4166. Borgono, J.M.; Greiber, R. 1972. Epidemiological study of arsenium in the city of Antofagasta. In: Trace Substances in Environmental Health-V, D.C. Hempfill, ed. Proceedings of the 5th Annual Conference, University of Missouri, Columbia, pp. 13-24.

4167. Huang, Y.Z.; Qian, X.C.; Wang, G.Q.; et al. 1985. Endemic chronic arsenium in Xinjiang. Chin. Med. J. (Eng) 98:219-222.

4168. Watrous, R.M.; McCaughey, M.B. 1945. Occupational exposure to arsenic in the manufacture of arsphenamine and related compounds. Ind. Med. 14:639-646.

4169. Perry, K.; Bowler, R.G.; Buckell, H.M.; Druett, H.A.; Schilling, R.S.F. 1948. Studies in the incidence of cancer in a factory handling inorganic compounds of arsenic--II: Clinical and environmental investigations. Br. J. Ind. Med. 5:6-15.

4170. Arguello, R.A.; Dahlgren, E.; Jansson, C.-D.; Rehnlund, S. O. 1938. [Title not given]. Rev. Argent. Dermatosifig. 22:461-487. As reported in 4113.

4171. Zaldivar, R.; Guillier, A. 1977. [Title not given]. Zentralbl. Bakteriol. Hyg. 65:226-235. As reported in 4025.

4172. Heyman, A.; Pfeiffer, J.B.; Willett, R.W.; Taylor, H.M. 1956. Peripheral neuropathy caused by arsenical intoxication. New England J. Med. 254(9): 401-409.

4173. Hindmarsh, J.T.; McLetchie, O.R.; Heffernan, L.P.; Haynie, O.A.; Ellenberger, H.A.; McCurdy, R.F.; Thiebaux, H.J. 1977. Electromyographic abnormalities in chronic environmental arsenicalism. J. Anal. Toxicol. 1:270-276.

4174. Valentine, J.L.; Campion, D.S.; Schluchter, M.D.; Massey, F.J. 1982. Arsenic effects on human nerve conduction. In: Trace Element Metabolism in Man and Animals. J.C. Howell, J.M.Hawthorne, L. White, eds. Canberra: Australian Academy of Science, pp. 409-411.

4175. Kreiss, K.; Feldman, R.G.; Landrigan, P.J.; Boyd, M.H.; Cox, D.H. 1983. Neurological evaluation of a population exposed to arsenic in Alaskan well water. Arch. Environ. Health 38:116-121.

4176. Tay, C.-H.; Seah, [illegible]. 1975. Arsenic poisoning from anti-asthmatic herbal preparations Med. J. Aust. 2:424-428.

4177. Feldman, R.G., Niles, C.A., Kelly-Heyes, M., Sax, D.S., Dixon, W.J., Thompson, D.J., Landau, E. 1979. Peripheral neuropathy in arsenic smelter workers. Neurology 29:939-944.

4178. Blom, S.; Lagerkvist, B.; Linderholm, H. 1985. Arsenic exposure to smelter workers: clinical and neurophysiological studies. Scand. J. Work Environ. Health 11:265-270.

4179. Landau, E.D.; Thompson, D.J.; Feldman, R.G.; Goble, G.J.; Dixon, W.J. 1977. Selected Noncarcinogenic Effects of Industrial Exposure to Inorganic Arsenic. U.S. Environmental Protection Agency, Washington, DC. EPA 569/6-77-018.

4180. Wingren, G.; Axelson, O. 1985. Mortality pattern in a glass producing area in SE Sweden. British J. Indust. Med. 42:411-414.

4181. Lagerkvist, B.; Linderholm, H.; Nordberg, G.F. 1986. Vasospastic tendency and Raynaud's phenomenon in smelter workers exposed to arsenic. Environ. Res. 39:465-474.

4182. Lin, S.M.; Yang, M.H. 1988. Arsenic, selenium, and zinc in patients with Blackfoot disease. Biol. Trace Metal Res. 15:213-221.

4183. Burgdorf, W.; Kurvink, K.; Cervenka, J. 1977. Elevated sister chromatid exchange rate in lymphocytes of subjects treated with arsenic. Hum. Genet. 36:69-72.

4184. Beckman, G.; Beckman, L.; Nordenson, I. 1977. Chromosome aberrations in workers exposed to arsenic. Environ. Health Perspect. 19:145-146.

4185. Nordenson, I.; Salmonsson, S.; Brun, E.; Bechman, G. 1979. Chromosome aberrations in psoriatic patients treated with arsenic. Hum. Genet. 48:1-8.

4186. Nordenson, I.; Sweins, A.; Beckman, L. 1981. Chromosome aberrations in cultured human lymphocytes exposed to trivalent and pentavalent arsenic. Scand. J. Work Environ. Health 7:277-281.

4187. Nordenson, I; Beckman, G.; Beckman, L.; Nordstrom, S. 1978b. Occupational and environmental risks in and around a smelter in northern Sweden. II. Chromosome aberrations in workers exposed to arsenic. Hereditas 88:47-50. (Cited in RfD)

4188. Petres, J; Baron, D.; Hagedorn, M. 1977. Effects of arsenic on cell metabolism and cell proliferation: cytogenetic and biochemical effects. Environ. Health Perspect. 19:223-227.

4189. Wen, W.-N.; Lieu, T-L.; Chang, H-J.; Wuu, S.W.; Yau, M-L.; Jan, K.Y. 1981. Baseline and sodium arsenite-inducted sister chromatid exchanges in cultured lymphocytes from patients with Blackfoot disease and healthy persons. Hum. Genet. 59:201-203.

4190. Vig, B.K.; Figueroa, M.L.; Cornforth, M.N.; Jenkins, S.H. 1984. Chromosome studies in human subjects chronically exposed to arsenic in drinking water. Am. J. Ind. Med. 6:325-338.

4191. Nordstrom, S.; Beckman, L.; Nordenson, I. 1978. Occupational and environmental risks in and around a smelter in northern Sweden. I. Variations in birth weight. Hereditas 88:43-46.

4192. Nordstrom, S.; Beckman, L.; Nordenson, I. 1978. Occupational and environmental risks in and around a smelter in northern Sweden. III. Frequencies of spontaneous abortion. Hereditas 88:51-54.

4193. Nordstrom, S.; Beckman, L.; Nordenson, I. 1978. Occupational and environmental risks in and around a smelter in northern Sweden. V. Spontaneous abortion among female employees and decreased birth weight in their offspring. Hereditas 90:291-296.

4194. Nordstrom, S.; Beckman, L.; Nordenson, I. 1978. Occupational and environmental risks in and around a smelter in northern Sweden. VI. Congenital malformations. Hereditas 90:297-302.

4195. Lyster, W.R. 1977. Arsenic and sex ratio in man. Med J. Aust. 2:442.

4196. Datta, D.V. 1976. Arsenic and non-cirrhotic portal hypertension. Lancet 1:433.

4197. Viallet, A.; Guillaume, I.; Cote, J.; Legare, A.; Lavoie, P. 1972. Presinusoidal portal hypertension following chronic arsenic intoxication. Gastroenterology 62:177.

4198. Morris, J.S.; Schmid, M.; Newman, S.; Scheuer, P.J.; Sherlock, S. 1974. Arsenic and noncirrhotic portal hypertension. Gastroenterology 64:86-94.

4199. Zaldivar, R. 1980. A morbid condition involving cardio-vascular, bronchopulmonary, digestive and neural lesions in children and young adults after dietary arsenic exposure. Zbl. Bakt. I. Abt. Orig. B 170:44-56.

4200. U.S. Environmental Protection Agency (U.S. EPA) 1983. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983.

4201. U.S. Environmental Protection Agency (U.S. EPA) 1986. Test Methods for Evaluation of Solid Waste, 3rd ed., November 1986. USEPA SW-846,

4202. U.S. Environmental Protection Agency (U.S. EPA) 1988. National Primary Drinking Water Regulations, Analytical Techniques". Federal Register, Vol. 53: 5142-5147. 40 CFR Parts 141 and 143.

4203. Lee, T.-C.; Huang, R.Y.; Jan, K.Y. 1985. Sodium arsenite enhances the cytotoxicity, clastogenicity and 6-thioguanune-resistant mutagenicity of ultraviolet light in Chinese hamster ovary cells. Mutat. Res. 148: 83-89.

4204. Lee, T.-C.; Lee, K.C.; Tzena, Y.J.; Huang, R.Y.; Jan, K.Y. 1986. Sodium arsenite potentiates the clastogenicity and mutagenicity of DNA crosslinking agents. Environ. Mutagenesis 8:119-128.

4205. Rossman, T.G. 1981. Enhancement of UV-mutagenesis by low concentrations of arsenite in E. coli. Mutat. Res. 91:207-211.

4206. Leonard, A. 1988. Mechanisms in metal genotoxicity: the significance of in vitro approaches. Mutat. Res. 198:321-326.

4207. Sobel, W.; Bond, G.C.; Baldwin, C.L.; Ducommun, D.J. 1988. An update of respiratory cancer and occupational exposure to arsenicals. Am. J. Indust. Med. 13;263-270.

4208. Ferguson, J.F.; Gavis, J. 1972. A review of the arsenic cycle in natural waters. Water Res. 6:1259-1274.

4209. U.S. Environmental Protection Agency (U.S. EPA) 1989. National Primary Drinking Water Regulations. 40 CFR Parts 141, Subpart B - Maximum contaminant levels, § 141.11 Maximum contaminant levels for inorganic chemicals.

4210. Lemmo, N.V.; Faust, S.D.; Belton, T.; Tucker, R. 1983. Assessment of the chemical and biological significance of arsenical compounds in a heavily contaminated watershed: 1. The fate and speciation of arsenical compounds in aquatic environments: A literature review. J. Environ. Sci. Health 18:335-388.

4211. Gulen, J.; et al. 1979. Chemical modeling in aqueous solutions. In: ACS Symposium Series, vol. 93. chapter 4. As reported in 4010.

4212. Huang, T.R. 1975. [Title not given]. Soil Sci. Am. Proceed. 39:271. As reported in 4210.

4213. Pierce, M.L.; Moore, C.B. 1982. [Title not given]. Water Research 16:1247. As reported in 4210.

4214. Stokinger, H. E. 1978. Arsenic. In Patty's Industrial Hygiene and Toxicology, 3rd ed., G.D. Clayton and F.E. Clayton, eds. New York: John Wiley and Sons. pp. 1517-1531.

4215. Barlow, S. M.; Sullivan, F. M. 1982. Arsenic and its compounds. In: Reproductive Hazards of Industrial Chemicals. New York: Academic Press. pp. 62-82.

4216. Hong, H.L.: Fowler, B.A.; Boorman, G.A. 1989. Hematopoietic effects in mice exposed to arsine gas. Toxicol. Appl. Pharmacol. 97:173-182.

4217. Fowler, B.A.; Woods, J.S. 1979. The effects of prolonged oral arsenate exposure on liver mitochondria of mice: morphometric and biochemical studies. Toxicol. Appl. Pharmacol. 50:177-187.

4218. Fowler, B.A.; Woods, J.S.; Schiller, C.M. 1979. Studies of hepatic mitochondrial structure and function. Morphometric and biochemical evaluation of in vivo perturbation by arsenate. Lab. Invest. 42:313-320.

4219. Brinckman, F.E.; Parris, G.E.; Blair, W.R.; Jewett, K.L.; Iverson, W.P., Bellama, J.M. 1977. Questions concerning environmental mobility of arsenic: needs for a chemical data base and means for speciation of trace organoarsenicals. Environ. Health Perspect. 19:11-24.

7000. Occupational Safety and Health Administration (OSHA) 1989. Air contaminants: final rule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7001. Occupational Safety and Health Administration (OSHA) 1978. Toxic contaminants: arsenic. 29CFR1910.1018, Fed. Regist., 5/5/78, 43:19624, as amended 1978, 43:28472 and 1980, 45:35282.

7003. Occupational Safety and Health Administration (OSHA) 1989. Hazardous waste operations and emergency response; final rule. 29CFR1910.120, Fed. Regist., 3/6/89, 54:9294-9336.

7004. U.S. Environmental Protection Agency (U.S. EPA) 1989. Notice of issuance of pesticide registration standards. Fed. Regist., 2/22/89, 54:7740.

7005. U.S. Environmental Protection Agency (U.S. EPA) 1971. Tolerances and exemptions from tolerances for pesticide chemicals in or on raw agricultural commodities. 40CFR180, Fed. Regist. 11/25/71, 36:22540, as revised 1976, 41:4537.

7009. U.S. Environmental Protection Agency (U.S. EPA) 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT) 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7011. U.S. Environmental Protection Agency (U.S. EPA) 1980. List of pollutants and applicability of part 61; inorganic arsenic. 40CFR61.01, Fed. Regist., 6/5/80, 45:37886.

7012. U.S. Environmental Protection Agency (U.S. EPA) 1986. National emission standards for inorganic arsenic emissions from glass manufacturing plants. 40CFR61.160-165, Fed. Regist., 8/4/86, 51:28025, as amended 51:35355.

7013. U.S. Environmental Protection Agency (U.S. EPA) 1986. National emission standards for inorganic arsenic emissions from primary copper smelters. 40CFR61.170-177, Fed. Regist., 8/4/86, 51:28029.

7014. U.S. Environmental Protection Agency (U.S. EPA) 1986. National emission standards for inorganic arsenic emissions from arsenic trioxide and metallic arsenic production facilities. 40CFR61.180-186, Fed. Regist., 8/4/86, 51:28033, as amended 51:35355.

7015. U.S. Environmental Protection Agency (U.S. EPA) 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. U.S. Environmental Protection Agency (U.S. EPA) 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. U.S. Environmental Protection Agency (U.S. EPA) 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. U.S. Environmental Protection Agency (U.S. EPA) 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. U.S. Environmental Protection Agency (U.S. EPA) 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020. U.S. Environmental Protection Agency (U.S. EPA) 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. U.S. Environmental Protection Agency (U.S. EPA) 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7022. U.S. Environmental Protection Agency (U.S. EPA) 1981. Timber products manufacturing point source category. 40CFR429, Fed. Regist., 1/26/81, 46:8285.

7023. U.S. Environmental Protection Agency (U.S. EPA) 1982. Ore mining and dressing point source category. 40CFR440, Fed. Regist., 12/3/82, 47:54609, as amended 1988, 53:18788.

7024. U.S. Environmental Protection Agency (U.S. EPA) 1983. Electrical and electronic components point source category. 40CFR469, Fed. Regist., 4/8/83, 48:15394, as revised 1983, 48:45250.

7045. U.S. Environmental Protection Agency (U.S. EPA) 1986. Health and safety data reporting. 40CFR716, Fed. Regist., 1/22/86, 51:2890, as last amended 1989, 54:51131.

7050. U.S. Environmental Protection Agency (U.S. EPA) 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7051. U.S. Environmental Protection Agency (U.S. EPA) 1975. Maximum contaminant levels for inorganic contaminants. 40CFR141.11, 12/24/75, 40:59570, as amended 1980, 45:57342 and 1982, 47:10998 and 1986, 51:11410.

7054. U.S. Environmental Protection Agency (U.S. EPA) 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. U.S. Environmental Protection Agency (U.S. EPA) 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7060. U.S. Environmental Protection Agency (U.S. EPA) 1987. Extremely hazardous substance list and threshold planning quantities. 40CFR355 (SARA Title III Section 302), Fed. Regist., 4/22/87, 52:13395, as revised 1987, 52:48073 and 1988, 53:5574.

7064. U.S. Environmental Protection Agency (U.S. EPA) 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7065. U.S. Environmental Protection Agency (U.S. EPA) 1989. Designation of extremely hazardous substances as CERCLA hazardous substances; proposed rule. 40CFR302, Fed. Regist., 1/23/89, 54:3388.

7066. U.S. Environmental Protection Agency (U.S. EPA) 1989. Reportable quantity adjustments; proposed rule. 40CFR302 and 355, Fed. Regist., 8/30/89, 54:35988.

7067. U.S. Environmental Protection Agency (U.S. EPA) 1985. Burning of waste fuel and used oil fuel in boilers and industrial furnaces. 40CFR266.40, Fed. Regist., 11/29/85, 50:49205.

7070. Food and Drug Administration (FDA). 1977. Bottled drinking water standards. 21CFR103.35, Fed. Regist., 3/15/77, 42:14325, as last amended 1984, 49:10090.

7074. U.S. Environmental Protection Agency (USEPA). 1980. Characteristic of EP toxicity. 40CFR261.24, Fed. Regist., 5/19/80, 45:33119, as amended 1981, 46:35247.

7076. U.S. Environmental Protection Agency (U.S. EPA) 1981. Hazardous wastes from specific sources. 40CFR261.32, Fed. Regist., 1/16/81, 46:4618, as last amended 1988, 53:35420.

7077. U.S. Environmental Protection Agency (U.S. EPA) 1981. Basis for listing hazardous waste. 40CFR261 Appendix VII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:35421.

7078. U.S. Environmental Protection Agency (U.S. EPA) 1980. Discarded commercial chemical products and their hazardous waste numbers. 40CFR261.33, Fed. Regist., 11/25/80, 45:78529 and 78541, as last amended 1988, 53:43881 and 43884.

7080. U.S. Environmental Protection Agency (U.S. EPA) 1982. Groundwater protection: concentration limits. 40CFR264.94, Fed. Regist., 7/26/82, 47:32350, as amended 1983, 48:14294.

7082. U.S. Environmental Protection Agency (U.S. EPA) 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7083. U.S. Environmental Protection Agency (U.S. EPA) 1988. Hazardous waste injection restrictions: waste specific prohibitions. 40CFR148.10-16, Fed. Regist., 8/16/88, 53:30908, as amended 1988, 53:41602 and 1989, 54:25422 and 26647.

7084. U.S. Environmental Protection Agency (U.S. EPA) 1988. Waste specific prohibitions - first third wastes. 40CFR268.33, Fed. Regist., 8/17/88, 53:31217.

7086. Council of European Communities Directive on Drinking Water, 16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7087. Council of European Communities Directive on Bathing Water Quality, 8 December 1975 (76/160/EEC-OJ L31, 5 February 1976, amended by 1851).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7093. Council of European Communities Directive on Toxic and Dangerous Waste, 20 March 1978, amended by 1851.

7095. Council of European Communities Directive on Classification, Packaging and Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7099. Proposal or a Council Directive on the Dumping of Waste at Sea, Comm (85) 373 Final, 4 July 1985.

7100. Council Directive on Major Accident Hazards of Certain Industrial Accidents. June 24, 1982; 82/501/EEC. Official Journal No. L 230/1, 87/21/216/EEC, OJ L 85, 28 March 1987, p. 36, amended by 87/216/EEC of 19 March 1987).

7104. Council Directive on the Combating of Air Pollution from Industrial Plants, 84/360/EEC, 228 June 1984.

7105. Council Decision Concluding the Convention for the Prevention of Marine Pollution From Land-Based Sources, 75/437/EEC, 3 March 1975.

7121. District of Columbia Department of Consumer and Regulatory Affairs. 1985. Water Quality Standards of the District of Columbia, Chapter II, Title 21 DCMR, effective 12/27/85.

7122. Mississippi Department of Environmental Quality. 1989. State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters; proposed amendments, 12/22/89.

7128. Minnesota Pollution Control Agency. 1989. Minnesota Rules Chapter 7050, Standards for the Protection of the Quality and Purity of the Waters of the State, proposed 12/8/89.

COMMON SYNONYMS:	CAS. Reg. No.: 7440-02-0 NIOSH No.: QR 5950000 EPA Hazardous Waste No.: ND
Nickel (dust, powder) Nickel 270 Nickel sponge NP 2 Raney nickel Raney catalyst 28 CI 77775	Chemical Symbol: Ni

REACTIVITY (6200)

Powdered nickel may ignite spontaneously in air. Flammable as dust or fume. Reacts violently with fluorine, ammonium nitrate, hydrazine, ammonia, hydrogen plus dioxane, performic acid, phosphorus, selenium, sulfur, and titanium plus potassium chlorate. Incompatible with oxidants such as bromine pentafluoride, peroxyformic acid, potassium perchlorate, chlorine, nitryl fluoride, and ammonium nitrate. Raney-nickel catalysts may initiate dangerous reactions with ethylene plus aluminum chloride; p-dioxane; hydrogen plus oxygen; magnesium silicate; methanol; organic solvents plus heat; sulfur compounds.

PHYSICO-CHEMICAL DATA

• Atomic Weight: 58.7	(6200)
• Atomic Number: 28	(6200)
• Group and Valence: 2, 0; seldom 1, 3, or 4	(6202)
• Physical State: Solid	(6200)
• Color: Silvery-white	(6200)
• Odor: Odorless	(6200)
• Odor Threshold: NA	
• Density: 8.90 at 25°C	(6200)
• Melting Point: 1455°C	(6200)
• Boiling Point: 2730°C	(6200)
• Flash Point: ND	
• Flammable Limits: ND	
• Autoignition Temperature: ND	
• Vapor Pressure: 1 mm at 1810°C	(6200)
• Saturated Concentration in Air: NA	

PHYSICO-CHEMICAL DATA (Cont.)

- Solubility in Water: Insoluble (6204)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: 2,000 - 40,000 (algae) (6204)
  40 (freshwater fish)

HANDLING PRECAUTIONS (6202,6205)

May cause dermatitis in sensitive individuals. Avoid repeated or prolonged exposure, wash promptly upon contamination. Change work clothing daily. Any supplied respirator with full face-plate and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive pressure mode.

COMMON SYNONYMS:	CAS. Reg. No.: 373-02-4 NIOSH No.: QR 6125000 EPA Hazardous Waste No.: ND
Nickel acetate Nickelous acetate Acetic acid, nickel(II) salt	Chemical Formula: $C_4H_6O_4 \cdot Ni$

REACTIVITY (6200)

When heated to decomposition nickel acetate will release irritating fumes.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 176.81	(6200)
• Physical State: Solid, crystalline	(6200)
• Color: Green	(6200)
• Odor: None	(6207)
• Odor Threshold: NA	
• Density: 1.74 at 20°C	(6207)
• Melting Point: NA/decomposes	(6207)
• Boiling Point: 16.6°C	(6228)
• Flash Point: NA	
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: ND	(6228)
• Viscosity: NA	
• Surface Tension: NA	
• Log (Octanol-Water Partition Coeff.): NA	
• Soil-Water Distribution Coeff.:	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (6207)

Avoid contact with solid and dust. Wear rubber gloves, safety goggles and protective clothing. Use Bureau of Mines approved respirator.

COMMON SYNONYMS:	CAS. Reg. No.: 15699-18-0 NIOSH No.: ND EPA Hazardous Waste No.: ND
Nickel ammonium sulfate Ammonium nickel sulfate Nickel ammonium sulfate hexahydrate Ammonium disulfatonickelate (II)	Chemical Formula: $NiSO_4 \cdot (NH_4) \cdot 6H_2O$

REACTIVITY (6207)

Toxic gases may be released when heated.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 395.0	(6207)
• Physical State: Solid, crystalline	(6201, 6207)
• Color: Dark green-blue	(6207)
• Odor: Odorless	(6207)
• Odor Threshold: NA	
• Density: 1.92 at 20° C	(6207)
• Melting Point: ND	
• Boiling Point: Decomposes	(6207)
• Flash Point: NA	
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: Sinks and mixes slowly	(6207)
• Viscosity: NA	
• Surface Tension: NA	
• Log (Octanol-Water Partition Coeff.): NA	
• Soil-Water Distribution Coeff.: NA	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (6207)
Use rubber gloves, face shield or safety glasses, Bureau of Mines approved respirator. Wear protective clothing.

COMMON SYNONYMS:	CAS. Reg. No.: 333-67-3 NIOSH No.: QR 6200000 EPA Hazardous Waste No.: NA
Nickel carbonate C.I. 77779 Nickelous carbonate	Chemical Formula: $CNiO_3$

REACTIVITY (6205)

Incompatible with strong acids. Toxic gases may be released when heated to decomposition.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 118.72 (6200)
- Physical State: Solid, crystalline (6200)
- Color: Light green (6200)
- Odor: ND
- Odor Threshold: ND
- Density: ND
- Melting Point: decomposes (6228)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 0.0093 g/ml (6228)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (6205)

Use goggles, barrier shields or other devices as necessary for personal protection. Use respirator with full facepiece and operated in a pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive pressure mode.

COMMON SYNONYMS:	CAS. Reg. No.: 134-39-3 NIOSH No.: QR 6300000 EPA Hazardous Waste No.: ND
Nickel carbonyl Nickel tetracarbonyl	Chemical Formula: $Ni(CO)_4$

REACTIVITY (6200)

Vapor and liquid are flammable and should not be exposed to heat, flame, or oxidizers. Moderate explosion hazard when exposed to heat or flame. Explodes when heated to 60°C. Violently reacts with air, oxygen, or dinitrogen tetraoxide. Produces an explosive reaction in combination with liquid bromine; mercury + oxygen; oxygen + butane. Releases carbon monoxide when heated to decomposition or when in contact with acids or acid fumes. Nickel carbonyl is highly lipid soluble and is soluble in alcohol, benzene, chloroform, acetone, and carbon tetrachloride.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 170.75	(6200)
• Physical State: Liquid	(6200)
• Color: Colorless to yellow	(6200, 6207)
• Odor: Musty, stale odor	(6207)
• Odor Threshold: ND	
• Density: 1.3185 at 17°C	(6200)
• Melting Point: -25°C/-19.3°C	(6207, 6200)
• Boiling Point: 43°C at 1 atm	(6207)
• Flash Point: <-4°C	(6200)
• Flammable Limits: 2% (LFL)	(6207)
• Autoignition Temperature: <200°C (vapor)	(6207)
• Vapor Pressure: 400mm at 25.8°C	(6200)
• Saturated Concentration in Air: Oxidizes in air	(6200)
• Solubility in Water: Insoluble	(6200)
• Viscosity: ND	
• Surface Tension: 15.9 dynes/cm at 20°C	(6207)
• Log (Octanol-Water Partition Coeff.): ND	
• Soil-Water Distribution Coeff.: NA	
• Henry's Law Constant: ND	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (6205, 6207)

Avoid contact with liquid or vapor. Wear protective clothing. Use respirator with full facepiece and operated in a pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive pressure mode.

COMMON SYNONYMS:	CAS. Reg. No.: 7791-20-0 NIOSH No.: QR 6480000 EPA Hazardous Waste No.: ND
Nickel chloride Nickel chloride hexahydrate Nickelous chloride	**Chemical Formula:** $NiCl_2$ $NiCl_2 \cdot 6H_2O$ (hexahydrate)

REACTIVITY (6200, 6201)

Nickel chloride is soluble in water, alcohol, and ammonium hydroxide. Reacts violently with potassium. At its heat of decomposition it emits very toxic chlorine fumes.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 237.73 for $Cl_2Ni \cdot 6H_2O$; 129.60 for $NiCl_2$ (6200)
- Physical State: Solid, crystalline (6200)
- Color: Green ($Cl_2Ni \cdot 6H_2O$); yellow ($NiCl_2$) (6207)
- Odor: None (6207)
- Odor Threshold: None (6207)
- Density: 3.55($NiCl_2$) at 15°C (6207)
- Melting Point: 1001°C (6207)
- Boiling Point: sublimes at 987°C (6200)
- Flash Point: Nonflammable (6200)
- Flammable Limits: NA (6200)
- Autoignition Temperature: NA (6200)
- Vapor Pressure: 1 mm Hg at 671°C (6200)
- Saturated Concentration in Air: ND
- Solubility in Water: 64.2 g $NiCl_2$/100 ml; 254 g $NiCl_2 \cdot 6H_2O$/100 ml (6228)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (6207)
Avoid contact with solid and dust. Wear goggles or face shield; protective gloves. Wear protective clothing; Bureau of Mines approved respirator.

COMMON SYNONYMS:	CAS. Reg. No.: 557-19-7 NIOSH No.: QR 649500 EPA Hazardous Waste No.: NA
Nickel cyanide Nickel(II) cyanide	Chemical Formula: $Ni(CN)_2 \cdot 4H_2O$

REACTIVITY (6207)

Incandescent reaction when heated with magnesium. When heated to decomposition, nickel cyanide will release highly toxic CN^- fumes.

HANDLING PRECAUTIONS (6207)

- Molecular Weight: 110.73 (6228)
- Physical State: Solid (6207)
- Color: Light green or yellow-brown (6207)
- Odor: Weak cyanide or almond-like odor (6207)
- Odor Threshold: ND
- Density: 2.4 at 25°C (6207)
- Melting Point: Loses 4 H_2O at 200°C (6201)
- Boiling Point: Decomposes (6207)
- Flash Point: NA
- Flammable Limits: NA
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: Insoluble (6228)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (6207)
Wear rubber gloves and goggles. Wear respirator or dust mask.

COMMON SYNONYMS:	CAS. Reg. No.: 12054-48-7 NIOSH No.: QR 7040000 EPA Hazardous Waste No.: NA
Nickel hydroxide Nickel(II) hydroxide Nickelous hydroxide Nickelic hydroxide	Chemical Formula: $Ni(OH)_2$

REACTIVITY

No data were located regarding special considerations for the reactivity of nickel hydroxide.

PHYSICO-CHEMICAL DATA

- *Molecular Weight: 92.70* (6228)
- Physical State: Solid (6201)
- Color: Green (6201)
- Odor: ND
- Odor Threshold: ND
- Density: 4.15 (6228)
- Melting Point: Decomposes at 230°C (6228)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 0.013 g/ml (6228)
- Viscosity: ND
- *Surface Tension: ND*
- Log (Octanol-Water Partition Coeff.): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: ND
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (6207)
Use goggles, barrier shields or other devices as necessary for personal protection.

COMMON SYNONYMS:	CAS. Reg. No.: 13138-45-9 NIOSH No.: QR 7200000 EPA Hazardous Waste No.: NA
Nickel nitrate Nickel (II) nitrate	Chemical Formula: $Ni(NO_3)_2$

REACTIVITY (6200)

Contact of solid nickel nitrate with wood or paper may cause fire. When heated to decomposition nickel nitrate emits very toxic fumes of NO_x.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 182.73 (6200)
- *Physical State: Solid, crystalline* (6200)
- Color: Green (6200)
- Odor: NA
- Odor Threshold: NA
- Density: 2.05 (6200)
- Melting Point: 56.7°C (6200)
- Boiling Point: 136.7°C (6200)
- Flash Point: Nonflammable (6207)
- Flammable Limits: NA
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 238.5 g/ml (hexahydrate) (6228)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (6207)
Avoid contact with solid and dust. Wear gloves, face shield or safety goggles, protective clothing. Bureau of Mines approved respirator.

COMMON SYNONYMS:	CAS. Reg. No.: 1313-99-1 NIOSH No.: QR 8400000 EPA Hazardous Waste No.: ND
Nickel oxide Nickel monoxide Bunsenite Nickelous oxide Green nickel oxide Nickel protoxide	Chemical Formula: NiO

REACTIVITY (6200)

May react violently with fluorine, hydrogen peroxide, hydrogen sulfide, iodine, or barium oxide + air. In the presence of air, may react with calcium oxide to produce vivid incandescence or explosion. Insoluble in water and soluble in acids.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 74.71	(6200)
• Physical State: Solid, crystalline	(6200)
• Color: Green-black, yellow when hot	(6200)
• Odor: NA	
• Odor Threshold: NA	
• Density: 7.45	(6200)
• Melting Point: 1900°C	(6200)
• Boiling Point: NA	(6228)
• Flash Point: Nonflammable	(6200)
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: Insoluble	(6200)
• Viscosity: NA	
• Surface Tension: NA	
• Log (Octanol-Water Partition Coeff.): NA	
• Soil-Water Distribution Coeff.: NA	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (6205)

Use goggles, barrier shields, and other devices for personal protection. Use polyvinyl, not rubber, gloves. Wear protective clothing. Use carefully fitted mask or respirators if working with dust or gases.

COMMON SYNONYMS:	CAS. Reg. No.: 12035-72-2 NIOSH No.: QR 9800000 EPA Hazardous Waste No.: NA
Nickle subsulfide Nickel sulphide Nickel subsulphide Heazlewoodite Nickel sulfide	Chemical Formula: Ni_3S_2

REACTIVITY (6200)

When heated to decomposition, nickel subsulfide will emit toxic fumes of SO_x.

PHYSICO-CHEMICAL DATA

- Molecular Weight: 240.25 (6200)
- Physical State: Solid, crystalline (6200)
- Color: Bronze (6228)
- Odor: Odorless (6228)
- Odor Threshold: NA
- Density: 5.82 (6228)
- Melting Point: 790°C (6228)
- Boiling Point: NA (6228)
- Flash Point: Nonflammable
- Flammable Limits: NA
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: Insoluble (6228)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff.: NA
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (6205)

Wear protective clothing. Use respirator with full facepiece and operated in a pressure-demand or other positive pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode.

COMMON SYNONYMS:	CAS. Reg. No.: 7786-81-4 NIOSH No.: QR 9350000 EPA Hazardous Waste No.: NA
Nickel sulfate Nickelous sulfate Nickel(II) sulfate NCI-C60344	Chemical Formula: $NiSO_4$

REACTIVITY (6200)

When heated to decomposition or reacted with strong acids it will release toxic fumes of SO_x.

PHYSICO-CHEMICAL DATA

• Molecular Weight: 154.77	(6200)
• Physical State: Solid, crystalline	(6201)
• Color: Yellow-green	(6201)
• Odor: Odorless	(6207)
• Odor Threshold: NA	
• Density: 3.68	(6201)
• Melting Point: 840° C	(6201)
• Boiling Point: ND	
• Flash Point: Nonflammable	(6207)
• Flammable Limits: NA	
• Autoignition Temperature: NA	
• Vapor Pressure: NA	
• Saturated Concentration in Air: NA	
• Solubility in Water: 29.3 g/ml	(6228)
• Viscosity: NA	
• Surface Tension: NA	
• Log (Octanol-Water Partition Coeff.): NA	
• Soil-Water Distribution Coeff.: NA	
• Henry's Law Constant: NA	
• Bioconcentration Factor: ND	

HANDLING PRECAUTIONS (6205)

Wear protective clothing. Use respirator with full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive pressure mode.

PERSISTENCE IN THE SOIL-WATER SYSTEM (6206)

Nickel is extremely persistent in soil (primarily as nickel ferrite) and has an average residence time of 2,400 to 3,500 years. It may leach through soil and enter groundwater systems. Nickel is fairly mobile in low pH and low cation exchange capacity mineral soils, and is less mobile in basic mineral soils or those with higher organic content. Organic complexing agents may form organo-nickel complexes thereby restricting mobility. Acid rain will tend to increase nickel mobility and potential for groundwater contamination. There are no data suggesting volatilization of nickel from water. Water soluble forms such as nickel acetate, nickel chloride, nickel sulfate hexahydrate and nickel nitrate hexahydrate will be more mobile than insoluble forms.

PATHWAYS OF EXPOSURE

The primary pathways of concern are migration of nickel from soil/groundwater systems into drinking water supplies, and ingestion of nickel via its bioaccumulation in agricultural products and seafoods. Volatilization of nickel from groundwater sources is unlikely, but inhalation of nickel and nickel compounds in certain industrial settings may be significant.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure (6200, 6206, 6207, 6379):

With the exception of skin allergies in sensitized individuals, short-term toxic effects in humans are usually associated with inhalation of vapors or dusts containing nickel or nickel compounds. Inhalation of these may cause irritation of the respiratory tract resulting in coughing and shortness of breath. Inhalation exposure to nickel carbonyl is especially hazardous with short-term exposure causing respiratory tract irritation, eye irritation, headache, giddiness, dyspnea, weakness, tachycardia, and death. Signs and symptoms may also occur following ingestion, dermal or oral exposure. Exposure to nickel acetate may cause irritation of the eyes and respiratory tract, and vomiting. Intake of nickel sulfate and nickel chloride (1.63 g Ni/L) resulted in rapid onset of nausea, vomiting, abdominal discomfort, diarrhea, giddiness, lassitude, headache, cough, and shortness of breath.

Acute Toxicity Studies:

Inhalation:

LC_{Lo}	30 ppm: 30 min.	(nickel carbonyl)	Human	(6200)
TC_{Lo}	7 mg/m^3	(nickel carbonyl)	Human	(6200)
TC_{Lo}	15 mg/m^3	(nickel)	Guinea pig	(6200)
LC_{Lo}	360 ppm: 90 min.	(nickel carbonyl)	Dog	(6200)
LC_{Lo}	7.3 g/m^3: 50 min.	(nickel carbonyl)	Rabbit	(6200)
TC_{Lo}	0.97 mg/m^3: 6 hrs.	(nickel subsulfide)	Rat	(6200)

Oral:

LD_{Lo}	5 mg/kg	(nickel)	Guinea pig	(6200)
LD_{50}	>9,000 mg/kg	(nickel)	Rat	(6206)
LD_{50}	350 mg/kg	(nickel acetate)	Rat	(6200)
LD_{50}	105 mg/kg	(nickel chloride)	Rat	(6200)
LD_{50}	1,600 mg/kg	(nickel hydroxide)	Rat	(6206)
LD_{50}	>5,000 mg/kg	(nickel oxide)	Rat	(6206)
LD_{50}	1620 mg/kg	(nickel nitrate)	Rat	(6200)
LD_{50}	>5,000 mg/kg	(nickel subsulfide)	Rat	(6206)
LD_{50}	300 mg/kg	(nickel sulfate)	Rat	(6206)
LD_{50}	410 mg/kg	(nickel acetate)	Mouse	(6200)

Dermal:

Quantitative, acute toxicity data regarding dermal exposure were not located for nickel or nickel compounds.

HEALTH HAZARD DATA (Cont.)

Long-Term Effects:

Nickel dermatitis, respiratory irritation (rhinitis, sinusitis), and asthma in humans, and compromised immune system function in animals.

Pregnancy/Neonate Data:

Animal studies have provided evidence for developmental/reproductive toxicity due to nickel and/or nickel compounds.

Genotoxicity Data:

Equivocal data.

Carcinogenicity Classification:

IARC — Nickel and nickel compounds (nickel powder, subsulfide, oxide, hydroxide, carbonate, carbonyl, nickelocene, nickel iron-sulfide matec, nickelous acetate) are classified as Group 1 (carcinogenic to humans). Metallic nickel is classified as Group 2B (possibly carcinogenic to humans)

NTP — Results pending

EPA — Nickel dust and nickel subsulfide classified as Group A (human carcinogen). Nickel carbonyl classified as Group B2 (probable human carcinogen, inadequate evidence in humans, sufficient evidence in animals).

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards

- OSHA TWA (8-hr TWA): Nickel carbonyl: 0.007 mg Ni/m^3
  Nickel metal: 1 mg/m^3
  Insoluble nickel compounds: 1 mg Ni/m^3
  Soluble nickel compounds: 0.1 mg Ni/m^3
- OSHA STEL (15-min): None established
- AFOSH PEL (8-hr TWA): Nickel carbonyl: 0.007 mg Ni/m^3
  Nickel metal: 1 mg Ni/m^3
  Insoluble nickel compounds: 1 mg Ni/m^3
  Soluble nickel compounds: 0.1 mg Ni/m^3

Criteria

- NIOSH REL (8-hr TWA): Nickel carbonyl: 0.007 mg Ni/m^3
  Inorganic nickel compounds: 0.015 mg Ni/m^3
- NIOSH STEL (15-min ceiling): ND
- ACGIH TLV® (8-hr TWA): Nickel dust: 1.0 mg Ni/m^3
  Insoluble nickel compounds: 1.0 mg Ni/m^3
  Soluble nickel compounds: 0.1 mg Ni/m^3

  Listed under Notice of Intended Changes for 1989-1990: 0.05 mg Ni/m^3 (nickel metal, insoluble nickel compounds, soluble nickel compounds) (6375)
- ACGIH STEL (15-min): ND

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

WATER EXPOSURE LIMITS:

Drinking Water Standards (6407)

- MCLG (proposed): 100 µg/L
- MCL (proposed): 100 µg/L

EPA Health Advisories and Cancer Risk Levels (6407)

- The U.S. 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): 1000 µg/L
  - 10-day (child): 1000 µg/L
  - longer-term (child): 100 µg/L
  - longer-term (adult): 600 µg/L
  - lifetime (adult): 100 µg/L
  - DWEL: 600 µg/L
  - 1E-04 cancer risk level: none established for ingestion

WHO Drinking Water Guideline (6221)

- A health-based guideline for nickel is currently being developed.

EPA Ambient Water Quality Criteria (6362)

- Human Health
  - Based on ingestion of water and contaminated aquatic organisms, the ambient water criterion is 13.4 µg/L
  - Based on ingestion of contaminated aquatic organisms alone, the ambient water criterion is 100 µg/L.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- **Aquatic Life**

  —Freshwater species

  For total recoverable nickel, the criterion (in µg/L) for protection of freshwater species is defined by: $e^{(0.76[\ln(\text{hardness})] + 1.06)}$ as a 24-hour average and should not exceed at any time the numerical value defined by $e^{(0.76[\ln(\text{hardness})] + 4.02)}$.

  Acute toxicity:acute toxicity values for 22 species ranged from 510 µg/L (Daphnia magna) to 46,200 µg/L for banded killifish.

  Chronic toxicity: chronic data for two invertebrate species were 14.8 µg/L for Daphnia magna in soft water to 530 µg/L for the fathead minnow in hard water.

  —Saltwater species

  For total recoverable nickel the criterion (in µg/L) to protect saltwater species is 7.1 µg/L as a 24-hour average and should not exceed at any time 140 µg/L.

  Acute toxicity: acute toxicity values ranged from 152 µg/L for a mysid shrimp to 350,000 µg/L for the mummichog fish.

  Chronic toxicity: a chronic toxicity value of 141 µg/L was obtained for a mysid shrimp.

REFERENCE DOSES: (6377)

- **Inhalation:** ND
- **Oral:** 20 µg/kg/day (soluble nickel salts)

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- **Federal Programs**

Clean Water Act (CWA)
The following nickel compounds have been designated as hazardous substances under the CWA: nickel ammonium sulfate, nickel chloride, nickel hydroxide, nickel nitrate, and nickel sulfate (7015). The reportable quantity (RQ) limit has been set at 4.54 kg (10 lbs) for nickel hydroxide, and 45.4 kg (100 lbs) for the remaining hazardous nickel compounds (7016). Nickel and nickel compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (7017, 7018). Effluent limitations for nickel exist in the following point source categories: electroplating (7025), organic chemicals, plastics and synthetic fibers (7030), inorganic chemicals manufacturing (7019), iron and steel manufacturing (7032), nonferrous metals manufacturing (7020), steam electric power generating (7021), metal finishing (7026), ore mining and dressing (7023), battery manufacturing (7027), porcelain enameling (7037), copper forming (7039), and nonferrous metals forming and metal powders (7038). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)
Nickel is on the list of 83 contaminants required to be regulated under the SDWA Amendments of 1986 (7050). The Environmental Protection Agency (EPA) has established a maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) of 0.1 mg/L for nickel (6407). In states with an approved Underground Injection Control program, a permit is required for the injection of nickel-containing wastes designated as hazardous under RCRA (7054).

Resource Conservation and Recovery Act (RCRA)
Nickel carbonyl (#P073) and nickel cyanide (#P074) are identified under RCRA as acute hazardous wastes (7078). Nickel, nickel compounds, nickel carbonyl, and nickel cyanide are all listed as hazardous waste constituents (7080). A non-specific source of nickel-containing hazardous waste is wastewater treatment sludge from electroplating operations (#F006) (7075, 7077). Nickel is subject to land disposal restrictions when its concentration as a hazardous waste constituent exceeds designated levels. The following land disposal prohibition effective dates have been set for the designated nickel-containing hazardous wastes: August 8, 1988 for waste number F006, and June 8, 1989 for waste number P074. These wastes are prohibited from land

REGULATORY STATUS (Cont.)

disposal and underground injection unless designated treatment standards or the statutory no migration standards are met. A variance exists until May 8, 1990 for hazardous waste #P073 (nickel carbonyl) because a treatment standard has not yet been promulgated for it. Site-specific variances can be obtained for soil and debris contaminated with hazardous waste (7068). Effective August 8, 1990, liquid wastes containing nickel in concentrations greater than or equal to 134 mg/L are prohibited from underground injection (7083). Nickel 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 (7082).

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)

Nickel compounds designated as hazardous substances under CERCLA include: nickel, nickel(II) cyanide, nickel carbonyl, nickel sulfate, nickel nitrate, nickel hydroxide, nickel chloride, and nickel ammonium sulfate. Reportable quantities (RQs) are set at 4.54 kg (10 lbs) for nickel carbonyl, nickel(II) cyanide and nickel hydroxide, and 45.4 kg (100 lbs) for the remaining nickel compounds. Reportable quantities have also been issued for RCRA hazardous waste streams containing nickel, but these depend on the concentration of the chemical in the waste stream (7064). Nickel carbonyl is designated an extremely hazardous substance under SARA Title III Section 302. Under Sections 311 and 312, any facility at which nickel carbonyl is present in excess of its threshold planning quantity of one pound must notify state and local emergency planning officials. If nickel carbonyl is released from a facility in excess of its reportable quantity (RQ), local emergency planning officials must be notified (7061). Under SARA Title III Section 313, manufacturers, processors, importers, and users of nickel compounds must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

Occupational Safety and Health Act (OSHA)

Employee exposure to nickel carbonyl shall not exceed an 8-hour time-weighted average (TWA) of 0.001 ppm or 0.007 mg/m^3. Employee exposure to nickel metal and insoluble compounds shall not exceed an 8-hour time-weighted average (TWA) of 1.0 mg/m^3. Employee exposure to nickel soluble compounds shall not exceed an 8-hour time-weighted average (TWA) of 0.1 mg/m^3 (7001). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate

REGULATORY STATUS (Cont.)

certain hazardous waste treatment, storage, and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

Clean Air Act (CAA)
After consideration of the data regarding serious health effects from ambient air exposure to nickel, EPA has decided not to regulate nickel as a hazardous air pollutant (7063).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated the following nickel compounds as hazardous materials, subject to requirements for packaging, labeling and transportation: nickel, nickel ammonium sulfate, nickel carbonyl, nickel chloride, nickel(II) cyanide, nickel hydroxide, nickel nitrate, and nickel sulfate. Reportable quantities (RQs) have been set at 4.54 kg (10 lbs) for nickel carbonyl, nickel(II) cyanide, and nickel hydroxide, and 45.4 kg (100 lbs) for the remaining nickel compounds (7010).

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of oils or 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 (7009).

- **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:

DISTRICT OF COLUMBIA
The District of Columbia has an aquatic life criterion of 100.0 μg/L for nickel in class C surface waters (7121).

REGULATORY STATUS (Cont.)

NEW YORK
New York has an ambient water quality criterion of 7.1 μg/L for nickel in marine surface waters classed for fishing and fish propagation (SA,SB,SC) and 140 μg/L for marine surface waters classed for fishing and fish survival (SD) (7119).

NORTH CAROLINA
North Carolina has set a water quality criterion of 88 μg/L for nickel in all fresh surface waters (7113).

VIRGINIA
Virginia has set 7.1 μg/L as the water quality chronic criterion for the protection of aquatic life in saltwater surface waters (7115).

WYOMING
Wyoming has a water quality criterion of 0.2 mg/L for class II (agriculture) groundwaters (7120).

Proposed Regulations

- **Federal Programs**

  Safe Drinking Water Act (SDWA)
  Although it is not regulated at this time, the Environmental Protection Agency (EPA) is considering proposing a maximum contaminant level (MCL) and a maximum contaminant level goal (MCLG) of 0.1 mg/L for nickel as part of the Phase V proposal scheduled for June, 1990 (7053, 7057).

REGULATORY STATUS (Cont.)

Resource Conservation and Recovery Act (RCRA)
EPA has proposed that nickel carbonyl-containing hazardous wastes (#P073) be prohibited from land disposal or underground injection, effective May 8, 1990, unless designated treatment standards or statutory no migration standards are met. Final action on this rule is expected by May, 1990 (7085).

- **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 1990-91 (7058) (see Appendix 4).

ILLINOIS
Illinois has proposed a general use water quality criterion of 1.0 mg/L nickel in all state waters (7130).

REGULATORY STATUS (Cont.)

EEC Directives

Directive on Drinking Water (7086)
The mandatory values for total nickel in surface water treatment categories A1, A2 or A3 are 0.05 mg/L. No guideline values are given.

Directive on Discharge of Dangerous Substances (7088)
Nickel 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 the substances into ground water.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for nickel specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of nickel in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive on Ground Water (7091)
To ensure the effective protection of groundwater in the Community it is necessary to limit the discharge of nickel in groundwater. The purpose of this directive is to prevent pollution of groundwater substances belonging to substances listed in the Annex of this directive. Nickel shall be subject to prior review so as to limit discharge into groundwater. Member states may grant authorization, provided that all technical precautions for preventing groundwater pollution by nickel has been observed.

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
The maximum admissible concentration for nickel is 50 µg/L. No guide level is given for nickel.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Nickel carbonyl is classified as a flammable, toxic substance and is subject to packaging and labeling regulations. Nickel carbonyl may contain a stabilizer. If the stabilizer changes the dangerous properties of this substance, substance should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

REGULATORY STATUS (Cont.)

Directive on Major Accident Hazards of Certain Industrial Activities (7100)
Nickel tetracarbonyl manufacturers are required to notify competent authorities if it is stored or processed in quantities in excess of 10 kg. If a major accident occurs, authorities must be provided with the circumstances of the accident, substances involved, emergency measures taken, and the data available for assessing the effects on man and the environment.

EEC Directives-Decisions

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7105)
The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials which must be eliminated; Part III substances, include less persistence organic substances and heavy metals, which must be reduced or eliminated, as appropriate; discharges must be subject to approval by representatives of the contracting party; and Part III, radioactive substances and waste discharges must be forestalled and, as appropriate, eliminated.

76.1 MAJOR USES

World mine production of nickel totaled 867,098 short tons in 1987 (6209). Although the sole U.S. nickel mine-smelter complex was closed permanently in January, 1987, domestic consumption of nickel was 164,820 short tons for that year (6209). A major part of the supply (approximately 10-20%) of nickel for consumption was recovered from scrap and used for the production of secondary nickel (6209, 6289, 6203). According to Mastromatteo (1986), the major uses of nickel include: 1) production of stainless steels; 2) production of nickel alloys; 3) production of nickel cast iron; 4) electroplating and electroforming; 5) manufacturing of alkaline (nickel-cadmium) batteries; 6) as catalysts; 7) manufacture of coins; 8) production of welding products; 9) production of sintered components; 10) inorganic pigments; and 11) electronics.

Nickel is used in more than 3000 metal alloys, including Ni-Cr-Fe alloys for the manufacture of cooking utensils and corrosion-resistant equipment; Ni-Cu alloys for coinage and for food processing, chemical, and petroleum equipment; Ni-Al alloys for magnets and aircraft parts; and Ni-Cr alloys for heating elements, gas-turbines, and jet-engines (6203). Alloys of nickel with zinc, manganese, cobalt, titanium, and/or molybdenum are used for special industrial activities, and alloys of nickel with precious metals are used for jewelry. Nickel is also used in molds for ceramic and glass containers, in surgical and dental prostheses.

76.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

Nickel can enter the environment from natural and anthropogenic sources. Schmidt and Andren (6270, cited in 6202) estimated that natural sources comprised approximately 17% of total emissions and that anthropogenic activities generated the remaining 83%, of which 52% was attributed to fossil fuel consumption alone.

Using emissions factors and statistics on the global production or consumption of industrial goods, Nriagu and Pacyna (6262) calculated the world wide emissions of trace metals to the three environmental compartments. Total emissions of nickel were estimated to be 2.4-8.7 $\times 10^7$ kg/yr to the atmosphere, 33-194 $\times 10^6$ kg/yr into aquatic ecosystems, and 1.06-5.44 $\times 10^8$ kg/yr into soil.

Nickel is released into the atmosphere in volcanic emissions and windblown dusts produced by the weathering of rocks and soils, from combustion of fossil fuels by stationary and mobile power sources, from the emissions of nickel mining and refining operations, from metal consumption in industrial processes, and from the incineration of wastes (6299, 6227). The nickel emitted into the atmosphere from fossil fuel combustion is primarily in the form of nickel sulfate (6204) along with smaller quantities of nickel oxide and more complex oxides of nickel (6242, cited in 6202).

Emissions into aquatic ecosystems are released mainly from the dissolution of rocks and soil, from biological cycles, atmospheric fallout, domestic wastewater, smelting and refining, and dumping of sewage sludge (6203). Although nickel is not a widespread contaminant in surface waters, sediment, or groundwaters, certain activities related to

mining and smelting, waste disposal or natural anomalies, result in elevated nickel in water or sediments (6258; 6272).

The earth's crustal abundance of nickel is approximately 60 ppm (6234). The effect of anthropogenic sources on the nickel content of soil is mainly local, but industrial and other manmade plumes combined with unusual climatic conditions may disperse nickel pollution over large areas (6234). Emissions into soils are primarily from coal and bottom fly ash, agriculture and food wastes, and animal wastes (manure) (6261). In addition to the deposition of airborne particulate matter, increased soil levels of nickel may result from the land application of sewage sludge (6202) and the use of commercial fertilizers with high nickel content (e.g. phosphates) (6227).

76.2.1 Transport in Soil/Ground-water Systems

76.2.1.1 Overview

Regardless of the sources of environmental contamination (natural or anthropogenic), soils and sediments are the ultimate receptacles of nickel (6268). Nickel is very persistent in the soil, but may also leach through soil to enter groundwater and/or may undergo absorption by plants. The fate of nickel in the soil is regulated by its soil chemistry (6268).

76.2.1.2 Sorption on Soils

The primary mechanisms for soil sorption of nickel are believed to be specific adsorption, ion exchange and/or co-precipitation (6233); the important sorbants appear to be iron and manganese oxides, clay minerals and, to some extent, organic matter (6216, cited in 6233).

Soil nickel has a particular affinity for iron and sulfur (6251). In terrestrial rocks, nickel occurs mainly in sulfides and arsenides, and most of it is in ferromagnesians, replacing iron; however, nickel is also associated with carbonates, phosphates, and silicates. During weathering, nickel is easily mobilized and then is coprecipitated, primarily with iron and manganese oxides. The state of nickel in soils is highly dependent on the nickel content of the parent rocks, but may also reflect soil-forming processes and pollution. In surface soils, nickel can occur as organically bound forms, some of which may be soluble chelates. When chelation is incomplete, species such as Ni^{2+}, $NiOH^{+}$, $HNiO_2^{+}$, and $Ni(OH)_3^{+}$ may be present in soil solution (6251).

Determinants of the sorption/movement of metals in soils, primarily chemical properties of the soil itself, include cation exchange capacity, Ph, organic matter, total iron, and surface area (6268, 6269, 6267, cited in 6269).

The cation exchange capacity (CEC) of the soil strongly affects the concentration and species distribution of nickel in soil solution (6279). In acidic sandy soils the cationic forms have been found, while in heavy soils, mainly negative species have been found, but to a lesser extent. Tyler and McBride (1982) demonstrated that adsorption

of nickel and other heavy metals resulted in a nearly stoichiometric desorption of Ca^{2+}, Mg^{2+}, Al^{3+}, Na^{+}, and K^{+}.

In studies with Indian Red Soil, Khan et al. (1982) observed that the decomposition of soil organic matter greatly increased the mobility of nickel whereas a rise in pH of the soil water system caused a decrease. Initial addition of all anions (Cl^{-}, HCO_3^{-}, CO_3^{-}, SO_4^{-}, PO_4^{-}, and MoO_4^{-} apparently enhanced mobility but high levels of SO_4^{-}, PO_4^{-}, and MoO_4^{-} reduced mobility. Compared with other metals, the mobility of nickel tested in soils saturated with different exchangeable cations was moderate.

In soils of high pH and high organic content (or in cases in which nickel was added to the soil in compost treatment), the movement of nickel was retarded and the concentration of the metal in the soil increased as a result of the formation of organo-nickel complexes (6276, 6268, 6264). Therefore, acid rain would be expected to increase the mobility of nickel in the soil, potentially resulting in contamination of groundwaters (6203); however, it appears that even under very acid conditions, organic matter can restrict the movement and availability of nickel (6276).

Measurements of nickel movement in soil systems indicate that when nickel is applied to the soil in sewage sludge its downward movement is limited. In one study, the movement of sludge-borne metals in an agricultural landscape following 10 years of annual sludge applications was examined in runoff from a terraced watershed (6239). Samples of soil water at a depth of 60 cm taken after 5 years of sludge application contained enough nickel to suggest a slight movement of the metal, but no evidence of movement was detected in year 6. In another study, Brown et al. (6235) examined samples from four types of soil that were collected after one year of application of sewage effluent. Increased concentrations of the applied nickel remained in the top 12.7 cm of soil. Nickel concentrations in leachate water, collected monthly from all soils at 1.5 m below the surface, were below the detection limits of 0.001 mg/L. The different characteristics of the four soils did not seem to affect the depth of movement. A typical landfill leachate may contain 0.01-1.2 mg/L of nickel (6271, cited in 6278, 6250); in one study, values in this range were considered to be low when compared with the concentrations of other metals (e.g. iron and zinc) (6250).

The extent of sorption is commonly described in terms of isotherms based on Langmuir or Freundlich constants. Typical sorption constants for nickel are listed and explained in Table 1 These values are based on limited data and caution is advised in using them (6233). Table 2 shows that Freundlich isotherms for nickel sorption vary according to soil type, with clay, clay loam and sand exhibiting generally higher values than sandy loam, loamy sand and silt loam (6216, cited in 6233).

Table 76-1

Typical Sorption Constants for Nickel

	Soils (Median Values)		
Parameter[a]	Mn Oxides	Fe Oxides	Clay
K_d (L/g)	40	100*	0.2**
S (μmol/g)	5.6	8.6	40
Am (μmol/g)	600**		
Log K_L (log M^{-1})	3.5**		
K_F (L/g)	0.27		
1/N	0.95		

* Only one value
** Only two values

[a]Definitions: K_d = distribution coefficient (L/g)
S = sorption (μmol/g)
A_m, K_L = Langmuir constants, where $S = (K_L A_m C)/(1 + K_L C)$ and S = moles sorbed at equilibrium per gram of solid, K_L = sorption constant related to binding energy of sorbate, and C = total sorbate concentration in solution at equilibrium
D_F, 1/N = Fruendlich constants for $S = D_F C^{1/N}$, where S = μmol/g and C = μM

Source: 6216

Table 76-2

Freundlich Isotherms for Nickel Sorption on Soils

Freundlich Isotherm	Clay	Clay Loam	Sand	Sandy Loam	Silt Loam	Loamy Sand
K_F(L/g)	0.6-0.73	0.51	0.31-0.50	0.11-0.48	0.057-0.44	0.005-0.01
1/N	0.95-1.03	1.02	1.01-1.18	0.81-0.99	0.57-0.9	60.87-0.92

[a]See definitions in Table 76-1

Source: 6216

76.2.1.3 Volatilization from Soils

No data were found to suggest that nickel compounds volatilize from soil surfaces.

76.2.2 Transformation Processes in Soil/Ground-water Systems

Although environmental fate processes may transform one nickel compound into another, nickel is a naturally occurring element which cannot be degraded in the environment (6202).

76.2.2.1 Soil

The residence time of nickel in the soil has been estimated to be 2400 years (6231, 6249, both cited in 6227) to 3500 years (6261, cited in 6202).

No data were found to indicate that nickel undergoes biodegradation in the soil. However, Francis and Dodge (6246) reported that native aerobic bacteria solubilized the nickel in two coal cleaning residues (fines fraction which is high in trace metals and relatively low in organic carbon and filter cake which is low in trace metals and relatively high in organic carbon) and altered its mobility. Based on the amount of metal released from the residues during incubation, approximately 30% of the nickel was mobilized from the fines fraction under aerobic conditions and 10% was mobilized from the filter cake. None was mobilized under anaerobic conditions.

Sadiq and Enfield (6269) determined experimentally that nickel ferrite ($NiFe_2O_4$) precipitates in soil. Species in solution that include Ni^{2+}, nickel sulfate ($NiSO_4$), and nickel phosphate ($NiHPO_4$), predominate in soils having Ph values of less than 7, while in soil solution of Ph above 8, hydroxy complexes are important (6268). Nickel aluminate and Ni_2SiO_4 can also form, under conditions of low iron levels.

76.2.2.2 Groundwater

Nickel enters groundwater as a result of the dissolution of rocks and soils, biological cycles, atmospheric fallout, and particularly from industrial processes and waste disposal (6203). Ionic nickel is quite stable in aqueous solutions and has the potential to migrate over long distances (6212). Nickel in surface waters or groundwaters is likely to occur at very low concentrations unless its presence is a result of industrial pollution or waste disposal (6258; 6227). Mean concentrations of nickel in U.S. groundwater are highly variable, ranging from 3.0 to 4430 µg/L in 1982. However, the typical concentration in groundwater was <50 µg/L (6241, cited in 6202).

No data were found to indicate the estimated residence time for nickel in ground water; however, Nriagu (1980, cited in 6202) estimates that the metal persists for approximately 23,000 years in deep oceans and for 19 years in near-shore coastal waters. Nickel exists in numerous soluble and insoluble forms depending upon chemical and physical properties of the water (6266). Nickel concentrations in sediments usually exceed those of water by several orders of magnitude (6272).

Speciation reactions of nickel in water include: acid-base dissociation, complexation, and redox reactions (6233). Aquo-nickel ions behave as acids in water (6214). The acid dissociation constants for nickel(2+) in aqueous solution (20-25°C, 0.1 M) are 10.2 (pK_1), 9.0 (pK_2), 10.8 (pK_3), and 14.0 (pK_4) (6263, cited in 6233).

Nickel tends form complexes with both organic and inorganic ligands in aquatic systems (6233). Limited data suggest that, in unpolluted waters, nickel may exist primarily as hexahydrate ions that are subsequently coprecipitated or sorbed by hydrous oxides of iron, silica, and manganese, leading to decreases in mobility and bioavailability (6212). In more organo-rich polluted waters, organic materials will keep nickel solubilized by complexation, and approximately half may exist as simple inorganic salts and half as stable organic complexes, e.g., with humic acids. Mantoura et al. (6219, cited in 6233) reported that the logarithms of the overall conditional stability constants, K_O, of Ni(II)-humate complexes ranged from 5.14 at Ph 8 and an ionic strength of 0.02 M. The fulvic acid fractions of horticultural peat and soil had overall conditional stability constants of 4.98 and 4.2-4.35, respectively. The overall conditional stability constant is defined on the basis of an "aggregate site-type":

$$KO = \frac{[ML]}{[M^{+2}]\,[L_T - ML]}$$

Where:

$[ML]$ = total complexed Ni(II)
$[M^{+2}]$ = total free aqueous Ni(II)
$[L_T]$ = total ligand concentration
$[L_T - [ML]$ = Total uncomplexed ligand

Under anaerobic (reducing) conditions and in the presence of sulfides, nickel will precipitate out of solution as nickel sulfide (6212).

Nickel is highly mobile in water and is sorbed only to a small extent (6212). Of all the factors that control the mobility of nickel in aquatic media (i.e. complexation, precipitation/dissolution, adsorption/desorption, and oxidation/reduction [6266]), sorption of the metal by amorphous oxides of iron and manganese are probably the most important (6212). Other properties such as sulfate concentration, iron oxide surface area, and pH also influence mobility (6266). Most nickel compounds are relatively soluble at pH values <6.5, whereas nickel exists predominantly as insoluble nickel hydroxides at pH values >6.7 (6203).

No data have been found which would suggest that nickel compounds volatilize from water or undergo biodegradation in water (6212).

76.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

Nickel in the soil or groundwater can be taken up by food plants or may eventually reach drinking water, resulting in exposure of the general population to the metal. Exposure levels may be exacerbated in industrial areas, such as Sudbury, Ontario, where the metal is released into the environment in excessive amounts (6275) or in locations with elevated soil concentrations of nickel as a result of the application of sewage sludge or nickel-containing fertilizers (6202). According to Mejstrik and Svacha (6257), trace elements in particle fallout from the atmosphere are not absorbed by plants through the leaf surface, but cause only surface contamination.

Nickel is readily taken up by plants from soil (6251). Adsorption is positively correlated with the soil nickel concentration until a certain concentration of the metal is attained in the plant. The uptake by plant roots of extractable nickel is influenced by physical factors such as soil texture, temperature, and water content; chemical factors such as organic content and redox potential; and biological factors such as plant species variability and microbial activity (6202); however, the single most important factor is soil pH. Naturally acid conditions enhance nickel uptake (6243, 6251, 6203).

Nickel is essential to urease-rich plants such as Jack beans and soybeans; in these plants the concentration of nickel is very high (6203). Numerous species of nickel-accumulating plants have been identified. One of these, Sebertia acuminata, native to nickel-rich New Caledonia, contains an exceptionally high concentration of nickel, 10 g/kg dry weight in leaves and 250 g/kg in latex. Elevated levels of citric and malic acids, present in such plants, are thought to be involved in the transport and storage of nickel (6203).

The average daily intake of nickel, for people in both urban and rural areas, is estimated to range from 120 to 520 µg/day, of which diet typically contributes 83 to 94% (6202). In Danish diets, nickel intake was estimated to average 130 to 150 µg/day, occasionally reaching 900 µg/day (6259, 6277). Among a number of common Danish food items analyzed for nickel content, the highest concentrations of the metal

(1-10 mg Ni/kg fresh weight) were found in cocoa, licorice, sucerne seeds, dried beans, peanuts, hazel nuts, sunflower seeds, oat meal and wheat bran (6277).

Individuals who may be exposed to higher levels of nickel include those whose diets contain foods naturally high in nickel, and those living in the vicinity of a nickel processing facility (6202). Nickel concentrations in agricultural soils typically range between 5 to 500 μg/g, with a typical level of 50 μg/g. In nonagricultural soil, nickel concentrations are generally in the range of 4 to 80 μg/g, with a median of 26 μg/g (6211). Levels as high as 24,000 μg/g soil have been found near metal refineries (6241, cited in 6202).

Nickel or any other contaminant in groundwater would be of concern because groundwater, which comprises more than 96% of all fresh water, is the source of a majority of water supplies for large cities and more than 50% of the total population depend on groundwater resources (6278). Drinking water samples may contain much higher concentrations of nickel, due to pollution of the water supply or leaching from nickel-containing pipes or nickel-plated spigots (6229). The average concentration of nickel in municipal drinking water near large open-pit mines was ~200 μg/L compared with a concentration of 1 μg Ni/L in a control area (6227).

The average daily exposure to nickel in drinking water has been estimated to be <20 μg, based on a typical concentration of <10 μg/L nickel in drinking water (6273, cited in 6202) and assuming that the average intake of water by a human adult is 2 L/day (6202).

Sunderman et al. (6382) examined nickel absorption an kinetics in human volunteers who were given nickel sulfate (12 to 50 μg/kg) in drinking water or in food. Nickel absorption averaged 27±17% of the dose ingested in water versus 0.7±0.4% of the same dose ingested in food, thereby indicating a 40-fold difference in nickel absorption.

76.2.4 Other Sources of Human Exposure

Occupational exposure to nickel may occur at any stage in the production or use of nickel (6256). NIOSH estimated that 250,000 workers in the U.S. were exposed to nickel and its inorganic compounds (6260, cited in 6256). Exposure to water-insoluble, nickel compounds usually occurs through the inhalation of fumes or dusts (6203).

In the primary production of nickel, the following groups or occupational categories are subjected to airborne nickel (6280, cited in 6256): underground miners, sulfide mines (0.025 mg/m^3); open pit miners, laterite mines (0.05 mg/m^3); grinders and concentrating nickel (<0.05 mg/m^3); smelter workers (0.05-1.0 mg/m^3); nickel refinery workers (<1.0 mg/m^3); packaging nickel powders (<1.0 mg/m^3); calcining and sintering operations (25-30 mg/m^3) (these operations have now been eliminated); electrolytic tank house worker (0.02-0.3 mg/m^3) (soluble forms); and carbonyl refinery worker (<0.35 mg/m^3) (gaseous form). Another process, the Mond process, gives rise to nickel tetracarbonyl, a very toxic intermediate.

The following industrial uses of nickel are also sources of exposure: production of high nickel alloys (0.06-0.1 mg/m^3); manufacture and welding of stainless steel (0.01-0.1 mg/m^3); nickel foundry workers (0.01-0.3 mg/m^3); electroplating of nickel (0.004-0.01 mg/m^3) (soluble forms); nickel cadmium battery workers (0.4 mg/m^3); production wrought nickel (1.5 mg/m^3). Some of these levels are outside the current OSHA PELs of 1 mg/m^3 for nickel and its inorganic compounds and 0.007 mg/m^3 for nickel carbonyl (6237, cited in 6256).

In ambient air the mean nickel concentration is an estimated 20 ng/m^3 (6231). Near a nickel refinery in West Virginia atmospheric nickel concentrations averaged 1.2 μg/m^3, compared with 0.04 μg/m^3 at six other, apparently uncontaminated, sampling stations (6258).

Nickel, present in sea water at concentrations of ~0.1 to 0.5 μg nickel/L and in surface waters at ~15 to 20 μg of nickel/L (6256), has been detected at fairly low levels in the following edible seafood and fish: oysters (1.5 ppm fresh weight [f.w.]), mollusks (0.74 ppm f.w.), clams (0.58 ppm f.w.), Japanese shellfish (0.14 ppm f.w.), scallops (0.04 ppm f.w.), lobster, claw (0.66 ppm f.w.), crabmeat, canned (0.03 ppm f.w.), anchovies, canned (0.72 ppm f.w.), salmon (1.7 ppm f.w.), swordfish (0.02 ppm f.w.), and samples of dressed whitefish, pike, smelt and perch (0.2 ppm f.w.) (6258). Even fish that were collected in two lakes known to have elevated surface concentrations of the elements in their sediments had low levels of nickel (6248). Dietary intake of nickel can be increased by the use of stainless steel cookware and the use of nickel catalysts in hydrogenation (6202), or by dissolved nickel from drinking water pipes and beverage containers (6227).

Cigarette smoking can increase inhaled nickel by as much as 0.2 μg/cigarette (6227). Nickel-containing jewelry (particularly earrings), dental alloys and surgical implants, and dialysate fluids may be other sources of exposure (6256).

Surgically implanted hip or knee prostheses are also of concern as potential sources of human exposure to nickel. In one study, serum and urine samples from patients implanted with hip or knee porous-coated prostheses fabricated of either cobalt-chromium (containing <0.1% nickel) or Ti-Al-V (containing <0.2% nickel) were examined for the presence of cobalt, chromium, and nickel (6381). Samples were assayed at intervals ranging from 1 day to 2.5 years after surgery and the results were compared with those from two groups of controls. Only nickel concentrations are considered here. On days 1-2 postsurgery, serum nickel concentrations were elevated in 3/6 of the subjects with Ti-Al-V implants (1.2 μg/L; $p<0.05$) and 7/7 patients with cobalt-chromium implants (3.3 μg/L; $p<0.05$), compared with both presurgery and healthy control values (0.3 and 0.2 μg/L, respectively). All but one of the patients in the two groups with implants also had increased urine nickel levels. Within two weeks nickel concentrations in serum and urine had decreased to control values and remained at those levels for the duration of the study.

Hopfer et al. (6383) provided documentation for hypernickelemia in patients with end-stage renal disease who receive chronic hemodialysis therapy. It was found that serum nickel concentrations after hemodialysis were similarly elevated in subjects from

an area with high nickel content (109 µg/L) in the tap water (Sudbury, Ontario, Canada) and in subjects from Hartford, Connecticut, and area with much lower nickel content in the tap water (0.2 µg/L). In summary, the study confirmed hypernickelemia in hemodialysis patients. The study demonstrated the efficiency of deionization processes used in Sudbury for preparation of hemodialysis solutions.

The results of field studies and laboratory experiments suggest that there is little transfer of nickel through the aquatic food chain (6272). For example, levels of 500-600 µg/g were achieved in macrophytes (e.g. Lemna perpusilla) in 10 days (exposure levels not available) (6238, cited in 6272), but concentrations of only ≤4.2 µg/g of nickel were detected in rainbow trout after 180 days of exposure to 1 mg nickel/L. When the organisms were placed in clean medium, the plant nickel levels returned to background and losses of 59-75% were observed in the fish (6238, 6240, both cited in 6272).

Concentrations of nickel in the dorsal muscle of two bottom-feeding omnivores, white suckers (Catostomus commersoni) and brown bullheads (Ictalurus nebulosus), were 0.21 and 0.4 µg dry wt., respectively (6248). The fish were collected in two lakes known to have elevated surface concentrations of the element in their sediments. Several good potential food sources (insects, crayfish, fingerling bullheads) were analyzed for the presence of the metal. The biomagnification ratio (BR) was calculated from the ratio of the average concentration found in fish muscle to the average concentrations found in its foods). In this study, BR values of <1 indicate no magnification, while values >1 indicate magnification. A value of 1 indicated no net accumulation. The BR value for nickel in insects was not measurable, but ratios were 1.2 from the crayfish and >3 from fingerling bullheads, indicating some potential for biomagnification.

At successive trophic levels, bioconcentration factors decrease (6272). For example, green alga (Scenedesmus obliquus), exposed to nickel in solution, exhibited a concentration factor of 30-300 times, while for Daphnia, the concentration factor was only 2-12 times. Other bioconcentration factors (BCFs) for selected organisms are as follows: marine phytoplankton, <20-8000; freshwater plants, 100; freshwater fish, 40; seaweeds, 550-2000; algae, 2000-40,000; marine fish, 100; and skipjack tuna, 50 (6212). A BCF of <1000 suggests that bioaccumulation would not be significant" (6252, cited in 6202).

76.2.5 Biological Monitoring

Nickel may be monitored in several tissues and body fluids (6290). Electrothermal atomic absorption spectrophotometry of methyl isobutyl ketone-extracted ammonium pyrrolidine dithiocarbamate-complexed nickel is reportedly the most sensitive and reliable method for quantifying nickel in biological samples. The detection limits of nickel in biological samples depends on the instrumentation and sample preparation. Detection limits as low as 1 ng/L for whole blood, urine, saliva, and tissue homogenates have been achieved with dimethylglyoxime-sensitized differential pulse anodic stripping voltammetry (DPASV) (6203). Care should be taken to avoid contamination of the samples from such sources as nickel-containing containers and instruments

(e.g. stainless steel), and human sweat which contains high levels of nickel. Tissue and fluids that are routinely used for monitoring of nickel exposure include, hair, nails, urine, whole blood and serum, liver, lung, kidney, sweat, and excreta. The biological monitoring of nickel is described extensively by ATSDR (6290) and Sunderman et al. (6380).

76.3 HUMAN HEALTH CONSIDERATIONS

76.3.1 Animal Studies

76.3.1.1 Carcinogenicity

Overall, carcinogenicity studies in animals have produced varied results depending on the nickel compound used. However, several nickel compounds have been shown to induce cancers of the respiratory tract (6281) and nickel subsulfide produces renal malignancies in rats (6368, 6369). IARC (6288) summarized available data and found there to be sufficient evidence for carcinogenicity of nickel in animals. Several reviews (6283, 6291, 6204) of nickel carcinogenicity affirmed the carcinogenic potential of several nickel compounds. A review of cellular and molecular mechanisms of nickel carcinogenicity summarized studies examining such factors as cellular uptake and translocation of nickel, morphological transformation and mutagenesis of mammalian cells (human and animal), mitotic aberrations and sister chromatid exchanges, DNA-strand-breaks and protein crosslinking, alteration of DNA replication, lipid peroxidation, tumor promotion, and alteration of natural killer cell activity (6282). In animal carcinogenicity studies, nickel subsulfide appears to be the most potent nickel compound (6283).

Malignant tumors of pluripotential origin following subcutaneous implantation of nickel subsulfide was reported (6287), and the production of malignant melanoma-type tumors in the normally highly tumor-resistant Japanese newt, Cynops pyrrhogaster, by intraocular injection of nickel subsulfide (Okamoto, 1987) affirm the potential carcinogenicity of nickel subsulfide in several species and by several routes of administration.

Unilateral intrarenal injection of nickel subsulfide in rats produced erythrocytosis within one month and malignant renal neoplasms after eight months (6368). The development of malignant neoplasms in male F344 rats within 21 months after unilateral intrarenal injection of nickel subsulfide (20 mg/rat) was reported by Sunderman et al. (6369). The malignancies, five sarcomas and one carcinoma, occurred in the kidneys of six out of 28 treated rats. Vehicle controls exhibited no malignant neoplasms.

Exposure of male and female F344 rats to nickel sulfide (0.97 mg/m^3) for 78 weeks (5 days/week, 6 hrs/day) resulted in a significantly higher incidence of pulmonary hyperplastic and neoplastic lesions and lung tumors compared to filtered room air controls (6285). The preneoplastic changes were observed in both bronchiolar and alveolar regions. The tumor incidence was 14% in treated rats and 1% in controls. The incidence of specific tumors was reported as adenomas (7% in males and females),

adenocarcinomas (5% in males, 4% in females), squamous cell carcinomas (2% in males, 1% in females), and fibrosarcomas (1% in males, 0% in females).

McNeil et al. (6384) conducted a comparative study of the pulmonary tumorigenic response of male Strain A mice following intratracheal instillation or intraperitoneal injection of nickel subsulfide. Groups of 30 mice received nickel subsulfide at doses of 0.053 or 0.160 mg/kg by either route of administration. Dosing regimens included once per week, once every two weeks, or once every three weeks. Positive controls for each route of administration received a single dose (50 mg/kg) of urethane. Untreated controls received saline. Mice were sacrificed at 20 weeks or 45 weeks after the first dosing. Urethane by either route of administration produced a significant increase in pulmonary tumor incidence but nickel subsulfide failed to produce a dose-dependent response by either route when compared to age-matched controls.

Wehner et al. (6350) reported the effects of lifetime exposure (5 days/week, 7 hrs/day) of male Syrian golden hamsters to nickel oxide (~ 55 mg/m^3). Heavy pulmonary burdens of nickel oxide resulted in pneumoconiosis, but no significant carcinogenicity.

Horie et al. (6297) evaluated the effects of nickel oxide inhalation exposure (0.6-8.0 mg/m^3) in male Wistar rats exposed to the compound for 6 hours/day, 5 days/week for one month. Animals were sacrificed and examined immediately after exposure, and at 12 or 20 months after exposure. An adenocarcinoma was detected in one of six rats 20 months after exposure to 0.6 mg NiO/m^3 but no carcinomas were found in the eight rats exposed to the 8.0 mg/m^3 concentration. Some neoplastic lesions were noted in rats of all groups except those examined immediately after exposure, but were attributed to age rather than to the test article. The authors concluded that carcinogenic effects were not a prominent effect of nickel oxide exposure but that the long residence time of the nickel oxide particles in the peripheral lung regions might contribute to the promotion of bronchioalveolar cell hyperplasia.

Intramuscular injection of nickel(II) hydroxide air-dried gel (120 µmol), crystalline industrial nickel(II) hydroxide (120 µmol), or nickel subsulfide (40 µmol) in rats resulted in a local sarcoma incidence of 5/20, 3/20, and 16/20, respectively (6286). Intramuscular injections of nickel(II) sulfate (66 µmol) or precipitated nickel(II) hydroxide (120 µmol) did not produce tumors. In vitro solubilization rates of the tested compounds in human blood serum, artificial lung fluid, and acetate buffer indicated an inverse relation between tumor yield and rate of solubilization.

IARC (6288) summarized the evidence for carcinogenicity in animals and also indicates nickel subsulfide to be capable of inducing benign and malignant tumors in rats following inhalation exposure and produced malignant tumors following multiple intratracheal instillations. Subcutaneous injection of nickel subsulfide produced sarcomas in mice and rhabdomyosarcomas and fibrous histiocytomas in rats. Dose-response relationships have been demonstrated for the production of local sarcomas following intramuscular injections of nickel subsulfide in rats and hamsters. Malignant tumors in the peritoneal cavity were reported for repeated intraperitoneal injections of nickel chloride or nickel acetate. Nickel powder, nickel oxide, nickel hydroxide, nickel

carbonate, nickelocene, and nickel-iron sulfide have produced local sarcomas in mice, rats, hamsters, and rabbits following intramuscular administration (6288).

76.3.1.2 Genotoxicity

IARC (6288), U.S. EPA (6204) and Sunderman (6291) have reviewed the genotoxicity of nickel. Several inorganic nickel-containing compounds have been evaluated regarding genotoxic effects using various model systems including in vivo studies using laboratory species, bacterial mutagenicity studies, and mammalian cell systems (6283).

Data indicate that nickel genotoxicity is organ-specific in animals (6309, 6310) with the kidney and lung being primary targets as determined by intraperitoneal injections of nickel carbonate into rats. Waksvik and Boysen (6376) reported negative results regarding sister chromatid exchanges in blood lymphocytes of refinery workers exposed to nickel. The workers of the study groups had been exposed to nickel levels of 0.1 to 1.0 mg Ni/m^3 for an average of 21.2 years or 0.1 to 0.5 mg Ni/m^3 for an average of 25.2 years.

Based on an evaluation of in vivo chromosomal aberration studies, a lack of clastogenic activity was indicated for nickel (6204). However, data are available for mice indicating that nickel affects male germ cells resulting in a reduction of fertilized eggs, but no data are available regarding the effects of nickel on female germ cells. Micronucleus tests using mouse bone marrow cells and nickel chloride at 25 mg/kg or nickel nitrate at 56 mg/kg did not yield significantly greater numbers of micronucleated cells compared to controls (6311). Jacquet and Mayence (6312) also found nickel nitrate not to be clastogenic following administration to mice at doses of 40 or 55 mg/kg. In another study, Mathur et al. (6326) did not detect chromosomal aberrations in bone marrow and spermatogonia cells of rats administered 3 or 6 mg of nickel sulfate intraperitoneally for 7 or 14 days.

An analysis of available in vitro chromosomal aberration studies revealed either negative data or deficient studies (6204), and that further research would be needed to unequivocally confirm the clastogenicity of nickel in cultured mammalian cells. However, various reports have provided data indicating that nickel compounds (nickel sulfate, nickel subsulfide, nickel chloride) produced sister chromatid exchanges in cultured human lymphocytes (6315), Chinese hamster Don cells (6316), and Syrian hamster cells (6317). The results of most studies examining chromosomal effects of nickel are contradictory, a condition that may be remedied by a more thorough understanding of the cellular uptake and availability of metal ions.

More recently, however, Sunderman et al. (6369) reported on the chromosomal abnormalities, gene amplification, and time-course of erythrocytosis in rats administered nickel subsulfide (20 mg/rat) by unilateral intrarenal injection. Blood hematocrit values were increased during two to six weeks post injection, attained a maximum increase of 77% at 16 weeks, and returned to normal at 40 weeks. Karyotypes of three of six renal neoplasms exhibited prominent marker chromosomes, oncogene amplification was detected in two of six neoplasms, and erythropoietin gene was not consistently amplified in the DNA from kidneys of treated rats.

The results of bacterial mutagenicity studies are summarized in U.S. EPA (1986) and Coogan et al. (6283). Generally, these studies indicate that nickel compounds are only weakly or not at all mutagenic. Nickel was found to be positive in forward mutation assays at the HGPRT locus of Chinese hamster V79 cells and the TL locus of mouse lymphoma cells (6283). Additionally, two studies evaluated by the U.S. EPA (6204) showed that nickel chloride gave positive responses in fluctuation tests using Salmonella typhimurium and Corynebacterium.

A summary of in vitro and in vivo genotoxicity study results is presented in Tables 76-3 and 76-4, respectively.

76.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Developmental toxicity of some nickel compounds has been reported for various species and includes embryotoxic as well as teratogenic effects. Additionally, data are available indicating reproductive toxicity and maternal hormonal effects. A variety of nickel compounds including, metallic nickel, nickel carbonyl, nickel chloride, nickel sulfate, nickel subsulfide, nickel carbonate, and nickel nitrate were employed in these studies. Reviews of the developmental toxicity of nickel and nickel compounds appear in U.S. EPA (6204), Sunderman et al. (1984), ATSDR (6206) and Coogan et al. (6283). As summarized in Coogan et al. (6283), exposure of animal species to nickel during organogenesis reportedly results in a variety of teratogenic effects including acephalia, exencephaly, cerebral hernia, skeletal anomalies, micromelia, club foot, cleft palate, and cystic lungs. Nickel is known to cross feto-maternal barriers (6319), is taken up by the embryo during early gestation (6323, 6320), and is excreted into and may change the composition of rat milk (6324). The possible role of nickel-induced hyperglycemia in the teratogenicity observed in rats has been investigated by Mas et al. (6320).

Administration of an unspecified nickel salt (5 ppm nickel) in drinking water to three generations of rats resulted in an increased incidence of perinatal mortality in all generations, and an increased incidence of runts in two generations (6318).

Embryonic mortality without maternal toxicity was noted by Sunderman et al. (6319) for pregnant rats given nickel chloride intramuscularly (16 mg Ni/kg) on day 8 of gestation. Specifically, a decrease in the number of live pups per dam, and an increased ratio of dead fetuses to implantation sites was observed. Mean fetal weight was decreased and remained so for the growing pups even at eight weeks of age. Sunderman et al. (6319) also reported that nickel subsulfide dust suspended in penicillin G and injected intramuscularly (80 mg nickel/kg) into Fisher 344 rats on gestational day 6 caused a reduction in the number of live fetuses per dam and an increase in the ratio of dead and resorbed fetuses to the total number of implantation sites.

Table 76-3

Genotoxicity of Nickel and Nickel Compounds

End Point	Species/test system	Compound	Results	Reference
Gene mutation	Salmonella typhimurium	Nickel chloride Nickel sulfate	Mixed	(6385) (6386)
	Escherichia coli	Nickel chloride	-	(6387)
	Corynebacterium sp.	Nickel chloride	+	(6388)
	Saccharomyces cerevisiae	Nickel sulfate	-	(6389)
	CHO cells	Nickel chloride	Inconcl.	(6390)
	Mouse lymphoma cells	Nickel chloride	+	(6391)
	Chinese hamster V79 cells	Nickel chloride	Inconcl.	(6392)
DNA damage	Bacillus subtilis	Nickel oxide Nickel trioxide	-	(6393)
	CHO cells		+	(6394)
SCE	Hamster cells	Nickel sulfate Nickel chloride	+	(6316) (6317)
	Human lymphocytes	Nickel sulfate Nickel sulfide	+	(6315, 6317) (6229) (6395)
Chromosome aberrations	Hamster cells	Nickel sulfate Nickel chloride	+	(6396) (6317)
	Human lymphocytes	Nickel sulfate	+	(6317)
	Human bronchial epithelial cells	Nickel sulfate	+	(6397)
Cell transformations	Hamster cells and C3H/10T1/2 cells	Nickel subsulfide and Nickel chloride	+	(6398) (6399) (6400, 6395)

Source: 6206

Table 76-4

Genotoxicity of Nickel and Nickel Compounds In Vivo

Endpoint	Species/Strain	Compound	Result	Reference
Gene mutation	Drosophila melanogaster	Nickel nitrate Nickel chloride	Negative	(6401)
Recessive lethal	Drosophila melanogaster	Nickel sulfate	Negative	(6402)
Chromosome aberrations and SCE	Human lymphocytes	Nickel	Negative	(6376)
Chromosome aberrations	Rat bone marrow and spermatogonial cells	Nickel sulfate	Negative	(6326)
Micronucleus test	Mouse bone marrow cells	Nickel chloride	Negative	(6311)
Dominant lethal	Mouse	Nickel acetate	Negative	(6311)

Source: 6206

Embryotoxicity in mice was observed for nickel chloride administered i.p. (1.2, 2.3, 3.5, 4.6, 5.7, or 9.6 mg/kg) to pregnant CD-1 mice on each of gestational days 7 through 11 (6321). The two highest doses, however, resulted in maternal deaths. A dose-related increase in skeletal and soft tissue abnormalities was noted but these were always associated with a dose that also produced an increase in fetal deaths.

Inhalation exposure of pregnant Syrian hamsters on days 4, 5, 6, 7, or 8 of gestation to nickel carbonyl (0.06 mg $Ni[CO]_4$/L/15 min.) was studied by Sunderman et al. (6363). Exposure on the 4th or 5th day of gestation resulted in malformations in 5.5% and 5.8% of the progeny, respectively, versus 0% in non-exposed controls. Similarly, the proportion of litters with malformed fetuses was 33% and 24% for these exposure days versus 0% for controls. Malformations included cystic lungs, exencephaly, exencephaly with a fused rib, and anophthalmia with cleft palate. For the same exposure protocol, an increase (18% and 25% for 4th and 5th day exposures, versus 0% for controls) in hemorrhage into serous cavities of fetuses was observed. Compared to controls, no significant difference in the number of live pups was noted for females exposed to nickel carbonyl (0.06 mg/L/15 min.) on day 5 of gestation and allowed to deliver their litters. However, by postpartum day 4 neonatal mortality was increased in these litters (7.6 live pups/litter) compared to controls (9.6 live pups/litter).

Mas et al. (6320) reported teratogenic effects of nickel chloride administered intraperitoneally to pregnant rats at doses of 2 or 4 mg Ni/kg on day 8 or day 12 of gestation.

Research Triangle Institute (6322) conducted a two-generation reproduction and fertility study wherein rats were exposed to nickel chloride in drinking water at concentrations of 50, 250, 500, or 1000 ppm Ni. Excessive mortality after only two weeks of exposure of the P_0 generation dictated discontinuation of that exposure concentration. The P_0 breeders exhibited no significant compound-related effects nor were fertility or reproductive performance of the F_1 breeders significantly affected. However, live litter size and average pup weight of the F_1 breeders receiving 500 ppm Ni were significantly decreased. No dose-related embryotoxicity or teratogenic effects were observed.

The embryotoxic and teratogenic effects of nickel carbonyl and nickel subsulfide were investigated by Sunderman et al. (6342). Intravenous injection of nickel carbonyl (11 mg Ni/kg) to female F-344 rats on day 7 of gestation caused increased fetal mortality, reduced body weight of live pups, and an increased incidence of fetal malformations (ocular anomalies and hydronephrosis). Inhalation exposure of male rats to nickel carbonyl (0.05 mg Ni/L for 15 minutes) two to six weeks prior to breeding did not affect fertilization rates or reproductive yields, but intravenous injection of nickel carbonyl (22 mg Ni/kg) reduced the number of live pups in litters sired during the 5th week. The latter effect was consistent with chromosomal damage during the meiotic stage of spermatogenesis. Lastly, nickel subsulfide administered intrarenally (30 mg Ni/kg) to female rats one week prior to breeding produced erythrocytosis in the dams but not pups. However, at two weeks postpartum, pups of nickel subsulfide-treated dams exhibited decreased blood hematocrits.

Several studies have reported effects of various nickel compounds on the male reproductive system. A single, subcutaneous injection of nickel sulfate (0.04 mmol/kg) to male rats resulted in damage of seminiferous tubules, shrinkage of the epididymis, and complete degeneration of spermatozoa at 18 hours after treatment (6325). Dermal exposure of male rats to nickel sulfate at doses of 40, 60, or 100 mg Ni/kg/day for up to 30 days did not produce general toxic effects or mortality (6326). However, a dose-related testicular tubular damage and sperm degeneration were noted for the 60 and 100 mg/kg doses. No testicular effects were observed for the lower doses or for any dose applied for only 15 days.

A concern with the possible effects on implantation or developing embryos of nickel-containing intrauterine devices was investigated by Chang et al. (6327). Nickel reduced the number of implantations and increased the number of resorption sites in the uterine horns of rats in which nickel-containing intrauterine devices were placed.

76.3.1.4 Other Toxicologic Effects

76.3.1.4.1 Short-term Toxicologic Effects

The oral LD_{50} values of various nickel compounds in animals are presented in Table 76-5. The causes of death pertaining to the reported values were not specified. Inhalation LC_{50} values were not found in the available literature but TC_{Lo} values for some nickel compounds are presented in the acute toxicity section of the health hazard summary box in the front section of this chapter.

A fatal case of acute nickel toxicity was reported for a 2 1/2-year old girl who ingested 15 g of nickel sulfate crystals. Auscultation revealed pulmonary rales prior to death due to cardiac arrest (6360).

The acute toxicity in 32 electroplating plant workers who drank water contaminated with nickel chloride and nickel sulfate (1.63 g/L) was described by Sunderman et al. (6379). Twenty of the workers developed symptoms including nausea, vomiting, abdominal discomfort, diarrhea, headache, giddiness, lassitude, cough, and shortness of breath. In most cases these symptoms lasted a few hours but in seven case persisted for 1-2 days. The nickel doses in these individuals were estimated to range from 0.5 to 2.5 g and serum nickel levels (measured 1 day postexposure) ranged from 13 to 1,340 µg/L and urine levels of nickel ranged from 0.15 to 12 mg/g creatinine. All of the subjects had an uneventful recovery and returned to work by the eighth day after the exposure.

A number of studies summarized by ATSDR (6206) and U.S. EPA (6284) have been conducted using parenterally administered nickel compounds in various laboratory species. In these studies, toxic effects including proteinuria, aminoaciduria, histopathology of the renal glomeruli, and renal tubular lesions were observed following parenterally administered nickel or nickel chloride. Intrarenal administration of nickel subsulfide produced erythrocytosis and arteriosclerosis. It is of interest to note that Sunderman et al. (1986) found a significant rank correlation between incidence of erythrocytosis and renal cancer in nickel-treated rats.

Exposure of female Swiss albino mice to nickel chloride aerosol (250 µg Ni/m^3) for two hours resulted in a significant decrease in the number of specific antibody-producing spleen cells (Graham et al., 1978). This study also reported that intramuscular administration of nickel sulfate (3.09 µg Ni/g) or nickel oxide (9.25 µg Ni/g) resulted in significant immunosuppression.

Inhalation exposure of rats and mice to nickel sulfate at 0.8, 1.7, 3.3, 6.7, or 13 mg/m^3, 6 hrs/day, 5 days/week for up to 12 days resulted in death of rats exposed to $\geq$3.3 mg/m^3 and death of mice exposed to $\geq$1.7 mg/m^3 (6374). A similar exposure protocol using green nickel oxide at 0.9 to 23.6 mg/m^3 did not result in deaths of rats or mice (6334). Exposure of male and female rats to 1000 ppm nickel chloride in drinking water resulted in excessive deaths following only two weeks exposure, however, exposure to 500 ppm or less did note result in increased mortality (6322).

Table 76-5

Oral LD_{50} Values for Nickel Compounds Administered to Rats

Compound	LD_{50} (mg compound/kg)	LD_{50} (mg/Ni/kg)	Reference
Nickel acetate	355	118	(6405)
Nickel hydroxide	1600	1021	(6256)
Nickel sulfate hexahydrate	300	67	(6256)
Nickel oxide (green and black)	>5000	>3929	(6256)
Nickel sulfide	>5000	>3233	(6256)
Nickel subsulfide	>5000	>3666	(6256)
Nickel powder	>9000	>9000	(6256)

Source: 6206

Exposure levels of 0.0, 0.6, 1.2, 2.5, 5.0, and 10.0 mg/m^3 (equivalent to 0.0, 0.4, 1.8, 3.6, and 7.3 mg Ni/m^3) were selected to bracket the current TLV of 1.0 mg/m^3 for nickel subsulfide in a short-term (6 hours/day, 7 days/week for 12 days) whole-body inhalation study using male and female F-344 rats and B6C3F$_1$ mice (6344). At the lowest exposure level, rats exhibited degeneration of respiratory epithelium and atrophy of olfactory epithelium, but no clinical signs of toxicity. Mice exhibited similar histopathological effects at the 1.2 mg/m^3 exposure. The incidence, but not the severity, of these lesions increased with higher exposure levels and all rats and mice exposed to the highest concentration developed labored breathing after five days of exposure. Rats exposed to 5.0 or 10.0 mg Ni_3S_2/m^3 developed emphysema and fibrosis was observed in mice exposed to the compound at 5.0 mg/m^3.

Another study by Benson et al. (6343) using the same species and a similar exposure protocol tested the effects of nickel sulfate hexahydrate (0.0, 3.5, 7.0 15, 30, or 60 mg/m^3 equivalent to 0.0, 0.84, 1.7, 3.3, 6.7, and 13.5 mg Ni/m^3). A high incidence of mortality occurred in the higher dose groups and exposure to 3.5 and 7.0 mg $NiSO_4 \cdot H_2O$ produced pulmonary lesions in both rats and mice.

Subcutaneous injection of F-344 rats with various nickel salts at doses of 500 µmol/kg produced two-fold increases of TBA-chromogens in the liver and kidney, and a dose-related increase in serum AST activity was observed for rats 24 hours after injections of nickel chloride (0, 125, 250, 500, or 750 µmol/kg). The studies indicated that acute nickel hepatotoxicity in rats is associated with lipid peroxidation (6335).

A single intratracheal instillation of nickel subsulfide (11.8 µg/mouse) resulted in pulmonary hemorrhage and decreased body weight 3 to 7 days after dosing. Lung

lavage fluid from nickel-treated rats contained blood and increased numbers of polymorphonuclear leukocytes. Much of the nickel burden from early stages was cleared to the gastrointestinal tract, and long-term clearance rates from the lung, kidney and blood supported the hypothesis that nickel was first solubilized in the lung and subsequently transported via the blood (6336).

Nickel-induced hypothermia lasting four hours was observed for rats receiving a single intraperitoneal (100 μmol/kg) or subcutaneous (250 or 375 μmol/kg) injection of nickel chloride. The 375 μmol dose, however, resulted in death of three of four rats three days following the injection. In addition to causing hypothermia, the treatments also altered the circadian rhythm of thermoregulation (6337).

A comparison of the acute toxicity of intratracheally instilled nickel oxide, nickel sulfate, nickel subsulfide, and nickel chloride to rats indicated a toxicity ranking of nickel subsulfide ~ nickel sulfate ~ nickel chloride >> nickel oxide (6339). For each compound, rats were administered a single dose of 0.0, 0.01, 0.10, or 1.0 μmol Ni and sacrificed 1 or 7 days after treatment. Pulmonary clearance was most rapid for nickel chloride and nickel oxide, and only minimal changes in assessed parameters were detected one day after dosing. Nickel oxide did not produce any significant toxic effects but nickel sulfate, nickel subsulfide, and nickel chloride caused an increase in lactate dehydrogenase (LDH), ß-glucuronidase (BG), total protein (TP), glutathione reductase (GR), sialic acid (SA), and total nucleated cells at 7 days after dosing. Histological evidence of alveolitis was also observed for these rats at seven days after dosing.

Nickel-induced dysfunction of host defenses was reported for female pathogen-free Swiss albino mice exposed (inhalation, head-only) to nickel chloride (500 μg Ni/m^3) for two hours and subsequently exposed for 15 minutes to an aerosol of viable Streptococcus pyogenes, group C (6340). The exposure to nickel caused a depression of phagocytic and bactericidal function of alveolar macrophages, and depressed ciliary activity of the upper respiratory tract. An additional study employing a single intramuscular injection of nickel chloride (18.3 mg/kg) into male CBA/J and female C57BL/6J mice demonstrated a significant reduction in murine splenic natural killer cell activity (6341).

76.3.1.4.2 Subchronic and Chronic Toxicity

Pulmonary toxicity

A considerable amount of data are available regarding the effects of nickel following subchronic or chronic inhalation exposure of animals to both soluble and insoluble nickel compounds. Although the carcinogenicity of some nickel compounds has been confirmed, the studies described in the following section indicate that exposure to nickel compounds may result in noncarcinogenic effects at exposure levels which are similar to those encountered in occupational situations. Moreover, these studies also confirm the portal-of-entry effects of inhaled nickel compounds. A summary of inhalation toxicology studies employing various nickel compounds is presented in Table 76-6.

The effects on male Wistar rats of inhalation exposure to nickel chloride (109 $\mu g/m^3$) or to nickel oxide (120 $\mu g/m^3$) for 12 hours/day, 6 days/week for periods up to several months were reported by Bingham et al. (6345). The exposure to nickel oxide produced an increase in the number of alveolar macrophages (9.6×10^6/g of lung) relative to non-exposed controls (3.8×10^6/g lung) but nickel chloride exposure produced no such effect. Nickel oxide exposure also produced an accumulation of macrophages in alveolar space and a thickening of alveolar walls. Hyperplasia of the bronchial epithelium and increased mucus production resulted from the nickel chloride exposure.

A 78-week exposure (6 hours/day, 5 days/week) of male and female F344 rats to 0.97 mg nickel sulfate/m^3 resulted in increased mortality, decreased body weight and an increase in pulmonary lesions (pneumonitis, atelectasis, bronchitis) (6285).

Speigelberg et al. (6347) provided evidence for pulmonary immunotoxicity in male Wistar rats (12/group) exposed to nickel oxide at concentrations of 400 and 800 $\mu g/m^3$ (nickel equivalent of 314.4 and 628.7 μg Ni/m^3, respectively) for four weeks. Rats of these exposure groups exhibited a decrease in the number of alveolar macrophages relative to unexposed controls. The 800 $\mu g/m^3$ exposure also resulted in a high percentage of dead macrophages and loss of morphological integrity of the macrophages. Two additional groups of rats (12/group) were exposed to nickel oxide at concentrations of 25 $\mu g/m^3$ (19.6 μg Ni/m^3) or 150 $\mu g/m^3$ (117.9 $\mu g/m^3$) for four months. Serum antibody titer and antibody production by spleen cells following injection of the rats with sheep erythrocytes were used to assess immune response. For the four-week exposures, doses $\geq$200 $\mu g/m^3$ suppressed both the antibody titer and the antibody production. The four-month exposure to 150 μg NiO/m^3 but not 25 μg NiO/m^3 produced similar effects. It was concluded that about the same exposure level, regardless of duration, significantly affected alveolar macrophages and the humoral immune system.

A dose-dependent increase in lung weight, lung density and phagocytic activity of pulmonary macrophages was noted for New Zealand white rabbits exposed to nickel dust at concentrations of 0.45 or 2.02 mg/m^3 for 6 hours/day, 5 days/week for four weeks (6348). Altered surface membranes, eccentrically placed polymorphic nuclei with chromatin margins and membrane-bound laminated structures in lung macrophages were detected in the nickel-treated rabbits.

The pathological effects of inhaled nickel chloride (0.3 mg Ni/m^3) and metallic nickel dust (0.1 or 1.0 mg/m^3) were assessed using rabbits exposed to the test articles for up to six months (6349). Exposures to both the nickel dust and the nickel chloride resulted in heavily burdened and inactive alveolar macrophages after three months of exposure. A dose-dependent increase in lung phospholipids was detected over the

TABLE 76-6

Effects of Inhalation Exposure of Laboratory Animals to Nickel Dust or Nickel Compounds

Species	Exposure level	Effect	Reference
Rat	109 μg $NiCl_2/m^3$, 12 hrs/day, 6 days/week for several weeks	Histological alterations in the lung and in alveolar macrophages	(6345)
Rat	120 μg NiO/m^3, 12 hrs/day, 6 days/week for several weeks	Histological alterations in the lung and in alveolar macrophages	(6345)
Rat	0.8 mg Ni/m^3 as NiO, continuous exposure for 3 weeks	Increased lung weight, increased enzyme activity levels, decreased body weight	(6353)
Rat	109 μg NiO/m^3, 8 hrs/day, 5 days/week for 18 days	Altered enzyme activity in pulmonary lavage fluid and in alveolar macrophages	(6358)
Rat	120 μg $NiCl_2/m^3$, 8 hrs/day, 5 days/week for 18 days	Altered enzyme activity levels in pulmonary lavage fluid and alveolar macrophages	(6358)
Rat	39 to 629 μg Ni/m^3 as NiO, *continuous for 1 month*	Pulmonary immunotoxic effects at the higher exposure levels	(6406)
Rat	0.4 to 7.3 μg Ni/m^3 as Ni_3S_2, 6 hrs/day, 5 days/week for 12 days	Histopathological changes in the respiratory tract	(6339)
Rat	0.84 to 13.5 mg Ni/m^3 as $NiSO_4 \cdot 6H_2O$	Increased mortality at the highest dose, pulmonary lesions at doses ≥ 3.5 mg Ni/m^3	(6339)
Rat	0.9 mg Ni/m^3 as nickel dust, 6 hrs/day, 5 days/week for 3 or 6 months	Increased number of pulmonary macrophages, elevated pulmonary phospholipid content	(6352)
Rat	0.2 to 1.0 mg Ni/m^3 as nickel dust, 6 hrs/day, 5 days/week for 1,3, or 6 months	Histomorphometric changes in alveolar macrophages, Elevated pulmonary phospholipid content	(6359)
Rabbit	1.0 mg Ni/m^3 as nickel dust, 5 hrs/day 5 days/week for 3 or 6 months	Histomorphometric changes in alveolar macrophages, elevated pulmonary phospholipid content	(6354)
Rabbit	0.1 mg Ni/m^3 as nickel dust, 6 hrs/day, 5 days/week for 4 or 8 months	Reduced pulmonary lysozyme levels	(6355)
Rabbit	0.13 mg Ni/m^3 as nickel dust, 6 hrs/day, 5 days/week for 4 or 8 months	Elevated pulmonary phospholipidosis, transient reduction in surface tension	(6356)

TABLE 76-6 (Cont.)

Species	Exposure Protocol	Effect	Reference
Rabbit	0.3 mg Ni/m^3 as nickel dust, 6 hrs/day, 5 days/week for 1 month	Increased lung weight, elevated phospholipid content, histological alterations	(6357)
Rabbit	0.1 to 1.0 mg Ni/m^3 as nickel dust, 6 hrs/day 5 days/week for 4 to 6 weeks	Histomorphometric changes in alveolar macrophages and alveolar type II cells	(6348)
Hamster	61 μg NiO/m^3, 4 hrs/day, 5 days/week for 3 months	No acute toxicity, moderate pulmonary retention of nickel	(6350)

treatment period with nickel dust and nickel chloride. Furthermore, an increase in volume density of Type II cells was also noted following the exposures with the nickel

Renal Toxicity

As with many heavy metals, nickel is nephrotoxic. Most available data were derived from studies employing parenterally administered nickel and nickel compounds, however, some reports are available for environmentally relevant routes of exposure.

Renal tubular degeneration was observed in rats fed a diet containing nickel acetate. The concentration of the test compound was successively increased from 0.1 to 1.0% over a period of several weeks but the exposure level or time point producing this effect was not defined (6328).

In another study (6329), an exposure-related increase in mild nephrosis was detected in mice receiving nickel sulfate in the drinking water at concentrations of 5 and 10 g/L for 180 days. The lesions were not detected in those rats exposed to nickel sulfate concentrations of 1 g/L.

An inhalation exposure study was conducted in which groups of rats (30/group) were exposed to nickel chloride (1 mg/m^3) 5 days/week for 3 or 6 months (6330). Although nickel accumulation in the kidneys did occur, no lesions were detected.

Hematologic Effects

A number of studies of varying exposure duration and using various animal species have provided information indicating hematologic and hematopoietic effects of nickel compounds.

A 91-day exposure study in which rats were given nickel chloride hexahydrate (0, 5, 35, or 100 mg Ni/kg/day) by gavage resulted in the death of all rats in the high dose

group by day 78, and an increase in white blood cell counts for the 35 mg/kg dose group at an interim sacrifice (6332). At final sacrifice, males of the 35 mg/kg dose group had elevated platelet counts and lowered blood glucose levels. Dietary exposure of weanling rats to 500 or 1000 ppm nickel acetate produced a lowered hematocrit and hemoglobin concentration relative to controls and the lower dose (100 ppm) group (6333).

In a 2-year dietary exposure study using dogs, nickel sulfate at 2500 ppm but not at 1000 ppm resulted in histopathology of the bone marrow (6331). A 25% decrease in bone marrow cellularity was reported for mice receiving 5 or 10 g Ni/L in drinking water for 180 days (6329). This study also reported a change in stem cell proliferative responses associated with a decrease in glucose-6-phosphate dehydrogenase activity.

76.3.2 Human and Epidemiologic Studies

76.3.2.1 Short-term Toxicologic Effects

Respiratory Effects

Regarding acute toxicity of nickel and nickel compounds, nickel carbonyl is probably of greatest concern. Acute exposure to this compound may result in fulminant interstitial pneumonitis accompanied by coughing, dyspnea, tachycardia, and cyanosis (6222). Neurological symptoms are manifested by headache, giddiness, vertigo, and weakness. Adrenal insufficiency, hyperglycemia, hepatic toxicity and acute renal damage (renal edema with hyperemia and parenchymatous degeneration) have also been reported, with death resulting from severe respiratory impairment, and cerebral edema or hemorrhage. Evidence is also available for acute toxicity resulting from exposure to nickel metal, and nickel compounds such as nickel oxide, and nickel sulfide.

The acute toxicity of nickel carbonyl is exemplified by a refinery accident in 1953 in which 100 workers were exposed to nickel carbonyl in an enclosed area. Thirty two of the men required hospitalization and two men died (6282). The immediately occurring signs and symptoms following this exposure included headache, dizziness, sternal and epigastric pain, nausea and vomiting. It was noted that these effect disappear upon removal of the subject to uncontaminated air. A latent period of 1 to 5 days, during which subjects may be asymptomatic, may occur prior to the onset of delayed effects such as constriction in the chest, chills, sweating, dyspnea, dry cough, weakness and fatigue, gastrointestinal symptoms (diarrhea, abdominal distention), and convulsions and delirium which may in some instances lead to death. In the refinery accident the deaths occurred on the 4th and 11th day after exposure. BAL (British Anti - Lewisite) was administered and was no doubt instrumental in saving lives.

Sunderman (6298) provided nickel levels for lung and liver tissue of a man dying five days following exposure to nickel carbonyl. The lung and liver nickel content was 17.3 and 5.3 μg Ni/100 g wet wt. of tissue, respectively. These concentrations were respectively 11 and 6 times greater than the average nickel content of these tissues.

An additional report by Sunderman (6298) attests to the use of diethyldithiocarbamate trihydrate as an efficacious treatment of nickel carbonyl exposure. The exposure occurred in 156 workers at the Toa Gosei Chemical plant in Nagoya, Japan. Of the 136 victims exhibiting symptoms of exposure, 96 were hospitalized and the critically ill patients treated with Antabuse until supplies of diethyldithiocarbamate trihydrate arrived. Thirty six hours after exposure seven individuals became delirious and unconscious and were administered Diothiocarb. All of the victims receiving diethyldithiocarbamate trihydrate therapy recovered, although three experienced protracted convalescence, and no fatalities occurred.

A report of 179 cases of nickel carbonyl poisoning occurring in China since 1961 were analyzed for clinical signs and symptoms, exposure concentrations, contact time, and general data regarding the subjects and cause of the exposure (6338). The subjects were both male and female and ranged in age from 18 to 53. Causes of exposure were: 1) accidental spills or leaks of nickel carbonyl liquid or vapor (the most common cause), 2) feed in raw material, 3) checking and repairing of apparatus and tubes, and 4) fire fighting. Contact times were summarized as < 30 minutes (59 cases), one hour (51 cases), one to two hours (48 cases), and > two hours (21 cases). The most frequent symptoms related to the pulmonary and nervous systems. Although a wide range of clinical symptoms were presented, the most common were chest tightness, dryness of the throat, cough, dizziness, headache, nausea, and weakness. The most prevalent clinical signs were hyperemia of the conjunctiva, hyperemia of the throat, tachycardia, and high blood pressure. Treatment was dependent upon severity of exposure and included removal from exposure, use of bronchodilators and symptomatic drugs, administration of oxygen, glucose vitamin C and corticosteroids, administration of Dithiocarb, and symptomatic treatment of secondary sequelae.

Immunological Effects

In addition to carcinogenic effects, nickel and nickel compounds are also associated in varying degrees with allergic contact dermatitis and asthma (6283). Numerous case reports are available attesting to the fact that nickel is a common cause of contact dermatitis with an especially high incidence in women (five to ten-fold greater than in men). Sources of exposure include jewelry, clothing fasteners, kitchen utensils, coins, and dental prostheses. Occupational asthma has also been reported for nickel-sensitive workers, and some evidence indicates that this may be an IgE type I immunopathogenic process (6300, 6301).

A case of asthma in a 24-year old man following occupational exposure to nickel was reported by McConnell et al. (6304). The man developed pruritic vascular eruptions on areas of his body that had been in contact with nickel plated metal parts. Use of gloves somewhat reduced the dermatitis on his hands but after two weeks he developed a dry cough, chest tightness, and wheezing which became worse during work and subsided at home. Shortly thereafter he was admitted to a hospital with elevated blood pressure and pulse rate, wheezing, and a vesicular rash on his arms. A chest X-ray was normal. Immunologic studies showed antibodies to nickel salts and the reaction could be elicited by controlled inhalation exposure to nickel sulfate.

A report by Novey et al. (6301) provided evidence for immunologic mechanisms in nickel-induced asthma. The study was based on a case of de novo asthma due to occupational exposure of a 32-year old man to fumes of nickel and chromium salts in an electroplating process. An inhalation challenge with chromium sulfate and nickel sulfate each produced an asthma-like response. A radio-immunoassay incorporating the challenge material indicated specific IgE antibodies to nickel sulfate and chromium sulfate. The authors suggested that the asthma condition could be specifically induced by fumes of chromium and nickel salts even in a previously nonallergic subject, and that an IgE type I immunopathogenic mechanism is involved. Another study by Nieboer et al. (6307) also affirmed the immunologic mechanism for nickel-induced asthma by identifying antibodies which bind to $^{63}Ni^{2+}$ and similar findings were reported by Malo et al. (6308) for a subject exposed to nickel sulfate.

A case of contact dermatitis possibly resulting from release of nickel from blackboard chalk was reported (6302). A 47-year old female school teacher suffered from a vesicular dermatitis for 4 years. Avoidance of contact with the chalk resulted in improvement of the condition. Patch testing resulted in a positive reaction to nickel sulfate. Analysis of the chalk revealed a nickel content of 2 ppm. Although most patients tested for nickel sensitivity react to nickel levels higher than 2 ppm, several reports were cited which also suggested the possibility of dermatitis caused by nickel in blackboard chalk, and that the exposure may be enhanced by perspiration on the hands.

Romageura et al. (6303) conducted tests to determine the source of contact dermatitis due to nickel. The study used 964 patients having had contact dermatitis from metals (mostly imitation jewelry) and 200 controls with no such prior history. Sixty-five per cent of the subjects (63% female, 2% male) who did not tolerate imitation jewelry or metal ornaments (containing nickel), or did not tolerate occupational exposure to metals, were sensitive to nickel sulfate. Of the patients having a positive patch test to nickel sulfate, 50% of these also had a positive reaction to a patch test with a nickel washer.

The bioavailability of nickel from consumer products and estimation of a provocation threshold was reported by Emmett et al. (6303) for 12 subjects sensitive to nickel. Patch testing with serial dilutions (1%, 0.316%, 0.1%, 0.0316%, 0.01%, or 0.00316%) of nickel sulfate in water or in petrolatum resulted in a provocation threshold of 5.2 mg (2.5%) for the aqueous nickel sulfate and 0.47 μg (0.01%) for the nickel sulfate in petrolatum. The bioavailability of nickel from verified dermatitis-inducing earrings and a necklace was determined by immersing these items in plasma, normal saline, and at various pH values (5.3, 6.6, or 7.8) of synthetic sweat (0.1% urea, 0.1% lactic acid, 0.5% sodium chloride and buffered ammonium hydroxide) for 2 or 7 days. The nickel leaching under these conditions frequently exceeded the provocation threshold by as much as 1.4 (earring in synthetic sweat for 7 days, pH 7.4) to 93-fold (earring in plasma for 7 days) depending on the jewelry item used and the time course. Plasma was found to be most efficient at removing nickel from the jewelry items and possibly explains the frequent induction of nickel sensitization by ear piercing.

Nickel sensitivity is steadily increasing. Of 2500 individuals tested, 410 were found to be nickel positive (6305). A single dose challenge of 10 mg of nickel sulfate in water to 25 nickel-sensitive women resulted in a generalized flare-up or localized reactions (localized flare-up, itching) in 18 of the subjects. Fifteen days later and for a period of three months, 17 of these subjects were administered gradually increasing daily doses of nickel sulfate in water. Of these subjects, three were intolerant of the treatment and developed worsening cutaneous reactions, and 14 ended the trial without incident. The authors concluded that the sensitized subjects could not adapt to the single dose of 10 mg of nickel sulfate but a gradual intake permitted, probably via intestinal absorptions mechanisms rather than immunological tolerance, most subjects to tolerate the nickel intake.

Nielsen et al. (6378) provided data indicating that nickel-sensitive individuals may experience exacerbation of nickel-induced eczema when challenged with a diet containing a higher than normal (5-fold) nickel content.

An assessment of pulmonary accumulation of nickel in humans was estimated by Edelman and Roggli (6306) using data from previously published reports. Nickel levels in the lung were much greater for occupationally exposed individuals (0.5 - 1350 μg/g wet wt. of lung) versus individuals with no known occupational exposure (0.004 - 7.4 μg/g wet wt. of lung). A dosimetry model was developed to estimate lung nickel burden resulting from ambient air exposure and from cigarette smoking. Based on existing data and application of the model, cigarette smoking was determined to significantly increase the pulmonary burden of nickel (0.17 μg/g) over a 40-year period.

76.3.2.2 Chronic Toxicologic Effects

Chronic exposure to inhalation of nickel dusts and aerosols may contribute to chronic respiratory disorders such as asthma, bronchitis, rhinitis, sinusitis, perforation of the nasal septum, and pneumoconiosis (6222). Sufficient evidence is available for nickel-induced carcinogenicity in humans, specifically cancer of the lungs and nasal sinuses (6288).

Human epidemiologic studies of nickel refinery workers have strongly suggested increased incidence of nasal and lung cancers following inhalation exposure to nickel (6283). In summarizing epidemiologic studies conducted prior to 1975, the National Academy of Sciences (6289) indicated that nickel refinery workers showed an increased risk of pulmonary and nasal cavity cancers with epidermoid, anaplastic, and pleomorphic carcinomas being the most common.

Morgan (6294) provided data on the number of workers, the length of employment, year of entry into employment, and the number of cases of lung cancer for workers at the Clydach, Wales nickel refinery. The rate of nasal cancer and lung cancer was highest for those workers employed between 1900 and 1924, a time during which workers were not using respirators or filtering masks.

An increased risk of nasal cavity and lung cancer was indicated for 937 individuals employed for at least five years at the Clyuach nickel refinery in Wales during 1902-

1944 (6292). A follow-up study (to 1971) revealed 145 lung cancers and 56 nasal sinus cancers. Based on SMRs determined using age and time-specific rates of cancer in England and Wales, a very high risk for nasal sinus cancer (9,000 to 64,900 depending on year) was determined. The incidence of nasal sinus cancer was not significant after 1924 and, as previously mentioned, probably coincides with the use of respirators.

A third report using data from the Clydach refinery extended the follow-up period of the previous report to 1981 (6295). Workers in the calcining furnace area, calcining crushing operations, copper sulfate area, and the Orford furnace area exhibited statistically higher rates of lung cancer, nasal cancer, or lung and nasal cancer combined. A positive relationship was found between nasal cancer and age at first exposure, but no such relationship was noted for lung cancer. An increased risk for both lung and nasal cancer relative to increasing duration of exposure to high nickel levels was noted. The risks for both lung and nasal cancer was low for the first 20 years after initial exposure and increased up to 40 years after first exposure for lung cancer and greater than 50 years for nasal cancer.

A number of studies are published regarding the International Nickel Company, Inc. of Ontario, Canada. Sutherland (6296) studied a cohort of 2,355 workers employed for at least 5 years at the plant. Mortality data for the period 1930 through 1957 was examined and indicated that 19 of 245 deaths were attributed to lung cancer and that only 8.45 were expected ($P<0.001$). The excess deaths due to lung cancer were most prevalent for those working in the furnace exposure area (SMR=380). Nasal sinus cancer was also found to be greater with seven deaths recorded and only 0.19 expected ($P<0.001$) but follow-up studies indicated that it was not limited to just the furnace workers. Additional follow-up studies (summarized by the U.S.EPA in reference 6204) using more sophisticated analyses also showed increased risk of lung and nasal cancer due to nickel exposure.

An evaluation of all pertinent epidemiologic studies of occupational exposure to nickel indicated that each study was deficient in some respect but the available data strongly indicated that nickel from calcining and sintering operations is a potent carcinogen with respect to nasal and pulmonary cancer (6293) . However, none of the studies provided data that could identify any one nickel compound as the carcinogenic form. Increased cancer risk in nickel-using industries could not be confirmed from the available data, nor could they exclude the possibility of cancer risk due to nickel exposure.

An evaluation of the health of workers in high-nickel (75%) alloy welding was conducted where a time-weighted average exposure was determined to be 0.44 mg Ni/m^3 (0.07 to 1.1 mg Ni/m^3 range) (6361). Eleven workers were examined for whom nickel exposure was 5.6 hr/day, 4 days/week for 6 weeks. A group of ten individuals matched for smoking habits and with no previous occupational exposure to nickel served as controls. Although not correlated with nickel exposure level, urine levels of nickel were significantly higher on Thursday afternoons relative to Monday mornings. The nickel-exposed workers experienced a significant ($P<0.006$) increase in the incidence of airway irritations, eye irritations, headaches, and tiredness. No changes in

vital capacity or one-second forced expiratory volume were noted for the nickel-exposed workers.

76.3.3 Levels of Concern

Based on epidemiology data, quantitative unit cancer risk estimates for inhalation exposure to nickel have been established by the U.S. EPA (6204). Lifetime cancer risk levels of 4E-01, 4E-02, and 4E-03 $\mu g/m^3$ have been estimated at 1E-04, 1E-05, and 1E-06, respectively for inhalation exposure to nickel dust. For inhalation exposure to nickel subsulfide, corresponding estimates are 2E-01, 2E-02, and 2E-03 $\mu g/m^3$, respectively. An incremental unit-risk slope for carcinogenic potency of 2.4E-04 $(\mu g/m^3)^{-1}$ for nickel refinery dust and 4.8E-04 $(\mu g/m^3)^{-1}$ for nickel subsulfide have been calculated (6204). The unit risk for nickel subsulfide should not be used if air concentrations exceed 20 $\mu g/m^3$. The U.S.EPA (6377) classifies nickel dust and nickel subsulfide as Group A (human carcinogen), and nickel carbonyl is classified as Group B2 probable human carcinogen (inadequate evidence in humans, sufficient evidence in animals).

IARC (6288) classifies nickel and nickel compounds as Group 2A (limited evidence in humans, sufficient evidence in animals). The nickel compounds of concern regarding this classification are nickel powder, nickel subsulfide, nickel oxide, nickel hydroxide, nickel carbonate, nickel carbonyl, nickelocene, nickel iron-sulfide matee, and nickelous acetate.

OSHA (7000) has established an 8-hr TWA of 0.007 mg/Ni/m^3 (0.001 ppm) as nickel carbonyl, 1 mg Ni/m^3 as nickel metal or insoluble nickel compounds, and 0.1 mg Ni/m^3 as soluble nickel compounds. ACGIH (6367) has established a TLV (8-hr TWA) of 1.0 mg Ni/m^3 as nickel dust or insoluble nickel compounds and 0.1 mg Ni/m^3 for soluble nickel compounds. More recently, however, ACGIH (6375) has listed nickel and nickel compounds on its 1989-1990 List of Intended Changes in which the following proposed changes to the TWA were indicated: 0.05 mg/m^3 for nickel metal, soluble nickel compounds and insoluble nickel compounds. NIOSH (as cited in 6206) has established a time-weighted average-threshold value (TWA-TLV) of 15 $\mu g/m^3$ for elemental nickel and all nickel compounds except organo-nickel compounds with a covalent carbon-nickel bond (e.g. nickel carbonyl).

U.S. EPA (6362) has established an ambient water quality criterion of 13.4 $\mu g/L$ for the protection of human health from the toxic effects of nickel ingested through water and contaminated organisms. For protection from toxic effect due to ingestion of aquatic organisms alone, a criterion of 100 $\mu g/L$ has been established. An MCL and MCLG of 100 $\mu g/L$ has been established by the U.S. EPA (6407). Health advisories regarding water exposure limits have also been established by the U.S. EPA (6365) and are as follows:

1-day (child): 1000 $\mu g/L$
10-day (child): 1000 $\mu g/L$
longer-term (child): 100 $\mu g/L$
longer-term (adult): 600 $\mu g/L$
lifetime (adult): 100 $\mu g/L$
DWEL: 600 $\mu g/L$

No health-based drinking water guideline has been established by the World Health Organization (6221).

The U.S. EPA (6377) has established a reportable quantity (RQ) of 1 lb for nickel metal (<100 μm in diameter), nickel carbonyl, and nickel cyanide. The RQ for nickel hydroxide is 1000 lb. and for nickel ammonium sulfate, nickel chloride, nickel nitrate, and nickel sulfate, the RQ is 5000 lb. The threshold planning quantity (TPQ) as established under the authority of SARA (Sect. 302) is 10,000 lb for nickel and 1 lb for nickel carbonyl (EPA, 1987).

The Food and Drug Administration (6366) classifies nickel as a GRAS (generally recognized as safe) direct food additive.

Oral and dermal exposure of humans to natural concentrations of nickel in waters, soils, and foods was not considered to be a biological threat (6289).

76.3.4 Hazard Assessment

Animal studies have provided evidence for respiratory tract cancer (6346, 6281) and renal malignancies (6368, 6369). A review of the literature indicated nickel subsulfide to be the most potent carcinogenic nickel compound (6283). A number of epidemiological studies have provided evidence for nickel-induced nasal cancer in refinery workers, especially prior to the use of respirators. Nickel compounds have been classified as Group 1 (carcinogenic to humans) by IARC (6288). Metallic nickel is considered by IARC to be in Group 2B (possibly carcinogenic to humans). The U.S. EPA (6204) classified nickel dust and nickel subsulfide as Group A carcinogens (human carcinogen), and nickel carbonyl as a Group B2 carcinogen (probable human carcinogen; inadequate evidence in humans, sufficient evidence in animals).

Investigations assessing the genotoxic potential of nickel and nickel compounds provided equivocal results. In evaluating available data, the U.S. EPA (6204) concluded that nickel did not exhibit clastogenic activity. However, Sunderman et al. (6369) reported chromosomal abnormalities, and gene amplification, in rats receiving intrarenal injections of nickel subsulfide. Bacterial mutagenicity assays indicated that nickel compounds are only weakly or not at all mutagenic (6204, 6283).

Animal studies have indicated that nickel is known to cross feto-maternal barriers (6319), is taken up by the embryo during early gestation (6323, 6320), and is excreted into the milk of rats (6324). Evaluated data indicate that inhalation, oral or parenteral exposure of animals to nickel during gestation may result in developmental and reproductive toxicity in laboratory animals.

Numerous animal studies are available affirming the noncarcinogenic toxicity of nickel and nickel compounds following short-term or long-term inhalation or oral exposure. Depending on the exposure concentration, effects may range from minor histological alterations to death and may involve the lungs and/or kidneys. The highly toxic effects of acute inhalation exposure to nickel carbonyl are well documented and,

therefore, acute exposure to this compound at even low concentrations is very dangerous.

Contact dermatitis and nickel-induced asthma are well documented in humans. These responses are known to occur following exposure to a wide variety of nickel compounds and nickel-containing products such as jewelry, chalk, kitchen utensils, coins, dental prostheses, etc. There is evidence suggesting that some of these responses are immunologically mediated.

76.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of nickel concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following sequence of reagents to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is required for solid samples other than storage at 4°C until sample analysis. All samples should be analyzed within 180 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (6371).

Analytical methods available for analyzing inorganic nickel in water, soils and waste include atomic absorption (Methods 249.1 and 249.2) and inductively coupled plasma atomic emission spectrometry (Method 200.7) techniques. Depending upon the analytical method, treatment with acid or a combination of acid with hydrogen peroxide is used to digest the samples. Sample preparation procedures specific to each analytical technique are described in Methods 200.0, and 200.7 for aqueous samples and Methods 3005, 3010, 3020, 3040, and 3050 for solid or waste samples. Quality control samples should be processed with the samples to determine whether analyte losses have occurred during the sample dissolution procedure (6372).

The atomic absorption techniques are probably the most common procedures for determining the concentration of nickel in water, soil and waste samples. Following the appropriate digestion of the sample, a representative aliquot of the digestate is atomized by either directly aspirating it into a flame or by charring it in a graphite tube furnace. The absorption of hollow cathode or electrodeless discharge lamp radiation at 232.0 nm will be proportional to the nickel concentration. The detection ranges are 0.3-5 mg/L and 5-50 µg/L for the flame and the furnace atomic absorption techniques, respectively. No U.S. EPA data is currently available to document the precision and

accuracy of the graphite furnace technique. In a single U.S. EPA study, using mixed industrial-domestic waste effluent, the standard deviation of results ranged from 1-5%. The recovery at the 0.2-5 mg Ni/L ranged from 93-100% (6371).

The U.S. EPA also approves the use of the inductively coupled plasma (ICP) atomic emission method for determining nickel in support of environmental monitoring (6370). The technique is based upon the simultaneous or sequential multi-element measurement of atomic emission of trace metals. A preserved and/or digested sample is nebulized to form an aerosol that is introduced into a high temperature plasma where atomic excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma and are dispersed by a grating spectrometer. The line intensities, which are a measurement of elemental concentrations, are monitored by photomultiplier tubes. Optical compensation techniques are used to correct for spectral interferences. In a U.S. EPA evaluation of the reproducibility and accuracy of the ICP method, the mean percent relative standard deviation for triplicate analysis of 22 elements was found to be 9%. The mean percent recovery of spiked elements for all waste samples was 93% (6371).

Detection Limit	Method
15 µg/L (aqueous & nonaqueous)	200.7
40 µg/L (aqueous & nonaqueous)	249.1
1 µg/L (aqueous & nonaqueous)	249.2

76.5 REFERENCES

Note: The numbering sequence of the references reflects the order of references as they appear in the master bibliography.

6200. Sax, N.I.; Lewis, R.J., Sr., eds. 1989. Dangerous Properties of Industrial Materials. 7th ed. New York: Van Nostrand Reinhold.

6201. Hawley, G.G., ed. 1981. The Condensed Chemical Dictionary. 10th ed. New York: Van Nostrand Reinhold.

6202. Windholz, M. ed. 1983. The Merck Index. Rahway, New Jersey: Merck and Co., Inc.

6203. Sunderman, F.W., Jr.; Oskarsson, A. 1987. Nickel. In: E. Merian, ed. Metals and Their Compounds in the Environment.

6204. U.S. Environmental Protection Agency (U.S. EPA) 1986. Health Assessment Document for Nickel and Nickel Compounds. Environmental Criteria and Assessment Office. EPA/600/8-83/012FF.

6205. National Institute for Occupational Safety and Health (NIOSH). 1987. NIOSH Pocket Guide to Chemical Hazards. U.S. Dept. of Health and Humans Services, Public Health Service.

6206. Agency for Toxic Substances and Disease Registry (ATSDR). 1988. Toxicological Profile for Nickel. Prepared by Syracuse Research Corp. under Contract No. 68-68-0004 for Agency for Toxic Substances and Disease Registry and the U.S. Public Health Service. ATSDR/TP-88/19.

6207. Weiss, G. ed. 1980. Hazardous Chemicals Data Book. Noyes Data Corp.. Park Ridge, NJ.

6208. Tien, J.K; Howson, T.E. 1981. Nickel and nickel alloys. In: Grayson, M.; Eckroth, D., eds. Kirk-Othmer Encyclopedia of Technology, 3rd ed., vol 15. John Wiley and Sons, New York. pp. 787-801.

6209. Kirk, W.S. 1987. Nickel. In: Minerals Yearbook, Vol 1., Metals and Minerals. Bureau of Mines. pp 641-651.

6210. Berrow, M.L.; Burridge, J.C. 1980. Trace element levels in soils: effects of sewage sludge. In: Inorganic Pollution and Agriculture. MAFF Reference Book 326, London. pp 159-183. (As cited in 6211).

6211. Bennett, B.G. 1984. Environmental nickel pathways to man. In: Sunderman, F.W., Jr, et al., eds. Nickel in the Human Environment. IARC Scientific Publication No. 53. pp 487-495.

6212. Callahan, M.A.; Slimak, M.W.; Gabel, N.W.; May, I.P., Fowler, C.F.; et al. 1979. Water-related environmental fate of 129 priority pollutants. Vol 1. EPA-440/4-79-029a. pp15-1 to 15-9.

6213. Lee, G.F. 1975. Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel, P.A. ed. Heavy Metals in the Aquatic Environment. Pergamon Press, Oxford, England. pp 15-3 to 15-9. (As cited in 6212).

6214. Environmental Inorganic Chemistry 1988. Bodek, I.; Lyman, W.J.; Reehl, W.F.; . Rosenblatt, D.H., eds. Pergamon Press, Oxford, England. pp. 7.11-1 to 7.11-7.

6215. Jackson, K.S.; Shippen, G.B. 1978. Geochemical dispersion of heavy metals via organic complexing: a laboratory study of copper, lead, zinc, and nickel behavior at a simulated sediment-water boundary. J. Geochem. Explor. 10:117-138. (As cited in 6214).

6216. Rai, D.; Zachara, J.; Schwab, H.; Schmidt, R.; Given, D.; Rogers, J. 1984. Chemical attenuation rates, coefficients, and constants in leachate migration. Vol. 1: A critical review. Report EA-3356 to EPRI by Pacific Northwest Laboratories (Batelle Institute), Richland, WA. (As cited in 6214).

6217. Bowman, R.S.; Essington, M.E.; O'Connor, G.A. 1981. Soil sorption of nickel: influence of solution composition. Soil Sci. Soc. Amer. J. 46:860-865. (As cited in 6214).

6218. Rashid, M.A.; Leonard, J.D. 1973. Modifications in the solubility and precipitation behavior of various metals as a result of their interaction with sedimentary humic acid. Chem. Geol. 11:89-97. (As cited in 6214).

6219. Mantoura, R.F.C.; Dichson, A.; Riley, J.P. 1978. The complexation of metals with humic materials in natural waters. Estuarine Coastal Mar. Sci. 6:387-408. (As cited in 6214).

6220. Caton, F.A; Wilkinson, G. 1972. Advanced Inorganic Chemistry. 5th Ed. Interscience Publ., New York. pp. 743-752.

6221. World Health Organization (WHO) 1984. Guidelines for drinking water quality. Vol. 2 Health criteria and other supporting information. World Health Organization, Geneva. pp. 124-127.

6222. Sunderman, F.W., Jr. 1986. Sources of exposure and biological effects of metals. In: O'Neill, I.K.; Schuller, P.; Fishbein, L., eds. Environmental Carcinogenesis - Selected Methods of Analysis. International Agency for Research on Cancer, Lyon, France. pp. 79-92.

6223. National Academy of Sciences (NAS) 1977. Geochemistry and the environment. Vol. II. The relation of other selected trace elements to health and disease. Washington, D.C. (As cited in 6225).

6224. Ellen, G.F.; Cigna-Rossi, L.; Santorini, G.P. 1980. Nickel in foods and dietary intake of nickel. In: Nriagu, J.O. ed. Nickel in the Environment. John Wiley and Sons, New York. pp. 493-498. (As cited in 6225).

6225. Bennett, B.G. 1982. Exposure of man to environmental nickel - an exposure commitment assessment. Sci. Total Environ. 22:203-212.

6226. Stahly, E.E. 1973. Some considerations of metal carbonyls in tobacco smoke. Chem. Ind. 13:620-623.

6227. Grandjean, P. 1984. Human exposure to nickel. In: Sunderman, F.W., Jr., ed. Nickel in the Human Environment. IARC Scientific Publ. No. 53. International Agency for Research on Cancer, Lyon, France. pp. 469-485.

6228. Weast, R.C.; Astle, M.J.; Beyer, W.H., eds. 1989. CRC Handbook of Chemistry and Physics. CRC Press, Boca Raton, Florida.

6229. Andersen, K.E.; Nielsen, Gitte D.; Flyvholm, M.; Fregert, S.; Bruvgerge, B. 1983. Nickel in tap water. Contact Derm. 9: 140-143.

6230. Bennett, B.G. 1986. Exposure assessment for metals involved in carcinogenesis. In: IARC Sci. Publ. 71, Environmental Carcinogens Selected Methods of Analysis 8:115-128.

6231. Bennett, B.G. 1981. Summary exposure assessments for mercury, nickel, tin. In: Exposure Commitment Assessments of Environmental Pollutants, Vol. 1, No. 2, London: Monitoring and Assessment Research Centre, pp. 17-30. (Cited in 6227)

6232. Bennett, B.G. 1984. Environmental nickel pathways to man. Symposium on Nickel in the Human Environment, Lyon, France, March 8-11, 1983. Lyon: International Agency for Research on Cancer, pp. 467-495. IARC Scientific Publication No. 53.

6233. McComish, M.F.; Ong, J.H. 1988. Trace metals. In: Bodek, I. et al., eds. Environmental Inorganic Chemistry. Walton, B.T.; Conway R.A., Eds. New York: Pergamon Press, pp. 2.7-12, 7.11-1 - 7.11-7.

6234. Boyle, R.W.; Robinson, H.A. 1988. Nickel in the natural environment. In: Metal Ions in Biological Systems, Vol. 23, Nickel and its Role in Biology. Sigel, H., Ed. New York: Marcel Dekker, Inc., pp. 1-29.

6235. Brown, K.W.; Thomas, J.C.; Slowey, J.F. 1983. The movement of metals applied to soils in sewage effluents. Water, Air, Soil Pollut. 19:43-54.

6236. Callahan, M.A.; Slimak, M.W.; Gabel N.W. et al. 1979. Water-related Environmental Fate of 129 Priority Pollutants, Vol. I: Introduction and Technical Background, Metals and Inorganics, Pesticides and PCBs. Washington, D.C.: Office of Water and Waste Management, U.S. Environmental Protection Agency, pp. 15-1 to 15-9.

6237. CFR Title 29. Chapter 17, Part 1910, Subpart Z. (Cited in 6256)

6238. Clark, J.R.; Van Hassel, J.H.; Nicholson, R.B.; Cherry, D.S.; Cavins, J., Jr. 1981. Ecotoxicol. Environ. Safety 5: 87. (Cited in 6272)

6239. Dowdy, R.H.; Bidwell A.M.; Clapp, C.E. 1987. Trace metal movement in an agricultural watershed. International Conference on Heavy Metals in the Environment, Vol. 1., New Orleans, Sept. 1987. Lindberg, S.E.; Hutchinson, T.C., Eds. pp. 384-386.

6240. EIFAC (European Inland Fisheries Advisory Commission) 1984. Technical Paper 45, Food and Agriculture Organization of the United Nations, p. 20. (Cited in 6272)

6241. U.S. Environmental Protection Agency (U.S. EPA) 1986a. Health Assessment Document for Nickel and Nickel Compounds. Final Report. ORD, OHEA, ECAO-RTP. EPA 600/8-83-012FF. NTIS PB86-232212. (Cited in 6202)

6242. U.S. Environmental Protection Agency (U.S EPA) 1986b. Assessment of nickel subsulfide and nickel carbonyl as potentially toxic air pollutants. Fe. Reg. 51(186: 34135-34139. (Cited in 6202)

6243. Farago, M.E.; Cole M.M. 1988. Nickel and plants. In: Metal Ions in Biological Systems, Vol. 23, Nickel and its Role in Biology. Sigel, H., Ed. New York: Marcel Dekker, Inc., pp. 47-90.

6244. Filkova, L. 1985. The danger of contamination of the living environment with nickel carbonyl. Cesk. Hyg. 30: 243-249.

6245. Filkova, L.; Jäger, J. 1986. Non-occupational exposure to nickel tetracarbonyl. Cesk. Hyg. 31: 255-259.

6246. Francis, A.J.; Dodge, C.J. 1987. Anaerobic microbial dissolution of toxic metals from energy residues. International Conference on Heavy Metals in the Environment, Vol. 1., New Orleans, Sept. 1987. Lindberg, S.E.; Hutchinson, T.C., Eds. pp. 427-429.

6247. Grandjean, P. 1984. Human exposure to nickel. Symposium on Nickel in the Human Environment, Lyon, France, March 8-11, 1983. Lyon: International Agency for Research on Cancer, pp. 469-485. IARC Scientific Publication No. 53.

6248. Heit, M.; Klusek, C.S. 1985. Trace element concentrations in the dorsal muscle of white suckers and brown bullheads from two acidic Adirondack lakes. Water, Air, Soil Pollut. 25:87-96.

6249. Hovmand, M.F. 1981. Nickel. In: Agricultural Use of Sewage Sludge, Vol 2. Andersen, A.; Jepsen, A.; Larsen, K.E. et al., Eds. Copenhagen: Polyteknisk Forlag, pp. 121-124. (In Danish) (Cited in 6227)

6250. Johansen, O.J.; Carlson, D.A. 1976. Characterization of sanitary landfill leachates. Water Res. 10:1129-1134.

6251. Kabata-Pendias, A.; Pendias, H. 1984. Trace Elements in Soils and Plants. Boca Raton, FL: CRC Press, pp. 1-68, 246-254.

6252. Kenega, E.E. 1980. Predicted bioconcentration factors and soil sorption coefficients of pesticides and other chemicals. Ecotox. Environ. Safety 4; 26-38. (Cited in 6202)

6253. Khan, S.; Nandan, D.; Khan, N. 1982. The mobility of some heavy metals through Indian red soil. Environ. Pollut. (Series B) 4:119-125.

6254. Kirk, W.S. 1989. Nickel. In: Minerals Yearbook 1987, Vol. I. Metals and Minerals. Washington, DC: Bureau of Mines, U.S. Dept. of the Interior, pp. 641-651.

6255. Mantoura, R.F.C.; Dickson, A.; Riley, J.P. 1978. The complexation of metals with humic materials in natural waters. Estuarine Coastal Mar. Sci. 6: 387-408. (Cited in Bodek et al. 1988)

6256. Mastromatteo, D. 1986. Nickel. Am. Ind. Hyg. Assoc. J. 4:589-601.

6257. Mejstrik, V.; Svacha, J. 1988. Concentrations of Co, Cd, Cr, Ni, and Zn in crop plants cultivated in the vicinity of coal-fired power plants. Sci. Total Environ. 72:57-67.

6258. NAS (National Academy of Sciences) 1975. Medical and Biologic Effects of Environmental Pollutants: Nickel. Washington, DC: National Academy of Sciences, 277 pp.

6259. Nielsen, G.D.; Flyvholm, M. 1984. Risks of high nickel intake with diet. In: Nickel in the Human Environment. IARC Scientific Publications No. 53. Lyon: International Agency for Research on Cancer, pp. 333-338.

6260. National Institute of Occupational Safety and Health (NIOSH) 1977. Criteria for a recommended standard for occupational exposure to inorganic nickel. Washington, D.C.: U.S. Dept. of Health, Education and Welfare. (Cited in 6256)

6261. Nriagu, J.O. 1980. Global cycle of nickel. In: Nickel in the Environment. New York: John Wiley & Sons, pp. 1-26. (Cited in 6202)

6262. Nriagu, J.O.; Pacyna, J.M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333:134-139.

6263. Perrin, D.D. 1981. Ionization Constants of Inorganic Acids and Bases in Aqueous Solutions, IUPAC Chemical Data Series, No. 29. New York: Pergamon Press. (Cited in Bodek et al. 1988)

6264. Petruzzelli, G.; Paris, P.; Guidi, G.; Lubrano, L.; Poggio, G. 1987. Heavy metals solubility in compost treated soil. Results from field experiments. International Conference on Heavy Metals in the Environment, Vol. 1., New Orleans, Sept. 1987. Lindberg, S.E.; Hutchinson, T.C., Eds. pp. 414-416.

6265. Rai, D.; Zachara, J.; Schwab, A.; Schmidt, R.; Girvin, D., and Rogers, J. 1984. Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration. Vol. 1. A Critical Review. Richland, WA: Pacific Northwest Laboratories (Battelle Inst.) (To EPRI). Report EA-3356. (Cited in Bodek et al. 1988)

6266. Richter, R.O.; Theis, T.L. 1980. Nickel speciation in a soil/water system. In: Nickel in the Environment. New York: John Wiley & Sons, pp. 189-202.

6267. Sadiq, M.; Zaidi, T.H. 1981. The adsorption characteristics of soils and sorption of cadmium and nickel from wastewaters. Water, Air, Soil Pollut. 16:293-298. (Cited in 6269)

6268. Sadiq, M.; Enfield, C.G. 1984a. Solid phase formation and solution chemistry of nickel in soils. 2. Experimental. Soil Sci. 138:335-340.

6269. Sadiq, M.; Enfield, C.G. 1984b. Solid phase formation and solution chemistry of nickel in soils: 1. Theoretical. Soil Sci. 138:262-270.

6270. Schmidt, J.A.; Andren A.W. 1980. The atmospheric chemistry of nickel. In: Nickel in the Environment. Nriagu, J.O., Ed. New York: John Wiley & Sons. (Cited in 6202)

6271. Steiner, R.L. et al. 1971. Criteria for sanitary landfill development. Public Works 102:77. (Cited in 6278)

6272. Stokes, P. 1988. Nickel in aquatic systems. In: Metal Ions in Biological Systems, Vol. 23, Nickel and its Role in Biology. Sigel, H., Ed. New York: Marcel Dekker, Inc., pp. 31-46.

6273. Sunderman, F.W., Jr. 1986. Sources of exposure and biological effects of nickel. In: Environmental Carcinogens Selected Methods of Analysis, Vol. 8. Lyon: International Agency for Research on Cancer, pp. 79-92. IARC Scientific Publications No. 71.

6274. Sunderman, F.W., Jr.; Oskarsson, A. 1987. Nickel. In: Metals and their Compounds in the Environment. Merian, E., Ed. Unpublished.

6275. Taylor, G.J.; Crowder, A.A. 1983. Accumulation of atmospherically deposited metals in wetland soils of Sudbury, Ontario. Water, Air, Soil Pollut. 19:29-42.

6276. Tyler, L.D.; Mcbride, M.B. 1982. Mobility and extractability of cadmium, copper, nickel, and zinc in organic and mineral soil columns. Soil Sci. 134: 198-205.

6277. Veien, N.K.; Andersen, M.R. Nickel in Danish food. Acta Derm. Venereol. (Stockh) 66: 502-509.

6278. Venkataramani, E.S.; Ahlert, R.C.; Corbo, P. 1984. Biological treatment of landfill leachates. CRC Crit. Rev. Environ. Contr. 14:333-76.

6279. Verloo, M.; Willaert, G.; Eeckhout, M.; De Spiegeleer, F. 1987. Chemical and biological implications of metal speciation in contaminated soils. International Conference on Heavy Metals in the Environment, Vol. 1., New Orleans, Sept. 1987. Lindberg, S.E.; Hutchinson, T.C., Eds. pp. 253-255.

6280. Warner, J.S. 1984. Occupational exposure to airborne nickel in producing and using primary nickel products. In: Nickel in the Human Environment. IARC Scientific Publications No. 53. Lyon: International Agency for Research on Cancer, pp. 419-437. (Cited in 6256)

6281. Lauwreys, R.R. 1989. Metals- epidemiological and experimental evidence for carcinogenicity. In: Chambers, P.L.; Chambers, C.M.; Green, H., eds. Biological Monitoring of Exposure and the Response at the Subcellular Level to Toxic Substances. Proc. Europ. Soc. Toxicol. Springer-Verlag, New York.

6282. Sunderman, F.W., Jr. 1989. Mechanistic aspects of nickel carcinogenicity. In: Chambers, P.L.; Chambers, C.M.; Green, H., eds. Biological Monitoring of Exposure and the Response at the Subcellular Level to Toxic Substances. Proc. Europ. Soc. Toxicol. Spronger-Verlag, New York.

6283. Coogan, T.P.; Latta, D.M.; Snow, E.T.; Costa, M. 1989. Toxicity and carcinogenicity of nickel compounds. In: McClellan, R.O. et al., eds. Critical Reviews in Toxicology. Vol. 19(4):341-384. CRC Press, Inc., Boca Raton, Florida.

6284. United States Environmental Protection Agency (U.S. EPA) 1986. Health Assessment Document for Nickel and Nickel Compounds. EPA/600/8-83/012FF.

6285. Ottolenghi, A.D.; Haseman, J.K.; Payne, W.W.; Falk, H.L.; MacFarland, H.N. 1974. Inhalation studies of nickel sulfide in pulmonary carcinogenesis of rats. J. Natl. Cancer Inst. 54:1165-1172.

6286. Kasprzak, K.; Gabryl, P.; Jarczewska, K. 1983. Carcinogenicity of nickel(II) hydroxide and nickel(II) sulfate in Wistar rats and its relation to in vitro dissolution rates. Carcinogenesis 4:275-280.

6287. Lamb, G.D.; Sunderman, F.W.; Schneider, H.P.; Chow, H.P. 1987. Histogenesis of subcutaneous malignant tumors resulting from nickel subsulfide implantation. Ann. Clin. Lab. Sci. 17:286.

6288. International Agency for Research on Cancer (IARC) 1987. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Sup[l. 7. Lyon, France. pp.265-266.

6289. National Academy of Sciences (NAS) 1975. Nickel. Nationai Acad. of Sci. Committee on Medical and Biological Effects of Environmental Pollutants. Washington, D.C. (As cited in 6206).

6290. Agency for Toxic Substances and Disease Registry (ATSDR) 1988. Toxicology Profile for Nickel. ATSDR/TP-88/19.

6291. Sunderman, F.W., Jr. 1984. Recent progress in nickel carcinogenesis. Toxicol. Environ. Chem. 8:235-252.

6292. Doll, R.; Mathews, J.D.; Morgan, L.G. 1977. Cancers of the lung and nasal sinuses in nickel workers. A reassessment of the period of risk. Br. J. Ind. Med. 34:102-105.

6293. Grandjean, P.; Andersen, O.; Nielsen, G.D. 1988. Carcinogenicity of occupational nickel exposures: an evaluation of the epidemiological evidence. Am. J. Ind. Med. 13:193-209.

6294. Morgan, J.G. 1958. Some observations on the incidence of respiratory cancer in nickel workers. Br. J. Ind. Med. 15:224-234. (As cited in 6206).

6295. Peto, J.; Cuckle, H.; Doll, R.; Herman, C.; Morgan, L.G. 1984. Respiratory cancer mortality of Welsh nickel refinery workers. In: Sunderman, F.W., Jr. ed. Nickel in the Human Environment. IARC Publ. No. 53. International Agency for Research on Cancer, Lyon, France.

6296. Sutherland, R.B. 1959. Summary of report on respiratory cancer mortality 1930-1957. Port Colborne, Ontario, Canada: International Nickel Co. of Canada, Ltd. Unpubl. (As cited in 6204).

6297. Horie, A.; Tanaka, I.; Harataka, J.; Kodama, Y.; Tsuchiya, K. 1985. Electron microscopy of pulmonary lesions, including carcinoma induced by inhalation exposure of rats to nickel oxide aerosol. In: Sunderman, F.W., Jr. ed. Progress in Nickel Toxicology. pp. 41-44.

6298. Sunderman, F.W. 1989. A pilgrimage into the archives of nickel toxicology. Ann. Clin. Lab. Sci. 19:1-16.

6299. Sunderman, F.W., Jr. 1986. Nickel. In: Seiler, H.G.; Sigel, H., eds. Handbook of Toxicology of Inorganic Compounds. Marcel Dekker, New York.

6300. Dolovich, J.; Evans, S.L.; Niebor, E. 1980. Occupational asthma from nickel sensitivity. I. Human serum albumin in the antigenic determinant. Br. J. Ind. Med. 41:51. (as cited in 6283).

6301. Novey, H.S.; Habib, M.; Wells, I.D. 1983. Astham and IgE antibodies induced by chromium and nickel salts. J. Allergy Clin. Immunol. 72:407 (as cited in 6283).

6302. Zanca, A.; Nigro, M.; Luciani, P.; De Agostina, F.; Chiergato, G.C. 1988. The release of nickel from blackboard chalk may cause contact dermatitis. Contact Dermatitis 19:143.

6303. Romaguera, C.; Grimalt, F.; Vilaplana, J. 1988. Contact dermatitis from nickel: an investigation of its sources. Contact Dermatitis 19:52-57.

6303. Emmett, E.A.; Risby, T.H.; Jiang, L.; Ng, S.K. Feinman, S. 1988. Allergic contact dermatitis to nickel: bioavailability from consumer products and provocation threshold. J. Am. Acad. Dermatol. 19:314-322.

6304. McConnell, L.H.; Fink, J.N.; Schlotter, D.P. 1973. Asthma caused by nickel sensitivity. Ann. Int. Med. 78:888-890.

6305. Santucci, B.; Cristaudo, A.; Cannostaci, C.; Picado, M. 1988. Nickel sensitivity: effects of prolonged oral intake of the element. Contact Dermatitis 19:202-205.

6306. Edelman, D.A.; Roggli, V.L. 1989. The accumulation of nickel in human lungs. Environ. Health Perspec. 81:221-224.

6307. Niebor, E.; Lewan, S.; Dolovich, J. 1984. Occupational asthma from nickel sensitivity: II. Factors influencing the interaction of Ni^{2+}, HSA, and serum antibodies with nickel related specificity. Br. J. Ind. Med. 41:56-63.

6308. Malo, J.-L.; Cartier, A.; Doepner, M.; Niebor, E.; Evans, S.; Dolovich, J. 1982. Occupational asthma caused by nickel sulfate. J. Allergy Clin. Immunol. 69:55-59.

6309. Ciccarelli, R.B., Wetterhahn, K.E. 1984a. Molecular basis for activity of nickel. In: Sunderman, F.W., Jr., ed. Nickel in Human Environment. IARC Mongr. Ser. No. 53. IARC Scientific Publications, Lyon, France.

6310. Ciccarelli, R.B.; Wetterhahn, K.E. 1984b. Nickel-bound chromatin, nucleic acids and nuclear proteins from kidney and liver of rats treated with nickel carbonate in vivo. Cancer Res. 44:3892 (as cited in 6283).

6311. Deknudt, G.H.; Leonard, A. 1982. Mutagenicity tests with nickel salts in the mouse. Toxicology 25:2890292 (as cited in 6204).

6312. Jacquet, P.; Mayence, A. 1982. Application of the in vitro embryo culture to the study of the mutagenic effects of nickel in male germ cells. Toxicol. Lett. 11:193-197 (as cited in 6204).

6313. Mathur, A.K.; Dikshith, T.S.S.; Lala, M.M.; Tandon, S.K. 1978. Distribution of nickel and cytogenetic changes in poisoned rats. Toxicology 10:105-113 (as cited in 6204).

6314. Leonard, A. 1988. Mechanisms in metal genotoxicity: the possible significance of in vitro approaches. Mutat. Res. 198:321 (as cited in 6283).

6315. Wulf, H.C. 1980. Sister chromatid exchanges in human lymphocytes exposed to nickel and lead. Dan. Med. Bull. 27:40-42 (as cited in 6204).

6316. Ohno H.; Hanaka, F.; Yameda, M. 1982. Inducibility of sister chromatid exchanges by heavy metal ions. Mutat. Res. 104:141-145 (as cited in 6204).

6317. Larramendy, M.L.; Popsecu, N.C.; Dipaolo, J.A. 1981. Induction by inorganic metal salts of sister chromatid exchanges and chromosome aberrations in human and Syrian hamster cell strains. Environ. Mutag. 3:597-606 (as cited in 6204).

6318. Schroeder, H.A.; Mitchener, M. 1971. Toxic effects of trace elements on the reproduction of mice and rats. Arch. Environ. Health 23:102-106.

6319. Sunderman, F.W., Jr.; Shen, S.; Mitchell, S.K.; Allpass, J.M.; Damjanov, I. 1978a. Embryotoxicity and fetal toxicity of nickel in rats. Toxicol. Appl. Pharmacol. 43:381-390.

6320. Mas, A.; Holt, D.; Webb, M. 1985. The acute toxicity and teratogenicity of nickel in pregnant rats. Toxicology 35:47-57.

6321. Lu, C.C.; Matsumoto, N.; Iijima, S. 1979. Teratogenic effects of nickel chloride on embryonic mice and its transfer to embryonic mice. Teratology 19:137.

6322. Research Triangle Institute (RTI) 1986. Two-generation reproduction and fertility study of nickel chloride administered to CD rats in the drinking water. Unpublished Report.

6323. Olsen, I.; Jonsen, J. 1979. Whole-body autoradiography of ^{63}Ni in mice throughout gestation. Toxicology 12:165-172.

6324. Dostal, L.A.; Hopkins, S.M.; Lin, S-M.; Sunderman, F.W., Jr. 1989. Effects of nickel chloride on lactating rats and their suckling pups, and the transfer of nickel through rat milk. Toxicol. Appl. Pharmacol. 101:220-231.

6325. Hoey, M.J. 1966. The effects of metallic salts on the histology and functioning of the rat testis. J. Reprod. Fertil. 12:461-471.

6326. Mathur, A.K.; Datta, K.K.; Tandon, S.K. 1977. Effects of nickel sulfate on male rats. Bull. Environ. Contam. Toxicol. 17:241-248.

6327. Chang. C.C.; Tatum, H.J.; Kincl, F.A. 1970. The effect of intrauterine copper and other metals on implantation in rats and hamsters. Fertil. Steril. 22:274-278.

6328. Ashrof, M.; Sybers, H.D. 1974. Lysis of pancreatic exocrine cells and other lesions in rats fed nickel acetate. Am. J. Pathol. 74:102a. (as cited in 6206).

6329. Dieter, M.P.; Jameson, C.W.; Tucker, A.N.; et al. 1987. National Toxicology Program.

6330. Clary, J.J. 1977. Report on six months inhalation study (1 gm/m^3) using rats and guinea pigs. U.S. Dept. of Health, Education, and Welfare, Public Health Service Centers for Disease Control. National Institute of Occupational Safety and Health (as cited in 6206).

6331. Ambrose, A.M.; Larson, P.S.; Borzelleca. J.R.; Hennigar, G.R., Jr. 1976. Long term toxicologic assessment of nickel in rats and dogs. J. Food Sci. Technol. 13:181-187 (as cited in 6206).

6332. American Biogenics Corp. 1986. Ninety day gavage study in albino rats using nickel. Draft final report submitted to Research Triangle Inst. (as cited in 6206).

6333. Whanger, P.D. 1973. Effects of dietary nickel on enzyme activities and mineral content in rats. Toxicol. Appl. Pharmacol. 25:322-331.

6334. Dunnick, J.K.; Jameson, C.W.; Benson, J.M. 1985. Toxicology and carcinogenesis studies of nickel oxide, nickel sulfate and nickel subsulfide: Design of study and characterization of nickel compounds. In: Brown, S.S.; Sunderman, F.W., Jr., eds. Progress in Nickel Toxicology. Blackwell Publ., Oxford, UK. pp. 49-52.

6335. Sunderman, F.W., Jr. 1987. Lipid peroxidation as a mechanism of acute nickel toxicity. Toxicol. Environ. Chem. 15: 59-69.

6336. Finch, G.L.; Fisher, G.L.; Hayes, T.L. 1987. The pulmonary effects and clearance of intratracheally instilled Ni_3S_2 and TiO_2. Environ. Res. 42:83-95.

6337. Hopfer, S.M.; Sunderman, F.W., Jr. 1988. Hypothermia and deranged circadian rhythm of core body temperature in nickel chloride-treated rats. Res. Comm. Chem. Pathol. Pharmacol. 62:495-505.

6338. Zhicheng, S. 1986. Acute nickel carbonyl poisoning: a report of 179 cases. Br. J. Ind. Med. 43:422-424.

6339. Benson, J.M.; Henderson, R.F.; McClellan, R.O.; Hanson, R.L.; Rebar, A.H. 1986. Comparative acute toxicity of four nickel compounds to F344 rat lung. Fund. Appl. Toxicol. 7:340-347.

6340. Gardner, D.E. 1980. Dysfunction of host defenses following nickel inhalation. In: Brown, S.S.; Sunderman, F.W., Jr., eds. Nickel Toxicology. Acad. Press, New York. pp. 121-124.

6341. Smialowicz, R.J.; Rogers, R.R.; Riddle, M.M.; Gardner, R.J.; Rowe, D.G.; Luebke, R.W. 1985. Immunologic effects of nickel II. Suppression of natural killer cell activity. Environ. Res. 36:56-66.

6342. Sunderman, F.W., Jr.; Reid, M.C.; Shen, S.K.; Kevorkian, C.B. 1983. Embryotoxicity and teratogenicity of nickel compounds. In: Clarkson, T.W.; Nordberg, G.F.; Sager, P., eds. Reproductive and Developmental Toxicity of Metals. Plenum Publ. Corp., New York. pp. 399-416,.

6343. Benson, J.M.; Burt, D.G.; Carpenter, R.L.; et al. 1988. Comparative inhalation toxicity of nickel sulfate to F344/N rats and B6C3F$_1$ mice exposed for twelve days. Fundam. Appl. Toxicol. 10:164-178.

6344. Benson, J.M.; Carpenter, R.L.; Hahn, F.F.; et al. 1987. Comparative inhalation toxicity of nickel subsulfide to F344/N rats and B6C3F$_1$ mice exposed for twelve days. Fundam. Appl. Toxicol. 9:251-256.

6345. Bingham, E.; Barkley, W.; Zerwas, M.; Stemmer, K.; Taylor, P. 1972. Responses of alveolar macrophages to metals. I. Inhalation of lead and nickel. Arch. Environ. Health 25:406-414.

6346. Ottolenghi, A.D.; Haseman, J.K.; Payne, W.W.; Falk, H.L.; McFarland, H.N. 1974. Inhalation studies of nickel sulfide in pulmonary carcinogenesis of rats. J. Natl. Cancer Inst. 54:1165-1172.

6347. Spiegleberg, Th.; Kordel, W.; Hochrainer, D. 1984. Effects of NiO inhalation on alveolar macrophages and the humoral immune system of rats. Ecotoxicol. Environ. Safety 8:516-525.

6348. Camner, P.; Johansson, A.; Lundborg, M. 1978. Alveolar macrophages in rabbits exposed to nickel dust. Ultrastructural changes and effect on phagocytosis. Environ. Res. 16:226-235.

6349. Camner, P.; Casarette-Bruce, M.; Curstedt, T.; et al., 1984. Toxicology of nickel. In; Sunderman, F.W., Jr.; Aito, A.; Berlin, A.; et al., eds. Nickel in the Human Environment. IARC Scientific Publ. No. 53. IARC, Lyon, France. pp. 267-276.

6350. Wehner, A.P.; Craig, D.K. 1972. Toxicology of inhaled nickel monoxide and cobalt monoxide in Syrian hamsters. Amer. Ind. Hyg. Assoc. J. 33:146-155.

6351. Wehner, A.P.; Busch, R.H.; Olson, R.J.; Craig, D.K. 1975. Chronic inhalation of nickel oxide and cigarette smoke by hamsters. Amer. Ind. Hyg. Assoc. J. 36:801-810.

6352. Bruce, M.C.; Camner, P.; Curstedt, T. 1980. Influence of chronic inhalation exposure to nickel dust on accumulation of lung lipids. Pulmonary Toxicol. Respir. Particles DOE Symp. Series. 53:357-364.

6353. Weischer, C.H.; Oldiges, H.; Hochrainer, D.; Kordel, W. 1980. Subchronic effects induced by NiO-inhalation in Wistar rats. Dev. Toxicol. Environ. Sci. 8:555-558.

6354. Johansson, A.; Camner, P.; Roberston, B. 1981. Effects of long-term nickel dust exposure on rabbit alveolar epithelium. Environ. Res. 25:391-403.

6355. Lundborg, M.; Camner, P. 1982. Decreased level of lysozyme in rabbit lung lavage fluid after inhalation of low nickel concentrations. Toxicology 22:353-358.

6356. Curstedt, T.; Hagman, M.; Roberston, B.; Camner, P. 1983. Rabbit lungs after long-term exposure to low nickel dust concentrations. Environ. Res. 30:89-94.

6357. Johansson, A.; Curstedt, T.; Robertson, B.; Camner, P. 1983. Rabbit lung after inhalation of soluble nickel. II. Effects on lung tissue and phospholipids. Environ. Res. 31:399-412.

6358. Murthy, R.C.; Barkley, W.; Hollingsworth, L.; Bingham, E. 1983. Enzymatic changes in alveolar macrophages of rats exposed to lead and nickel by inhalation. J. Amer. Coll. Toxicol. 2:193-199.

6359. Johansson, A.; Camner, P. 1980. Effects of metallic dust on rabbit lungs. In: Sanders, C.L.; et al., eds. Pulmonary Toxicology of Respirable Particles. Proc. 19th Annual. Hanford Life Science Symposium. Tech. Info. Ctr., U.S. Dept. of Energy, CONF-791002.

6360. Daldrup, T.; Haarhoff, K.; Szathmary, S.C. 1983. Toedliche nickel sulfate intoxikation. Berichte zur Gerichtlichen Medizin 41:141-144 (as cited in 6206).

6361. Akesson, B.; Skervfing, S. 1985. Exposure in welding of high nickel alloy. Int. Arch. Occup. Environ. Health 56:111-117.

6362. United States Environmental Protection Agency (U.S. EPA) 1980. Ambient Water Criteria for Nickel. EPA 440/5-80-060.

6363. Sunderman, F.W., Jr,; Shen, S.K.; Reid, M.C.; Allpass, P.R. 1980. Teratogenicity and embryotoxicity of nickel carbonyl in Syrian hamsters. Teratogen. Carcinogen. Mutagen. 1:223-233.

6364. National Institute of Occupational Safety and Health (NIOSH) 1977. Criteria for a recommended standard. Exposure to inorganic nickel. Washington., D.C.. Publ. No. 77-164. (as cited in 6206).

6365. United States Environmental Protection Agency (U. S. EPA) 1987. Extremely hazardous substances list and threshold planning quantities; emergency planning and release notification requirements. Fed. Reg. 52(77):13378-13379,13410 (as cited in 6206).

6366. U.S. Food and Drug Administration (FDA) 1983. Direct food additives affirmed as generally recognized as safe. Fed. Reg. 48(219):51617-51618.

6367. American Conference of Governmental Industrial Hygienists (ACGIH) (1986. Documentation of the threshold limit values and biological exposure Indices. 5th ed. Cincinnati, Ohio, pp. 422-426 (as cited in 6206).

6368. Jasmin, G. 1973. Experimental production of polycythemia in rats with nickel sulfide. Clin. Res. 21:1068.

6369. Sunderman, F.W., Jr.; Hopfer, S.M.; Nichols, W.W.; et al. 1990. Chromosomal abnormalities and gene amplification in renal cancers induced in rats by nickel subsulfide. Ann. Clin. Lab. Sci. 20:60-72.

6370. United States Environmental Protection Agency (U.S. EPA) 1985. National Primary Drinking Water Regulations; Synthetic Organic Chemicals, Inorganic Chemicals and Microorganisms; Proposed Rule. 40 CFR Part 141. Federal Register, Vol. 50, No. 219, November 13, pp. 46936-46982.

6371. United States Environmental Protection Agency (U.S. EPA) 1983. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983.

6372. United States Environmental Protection Agency (U.S. EPA) 1986. Test Methods for Evaluation of Solid Waste, 3rd ed., U.S. EPA SW-846.

6373. Sittig, S. 1981. Handbook of Toxic and Hazardous Chemicals. Noyes Publications: Park Ridge, New Jersey, pp. 491-483.

6374. Dunnick, J.K.; Hobbs, C.H.; Benson, J.M. et al. 1987. Comparative toxicity of nickel oxide, nickel sulfate, and nickel subsulfide in the F344/N rat and B6C3F$_1$ mouse. Toxicol. 7: 789.

6375. American Conference of Governmental Industrial Hygienist (ACGIH) 1990. Values and biological exposure indices for 1989-1990. ACGIH, Cincinnati, Ohio. pp 44-45.

6376. Waksvik, H.; Boysen, M.; Broegger, A.; Saxholm, H.; Reith, A. 1980. In vivo and in vitro studies of mutagenicity and carcinogenicity of nickel compounds in man. 10th Ann. Meeting Eur. Environ. Mutagen Soc. Athens, Poster No. 32.

6377. United States Environmental Protection Agency (U.S. EPA). 1988. Integrated Risk Information System (IRIS). Revised March 1988 ed. Cincinnati, OH: U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office.

6378. Nielsen, G.D.; Jepsen, L.V.; Jorgensen, P.J.; Grandjean, P.; Brandrup, F. 1990. Nickel-sensitive patients with vesicular hand eczema: oral challenge with a diet naturally high in nickel. Brit. J. Dermat. 122: 299-308.

6379. Sunderman, F.W., Jr.; B. Dingle; S.M. Hopfer, T. Swift. 1988. Acute nickel toxicity in electroplating workers who accidentally ingested a solution of nickel sulfate and nickel chloride. Am. J. Indust. Med. 14:257-266.

6380. Sunderman, F.W., Jr.; A. Aitio; L.G. Morgan; T. Norseth. 1986. Biological monitoring of nickel. Toxicol. Ind. Health 2:17-78.

6381. Sunderman, F.W.; Hopfer, S.M.; Swift, T. et al. 1989. Cobalt, chromium, and nickel concentrations in body fluids of patients with porous-coated knee or hip prostheses. J. Orthopaed. Res. 7:307-315.

6382. Sunderman, F.W., Jr.; S.M. Hopfer; K.R. Sweeney; A.H. Marcus; B.M. Most; J.Creason. 1990. Nickel absorption and kinetics in human vounteers. Soc. Exp. Biol. Med. 191:5-11.

6383. Hopfer, S.M.; W.P. Fay; F. W. Sunderman, Jr. 1989. Serum nickel concentrations in hemodialysis patients with environmental exposure. Ann. Clin. Lab. Sci. 19:161-167.

6384. McNeill, D.A.; C. E. Chrisp; G. L. Fisher. 1990. Tumorigenicity of nickel subsulfide in strain A/J mice. Drug. Chem. Toxicol. 13:71-86.

6385. LaVelle, J.M.; C.M. Witner. 1981. Mutagenicity of $NiCl_2$ and the analysis of mutagenicity of metal ions in a bacterial fluctuation test. Mutat. Res. 3:320.

6386. Arlauskas, A.; R.S. Baker; A.M. Bonin; R.K. Tandon; P.T. Crisp; J. Ellis. 1985. Mutagenicity of metal ions in bacteria. Environ. Res. 36:379-388.

6387. Green, M.H.L.; W.J. Muriel; B.A. Bridges. 1976. Use of a simplified flucuation test to detect low levels of mutagens. Muta. Res. 38:33-42.

6388. Pikalek, P.; J. Necasek. 1983. The mutagenic activity of nickel in Cornebacterium sp. Folia Microbiol. (Prague) 26:17-21.

6389. Singh. I. 1984. Induction of gene conversion and reverse mutation by manganese sulphate and nickel sulphate in Saccharomyces cerevisae. Mutat. Res. 137:47-49.

6390. Hsie, A.W.; N.P. Johnson; D.B. Couch; et al. 1979. Quantitative mammalian cell mutagenesis and a preliminary study of the mutagenic potential of metallic compounds. In: Kharasch, N., ed. Trace Metals in Health and Disease. New York, NY. Raven Press, pp. 55-69.

6391. Amacher, D.; S. Paillet. 1980. Induction of trifluorothymidine resistant mutants by metal ions in L5178Y/TK^{+}/ cells. Mutat. Res. 78:279-288.

6392. Miyaki, M.; N. Akamotsu; T. Ono; H. Koyami. 1979. Mutagenicity of metal cations in cultured cells from Chinese hamster. Mutat. Res. 68:259-263.

6393. Kanematsu, M.; M. Hara; T. Kada. 1980. Rec-assay and mutagenicity studies on metal compounds. Mutat. Res. 77:109-116.

6394. Patierano, S.R.; M. Costa. 1985. DNA-protein cross-links produced by nickel compounds in intact cultured mammalian cells. Chem. Biol. Interact. 55:75-91.

6395. Saxholm, H.J.K.; A. Reith; A. Brogger. 1981. Oncogenic transformation and cell lysis in C3H/10T1?2 cells and increased sister chromatid exchange in human lymphocytes by nickel sulfide. Cancer Res. 41:4136-4139.

6396. Sen, P.; M. Costa. 1986. Pathway of nickel uptake influences its interaction with heterochromatic DNA. Toxicol. Appl. Pharmacol. 84:278-285.

6397. Lechner, J.F.; T. Tokiwa; I.A. McClendon; A. Haugen. 1984. Effects of nickel sulfate on growth and differentiation of normal human bronchial epithelial cells. Carcinogenesis 5:1697-1703.

6398. Dipaolo, J.A.; B.C. Casto. 1979. Quantitative studies of in vitro morphological transformation of Syrian hamster cells by inorganic metal salts. Cancer Res. 39:1008-1013.

6399. Costa, M.; J.D. Heck; S.H. Robinson. 1982. Selective phagocytosis of crystalline metal sulfide particles and DNA strand breaks as a mechanism for the induction of cellular transformations. Cancer Res. 42:2757-2763.

6400. Hansen, K.; R.M. Stern. 1982. In vitro and transformation potency of nickel compounds. Danish Welding Institute, Copenhagen, Report 82/22, pp. 1-10.

6401. Rasmuson, A. 1985. Mutagenic effects of some water-soluble metal compounds in a somatic eye-color test system in Drosophila melanogaster. Mutat. Res. 157:157-162.

6402. Rodriguex-Arnaiz, R.; P. Ramos. 1986. Mutagenicity of nickel sulphate in Drosophila melanogaster. Mutat. Res. 170:115-117.

6405. Haro, R.T.; A. Furst; H. Falk. 1968. Studies on the acute toxicity of nickelocene. Proc. West. Pharmacol. Soc. 11:39-42.

6406. Spiegelberg, T.; W. Koerdel; D. Hochrainer. 1984. Effect of NiO inhalation on alveolar macrophages and the humoral immune system of rats. Ecotox. Environ. Safety. 8:516-525.

6407. United States Environmental Protection Agency (U.S. EPA). 1990. Drinking water and health advisories. November, 1990.

7001. Occupational Safety and Health Administration (OSHA). 1989. Air contaminants: finalrule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7003. Occupational Safety and Health Administration (OSHA). 1989. Nickel. Fed. Regist., 4/24/89, 54:16874.

7009. United States Environmental Protection Agency (U.S. EPA). 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT). 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7015. United States Environmental Protection Agency (U.S. EPA). 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. United States Environmental Protection Agency (U.S. EPA). 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. United States Environmental Protection Agency (U.S. EPA). 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. United States Environmental Protection Agency (U.S. EPA). 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. United States Environmental Protection Agency (U.S. EPA). 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020 United States Environmental Protection Agency (U.S. EPA). 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. United States Environmental Protection Agency (U.S. EPA). 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7023. United States Environmental Protection Agency (U.S. EPA). 1982. Ore mining and dressing point source category. 40CFR440, Fed. Regist., 12/3/82, 47:54609, as amended 1988, 53:18788.

7025. United States Environmental Protection Agency (U.S. EPA). 1981. Electroplating point source category. 40CFR413, Fed. Regist., 1/28/81, 46:9467, as revised 1983, 48:43681 and 32483.

7026. United States Environmental Protection Agency (U.S. EPA). 1983. Metal finishing point source category. 40CFR433, Fed. Regist., 7/15/83, 48:32485 as revised 1983, 48:41410 and 43682.

7027. United States Environmental Protection Agency (U.S. EPA). 1984. Battery manufacturing point source category. 40CFR461, Fed. Regist., 3/9/84, 49:9134 and 13879, as revised 1986, 51:30816.

7028. United States Environmental Protection Agency (U.S. EPA). 1985. Nonferrous metals forming and metal powders point source category. 40CFR471, Fed. Regist., 8/23/85, 50:34290, as revised 1986, 51:2884.

7030. United States Environmental Protection Agency (U.S. EPA). 1987. Organic chemicals, plastics, and synthetic fibers point source category. 40CFR414, Fed. Regist., 11/5/87, 52:42568, as amended 1989, 54:27351.

7032. United States Environmental Protection Agency (U.S. EPA). 1982. Iron and steel manufacturing point source category. 40CFR420, Fed. Regist., 5/27/82, 47:23284, as amended 1984, 49:21032 and 24726.

7037. United States Environmental Protection Agency (U.S. EPA). 1982. Porcelain enameling point source category. 40CFR466, Fed. Regist., 11/24/82, 47:53184, as revised 1985, 50:36543.

7039. United States Environmental Protection Agency (U.S. EPA). 1983. Copper forming point source category. 40CFR468, Fed. Regist., 8/15/83, 48:36957 and 50719, as revised 1986, 51:22521.

7050. United States Environmental Protection Agency (U.S. EPA). 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7053. United States Environmental Protection Agency (U.S. EPA). 1983. National revised primary drinking water regulations; advanced notice of proposed rulemaking. 40CFR141, Fed. Regist., 10/5/83, 48:45502.

7054. United States Environmental Protection Agency (U.S. EPA). 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7057. Personal communication with national Safe Drinking Water Hotline, 10/18/89, 1-800-426-4791.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. United States Environmental Protection Agency (U.S. EPA). 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7060. United States Environmental Protection Agency (U.S. EPA). 1987. Extremely hazardous substance list and threshold planning quantities. 40CFR355 (SARA Title III Section 302), Fed. Regist., 4/22/87, 52:13395, as revised 1987, 52:48073 and 1988, 53:5574.

7063. United States Environmental Protection Agency (U.S. EPA). 1986. Assessment of nickel as a hazardous air pollutant. 40CFR61.01, Fed. Regist., 9/25/86, 51:34135.

7064. United States Environmental Protection Agency (U.S. EPA). 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7068. United States Environmental Protection Agency (U.S. EPA). 1989. Waste specific prohibitions second third wastes. 40CFR268.34, Fed. Regist., 6/23/89, 54:26594.

7075. United States Environmental Protection Agency (U.S. EPA). 1981. Hazardous wastes from non-specific sources. 40CFR261.31, Fed. Regist., 1/16/81, 46:4617, as last amended 1986, 51:6541.

7077. United States Environmental Protection Agency (U.S. EPA). 1981. Basis for listing hazardous waste. 40CFR261 Appendix VII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:35421.

7080. United States Environmental Protection Agency (U.S. EPA). 1982. Groundwater protection: concentration limits. 40CFR264.94, Fed. Regist., 7/26/82, 47:32350, as amended 1983, 48:14294.

7082. United States Environmental Protection Agency (U.S. EPA). 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7083. United States Environmental Protection Agency (U.S. EPA). 1988. Hazardous waste injection restrictions: waste specific prohibitions. 40CFR148.10-16, Fed. Regist., 8/16/88, 53:30908, as amended 1988, 53:41602 and 1989, 54:25422 and 26647.

7085. United States Environemntal Protection Agency (U.S. EPA). 1989. Land disposal restrictions for third third scheduled wastes; proposed rule. 40CFR 148,261,264-5,268,271, Fed. Regist., 11/22/89, 54:48372.

7086. Council of European Communities Directive on Drinking Water, 16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7087. Council of European Communities Directive on Bathing Water Quality, 8 December 1975 (76/160/EEC-OJ L31, 5 February 1976, amended by 1851).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7089. Council of European Communities Directive on Fishing Water Quality, 18 July 1978 (76/659/EEC-OJ L222, 14 August 1978, amended by 1851).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7091. Council of European Communities Directive on Groundwater, 17 December 1979 (80/68/EEC-OJ L20, 26 January 1980).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7093. Council of European Communities Directive on Toxic and Dangerous Waste, 20 March 1978, amended by 1851.

7094. Council of European Communities Resolution on a Revised List of Second-Category Pollutants, 24 June 1975 (OJ C168, 25 July 1975, p. 4).

7095. Council of European Communities Directive on Classification, Packaging and Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7096. Council of European Communities Directive on Plant Products, 21 December 1978 (79/117/EEC-OJL53, 8 February 1979, amended by 83/131/EEC, 14 March 1983, amended by 85/298/EEEC, 22 May 1985).

7098. Council of European Communities Directive on the Limit Value and Quality Objectives for Discharges of Certain Dangerous Substances Included in List I of Annex Directive 76/464/EEC, 12 June 1987 (86/280/EEC-OJ, 4 July 1986, amended 25 June 1988, p. 35, OJ L 158).

7099. Proposal or a Council Directive on the Dumping of Waste at Sea, Comm (85) 373 Final, 4 July 1985.

7100. Council Directive on Major Accident Hazards of Certain Industrial Accidents. June 24, 1982; 82/501/EEC. Official Journal No. L 230/1, 87/21/216/EEC, OJ L 85, 28 March 1987, p. 36, amended by 87/216/EEC of 19 March 1987).

7101. Council of European Communities Directive. Proposal for a Council Regulation Concerning Export from and Import Into the Community of Certain Dangerous Chemicals, amended 22 June 1988, OJ L 155).

7102. Council of European Communities Directive on Disposal of Waste Oils, 16 June 1975 (75/439/EEC, OJ L 194, July 25, 1975, p. 23, amended by 387L0101 (OJ L 042, December 2, 1987, p. 43).

7104. Council Directive on the Combating of Air Pollution from Industrial Plants, 84/360/EEC, 228 June 1984.

7105. Council Decision Concluding the Convention for the Prevention of Marine Pollution From Land-Based Sources, 75/437/EEC, 3 March 1975.

7113. North Carolina Department of Natural Resources and Community Development. 1989. Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina, 15NCAC 2B.0200-0218, effective 10/1/89.

7115. Virginia Water Control Board. 1988. Commonwealth of Virginia Water Quality Standards, VR 680-21-00, effective 11/1/88.

7119. New York State Department of Environmental Conservation. 1987. Memorandum: New York Ambient Water Quality Standards and Guidance Values, 4/1/87.

7120. Wyoming Department of Environmental Quality. 1980. Chapter VIII, Quality Standards for Wyoming Groundwaters, effective 9/4/80.

7121. District of Columbia Department of Consumer and Regulatory Affairs. 1985. Water Quality Standards of the District of Columbia, Chapter II, Title 21 DCMR, effective 12/27/85.

7129. Illinois Environmental Protection Agency. 1986. Title 35: Environmental Protection, Subtitle F: Public Water Supplies, Chapter I: Pollution Control Board, effective 4/22/86.

7130. Illinois Environmental Protection Agency. 1989. Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter I: Pollution Control Board, proposed rule, 12/6/89.

7131. United States Environmental Protection Agency. 1987. Drinking Water Health Advisories. Fed. Regist. 52(175):34294.

COMMON SYNONYMS:	CAS. REG. NO.: 7440-50-8 NIOSH NO.: GL 5325000 EPA HAZARDOUS WASTE NO.: ND
Copper Allbri natural copper ANAC 110 C.I. 77400 C.I. Pigment metal 2	CHEMICAL SYMBOL: Cu

REACTIVITY (5802)

Cu + Water (g) → no reaction below 800°C
Cu + Ocean Air containing salt → basic chloride, $CuCl_2.3Cu(OH)_2$
Cu + Air containing sulfur dioxide → green patina of basic sulfate, $CuSO_4.Cu(OH)_2$
Cu + Air containing carbon dioxide → basic carbonate, $Cu_2(OH)_2CO_3$(5822)
Cu + Hydrazoic acid or hydrogen sulfide → violent reaction(5800)
Cu + Lead azide, sodium azide, or hydrazine mononitrate → violent reaction (5800)
Cu + Nitric acid → cupric nitrate + oxides of nitrogen
Cu + Dilute hydrochloric acid → no reaction
Cu + NaOH, KOH → no reaction
Cu + Ammonium nitrate, bromates, chlorates, iodates, → violent reaction(5800)
Cu + Chlorine, fluorine, hydrogen peroxide → violent reaction(5800)
Cu + Potassium peroxide, sodium peroxide → violent reaction (5800)

PHYSICO-CHEMICAL DATA

- Atomic Weight: 63.54 (5801)
- Atomic Number: 29 (5801)
- Physical State: Solid (at 20°C) (5804)
- Color: Reddish-brown (5804)
- Odor: NA
- Odor Threshold: NA
- Density: 8.96 g/cm^3 (at 20°C) (5801)
- Melting Point: 1083 ± 0.1°C (5801)
- Boiling Point: 2595°C (5801)

PHYSICO-CHEMICAL DATA (Cont.)

- Flash Point: NA
- Flammable Limits: NA
- Autoignition Temperature: NA
- Vapor Pressure: 1 mm Hg at 1628°C (5800)
- Saturated Concentration in Air: NA
- Solubility in Water: Insoluble (5801)
- Viscosity: 3.41 cP at 1145°C (5806)
- Surface Tension: 1104 dyn/cm at 1150°C (5806)
- Log (Octanol-Water Partition Coeff.): NA
- Soil-Water Distribution Coeff., K_d (mL/g): 1.4 - 333 (5807)
- Log K (Stab. Const. for humic acid-Cu^{2+} complex at pH 8): 5.0 (5813)
- Henry's Law Constant: NA
- Bioconcentration Factor: 28,200 (oysters) (5818)

HANDLING PRECAUTIONS (5815)

Gloves, goggles, and overalls should be worn. For copper dusts or mists, OSHA recommendations for respirator are given as follows:

5.0 mg/m^3	—	Any dust or mist respirator except single use apparatus.
10 mg/m^3	—	Any dust or mist respirator except single use and quarter-mask unit, or any supplied-air respirator, or any self-contained breathing apparatus.
25 mg/m^3	—	Any powered air purifying respirator with a dust and mist filter, or any supplied-air respirator operated in a continuous flow mode.
50 mg/m^3	—	Any air-purifying full facepiece respirator with a high efficiency particulate filter, or any self-contained breathing apparatus with a full facepiece, or any supplied-air respirator with a full facepiece, or any powered air-purifying respirator with a tight-fitting facepiece and a high efficiency particulate filter.
1,000 mg/m^3	—	Any supplied-air respirator operated in a pressure-demand or other positive pressure mode.
2,000 mg/m^3	—	Any supplied-air respirator with a full facepiece operated in a pressure-demand or other positive pressure mode

COMMON SYNONYMS:	CAS. REG. NO.: 7447-39-4 NIOSH NO.: ND EPA HAZARDOUS WASTE NO.: ND
Copper chloride Copper dichloride Copper bichloride	CHEMICAL FORMULA: $CuCl_2$

REACTIVITY (5875)

Corrosive to aluminum. Hydrogen chloride gas may be formed in fires or on contact with acids or acid fumes.

PHYSICO-CHEMICAL DATA (5875)

- Molecular Weight: 134.45
- Physical State: Microcrystalline powder
- Color: Yellow to brown
- Odor: ND
- Odor Threshold: NA
- Density: 3.39 g/cm^3 (at 25°C/4°C)
- Melting Point: 630°C (estimate)
- Boiling Point: 993°C, decomposes to cuprous chloride
- Flash Point: Not combustible
- Flammable Limits: Not combustible
- Autoignition Temperature: Not combustible
- Vapor Pressure: ND
- Saturated Concentration in Air: ND
- Solubility in Water: 73 parts per 100, at 20°C
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stab. Const. for humic acid complex): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5815, 5875)

Causes burns to skin and eyes. Also harmful if inhaled. For copper dusts or mists, wear protective clothing, gloves and eye goggles, and use respirator. OSHA recommendations for respirator use for exposures to copper dusts or mists are listed in Handling Precautions section for copper metal.

COMMON SYNONYMS:	CAS. REG. NO.: 3251-23-8 NIOSH NO.: QU7400000 EPA HAZARDOUS WASTE NO.: ND
Copper nitrate Cupric nitrate	CHEMICAL FORMULA: CuH_2NO_3

REACTIVITY (5875)

Strong oxidizing agent; may cause ignition, violent combustion, or explosion when in contact with readily oxidizable materials. Decomposes at 338°C releasing toxic gases of oxides of nitrogen.

PHYSICO-CHEMICAL DATA (5875)

- Molecular Weight: 187.56
- Physical State: Crystals
- Color: Blue-green
- Odor: ND
- Odor Threshold: ND
- Density: 2.07 g/cm^3 (trihydrate)
- Melting Point: 255-256°C
- Boiling Point: ND
- Flash Point: Not combustible
- Flammable Limits: Not combustible
- Autoignition Temperature: Not combustible
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: Soluble
- Viscosity: ND
- Surface Tension: ND
- Log (Octanol-Water Partition Coeff.): ND
- Log K (Stab. Const. for humic acid complex): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5875)

Contact may cause burns to the skin or eyes. Wear appropriate clothing and eye protection to avoid prolonged contact. OSHA recommendations for respirator use for exposures to copper dusts or mists are listed in Handling Precautions section for copper metal.

COMMON SYNONYMS:	CAS. REG. NO.: 7758-98-7 NIOSH NO.: GL 8800000 EPA HAZARDOUS WASTE NO.: ND
Copper sulfate Cupric sulfate Sulfuric acid, copper (2+) salt (1:1)	CHEMICAL FORMULA: $CuSO_4$

REACTIVITY (5802)

$CuSO_4$ + Boiling water → precipitate of basic copper sulfate +sulfuric acid
$CuSO_4 + Mg \rightarrow Cu_2O + H_2 + MgSO_4$
$CuSO_4 + NH_4Cl \rightarrow (NH_4)_2SO_4 + CuCl_2$
$CuSO_4$ + NaOH/KOH → $Cu(OH)_2 + Na_2SO_4/K_2SO_4$
$CuSO_4$ + Aq. NH_3 (small excess) → $Cu(NH_3)_2^{2+}$ $2OH^{1-}$

PHYSICO-CHEMICAL DATA (5801)

- Molecular Weight: 159.60
- Physical State: Rhombic crystals
- Color: Greenish white
- Odor: Odorless
- Odor Threshold: ND
- Density: 3.603 g/cm^3
- Melting Point: above 200°C
- Boiling Point: 650°C
- Flash Point: NA
- Flammable Limits: NA
- Autoignition Temperature: NA
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 14.3 g/100 mL (0°C), 75.4 g/100 mL(100°C)
- Solubility in Non-aqueous Media: Insoluble in alcohol
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stab. Const. for humic acid complex): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5810, 5824)

Goggles, gloves, and protective clothing should be worn (5810). Contact may cause burns to skin and eyes. Fire may produce irritating or poisonous gases. Runoff from fire control or dilution water may cause pollution (5824). OSHA recommendations for respirator use for exposures to copper dusts or mists are listed in Handling Precaution section for copper metal.

COMMON SYNONYMS:	CAS. REG. NO.: 1317-40-4 NIOSH NO.: GL8912000 EPA HAZARDOUS WASTE NO.: ND
Copper sulfide Cupric sulfide Copper monsulfide	CHEMICAL FORMULA: CuS

REACTIVITY (5875)

Reacts vigorously with hydrogen peroxide. Explodes on contact with a concentrated solution of chloric acid or chlorates of magnesium, cadmium or zinc.

PHYSICO-CHEMICAL DATA (5875)

- Molecular Weight: 95.61
- Physical State: Solid
- Color: Black
- Odor: ND
- Odor Threshold: ND
- Density: 4.6 g/cm^3
- Melting Point: 220° C (decomposes)
- Boiling Point: ND
- Flash Point: ND
- Flammable Limits: ND
- Autoignition Temperature: ND
- Vapor Pressure: NA
- Saturated Concentration in Air: NA
- Solubility in Water: 0.033 mg/100 mL (at 18° C)
- Viscosity: NA
- Surface Tension: NA
- Log (Octanol-Water Partition Coeff.): NA
- Log K (Stab. Const. for humic acid complex): ND
- Soil-Water Distribution Coeff.: ND
- Henry's Law Constant: NA
- Bioconcentration Factor: ND

HANDLING PRECAUTIONS (5815)

OSHA recommendations for respirator use for exposures to copper dusts or mists are listed in Handling Precautions section for copper metal.

PERSISTENCE IN THE SOIL-WATER SYSTEM

The mobility of copper in soluble forms such as copper sulfate depends largely on soil pH. Most of the soluble forms of copper are fairly tightly bound to the organic matter in the soil. At a pH <3, appreciable leaching of copper can take place. At pH 4.5, only 3 percent of copper was extractable with water from an organic spruce forest soil (5808).

PATHWAYS OF EXPOSURE

The probable routes of human exposure to copper are inhalation, ingestion, and dermal or eye contact. For the general population, ingestion through food is usually more important than intake through water unless the water is very soft and acidic and has been supplied through copper pipes.

HEALTH HAZARD DATA

Signs and Symptoms of Short-term Human Exposure:

Ingestion of gram quantities of copper sulfate is highly toxic causing severe abdominal pain, vomiting, diarrhea, hematuria and convulsions, which may be fatal. Patients who have recovered from acute poisoning may die later from necrosis of the kidneys. Inhalation of copper oxide dust and fumes causes metal fume fever accompanied by cough, vomiting, chills, muscle ache, irritated eyes, metal or sweet taste, cyanosis, abdominal distension, and diarrhea (5804, 5810).

Acute Toxicity Studies:

Inhalation:

No data

Oral:

LD_{Lo}	200 mg/kg	(copper chloride)	Human	(5871)
LD_{Lo}	200 mg/kg	(copper hydroxide)	Human	(5871)
LD_{50}	140 mg/kg	(copper chloride)	Rat	(5871)
LD_{50}	940 mg/kg	(copper nitrate trihydrate)	Rat	(5871)
LD_{50}	470 mg/kg	(copper oxide)	Rat	(5871)
LD_{50}	1440 mg/kg	(copper oxychloride)	Rat	(5875)
LD_{50}	300 mg/kg	(copper sulfate)	Rat	(5809)
LD_{50}	960 mg/kg	(copper sulfate pentahydrate)	Rat	(5871)

HEALTH HAZARD DATA (Cont.)

Acute Toxicity Studies:

Dermal:

No data

Long-Term Effects:

There is limited evidence that chronic exposure to copper results in toxic effects in humans (5804). Indian Childhood Cirrhosis has been attributed to high copper levels in the diet caused by the use of food and water storage containers made of copper alloys. Liver disease also occurs in patients with Wilson's disease, a genetic condition causing copper to be retained in the body.

Pregnancy/Neonate Data:

Intramuscular administration of 4 mg/kg of copper in early pregnancy affected the development of the central nervous system of rat fetuses (5814).

Genotoxicity Data:

Conflicting data have been reported on the potential genotoxicity of copper. Most copper compounds tested were found to be non-mutagenic in microbial assays. In contrast, copper sulfate was found to cause chromosomal aberrations, micronuclei, and sperm abnormalities when tested in vivo in mice.

Carcinogenicity Classification:

IARC — No data
NTP — No data
EPA — Group D (not classifiable)

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA

AIR EXPOSURE LIMITS:

Standards

- OSHA PEL (8-hr TWA): Copper fume (as Cu) 0.1 mg/m^3
  Copper dusts and mists (as Cu) 1 mg/m^3
- OSHA STEL (15-min): ND
- AFOSH PEL (8-hr TWA): Copper fume (as Cu) 0.1 mg/m^3
  Copper dusts and mists (as Cu) 1 mg/m^3

Criteria

- NIOSH IDLH (30-min): ND
- NIOSH REL (10-hr TWA): ND
- NIOSH STEL (15-min ceiling): ND
- ACGIH TLV® (8-hr TWA): Copper fume (as Cu) 0.2 mg/m^3
- ACGIH STEL (15-min): Copper dusts and mists (as Cu) 1 mg/m^3

WATER EXPOSURE LIMITS:

Drinking Water Standards (5889)

- MCLG (proposed): 1.3 mg/L
- MCL (proposed): 1.3 mg/L
- Secondary MCL: 1 mg/L

EPA Health Advisories and Cancer Risk Levels

- None established.

WHO Drinking Water Guideline

- No data

EPA Ambient Water Quality Criteria (5823)

- Human Health
  - None established. Using available organoleptic data for controlling undesirable taste and odor, the estimated level has been set at 1 mg/L.

ENVIRONMENTAL AND OCCUPATIONAL STANDARDS AND CRITERIA (Cont.)

- **Aquatic Life**

  — **Freshwater species**

  Acute toxicity: toxicity generally decreases with increasing hardness of water, alkalinity, and total organic carbon content. At a hardness of 50 mg/L, the sensitivity of 41 genera of freshwater animals was found to range from 16.74 µg/L for Ptychocheilus to 10,240 µg/L for Acroneuria.

  Chronic Toxicity: Chronic toxicity values, available for 15 freshwater species, range from 3.873 µg/L for brook trout to 60.36 µg/L for northern pike.

  Freshwater organisms and their uses should not be adversely affected if the 4-day average concentration (in µg/L) of copper does not exceed the numerical value given by $e^{(0.8545[\ln(\text{hardness})]-1.465)}$ more than once every three years on the average and if the 1-hour average concentration (in µg/L) does not exceed the numerical value given by $e^{(0.9422[\ln(\text{hardness})]-1.464)}$ more than once every three years on the average.

  — **Saltwater species**

  Acute toxicity: The acute sensitivity of saltwater species ranges from 5.8 µg/L for the blue mussel to 600 µg/L for the green crab.

  Chronic Toxicity: In long-term exposures, the bay scallop was killed at 5 µg/L. Unless there is a locally important highly sensitive species, saltwater organisms and their uses should not be adversely affected if the 1-hour average concentration of copper does not exceed 2.9 µg/L more than once every 3 years on the average.

REFERENCE DOSES (5819):

- **Inhalation:** ND
- **Oral:** 0.005 mg/kg/day (copper cyanide)

Recommended Safe and Adequate Dietary Intake (5888):

- Adults, 1.5-3.0 mg/day
- Children, 11+ yr old, 1.5-2.5 mg/day
- Children, 7-10 yr old, 1.0-2.0 mg/day
- Children, 4-6 yr old, 1.0-1.5 mg/day
- Children, 1-3 yr old, 0.7-1.0 mg/day
- Infants, 0.5-1 yr old, 0.6-0.7 mg/day
- Infants, 0-0.5 yr old, 0.4-0.6 mg/day

REGULATORY STATUS (as of 01-MAR-90)

Promulgated Regulations

- **Federal Programs**

Clean Water Act (CWA)
The following copper compounds have been designated as hazardous substances under the CWA: cupric acetate, cupric acetoarsenite, cupric chloride, cupric nitrate, cupric oxalate, cupric sulfate, ammoniated copper sulfate, and cupric tartrate (7015). The reportable quantity (RQ) limit has been set at 0.454 kg (1 lb) for cupric acetoarsenite, 4.54 kg (10 lbs) for cupric chloride and cupric sulfate, and 45.4 kg (100 lbs) for the remaining hazardous copper compounds (7016). Copper and copper compounds are listed as toxic pollutants, subject to general pretreatment regulations for new and existing sources, and effluent standards and guidelines (7017, 7018). Effluent limitations for copper exist in the following point source categories: electroplating (7025), organic chemicals, plastics and synthetic fibers (7030), inorganic chemicals manufacturing (7019), nonferrous metals manufacturing (7020), steam electric power generating (7021), timber products manufacturing (7022), metal finishing (7026), ore mining and dressing (7023), battery manufacturing (7027), metal molding and casting (7040), coil coating (7036), copper forming (7039), and nonferrous metals forming and metal powders (7028). Effluent limitations for total metals exist in the electroplating point source category (7025). Limitations vary depending on the type of plant and industry.

Safe Drinking Water Act (SDWA)
Copper is on the list of 83 contaminants required to be regulated under the SDWA Amendments of 1986 (7050). The Environmental Protection Agency (EPA) has set a nonenforceable secondary maximum contaminant level (SMCL) of 1 mg/L for copper in drinking water (7056). In states with an approved Underground Injection Control program, a permit is required for the injection of copper containing wastes designated as hazardous under RCRA (7054).

Resource Conservation and Recovery Act (RCRA)
Copper cyanide is identified as an acute hazardous waste (#P029) and a hazardous waste constituent (7078, 7079). Copper cyanide is subject to land disposal restrictions when its concentration as a hazardous waste constituent exceeds designated levels. Effective June 8, 1989, wastes containing copper cyanide are prohibited from land disposal unless the designated treatment standard or the statutory no migration standard are met. Site-specific variances can be obtained for soil and debris contaminated with copper cyanide hazardous waste (7068). Effective August 8, 1988, liquid hazardous waste having a pH less than or equal to 2.0 is prohibited from underground injection (7083). Copper 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 (7082).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Comprehensive Environmental Response Compensation and Liability Act (CERCLA)
Copper compounds designated as hazardous substances under CERCLA and their corresponding reportable quantity (RQ) limits include: copper cyanide, 4.54 kg (10 lbs); copper, 2270 kg (5000 lbs); cupric acetoarsenite, 0.454 kg (1 lb); cupric chloride and cupric sulfate, 4.54 kg (10 lbs); and cupric acetate, cupric nitrate, cupric oxalate, ammoniated cupric sulfate and cupric tartrate, 45.4 kg (100 lbs) (7064). Under SARA Title III Section 313, manufacturers, processors, importers, and users of copper compounds must report annually, to EPA and state officials, their releases of this chemical to the environment (7059).

Toxic Substances Control Act (TSCA)
Manufacturers, processors, or importers who possess health and safety studies on the three cuprate compounds listed under 40CFR716.120 must submit them to EPA (7045).

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
Pesticide registration standards for copper sulfate and other copper compounds have been issued by EPA (7004). Copper naphthenate, and copper salts of neodecanoic acid and 2-ethylhexanoic acid are exempt from the requirement of a tolerance when applied to growing crops (7006). Tolerances have been established for copper arsenate at 40CFR180.319 and for basic copper carbonate at 40CFR180.136 when they are used as pesticide chemicals in or on raw agricultural commodities. Copper is exempt from the requirement of a tolerance in meat, milk, poultry, eggs, fish, shellfish and irrigated crops when it results from the uses listed in 40 CFR180.1021 (7005).

Occupational Safety and Health Act (OSHA)
Employee exposure to copper fumes shall not exceed an 8-hour time-weighted average (TWA) of 0.1 mg/m^3. Employee exposure to copper dusts and mists shall not exceed an 8-hour time-weighted average (TWA) of 1 mg/m^3 (7000). Any substance or waste defined as hazardous under RCRA, CERCLA, or HMTA is subject to the amended Hazardous Waste Operations and Emergency Response standard listed under 29CFR1910.120, effective March 6, 1990. The standard is applicable to any clean-up operations at uncontrolled hazardous waste sites being cleaned-up under government mandate, certain hazardous waste treatment, storage, and disposal operations conducted under RCRA, and any emergency response to incidents involving hazardous substances. The standard lists employee protection requirements during initial site characterization analysis, monitoring activities, materials handling activities, training, and emergency response requirements (7003).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Clean Air Act (CAA)
After consideration of the data regarding serious health effects from ambient air exposure to copper and its compounds, EPA has decided not to regulate copper as hazardous air pollutants (7043).

Hazardous Materials Transportation Act (HMTA)
The Department of Transportation has designated the following copper compounds as hazardous materials, subject to requirements for packaging, labeling and transportation: copper, copper cyanide, cupric acetate, cupric acetoarsenite, cupric chloride, cupric nitrate, cupric oxalate, cupric sulfate, cupric sulfate ammoniated, and cupric tartrate. Reportable quantities (RQs) have been set at 0.454 kg (1 lb) for cupric acetoarsenite, 2270 kg (5000 lbs) for copper, 4.54 kg (10 lbs) for copper cyanide, cupric chloride and cupric sulfate, and 45.4 kg (100 lbs) for the remaining compounds (7010).

Marine Protection, Research, and Sanctuaries Act (MPRSA)
Ocean dumping of organohalogen compounds as well as the dumping of oils or 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 (7009).

Food, Drug, and Cosmetic Act (FDCA)
The level for copper in bottled drinking water is 1.0 mg/L. This level is identical to the secondary maximum contaminant level (MCL) given under the Safe Drinking Water Act (7070). A number of copper compounds, listed under 21CFR175 and 178 are approved for use as indirect food additives as components of adhesives, coatings, and food packaging materials (7072, 7073).}

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

- 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. The following states have promulgated additional or more stringent criteria:

CONNECTICUT
Connecticut has a water quality criterion of 1.0 mg/L for copper in public water supply (PWS) wells, public drinking water, and groundwater classed GAA (for PWS) or GA (private and potential PWS) (7117, 7118).

FLORIDA
Florida has set the following water quality criteria for copper in its surface waters: 0.5 mg/L general criterion for all surface waters; 30 μg/L for class I (potable water supply) and class III (fish and wildlife, recreation) fresh waters; 0.015 mg/L for class II (shellfish propagation/ harvesting) and class III (fish and wildlife, recreation) marine waters (7112).

NEW YORK
New York has an ambient water quality criterion of 2.0 μg/L for marine surface waters classed SA, SB, or SC (fishing and fish propagation), and 0.2 mg/L for surface water classed A, A-S, AA OR AA-S (drinking water supply). New York also has a water quality criterion of 1.0 mg/L for groundwater classed for drinking water supply (7119).

NORTH CAROLINA
North Carolina has set an action level of 7 μg/L for copper in all fresh surface waters (7113).

WISCONSIN
Wisconsin has a preventive action limit of 0.5 mg/L for copper in groundwater (7116).

WYOMING
Wyoming has water quality criterion for copper of 0.2 mg/L in class II agriculture groundwaters and 0.5 mg/L for class III livestock groundwaters (7120).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Proposed Regulations

- **Federal Programs**

  Safe Drinking Water Act (SDWA)
  The Environmental Protection Agency (EPA) has proposed a maximum contaminant level (MCL) and a maximum contaminant level goal (MCLG) of 1.3 mg/L for copper in drinking water entering the water distribution system after any treatment. Final action on this rule is expected in December of 1990 (7052).

- **State Water Programs**
  No proposed regulations are pending. 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 1990-91 (7058).

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

EEC Directives

Directive on Drinking Water (7086)
The mandatory value for copper in surface water treatment category A1 is 0.05 mg/L. No mandatory values are given for categories A2 and A3. Guideline values for categories A1 and A2 are 0.02 mg/L and 0.05 mg/L, respectively. No guideline value is given for treatment category A3.

Directive on Discharge of Dangerous Substances (7088)
Copper 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 the substances into ground water.

Directive on Fishing Water Quality (7089)
Copper products must not be present in salmonid and cyprinid waters in such quantifies that they: (1) from a visible film on the surface of the water or form coatings on the beds of water-courses and lakes, (2) impart a detectable "hydrocarbon" taste to fish and, (3) produce harmful effects in fish.

Directive on the Quality of Shellfish Waters (7090)
The mandatory specifications for copper specify that the concentration of each substances in the shellfish water or in the shellfish flesh must not reach or exceed a level which has harmful effects on the shellfish and larvae. The synergistic effects of other metals must be taken into consideration. The guideline specifications state that the concentration of copper in shellfish must be so limited that it contributes to the high quality of shellfish product.

Directive on Ground Water (7091)
To ensure the effective protection of groundwater in the Community it is necessary to limit the discharge of copper in groundwater. The purpose of this directive is to prevent pollution of groundwater substances belonging to substances listed in the Annex of this directive. Copper shall be subject to prior review so as to limit discharge into groundwater. Member states may grant authorization, provided that all technical precautions for preventing groundwater pollution by copper has been observed.

REGULATORY STATUS (as of 01-MAR-90) (Cont.)

Directive Relating to the Quality of Water Intended for Human Consumption (7092)
No maximum admissible concentration is given for copper; 100 µg/L is given for outlets of pumping and/or treatment works and their substations and 3000 µg/L after the water has been standing for 12 hours in the piping and at the point where the water is made available to the consumer. Above 3000 µg/L astringent taste discoloration and corrosion may occur.

Directive on the Classification, Packaging and Labeling of Dangerous Substances (7095)
Copper chloride, copper (I) chloride, copper naphthenate, and copper (I) oxide cyanide are classified as harmful substances and are subject to packaging and labeling regulations. These substances may contain a stabilizer. If the stabilizer changes the dangerous properties of these substance, substances should be labeled in accordance to rules in Annex I and EEC/884/490, July 22, 1989.

EEC Council Decision on the Convention On Marine Pollution From Land-Based Sources (7110)
The convention provides steps to be taken in preventing pollution of the North East Atlantic and The North Sea from land-based sources. These steps apply to three substances listed in Annex A: Part I substances include persistent chemical families or materials must be eliminated; Part III substances, include less persistence organic substances and heavy metals, which must be reduced or eliminated, as appropriate; discharges must be subject to approval by representatives of the contracting party.; and Part III, radioactive substances and waste discharges must be forestalled and, as appropriate, eliminated.

77.1 MAJOR USES

Copper production in the United States in 1982 was reported to be 2.41 million metric tons. In addition, 0.26 million metric tons were imported and 0.03 million metric tons were exported (5825). Most copper produced and/or imported into the U.S. is used as the metal or in metal alloys; 70% in electrical and electronic products, 15% in construction. 6% in industrial machinery and equipment, 4% in transportation, 2% in ordinance, and the remaining 3% for various other uses (5872). Copper and copper alloys are used in plumbing products, wire, telecommunications, power utilities, air conditioning, business electronics, and industrial valves and fittings (5872).

A small percentage of copper production goes into the manufacture of inorganic and organic copper compounds which have numerous commercial applications. Copper sulfate, the most important inorganic copper compound in terms of volume of production, is utilized for many purposes, particularly as an agricultural fungicide. Copper sulfate is also used as an algicide, a source of copper in animal nutrition, in fertilizers, in wood preservatives, in dye manufacture, in electroplating, in steel making, in the treatment of natural asphalts, in the petroleum industry, and in the manufacture of other copper compounds (5871, 5874). Copper hydroxide, copper ammonium carbonate, copper oxychloride, and copper oxychloride sulfate have been used as fungicides. Copper oxide is used in catalysts, batteries, electrodes, paints, insecticides, ceramic colorants, and for desulfurizing oils. Copper carbonate is used in pigments, pyrotechnics, insecticides, fungicides, and brass coloring. Copper chloride and nitrate have been used as disinfectants and feed additives, in metallurgy, photography, water purification and wood preservation, and for deodorizing and desulfurizing petroleum distillates. Copper nitrates have also been used in the manufacture of pharmaceuticals, paints, varnishes, and enamels (5871). Organic copper compounds that have commercial value include copper naphthenate and copper dimethylglyoxime which are used as rot-proofing agents for fabrics (5871).

77.2 ENVIRONMENTAL FATE AND EXPOSURE PATHWAYS

Copper constitutes 0.005% of the earth's crust (5812). Natural releases of copper into the atmosphere and into aquatic media are a result primarily of volcanic activity and weathering of soil. Anthropogenic releases result from such activities as mining and milling operations, agricultural and biocidal use of copper compounds, disposal of solid wastes and sludges, and discharge of industrial and sewage treatment plant effluents (5873). In 1975, it was estimated that 25% (18,500 metric tons) of worldwide copper emissions to the atmosphere was derived from natural sources (mostly from windblown dust) and 75% (56,300 metric tons) was derived from anthropogenic sources (mostly from nonferrous metal production and wood combustion). Coal combustion and waste incineration contributed 5,600 and 5,300 metric tons, respectively, to the atmospheric emission of copper. The major copper-processing states in the U.S. in 1984 were: Arizona (73.3%), Montana (8.4%), New Mexico (7.7%), Utah (4.8%), and Michigan (10.5%).

Natural copper concentrations in soil have been reported to range from 1 to 250 mg/kg dry weight (5827, 5873). Near industrial areas such as smelters, soil concentrations may be 10 to 30 times higher (5873). Copper has been found at 210 of 1177 hazardous waste sites on the National Priorities List (soil concentrations were not reported) (5873). In 1307 soil samples taken at hazardous waste sites, copper was found to be above normal background levels in 10.5% of the samples (5876).

77.2.1 Transport in Soil/Ground-water Systems

77.2.1.1 Overview

The mobility of copper in soil-water systems is strongly affected by the extent of adsorption on soil particles. Sorption of copper on soils is controlled by pH, organic substances, and manganese and iron oxides. Most of the copper in soil is tightly bound to soil components, reducing the potential for uptake by plants and for migration and contamination of groundwaters. However, elevated concentrations of copper have been found in some groundwaters (5873). The mobility of copper is enhanced in sandy, acidic, well oxidized soils containing relatively small amounts of organics. Mobility is considerably diminished by high pH levels, reducing conditions, or by the presence of high levels of manganese or iron oxides or high molecular weight organics.

77.2.1.2 Sorption on Soils

Sorption and mobility of copper in soils is affected primarily by soil pH, organic complexing substances, and soil mineral composition. In general, copper sorption decreases with increasing pH and increases with increasing levels of high molecular weight organic compounds, manganese and iron oxides, and clay minerals. The presence of low molecular weight organics may decrease adsorption through the formation of readily soluble copper complexes. The relative capacity of organic and inorganic soil components to exchange and adsorb metal ions follows the general pattern: MnO_2 > humic acid > iron oxide > clay minerals. Charge-unbalanced clay minerals nonspecifically adsorb copper, while iron and manganese oxides and hydroxides have a high specific copper affinity (5805). The capacity of manganese oxides is at least 10 times higher than that of iron oxides (5830).

Sorption on soil can be expressed in terms of the distribution coefficient, K_d, defined as the ratio of the elemental concentration in soil (μg/100 g) to that in water (μg/100 mL). In soil-water systems in equilibrium, the K_d for copper varies considerably, depending on the nature of the soil, the presence of water soluble complexing agents, and pH. The K_d value for copper ranges from 1.4 to 333 mL/g (5807).

Under typical soil conditions, readily soluble and exchangeable copper constitutes less than 5% of the total soil copper. The bulk of the copper is bound to organic compounds and iron and manganese oxides (5805), and therefore is less likely to be bioavailable and to leach to groundwater (5805). However, excessive application of copper containing sewage sludge or inorganic copper salts to soil increases the lability of soil copper and may increase migration of copper to subsoil horizons and

groundwater. Mobility of copper will be highest in sandy soils with low pH and containing relatively small amounts of organics. Mobility will be considerably diminished under reducing conditions due to the formation of insoluble copper sulfides.

In purely organic spruce forest soils, appreciable leaching of copper was observed at pH <3 (5829). It was estimated that about 50% of copper in the top few centimeters of these soils was organically bound, about 18% was in the hydroxy-carbonate form, about 7% was in the adsorbed state, about 11% was bound by other anions, and 6% was irreversibly adsorbed. Only 3% of the copper was extractable with water at pH 4.5. Increased mobilization of copper in these soils is expected under conditions such as land clearing, profile disruption and increased acid rain (5829).

77.2.1.3 Volatilization from Soils

These is no evidence that copper volatilizes from soil either directly or indirectly through chemical or biological processes.

77.2.2 Transformation Processes in Soil/Ground-water Systems

Naturally occurring copper occurs in soils as oxysulfates, carbonates, phosphates, oxides, and hydroxides (5805). Copper sulfides may form in poorly drained or submerged soils where reducing conditions exist. In copper-contaminated soils, CuS or CuFeS may be the most thermodynamically stable copper species under both oxidizing and reducing conditions (5805).

The speciation of copper in soil solutions is not precisely known because of uncertainties in thermodynamic equilibrium constants and lack of experimental techniques (5805). In the system $Cu\text{-}CO_2\text{-}H_2O$, the predominant soluble species shifts from the free ionic Cu^{+2} to $CuCO_3^\circ$ to $Cu(OH)_2^\circ$ with increasing pH. Free ionic copper is present as the hydrated ion $[Cu(H_2O)_6]^{+6}$ which is responsible for forming coordination complexes by ligand substitution of the aquo groups (5805). Much of the soluble copper in soil solution occurs in organic complexes, although levels of free ionic copper may be significant at low soil pH values.

77.2.3 Primary Routes of Exposure from Soil/Ground-water Systems

Human exposure to copper takes place mainly through the food chain. Dietary copper intake is usually greater than intake through drinking water and air. It has been estimated that a typical U.S. diet provides a daily copper intake of <2 to about 4 mg (5829).

Copper is an essential element in plants. It is taken up through the roots in readily soluble and exchangeable ion complexes; however, these complexes normally comprise less than 5% of the total soil copper (5805). Maximum absorption occurs with Cu^{+2}. The presence of chelating agents in the soil can enhances copper solubility, but reduce the rate of uptake by plants. Copper uptake may be enhanced in plants grown on copper-contaminated soil, and high soil concentrations may be phytotoxic. There is no evidence for the biomagnification of copper through the terrestrial food

chain (5873). The copper content of fruits and vegetables normally ranges from about 0.1 ppm to about 3 ppm, and that of meats and poultry is generally not more than 2 ppm; however, liver may contain as much as 60 ppm (5882).

Exposure to copper may also result from the use of groundwater as a source of drinking water. Copper levels in groundwater samples collected in New Jersey, were generally less than 100 ppb (90 percentile 64 ppb), but a maximum level of 2783 ppb was also reported (5873). In general, the concentration of copper in drinking water can vary from a few µg/L to >1 mg/L. The use of copper plumbing in water distribution systems can result in substantial increases in copper levels at the tap. Assuming a mean copper concentration of 0.13 mg/L in drinking water and a daily consumption of 2 L of water, the daily intake of copper through drinking water would be about 0.26 mg (5829). According to the USPHS Drinking Water Standards (1962), the recommended drinking water limit for copper is 1 mg/L, but this is based on organoleptic rather than health considerations (5836).

77.2.4 Other Sources of Human Exposure

Exposure to copper may also occur through inhalation of copper compounds present in the atmosphere as a result of emissions from natural and/or anthropogenic sources. Elemental copper, copper oxide, copper sulfides, copper sulfate, copper chloride, and possibly copper silicate may be emitted directly into the air or formed as a result of subsequent chemical transformations. The enhancement of copper deposition in remote areas, and the increased concentration of copper in snowfall and icesheets in Greenland indicate that long-range atmospheric transport of copper is possible.

According to data derived from EPA's National Air Surveillance Network for the years 1977, 1978, and 1979, median copper concentrations in urban areas were 133, 138, and 96 ng/m^3, respectively, while median concentrations in nonurban areas were 120, 179, and 76 ng/m^3 (5873). Significant exposure of the public to atmospheric copper is not expected. According to EPA estimates, atmospheric copper contributes no more than 1% to the total daily copper intake of an individual. However, considerable inhalation exposure may take place in locations close to the sources of emission (5829). Workers may be occupationally exposed to copper concentrations as high as 512 µg/m^3 (5829).

Copper is removed from the atmosphere through dry (dust fall) and wet deposition (rainfall and snowfall). Although the ratio of dry to wet deposition is dependent on the particle size distribution, topography of the area and meteorological conditions, the typical ratio is close to 1. The atmospheric residence times of copper aerosols in an unpolluted troposphere, in urban and polluted areas, and near an industrial point source have been reported to be 2-10 d, 0.1 to > 4 d, and <2.0 h, respectively (5829).

Atmospheric deposition plays a very important role in the overall loading of copper in large bodies of surface water. Surface runoff from agricultural and industrial areas, releases of treated and untreated wastewater, and leaching from solid waste disposal sites may also contribute to copper levels in local waterways (5873). Concentrations of copper in some landfill leachates were reported to range from 0.1-

1.0 ppm (5873). The concentration of copper in freshwater varies worldwide from 0.5-1000 µg/L with a median of 10 µg/L. The average concentration of copper in the U.S. freshwaters is <20 µg/L. Limited intake of copper would result from the use of such waters as a source of drinking water.

The bioconcentration factor (BCF) for copper in fish has been reported to range from 10 to 100, indicating a relatively low potential for bioconcentration. BCF levels up to 30,000 have been reported for some marine invertebrates (oysters), but there is no evidence for biomagnification through the food chain.

77.2.5 Biological Monitoring

Methods for biological monitoring of copper have been reviewed by EPA (5829). The two most commonly used methods are atomic absorption spectroscopy and inductively coupled-atomic emission spectroscopy. The first method has a detection limit of 0.1 -2 ppb. The second method has a detection limit of 2-3 ppb. X-ray fluorescence and neutron activation analysis have also been used for analyzing biological samples for copper.

77.3 HUMAN HEALTH CONSIDERATIONS

Copper is an essential element and is present in a wide variety of tissues such as liver, kidney, spleen, heart, lung, muscle, stomach, intestine, etc. It is highly concentrated in nails and hair (5829). The recommended safe and adequate dietary intake for copper is 1.5-3.0 mg/day for adults, 0.7-2.5 mg/day for children and adolescents, and 0.4-0.7 mg/day for infants (5888). Copper is an essential part of a number of enzymes such as catalases, peroxidases, cytochrome oxides, etc. (5864). The major effects of copper deficiency are hypochromic, microcytic anemia resulting from defective hemoglobin synthesis.

About 50% of copper ingested in food is absorbed. The half-time of injected copper in normal subjects was found to be about 4 weeks, but it is much longer in subjects with Wilson's disease (5827). The biological availability and activity of copper may be affected by other inorganic compounds. Zinc can inhibit the absorption of copper and consequently, zinc treatment has been used in patients suffering from Wilson's disease. High intakes of molybdenum and sulfur in the food of ruminants also decreases the availability of copper. In humans a high intake of molybdenum results in low blood copper levels and increased excretion of copper in the urine (5827).

77.3.1 Animal Studies

77.3.1.1 Carcinogenicity

The carcinogenicity of copper hydroxyquinoline has been investigated in $B6C3F_1$ and $B6AKF_1$ mice (5883). The compound was administered orally and by subcutaneous injection to both strains. In the latter case, a single dose of 180.6 mg of Cu/kg was injected subcutaneously to 18 male and 18 female 28-day-old animals. The mice were sacrificed when 78 weeks old. Histologic examination revealed that male

$B6C3F_1$ mice treated with copper hydroxyquinoline had an increased incidence of reticulum cell sarcomas compared with the controls (6/17 treated vs. 8/141 controls, p <0.001). No tumors were seen in the treated male $B6AKF_1$ mice. Female mice of both strains showed low incidences of reticulum cell sarcomas (1/18 vs. 1/154 controls in $B6C3F_1$ mice, and 3/18 vs. 5/157 controls in $B6AKF_1$ mice). In the oral dosing experiments, 18 male and 18 female 7-day-old mice of each strain were treated daily by gavage with 180.6 mg Cu/kg (suspended in 0.5% gelatin) until 28 days old, and then given 505.6 ppm Cu in their diet until 78 weeks old. The animals were then sacrificed and examined histologically. No statistically significant increases in the incidence of lymphatic leukemias, reticulum cell sarcomas, pulmonary adenomas or carcinomas, hepatomas, hepatic carcinomas, mammary carcinomas, skin carcinomas or cavernous angiomas were observed.

The carcinogenicity of cupric oxide, cupric sulfide, and cuprous sulfide was investigated in Wistar rats (5837). Groups of 30 or 32, 2- to 3-month-old animals (sex not reported) were given single intramuscular injections of 20 mg of each of the compound. The animals were maintained for up to 20 months, then sacrificed. The survival rates for the three experiments were 10/32 (CuO), 19/30 (CuS), and 18/30 (Cu_2S). No injection site tumor was observed in any of these animals. One mammary fibroadenoma and one reticulocytoma were found in the animals receiving cupric sulfide. One mammary fibroadenoma was found in the group receiving cuprous sulfide.

Overall, there are insufficient data to determine the carcinogenic potential of copper at this time. The U.S. EPA has placed copper in Group D (not classifiable as to human carcinogenicity) (5829).

77.3.1.2 Genotoxicity

Several copper compounds have been tested in microbial mutagenicity assays. Copper 8-quinolinolate was found to be mutagenic to Salmonella typhimurium strain TA100 when tested in the reverse mutation assay with metabolic activation (5837). The same compound was not mutagenic in tests with Escherichia coli and S. typhimurium strains TA98, TA1535, TA1537 and TA1538 (5837).

Copper sulfate was reported to be non-mutagenic in a reverse mutation assay using S. typhimurium strains TA98 and TA100 with and without metabolic activation (5837). Copper sulfate and copper chloride were also found to be non-mutagenic in assays using Saccharomyces cerevisiae D-7 (5834), and Bacillus subtilis (5835).

Copper sulfate was found to cause chromosomal aberrations, micronuclei, and sperm abnormalities when tested in vivo on inbred Swiss mice (5877).

The induction of simian adenovirus cell transformation in Syrian hamster embryonic cells was reported to be enhanced by the addition of 0.38 mM Cu_2S (5833). Induction of DNA strand breaks by CuS has been observed in Chinese hamster ovary cells (5836).

77.3.1.3 Teratogenicity, Embryotoxicity and Reproductive Effects

Copper deficiencies are known to cause teratogenic effects (such as neural degeneration, reduced growth, skeletal malformations and cardiovascular lesions) in various animals including sheep, goats, rats, guinea pigs, dogs and chickens (5838).

Some copper salts cause reproductive and developmental effects in laboratory animals. The intravenous administration of 2.13 mg Cu/kg, as copper sulfate, to 16 female hamsters on the 8th day of gestation resulted in 26% resorptions and 6% (12 of 155) abnormalities (thoracic wall hernias, encephalocoeles, spina bifida and microphthalmia). A dose of 4.25 mg Cu/kg, caused 86% resorptions and 8% abnormalities (exencephaly, hydrocephalus, abdominal hernia and abnormal spinal curvature), and a dose of 7.5 mg Cu/kg resulted in 100% embryo mortality, 74% resorptions, and 8% abnormalities. A dose of 10 mg Cu/kg was lethal to the dams. The animals were examined on gestational days 12 and 13 (5839). In the same study, copper citrate was found to be more toxic than copper sulfate. Doses of 0.25-1.5, 1.8 and 2.2 mg Cu/kg resulted in 16, 41, and 34% resorptions and 2, 17 and 35% abnormalities, respectively. A dose of 4.0 mg Cu/kg was lethal to both embryos and dams.

In studies on mice, two strains, C57BL and DBA, were maintained for one month on diets supplemented with 0, 500, 1000, 1500, 2000, 3000 or 4000 ppm copper sulfate. At the end of the period, the females were mated with the males of the respective strain. On the 19th day of gestation the pregnant dams were sacrificed and the fetuses were examined for morphological defects. In the C57BL mice, increased fetal weight (1.1-1.3 g vs. 1.1 g in the controls) and increased litter size (4.2-4.6/dam vs. 3.1/dam in the controls) were observed at low dietary levels of 500-1000 ppm copper (equivalent to 25.9-103.5 mg Cu/kg/day). At higher dietary copper levels (3000 and 4000 ppm, equivalent to 155.3 and 207.1 mg Cu/kg/day), average litter size was reduced (2.5 and 1.9, respectively), and average fetal weight was below that of the controls (1.0 vs. 1.1), One skeletal abnormality was seen at 25.9 mg Cu/kg and three at 103.5 mg/kg/day (5840). Similar results were seen in the DBA mice; increased litter size (5.1-5.4 vs. 4.5) and higher embryo weights 1.2 g vs. 1.0 g) at dietary levels of $\leq$1000 ppm, but reduced litter size (2.7-4.1), reduced embryo weights (1.1 g) and the occurrence of skeletal abnormalities at the highest doses. Decreased food intake at high dose levels may have adversely affected fetal development (5841).

Copper compounds have been shown to be spermicidal, and mammalian embryogenesis can be prevented by the use of copper-containing intrauterine devices (5886, 5887).

77.3.1.4 Other Toxicologic Effects

77.3.1.4.1 Short-term Toxicologic Effects

The acute and subchronic toxicity of copper has been investigated using oral, inhalation, and intraperitoneal exposures. Oral LD_{50} values for rats range from 140 mg/kg ($CuCl_2$) to 960 mg/kg ($CuSO_4 \cdot 5H_2O$) (5823). Deaths in animals given lethal doses of copper have been attributed to extensive hepatic centrilobular necrosis.

Short-term exposures to high oral doses of copper can result in liver and kidney damage and hematological changes. Rats treated with 100 mg/kg/day of copper sulfate for 20 days by gavage, had significant decreases in skeletal growth and weight gain, heavy deposition of copper in the livers and kidneys, parenchymal degeneration and perilobular sclerosis in the liver, and tubular engorgement and necrosis in the kidneys (5884). Hepatotoxicity has also been observed in young rats exposed to 2000 mg Cu/kg/day as copper sulfate in their diet for 4 weeks (5885). Prolonged exposures to the same dietary levels resulted in increased tolerances and some tissue regeneration (5879). Pigs exposed to dietary copper levels equivalent to 6.1 mg Cu/kg/day for 54 days exhibited decreased weight gain, reduced hemoglobin and hematocrit, and increased levels of copper in the liver (5847). Decreased hemoglobin and hematocrit values have also been reported in rats receiving 40 mg Cu/kg/day by gavage for 20 days (5845).

Short-term inhalation studies of copper compounds have focused primarily on direct toxic effects on pulmonary tissues. Rabbits exposed to 0.6 mg/m^3 cupric chloride, 6 h/day, 5 d/week for 4-6 weeks (5842, 5843) exhibited no gross signs of pulmonary change; however, a statistically significant increase in the number of alveolar type II cells was observed. In studies on mice, daily inhalation exposure to copper sulfate aerosol (5% aqueous solution) for 4 months resulted in focal accumulation of macrophages in alveoli and interstitial infiltration of cells (5844). Decreased tracheal cilia beating was observed in hamsters exposed to 3.3 mg Cu/m^3 as copper sulfate, and alveolar thickening was observed in mice exposed to copper sulfate (5878).

An intraperitoneal LD_{50} of 3.5 mg/kg has been reported for copper dust (5823). Male albino rats treated daily by intraperitoneal injection of 2 mg Cu/kg as cupric chloride showed statistically significant increases in brain dopamine and norepinephrine (5846).

77.3.1.4.2 Chronic Toxicity

Chronic toxicity studies on copper are rather limited. In one study, rats exposed to dietary levels of 5000 ppm cupric acetate monohydrate for 16 months, accumulated copper in kidney and liver tissue (5848). In another study, Sprague-Dawley rats, exposed to 1250 ppm cupric acetate monohydrate in drinking water for 902 days, showed heavy depositions of copper in liver and kidneys as well as in the brain and large and small intestines (5849). White rats maintained on a diet supplemented with copper sulfate (equivalent to dose levels of 21.3, 34.9, 46.0 mg/kg/day) exhibited dose-related decreases in food intake and weight gain as well as increased concentrations of copper in blood, liver and spleen (5841). Decreased body weight gain has also been observed in pigs exposed to 14.6 mg Cu/kg/day as Cu(II), and in mice consuming 4.2 mg Cu/kg/day as copper gluconate in drinking water over a lifetime (5873). Lifetime exposure of mice to 42.5 mg Cu/kg/day as copper gluconate in drinking water resulted in a 12.8% reduction in maximum lifespan (5881).

77.3.2 Human and Epidemiologic Studies

77.3.2.1 Short-term Toxicologic Effects

Short-term occupational exposures to copper dust or fumes can cause eye and respiratory tract irritation, headaches, vertigo, drowsiness, and a condition known as "metal fume fever". This 24-48 hr illness is characterized by influenza-like syndrome with chills, fever, aching muscles, and dryness in the mouth and throat (5811, 5827). In one study in which workers reported such symptoms, airborne copper dust levels were reported to be 0.075-0.12 mg/m^3 (5873).

Gastrointestinal, hepatic, and renal effects have occurred in humans following the accidental or intentional ingestion of large quantities of copper. Ingestion of milligram quantities of copper result in abdominal pain, diarrhea and vomiting. Ingestion of larger quantities can cause systemic toxicity including hemolysis, hepatic necrosis, gastrointestinal bleeding, oliguria, azotemia, hemoglobinuria, hematuria, proteinuria, hypotension, tachycardia, convulsions, coma, or death (5851). Gastrointestinal effects have occurred following ingestion of 0.07-1421 mg Cu/kg/day as Cu(II) (5873). In one case report, a whiskey sour containing 120-135 ppm copper (about 10 mg of copper/60-90 mL drink), produced abdominal cramps, vomiting, diarrhea within 10-90 min of ingestion (5850). In another case an 18-month-old boy drank a solution containing 3 g of copper sulfate (ca. 1.2 g Cu) and developed acute hemolytic anemia, reduced glucose-6-phosphate dehydrogenase activity, hematuria, glycosuria and proteinuria (5861). Two infants who were given water to drink containing 2.2-3.4 mg Cu/L developed hepatosplenomegaly and increased serum transaminase and serum bilirubin levels. Centrilobular liver necrosis and necrosis of renal tubular cells have been reported in adults consuming 5.7-637 mg Cu/kg/day (5873).

Several episodes of copper-induced hemolysis after hemodialysis have been reported. Copper was introduced into the dialysate from the copper tubing and copper-containing semipermeable membranes in the equipment. The clinical syndrome of copper intoxication included chills, nausea, abdominal pain, vomiting, and watery yellow stools. The concentration of copper in the dialysate ranged from 505 to 884 µg/100 mL (5852). Hemolytic anemia has also been reported in a case where copper sulfate crystals were applied to large areas of burned skin (5853).

77.3.2.2 Chronic Toxicologic Effects

There is limited evidence that toxicologic effects can result from prolonged exposure to copper, particularly in children. An increased dietary level of copper is thought to be partially responsible for a disease known as Indian Childhood Cirrhosis which usually occurs in children 6 months to 5 years old (5863). It has been suggested that the high dietary intake resulted from the storage of milk and water in copper and brass containers (5862). The disease is characterized by high levels of copper in the liver, Mallory's hyaline inclusions in hepatocytes, intralobular fibrosis, and widespread hepatic necrosis with poor hepatic regeneration (5863).

Copper toxicity is also associated with Wilson's disease, a genetic defect which results in an excessive accumulation of copper in liver, brain, kidneys, cornea, low serum ceruloplasmin level, elevated levels of copper not bound to ceruloplasmin, and high urinary excretion of copper (5812). The disease is characterized by hepatic cirrhosis, brain damage and demyelination, and kidney defects (5864).

Prolonged exposure to copper and chronic toxic effects might be expected in occupational exposure situations; however, in such cases it is difficult to distinguish chronic effects from those due to transient elevations in copper concentrations. Occupational exposure to copper fumes, dusts, and mists can cause "metal fume fever", a disorder characterized by influenza-like symptoms; however, this is not known to develop into a chronic ailment. Other effects attributed to occupational exposures to copper include respiratory tract irritation, contact dermatitis, leukocytosis and mild anemia, the latter reportedly occurring in workers exposed to 0.6-1 mg Cu/m^3 (5823, 5859, 5860). Exposure of Swedish workers for 17-40 years to dusts of mixed copper salts (basic copper nitrate and sulfate, copper silicate, and cupric oxide), which were generated through the handling of patinated copper sheeting, led to atrophic rhinitis with complaints of metallic taste, runny nose, and mucosal irritation in the mouth and eyes (5854).

Epidemiological studies have provided conflicting results on the potential effects of long-term occupational exposure to copper. Chilean copper miners, exposed for years to the water insoluble dusts of copper sulfide and oxide, were reported to have normal concentrations of copper in liver and serum (5858). An epidemiological study of 14,562 white male workers in the copper and zinc smelting industries revealed no overall increase in mortality rates as compared with the mortality rates for the total U.S. population (5865). However, Schrauzer et al. reported a positive correlation between blood copper concentrations and mortality due to cancer of the intestine in men, and between blood copper levels and cancer of the intestine, lung, breast and thyroid in women (5866).

Vineyard workers are exposed to copper in Bordeaux mixture (1-2% solution of copper sulfate neutralized with lime) widely used on grape vines to prevent mildew growth, particularly in France, Italy, and Portugal. Pulmonary copper deposition, fibrosis, granulomas and malignant tumors have been found in the lungs of some of these workers after years of exposure (5855, 5856, 5857). However, these studies are inconclusive because other chemicals such as arsenic are also present in Bordeaux mixture and may have contributed to the effects reported (5829).

77.3.3 Levels of Concern

Copper is an essential element in human nutrition, and the recommended safe and adequate dietary intake for adults is 1.5-3.0 mg/day (5888). A typical U.S. diet provides a daily copper intake of about <2 to about 4 mg. U.S. EPA reference doses have not been derived for copper.

Exposure of the general public through drinking water is not expected to be significant. Using as estimated average copper concentration of about 0.13 mg/L in

drinking water, and assuming a daily consumption of 2 L of water for adults, the average daily copper intake through drinking water would be 0.26 mg. The U.S. EPA secondary maximum contaminant level for copper in drinking water has been set at 1 mg/L, based on the organoleptic data for controlling taste and odor rather than health considerations.

No federal air quality standards for copper have been promulgated and the exposure to the general public is not expected to be significant. The mean concentration of copper in rural, urban, suburban areas and hot spots (areas close to the emission sources) have been estimated to be 25, 160, 190. and 449 ng/m^3, respectively; concentrations well below the OSHA standards. However, the potential exists for heavy deposition of copper on the soil near the smelters, and small children may ingest >5 mg Cu/day based on estimates that children may ingest an average of 100 mg soil/day. Atmospheric emissions from copper smelters may also adversely affect terrestrial and aquatic life downwind resulting in effects ranging from complete destruction of vegetation to disruption of nutrient cycling and elimination of sensitive species.

Exposure to excessively high levels of copper are likely to occur only in occupational exposure situations. The OSHA PEL for copper fumes and copper dusts and mists have been established at 0.1 mg/m^3 and 1.0 mg/m^3, respectively.

77.3.4 Hazard Assessment

Copper is an essential element and homeostatic mechanisms for absorption, distribution, storage, utilization, and excretion are well-developed. However, in cases where homeostatic mechanisms are disrupted as a result of genetic defects or abnormal development, and copper intake is not regulated, copper toxicosis may result.

Acute toxic effects following ingestion of large doses of copper, include abdominal pain, diarrhea, vomiting, gastrointestinal bleeding, hepatic necrosis, oliguria, azotemia, hemoglobinuria, hematuria, proteinuria, hypotension, tachycardia, convulsions, coma, and death (5851). The general public's exposure to copper mainly takes place through food and exposure to toxic levels is unlikely except in accidental cases such as drinking acidic beverages or food stored in copper or brass vessels. The latter is deemed to be the reason for Indian Childhood Cirrhosis. Symptoms of copper toxicosis are also exhibited by sufferers of Wilson's disease which is caused by a genetic defect affecting copper metabolism.

Workers occupationally exposed to copper have exhibited symptoms of atrophic rhinitis, runny nose, mucosal irritation in the mouth and eyes, contact dermatitis, mild anemia, and leukocytosis. Short-term exposure to copper fumes leads to "metal fume fever." Recovery takes place within days, usually without any sequelae (5811, 5827).

Several epidemiological studies have been reported in the literature but the results are inconclusive because there was simultaneous exposure to other chemicals. The overall weight-of-evidence from the animal studies suggest that there are insufficient data to determine the carcinogenic potential of copper at this time. The U.S. EPA lists copper in Group D (not classifiable as to human carcinogenicity).

The available data do not permit a definitive conclusion on the mutagenicity of copper. However, the teratogenicity of copper has been demonstrated in hamsters and mice. The spermicidal effect of small amounts of copper leaching out from intrauterine devices has also been shown.

77.4 SAMPLING AND ANALYSIS CONSIDERATIONS

Determination of copper concentrations in soil and water requires the collection of a representative field sample and the maintenance of proper storage conditions prior to laboratory analysis. Samples for metal determinations should be collected in either glass, polypropylene or teflon containers. The sample containers should have been previously cleaned with the following sequence of reagents to minimize bottle contamination: detergent, tap water, 1:1 nitric acid, tap water, 1:1 hydrochloric acid, tap water, and Type II water. Approximately 600 mL of aqueous sample should be collected to ensure a final sample digestion volume of 100 mL. To reduce the probability of metal hydrolysis, metal adsorption onto or leaching from the sample container, or chemical transformation through bacterial metabolism, the aqueous sample must be preserved with the addition of nitric acid such that the final pH is less than pH 2. At least 200 grams of solid sample should be collected to prepare a sample digestion volume of 100 mL. Usually no preservative procedure is required for solid samples other than storage at 4°C until sample analysis. All samples should be analyzed within 180 days of sample collection. In addition to the targeted samples, duplicates and spiked matrices should be included in the analytical program to ascertain the reproducibility and accuracy of the analytical determination (5868).

Analytical methods available for analyzing inorganic copper in water, soils and waste include atomic absorption (Methods 220.1 and 220.2) and inductively coupled plasma atomic emission spectrometry (Method 200.7) techniques. Depending upon the analytical method, treatment with acid or a combination of acid with hydrogen peroxide is used to digest the samples. Sample preparation procedures specific to each analytical technique are described in Methods 200.0, and 200.7 for aqueous samples (5868) and Methods 3005, 3010, 3020, 3040, and 3050 for solid or waste samples. Quality control samples should be processed with the samples to determine whether analyte losses have occurred during the sample dissolution procedure (5869).

The atomic absorption techniques are probably the most common procedures for determining the concentration of copper in water, soil and waste samples. Following the appropriate digestion of the sample, a representative aliquot of the digestate is atomized by either directly aspirating it into a flame or by charring it in a graphite tube furnace. The absorption of hollow cathode or electrodeless discharge lamp radiation at 324.7 nm will be proportional to the copper concentration. The detection ranges are 0.2-5 mg/L and 5-100 µg/L for the flame and the furnace atomic absorption techniques, respectively. No EPA data is currently available to document the precision and accuracy of the graphite furnace technique. An interlaboratory study of six synthetic samples has been undertaken to ascertain the precision and accuracy of the flame atomic absorption procedure. The standard deviation between laboratory results using

the flame technique ranged between 17-81%. The bias in results compared to the true values ranged from -2 to 30% (5868).

EPA has recently approved the use of the inductively coupled plasma (ICP) atomic emission method for determining compliance with existing National Primary (and Secondary) Drinking Water Regulations (5870). The technique is based upon the simultaneous or sequential multi-element measurement of atomic emission of trace metals. A preserved and/or digested sample is nebulized to form an aerosol that is introduced into a high temperature plasma where atomic excitation occurs. Characteristic atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma and are dispersed by a grating spectrometer. The line intensities, which are a measurement of elemental concentrations, are monitored by photomultiplier tubes. Optical compensation techniques are used to correct for spectral interferences. In an EPA evaluation of the reproducibility and accuracy of the ICP method, the mean percent relative standard deviation for triplicate analysis of 22 elements was found to be 9%. The mean percent recovery of spiked elements for all waste samples was 93% (5868).

Detection Limit	Method
6 µg/L (aqueous & nonaqueous)	200.7
20 µg/L (aqueous & nonaqueous)	220.1
1 µg/L (aqueous & nonaqueous)	220.2

77.5 REFERENCES

Note: The numbering sequence of the references reflects the order of references as they appear in the master bibliography.

5800. Irving Sax, N.; Lewis, Sr., R.J. 1989. Dangerous Properties of Industrial Materials, Seventh Edition, Vol. II, Van Nostrand Reinhold, NY.

5801. Weast. R.C. 1988-89. Handbook of Chemistry and Physics, 68th ed., The Chemical Rubber Company, Boca Raton, FL.

5802. Massey, A.G. Copper. In: Comprehensive Inorganic Chemistry, Bailar, Jr., J.C.; Emeleus, H.J.; Nyholm, R., eds., Pergamon Press, Oxford.

5803. Martin, R.B. 1988. Bioinorganic chemistry of toxicity. In: Handbook on toxicity of inorganic compounds, Sigel, H.; Seiler, H.G., eds. Marcel Dekker, Inc., NY.

5804. Browning, E. 1969. Toxicity of industrial metals. Appleton-Century-Crofts, London.

5805. Bingham, F.T.; Peryea, F.J.; Wesley J.M. 1986. Metal toxicity to agricultural crops. In: Metal Ions in Biological Systems, Vol. 20, Concepts on Metal Ion Toxicity, ed., Sigel, H., Marcel Dekker, NY, pp. 134-139.

5806. Tuddenham, W.M.; Dougall, P.A. 1984. Copper. In: Kirk-Othmer Encyclopedia of Chemical Technology, third edition, eds. Mark, H.F.; Othmer, D.F.; Overberger, C.G.; Seaborg, G.T. John Wiley & Sons, NY, pp 826-869.

5807. Baes, III, C.F.; Sharp, R.D.; Sjoreen, A.L.; et al. 1984. A review and analysis of parameters for assessing transport of environmentally released radionuclides through agriculture. Oak Ridge National Laboratory, Oak Ridge, TN. ORNL - 5786.

5808. Tyler, G. 1978. Water, Air, Soil Pollut 9:137-148, as cited in U.S. EPA 1987. Health issue assessment: copper. EPA/600/8-87/001.

5809. Registry of Toxic Effects of Chemical Substances, 1985-1986 Edition. U.S. Department of Health and Human Services, Washington, DC.

5810. National Institute for Occupational Safety and Health (NIOSH). 1985. NIOSH Pocket Guide to Chemical Hazards. U.S. Department of Health and Human Services, Washington, DC.

5811. National Research Council. 1977. Medical and Biological Effects of Environmental Pollutants. Copper. National Academy of Sciences, Washington, DC.

5812. Sarkar, B. 1988. Copper. In: Handbook on toxicity of inorganic compounds, eds., Seiler, H.G.; Sigel, H. Marcel and Dekker, NY, pp. 265-276.

5813. Pagenkopf, G.K. 1986. Metal speciation and toxicity in aquatic systems. In: Metal Ions in Biological Systems, ed., Sigel, H., Marcel Dekker, Inc., NY, p. 111.

5814. O'Shea, K.S.; Kaufman, M.H. 1979. Wilhelm Roux Arch. Dev. Biol. 186:297-302.

5815. International Technical Information Institute. 1986. Toxic and Hazardous Industrial Chemicals Safety Manual, p. 135.

5816. American Conference of Governmental Industrial Hygienists (ACGIH). 1988-89. Threshold Limit Values and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

5817. Occupational Safety and Health Administration (OSHA). 1989. 29 CFR Part 1910, Air Contaminants; Final Rule.

5818. United States Environmental Protection Agency (U.S. EPA). May 22, 1989. National Primary and Secondary Drinking Water Regulations; Proposed Rule. 40 CFR Parts 141, 142 and 143, Federal Register, Vol. 54, pp. 22062-22160.

5819. United States Environmental Protection Agency (U.S. EPA). 1988. Integrated Risk Information System (IRIS). Revised March 1988 ed. Cincinnati, OH: U.S. Environmental Protection Agency, Environmental Criteria and Assessment Office.

5820. Martindale. The Extra Pharmacopoeia, 28th ed, ed. JEF Reynolds, Pharmaceutical Press, London.

5821. Mellor, J.W. 1923. A comprehensive treatise on inorganic and theoretical chemistry, Vol. III.

5822. United States Environmental Protection Agency (U.S. EPA). 1989. Drinking Water Regulations and Health Advisories. Office of Drinking Water, Washington, DC.

5823. United States Environmental Protection Agency (U.S. EPA). 1987. Quality Criteria for Water, updated May 1, 1987. U.S. EPA 440/5-86-001.

5822. Cotton, F.A.; Wilkinson, G. 1980. Advanced Inorganic Chemistry. A Comprehensive Text, 4th ed., John Wiley & Sons, NY.

5823. Stokinger, H.E. 1981. Copper, Cu. In: Patty's Industrial Hygiene and Toxicology, 3rd rev. ed., Vol IIA, eds., Clayton, G.D. and Clayton, F.E., John Wiley and Sons, NY, pp 1620-1630.

5824. U.S. Department of Transportation. (DOT) 1987. Emergency Response Guidebook.

5825. SRI International. 1982. Chemical Economics Handbook.

5826. Kust, R.N. 1984. Copper Compounds. In: Kirk-Othmer Encyclopedia of Chemical Technology, third edition, eds., Mark, H.F.; Othmer, D.F.; Overberger, C.G.; Seaborg, G.T. John Wiley & Sons, NY, pp. 107-109.

5827. Aaseth, J.; Norseth, T. 1986. Copper. In: Handbook on the Toxicology of Metals, Second Edition, Vol. II. Specific Metals, eds., Friberg, L.; Nordberg, G.F.; Vouk, V.B. Elsevier, NY.

5828. Jørgensen, S.E.; Jensen, A. 1984. Processes of metal ions in the environment. In: Metal Ions in Biological Systems, ed., Sigel, H. Marcel Dekker, Inc., NY.

5829. United States Environmental Protection Agency (U.S. EPA). 1987. Summary review of the health effects associated with copper. Environmental Criteria and Assessment Office, Office of Health and Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH.

5830. Beijer, K.; Jernelov, A. 1986. Sources, transport and transformation of metals in the environment. In: Handbook on the toxicology of metals, Vol. 1, eds., Friberg, L.; Nordberg, G.F.; Vouk, V.B. Elsevier, NY.

5831. Robision, S.H.O.; Cantoni, O.; Costa, M. 1982. Strand breakage and decreased molecular weight of DNA induced by specific metal compounds. Carcinogenesis 3:657-662. As reported in 5829.

5832. Moriya, M.; Ohta, T.; Watanabe, T.; et al. 1983. Further mutagenicity studies on pesticides in bacterial reversion assay systems. Mutat. Res. 116:185-216. As reported in 5829.

5833. Casto, B.C.; Meyers, J.; DiPaolo. 1979. Enhancement of viral transformation for evaluation of the carcinogenic and mutagenic potential of inorganic metal salts. Cancer Res. 39:193. As reported in 5829.

5834. Singh, I. 1983. Induction of reverse mutation and mitotic gene conversion by some metal compounds in Saccharomyces cerevisiae. Mutat. Res. 117:149-152. As reported in 5829.

5835. Kanematsu, N.; Hara, M.; Kada, T. 1980. Rec assay and mutagenicity studies on metal compounds. Mutat. Res. 77:109-116. As reported in 5829.

5836. National Academy of Sciences (NAS). 1977. Drinking Water and Health. National Academy of Sciences, Washington, DC.

5837. Gilman, J.P.W. 1962. Metal Carcinogenesis II. A study on the carcinogenic activity of cobalt, copper, iron, and nickel compounds. Cancer Res. 22:158-166.

5838. Hurley, L.S.; Keen, C.L. 1979. Teratogenic effects of copper. Copper Environ 2:33-56. As reported in 5829.

5839. Ferm, V.H.; Hanlon, D.P. 1974. Toxicity of copper salts in hamster embryonic development. Biol. Reprod. 11:97-101. As reported in 5829.

5840. Lecyk, M. 1980. Toxicity of cupric sulfate in mice embryonic development. Zool. Pol. 28:101-105. As reported in 5829.

5841. Boyden, R.; Potter, V.R.; Elvehjem, C.A. 1938. Effect of feeding high levels of copper to albino rats. J. Nutr. 15:397-402. As reported in 5829.

5842. Johansson, A.; Curstedt, T.; Robertson, B.; et al. 1984. Lung morphology and phospholipids after experimental inhalation of soluble cadmium, copper, and cobalt. Environ. Res. 34:295-309. As reported in 5829.

5843. Lundborg, M.; Camner. 1984. Lysozyme levels in rabbit lung after inhalation of nickel, cadmium, cobalt, and copper chlorides. Environ. Res. 34:335-342. As reported in 5829.

5844. Eckert, H.; Jerochin, S. 1982. Z Erkr Atmungsorgane 158:270-276. As reported in 5827.

5845. Rana, S.V.S.; Kumar, A. 1980. Biological, hematological and histological observations in copper-poisoned rats. Ind Health 18:9-17. As reported in 5829.

5846. Malhotra, K.M.; Shukla, G.S.; Chandra, S.V. 1982. Neurochemical changes in rats coexposed to lead and copper. Arch Toxicol 49:331-336. As reported in 5829.

5847. Kline, R.D.; Hays, V.W.; Cromwell, G.L. 1971. Effects of copper, molybdenum and sulfate on performance, hematology and copper stores of pigs and lambs. J Anim Sci 33:771. As reported in 5829.

5848. Howell, J.S. 1959. Histochemical demonstration of copper in copper-fed rats and in hepatolenticular degeneration. J Pathol Bacteriol 77:473-484. As reported in 5829.

5849. Owen, Jr., C.A. 1974. Similarity of chronic copper toxicity in rats to copper deposition of Wilson's disease. Mayo Clin Proc 49:368-375. As reported in 5829.

5850. Anonymous. Acute copper poisoning-Pennsylvania. Morbid. Mortal. Week. Rep 24:99. As reported in 5811.

5851. Chuttani, H.K.; Gupta, P.S.; Gulati, S.; Gupta, D.N. 1965. Acute copper sulfate poisoning. Amer J Med 39:849-854.

5852. Manzler, A.D.; Schreiner, A.W. 1970. Copper-induced Acute Hemolytic Anemia. Ann Int Med 73:409-412.

5853. Holtzman, N.A.; Elliott, D.A.; Heller, R.H. 1966. Copper intoxication. Report of a case with observations on ceruloplasmin. New Engl J Med 275:347-352. As reported in 5811.

5854. Askergren, A.; Mellgren, M. 1975. Scand J Work Environ Health 1:45. As reported in 5823.

5855. Pimentel, J.C.; Marques, F. 1969. "Vineyard sprayer's lung": A new occupational disease. Thorax 24:678-688. As reported in 5823.

5856. Pimentel, J.C.; Menezes, A.P. 1975. Liver granulomas containing copper in vineyard sprayer's lung. A new etiology of hepatic granulomatosis. Amer Rev Respir Dis 111:189-195. As reported in 5823.

5857. Villar, T.F. 1974. Vineyard sprayer's lung. Clinical aspects. Amer Rev Respir Dis 110:545-555. As reported in 5823.

5858. Scheinberg, I.H.; Sternlieb, I. 1969. Metabolism of trace metals. In Duncan's Diseases of Metabolism, Vol. 2. Endocrinology and Nutrition, 6th ed., ed., Bondy, P.K. W. B. Saunders Co., Philadelphia. As reported in 5823.

5859. Finelli, V.N.; Boscolo, P.; Salimei, E., et al. 1984. Anemia in men occupationally exposed to low levels of copper. In: Proc. of the Int. Conference on Heavy Metals in the Environment. Co-sponsored by Commission of the European Communities and the World Health Organization, Amsterdam, September, 1981. pp. 475-478. As reported in 5829.

5860. Armstrong, C.E.; Moore, L.W.; Hackler, R.L.; et al. 1983. An outbreak of Metal Fume Fever: Diagnostic Use of Urinary Copper and Zinc Determinations. J Occup Med 25:886-888. As reported in 5829.

5861. Walsh, F.M.; Crosson, F.J.; Bayley, M.; et al. 1977. Acute copper intoxication. Pathophysiology and therapy with a case report. Am J Dis Child 131:149. As reported in 5829.

5862. Bhandari, B.; Sharda, B. 1982. Copper from cooking utensils as a cause of Indian childhood cirrhosis? Arch Dis Child 57:323. As reported in 5829.

5863. Pandit, A.N.; Bhave, S.A. 1983. Copper and Indian childhood cirrhosis. Indian Pediatr 20:893-899. As reported in 5829.

5864. Goyer, R.A. 1986. Toxic Effects of Metals. In: Casarett and Doull's Toxicology, 3rd ed., eds., Klaassen, C.D.; Amdur, M.O.; Doull, J. Macmillan Publishing Company, NY, pp 582-635.

5865. Enterline, P.E.; Marsh, G.M.; Esmen, N.; et al. 1986. Report on Mortality Among Copper and Zinc Smelter Workers in the United States. Report prepared for Smelter Environmental Research Association by the School of Public health, University of Pittsburgh. As reported in 5829.

5866. Schrauzer, G.N.; White, D.A.; Schneider, C.J. 1977. Cancer mortality correlation studies. IV. Association with dietary intakes and blood levels, notably Se-antagonists. Bioinorg Chem 7:35-36. As reported in 5829.

5867. Morton, M.S.; Elwood, P.C.; Abernethy, M. 1976. Trace elements in water and congenital malformations of the central nervous system in south wales. Br J Prev Soc Med 30:36-39. As reported in 5829.

5868. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983.

5869. Test Methods for Evaluation of Solid Waste, U.S. EPA SW-846, November 1986, Third Ed.

5870. Federal Register, Vol. 53, No. 33, February 19, 1988,pp. 5142-5147. "40 CFR Parts 141 and 143, National Primary Drinking Water Regulations, Analytical Techniques".

5871. Clayton, G.D., Clayton, F.E., eds. 1978. Patty's Industrial Hygiene and Toxicology, 3rd revised edition. New York: John Wiley and Sons. pp. 1620-1630.

5872. Jolly, J.L.W., Edelstein, D. 1987. Copper. 1987 Bureau of Mines Yearbook. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines. As cited in ASTDR 1989.

5873. Agency for Toxic Substances and Disease Registry (ATSDR). 1989. Toxicological Profile for Copper. U.S. Public Health Service, Agency for Toxic Substances and Disease Registry.

5874. Mannsville Chemical Products. 1984. Copper sulfate. Chemical products synopsis. Cortland, NY: Mannsville Chemical Products Corp.

5875. Hazardous Substances Data Bank (HSDB). 1989. National Library of Medicine. Bethesda, MD.

5876. Eckel, W.P., Langley, W.D. 1988. A background-based ranking technique for assessment of elemental enrichment in soils at hazardous waste sites. Superfund 88'. Proceedings of the 9th National Conference, Nov. 28-30. 1988. Washingtgon, D.C. pp. 282-286. As cited in 5873.

5877. Bhunya, S.P., Pati, P.C. 1987. Genotoxicity of an inorganic pesticide, copper sulfate, in mouse in vivo system. Cytologia 52:801-808.

5878. Drummond, J.G., Aranyi, C., Schiff, L.J. et al. 1986. Comparative study various methods used for determining health effects of inhaled sulfates. Environ. Res. 41:514-528.

5879. Haywood, S. 1980. The effect of excess dietary copper on the liver and kidney of the male rat. J. Comp. Pathol. 90:217-232.

5880. Haywood, S. 1985. Copper toxicoosis and tolerance in the rat. I. Changes in copper content of the liver and kidneys. J. Pathol. 145:149-158.

5881. Massie, H.R., Aiello, V.R. 1984. Excessive intake of copper: influence on longevity and cadmium accumulation in mice. Mech. Ageing Develop. 26:195-203. As reported in 5873.

5882. Pennington, J.A.T., Young, B.E., Wilson, D.B. 1986. Mineral content of food and total diests: the selected minerals in foos surveys, 1982-1984. J. Amer. Diet Assoc. 86:876-891. As reported in 5873.

5883. Bionetics Research Laboratories. 1968. Evaluation of carcinogenic, teratogenic, and mutagenic properties of selected pesticides and industrial chemicals. vol. 1. Carcinogenic study prepared for the National Cancer Institute. NCIDCCP-CG-1973-1-1. As cited in 5829.

5884. Rana, S.V.S.; Kumar, A. 1978. Simultaneous effects of dietary molybdenum and copper on the accunulation of copper in the liver and kidney of copper poisoned rats. A histochemical study. Ind. Health 18(1):9-17. As reported in 5829.

5885. Haywood, S. 1979. The effects of the sex of weaned rats on the accumulation of dietary copper in their livers. J. Comp. Pathol. 89:481-487. As reported in 5879.

5886. Oster, G.; Salgo, M.P. 1977. Copper in mammalian reproduction. Adv. Pharmacol. Chemothr. 14:327. As cited in 5829.

5887. Hurley, L.S.; Keen, C.L. 1979. Teratogenic effects of copper. Copper Environ. 2:33-56. As cited in 5829.

5888. National Research Council. 1989. Recommended Dietary Allowances. 10th ed. National Academy Press, Washington, DC.

5889 United States Environmental Protection Agency (U.S. EPA). 1990. Drinking water regulations and health advisories. November, 1990.

7000. Occupational Safety and Health Administration (OSHA). 1989. Air contaminants: final rule. 29CFR1910, Fed. Regist., 1/19/89, 54:2332-2983, as corrected 54:28054.

7003. Occupational Safety and Health Administration (OSHA). 1989. Hazardous waste operations and emergency response; final rule. 29CFR1910.120, Fed. Regist., 3/6/89, 54:9294-9336.

7004. U.S. Environmental Protection Agency (U.S. EPA). 1989. Notice of issuance of pesticide registration standards. Fed. Regist., 2/22/89, 54:7740.

7005. U.S. Environmental Protection Agency (U.S. EPA). 1971. Tolerances and exemptions from tolerances for pesticide chemicals in or on raw agricultural commodities. 40CFR180, Fed. Regist. 11/25/71, 36:22540, as revised 1976, 41:4537.

7006. U.S. Environmental Protection Agency (U.S. EPA). 1971. Exemptions from the requirement of a tolerance for pesticide chemicals. 40CFR180.1001, Fed. Regist. 11/25/71, 36:22540, as revised 1976, 41:4537.

7009. U.S. Environmental Protection Agency (U.S. EPA). 1977. Marine Protection, Research, and Sanctuaries Act; Constituents prohibited as other than trace contaminants. 40CFR227.6, Fed. Regist., 1/11/77, 42:2476, as revised 1978, 43:1071.

7010. Department of Transportation (DOT). 1989. Hazardous substances; final rule. 49CFR172, Fed. Regist., 8/21/89, 54:34666-34690.

7015. U.S. Environmental Protection Agency (U.S. EPA). 1978. Designation of hazardous substances. 40CFR116.4, Fed. Regist., 3/13/78, 43:10474, as last amended 1979, 44:66602.

7016. U.S. Environmental Protection Agency (U.S. EPA). 1985. Determination of reportable quantities of hazardous substances. 40CFR117.3, Fed. Regist., 9/29/86, 51:34547 as revised 1989, 54:33425.

7017. U.S. Environmental Protection Agency (U.S. EPA). 1979. Toxic pollutants. 40CFR401.15, Fed. Regist., 7/30/79, 44:44503, as last amended 1981, 46:2266 and 1981, 46:10724.

7018. U.S. Environmental Protection Agency (U.S. EPA). 1981. General pretreatment regulations for existing and new sources of pollution. 40CFR403, Fed. Regist., 1/28/81, 46:9439, as revised 1986, 51:20429 and 1988, 53:40562.

7019. U.S. Environmental Protection Agency (U.S. EPA). 1982. Inorganic chemicals manufacturing point source category. 40CFR415, Fed. Regist., 6/29/82, 47:28278, as revised 1982, 47:55226.

7020. U.S. Environmental Protection Agency (U.S. EPA). 1984. Nonferrous metals manufacturing point source category. 40CFR421, Fed. Regist., 3/8/84, 49:8790, as amended 1984, 49:26739 and 29795, and 1987, 52:25556.

7021. U.S. Environmental Protection Agency (U.S. EPA). 1982. Steam electric power generating source category. 40CFR423, Fed. Regist., 11/19/82, 47:52304, as amended 1983, 48:31404.

7022. U.S. Environmental Protection Agency (U.S. EPA). 1981. Timber products manufacturing point source category. 40CFR429, Fed. Regist., 1/26/81, 46:8285.

7023. U.S. Environmental Protection Agency (U.S. EPA). 1982. Ore mining and dressing point source category. 40CFR440, Fed. Regist., 12/3/82, 47:54609, as amended 1988, 53:18788.

7025. U.S. Environmental Protection Agency (U.S. EPA). 1981. Electroplating point source category. 40CFR413, Fed. Regist., 1/28/81, 46:9467, as revised 1983, 48:43681 and 32483.

7026. U.S. Environmental Protection Agency (U.S. EPA). 1983. Metal finishing point source category. 40CFR433, Fed. Regist., 7/15/83, 48:32485 as revised 1983, 48:41410 and 43682.

7027. U.S. Environmental Protection Agency (U.S. EPA). 1984. Battery manufacturing point source category. 40CFR461, Fed. Regist., 3/9/84, 49:9134 and 13879, as revised 1986, 51:30816.

7028. U.S. Environmental Protection Agency (U.S. EPA). 1985. Nonferrous metals forming and metal powders point source category. 40CFR471, Fed. Regist., 8/23/85, 50:34290, as revised 1986, 51:2884.

7030. U.S. Environmental Protection Agency (U.S. EPA). 1987. Organic chemicals, plastics, and synthetic fibers point source category. 40CFR414, Fed. Regist., 11/5/87, 52:42568, as amended 1989, 54:27351.

7036. U.S. Environmental Protection Agency (U.S. EPA). 1982. Coil coating point source category. 40CFR465, Fed. Regist., 12/1/82, 47:54244, as revised 1984, 49:33648.

7039. U.S. Environmental Protection Agency (U.S. EPA). 1983. Copper forming point source category. 40CFR468, Fed. Regist., 8/15/83, 48:36957 and 50719, as revised 1986, 51:22521.

7040. U.S. Environmental Protection Agency (U.S. EPA). 1985. Metal molding and casting point source category. 40CFR464, Fed. Regist., 10/30/85, 50:45247, as revised 1986, 51:21760.

7043. U.S. Environmental Protection Agency (U.S. EPA). 1987. Assessment of copper as a potentially toxic air pollutant. 40CFR61.01, Fed. Regist., 2/23/87, 52:5496.

7045. U.S. Environmental Protection Agency (U.S. EPA). 1986. Health and safety data reporting. 40CFR716, Fed. Regist., 1/22/86, 51:2890, as last amended 1989, 54:51131.

7050. U.S. Environmental Protection Agency (U.S. EPA). 1988. Notice of substituted contaminants and first drinking water priority list. 40CFR141 (SARA Section 110), Fed. Regist., 1/22/88, 53:1892-1902.

7052. U.S. Environmental Protection Agency (U.S. EPA). 1988. Drinking water regulations; maximum contaminant level goals and national primary drinking water regulations for lead and copper; proposed rule. 40CFR141-142, Fed. Regist. 8/18/88, 53:31516, as corrected 1988, 53:35952 and 36696.

7054. U.S. Environmental Protection Agency (U.S. EPA). 1983. Underground injection control program. 40CFR144, Fed. Regist., 4/1/83, 48:14189.

7056. U.S. Environmental Protection Agency (U.S. EPA). 1979. Secondary maximum contaminant levels. 40CFR143, Fed. Regist., 7/19/79, 44:42198.

7058. State Water Programs Telephone Survey. December, 1989 through January, 1990. Personal communication and documentation.

7059. U.S. Environmental Protection Agency (U.S. EPA). 1988. Toxic chemical release reporting; community right-to-know; final rule. 40CFR372, Fed. Regist., 2/16/88, 53:4500, as revised 1988, 53:23108.

7064. U.S. Environmental Protection Agency (U.S. EPA). 1985. Designation, reportable quantities, and notification of hazardous substances. 40CFR302, Fed. Regist., 4/4/85, 50:13474, as revised 1986, 51:34534, 1989, 54:33418 and 33426.

7068 United States Environmental Protection Agency (U.S. EPA). Waste specific prohibitions second third wastes. 40 CFR268.34, Fed. Regist., 6/23/89, 54:26594.

7070. Food and Drug Administration (FDA). 1977. Bottled drinking water standards. 21CFR103.35, Fed. Regist., 3/15/77, 42:14325, as last amended 1984, 49:10090.

7072. Food and Drug Administration (FDA). 1977. Indirect food additives; adhesives and components of coatings. 21CFR175, Fed. Regist., 3/15/77, 42:14534, as revised 42:56728.

7073. Food and Drug Administration (FDA). 1977. Indirect food additives; substances approved for use as antioxidants and/or stabilizers for polymers used in the manufacture of articles for use in food packaging. 21CFR178, Fed. Regist., 3/15/77, 42:14609.

7078. U.S. Environmental Protection Agency (U.S. EPA). 1980. Discarded commercial chemical products and their hazardous waste numbers. 40CFR261.33, Fed. Regist., 11/25/80, 45:78529 and 78541, as last amended 1988, 53:43881 and 43884.

7079. U.S. Environmental Protection Agency (U.S. EPA). 1981. Hazardous constituents. 40CFR261 Appendix VIII, Fed. Regist., 1/16/81, 46:4619, as last amended 1988, 53:43881.

7082. U.S. Environmental Protection Agency (U.S. EPA). 1987. Ground-water monitoring list. 40CFR264 Appendix IX, Fed. Regist., 7/9/87, 52:25942.

7083. U.S. Environmental Protection Agency (U.S. EPA). 1988. Hazardous waste injection restrictions: waste specific prohibitions. 40CFR148.10-16, Fed. Regist., 8/16/88, 53:30908, as amended 1988, 53:41602 and 1989, 54:25422 and 26647.

7086. Council of European Communities Directive on Drinking Water,16 June 1975 (75/440/EEC-OJ L194, 25 July 1975, OJ L271, 10 October 1979, p. 44).

7088. Council of European Communities Directive on the Discharge of Dangerous Substances, 4 May 1976 (76/464/EEC-OJ L129, 18 May 1976, p. 23).

7089. Council of European Communities Directive on Fishing Water Quality, 18 July 1978 (76/659/EEC-OJ L222, 14 August 1978, amended by 1851).

7090. Council of European Communities Directive on the Quality Required of shellfish Waters, 30 October 1979 (79/923/EEC-OJ L281, 10 November 1979, p. 47).

7091. Council of European Communities Directive on Groundwater, 17 December 1979 (80/68/EEC-OJ L20, 26 January 1980).

7092. Council of European Communities Directive Relating to the Quality of Water Intended for Human Consumption, 15 July 1980 (80/778/EEC-OJ L229, 30 August 1980 (Amended by 81/858, amended October 7, 1981, p. 19).

7095. Council of European Communities Directive on Classification, Packagingand Labeling of Dangerous Substances, 27 June 1967 (67/548/EEC - OJ L196, 16 August 1967; as amended by 69/81/EEEC, 19 March 1969; 70/189/EEC, 14 March 1970; 71/144/EEC, 29 March 1971; 73/146/EEC, 25 June 1973; 75/409/EEC, 14 July 1975; 83/467/EEC, 29 July 1983; amended OJ L 239, 21 August 1987; amended OJ L 259, 19 September 1988.

7102. Council of European Communities Directive on Disposal of Waste Oils, 16 June 1975 (75/439/EEC, OJ L 194, July 25, 1975, p. 23, amended by 387L0101 (OJ L 042, December 2, 1987, p. 43).

7110. Council of European Communities Decision on the Convention on Marine Pollution from Land-based Sources. 78/659-1978.

7112. Florida Department of Environmental Regulation. 1989. Florida Water Quality Standards, Chapter 17-3, effective 12/20/89.

7113. North Carolina Department of Natural Resources and Community Development. 1989. Classifications and Water Quality Standards Applicable to Surface Waters of North Carolina, 15NCAC 2B.0200-0218, effective 10/1/89.

7116. Wisconsin Department of Natural Resources. 1988. Wisconsin Chapter NR140, Groundwater Quality, effective 10/88.

7117. State of Connecticut Department of Health Services. 1985. Connecticut Standards for the Quality of Public Drinking Water, Section 19-13-B102, effective 12/24/85.

7118. State of Connecticut Department of Environmental Protection. 1987. Connecticut Water Quality Standards, effective 2/87.

7119. New York State Department of Environmental Conservation. 1987. Memorandum: New York Ambient Water Quality Standards and Guidance Values, 4/1/87.

7120. Wyoming Department of Environmental Quality. 1980. Chapter VIII, Quality Standards for Wyoming Groundwaters, effective 9/4/80.

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. In this volume, this listing also includes references regarding the toxicology of metals in addition to those references pertinent for the preceding volumes.

- 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 198?)

  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.

- Biological Monitoring of Metals in the Environment

  Authors: T.W. Clarkson, L. Friberg, G. F. Nordberg and P. R. Sager, eds.

  Available from: Plenum Press, New York and London

  Contents: Contains contributed papers and an overview of the Biological Monitoring of Metals Conference (Rochester, NY, June 2-6, 1986). Provides information on monitoring and analysis of metals in biological systems

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- 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.

  *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.

- **Handbook on Toxicity of Inorganic Compounds**

  Editors: H.G. Seiler, H.G. Sigel (1988)

  Available from: Marcel Dekker, Inc.
  New York, NY

  Contents: Presents information on commonly encountered and significant inorganic chemicals.

- **Handbook on the Toxicology of Metals**

  Editors: L. Friberg, G. Nordberg, V.B. Vouk (1986)

  Available from: Elsevier
  New York, NY

  Contents: Covers a wide range of topics relating to the chemistry and toxicology of metals. Includes metal-specific chapters.

- **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.)

- **Metals and Their Compounds in the Environment**

  Editor: E. Meriam (1987)

  Available from: VCH Verlagsgesellschaft
  Weinheim, Fed. Repub. Germany

  Contents: Provides both general and specific information on environmental fate and biological effects of metals.

- **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.

- **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.

- Toxicology of Trace Elements

  Editors: R.A. Goyer and M.A. Mehlman (1977)

  Available from: Hemisphere Publishing Co.
  Washington, D.C.

  Contents: Provides information on the fate and effects of trace elements in living systems.

- 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
  Tyndall AFB, FL 32403-6001
  AV 970-2097/2098
  Commercial: (904) 283-2097/2098

  USAF Engineering and Services Center
  Engineering and Services Laboratory
  Environics Division

  Responsible for IRP engineering research and development.

- Mr. Emile Y. Baladi
  USAF OEHL/TS
  Brooks AFB, TX 78235-5000
  AV 240-2158/2159
  Commercial: (512) 536-2158/2159

  USAF Occupational and Environmental Health Laboratory Technical Services Division

  Responsible for IRP Phase II technical program management.

- Dr. Jeffrey W. Fisher
  AAMRL/THA
  Wright-Patterson AFB, OH 45433-6573
  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
  USAF OEHL/ECO
  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 $\approx$ 4.88 mg/m^3 at 25°C.

- Conversion for Solutes in Water

1 mg/L $\approx$ 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

STATE WATER QUALITY AGENCIES AND CONTACTS

Alabama

Department of Environmental Management
Water Division
1751 Dickinson Drive
Montgomery, AL 36130
(205) 271-7823
Charles Horn

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Department of Environmental Conservation
Water Quality Management Section
3601 C Street
Suite 1334
Anchorage, AK 99503
(907) 563-6529
Bill Ashton

Department of Environmental Conservation
Drinking Water Program
Wastewater & Water Treatment Section
P.O.Box 0
Juneau, AK 99811
(907) 465-2653
Charlene Denys

For copies of Alaska's water regulations, contact:
The Michie Company
Customer Services Department
P.O. Box 7587
Charlottsville, VA 22906-7587
1-800-446-3410

Arizona

Department of Environmental Quality
Safe Drinking Water Unit
2655 East Magnolia
Phoenix, AZ 85034
(602) 257-2214
Diana Marsh

Department of Environmental Quality
2005 North Central
Room 300
Phoenix, AZ 85004
(602) 257-2333
Dave Woodruff

For copies of Arizona's water regulations, contact:
Office of Secretary of State
Publications Department
State Capitol, West Wing, Suite 706
Phoenix, AZ 85007
(602) 255-4285

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Department of Pollution Control & Ecology
Water Quality Division
P.O. Box 9583
Little Rock, AR 72219
(501) 562-7444
Bill Keith

Department of Health
Drinking Water Office
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Little Rock, AR 72205
(501) 661-2623
Bob Macon

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Water Resources Control Board
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Jessica Lacy/Dave Carlson

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Public Water Supply Branch
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Nadine Feletto/ David Spath

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(303) 293-1586/FTS 330-1586
Bob Erickson

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Marti Swicker

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4210 E. 11th Avenue
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Department of Environmental Protection
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Jim Murphy

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Preventable Diseases Division
Water Supplies Section
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(203) 566-1253
Cliff McClelland

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Department of Health Services
Drinking Water Office
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Dover, DE 19903
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Jane Lane/Jeff Beaman

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Water Quality Management Branch
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Mark Blosser

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John Labie

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Mary Rose Teves

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For copies of Idaho's water
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450 West State Street
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Robert Ware

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John Smither

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Department of Environmental Quality
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Department of Health & Hospitals
Office of Public Health
Safer Drinking Water Program
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Room 403
New Orleans, LA 70160
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Jay Ray

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INDEX 1
CROSS INDEX OF CHEMICAL, COMMON AND TRIVIAL NAMES FOR METALS AND METAL COMPOUNDS

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Br_2Cd
Cadmium bromide. See chapter 71.

$CH_3CH_2HgOPO(OH)_2$
Ethylmercuric phosphate. See chpater 73.

CH_3Hg^+
Methyl mercury. See chapter 73

$CH_3HgCNCNHNH_2$
Methylmercuric dicyandiamide. See chapter 73.

$CH_3O(CH_2)_2HgCH_2COOH$
Methoxyethylmercuric acetate. See chapter 73.

CH_5AsO_3
Methylarsinic acid. See chapter 75.

$CH_5AsO_3 \cdot Na$
Sodium methanearsonate. See chapter 75.

$CH_5AsO_3 \cdot 2Na$
Disodium methanearsonate. See chapter 75.

$CNiO_3$
Nickel carbonate. See chapter 76.

$C_2H_4O_4 \cdot Zn$
Zinc formate. See chapter 74.

$C_2H_7AsO_2$
Dimethylarsenic acid. See chapter 75.

$C_2H_7AsO_2 \cdot Na$
Sodium cacodylate. See chapter 75.

$C_3H_6AsCu_4O_{16}$
Cupric acetoarsenite. See chapter 75.

$C_4H_6CdO_4$
Cadmium acetate. See chapter 71.

$C_4H_{11}As$
Diethylarsine. See chapter 75.

$C_4H_6O_4 \cdot Ni$
Nickel acetate. See chapter 76.

$C_4H_6O_4 \cdot Zn$
Zinc acetate. See chapter 74.

$C_6H_5AsCl_2$
Phenyldichloroarsine. See chapter 75.

$C_6H_8AsNO_3$
Arsanilic acid. See chapter 75.

C_6H_5HgCl
Phenylmercury chloride. See chapter 73.

$C_6H_5HgOOCCH_3$
Phenylmercury acetate. See chapter 73.

$C_{12}H_{12}O_8S_2 \cdot Zn$
Zinc phenolsulfonate. See chapter 74.

$C_{18}H_{36}O_2 \cdot Cd$
Cadmium stearate. See chapter 71.

$C_{36}H_{72}O_{24} \cdot Zn$
Zinc stearate. See chapter 74.

$Ca_3(As0_4)_2$
Calcium arsenate. See chapter 75.

$CaCrO_4$
Calcium chromate. See chapter 72.

Cd
Cadmium. See chapter 71.

$CdCl_2$
Cadmium chloride. See chapter 71.

$Cd(NO_3)_2$
Cadmium nitrate. See chapter 71.

CdO
Cadmium oxide. See chapter 71.

$CdSO_4$
Cadmium sulfate. See chapter 71.

Cr
Chromium. See chapter 72.

$Cr(CH_3COO)_3$
Chromic acetate. See chapter 72.

$CrCl_2$
Chromous chloride. See chapter 72.

$CrCl_3$
Chromic chloride. See chapter 72.

CrO_3
Chromium trioxide. See chapter 72.

CrO_4Pb
Lead chromate. See chapter 72.

$Cr(SO_4)_3$
Chromic sulfate. See chapter 72.

Cu
Copper. See chapter 77.

$CuCl_2$
Copper chloride. See chapter 77.

CuH_2NO_3
Copper nitrate. See chapter 77.

CuS
Copper sulfide. See chapter 77.

$CuSO_4$
Copper sulfate. See chapter 77.

$H_2O_4S_2 \cdot Zn$
Zinc hydrosulfide. See chapter 74.

H_3AsO_4
Arsenic acid. See chapter 75.

Hg
Mercury. See chapter 73.

$Hg(CH_3COO)_2$
Mercuric acid. See chapter 73.

$HgCl_2$
Mercuric chloride. See chapter 73.

$Hg(CN)_2$
Mercuric cyanide. See chapter 73.

$Hg(CNO)_2$

Mercury fulminate. See chapter 73

$Hg(NO_3)_2$
Mercuric nitrate. See chapter 73.

HgO
Mercuric oxide. See chapter 73.

$Hg(SCN)_2$
Mecuric thiocyanate. See chapter 73.

$HgSO_4$
Mercuric sulfate. See chapter 73.

$Hg_2(NO_3)_2$
Mercurous nitrate. See chapter 73.

$KH_2H_2AsO_4$
Potassium arsenate. See chapter 75.

K_2CrO_4
Potassium chromate. See chapter 72.

Li_2CrO_4
Lithium chromate. See chapter 72.

$NaAsO_2$
Sodium arsenite. See chapter 75.

Na_2HAs0_4
Sodium arsenate. See chapter 75.

$(NH_4)_2CrO_7$
Ammonium chromate. See chapter 72.

$(NH_4)_2CrO_7$
Ammonium dichromate. See chapter 72.

Ni
Nickel. See chapter 76.

$NiCl_2 \cdot 6H_2O$
Nickel chloride. See chapter 76.

$Ni(CN)_2 \cdot 4H_2O$
Nickel cyanide. See chapter 76.

$Ni(CO)_4$
Nickel carbonyl. See chapter 76.

$Ni(NO_3)_2$
Nickel nitrate. See chapter 76.

NiO
Nickel oxide. See chapter 76.

$Ni(OH)_2$
Nickel hydroxide. See chapter 76.

$NiSO_4(NH_4) \cdot 6H_2O$
Nickel ammonium sulfate. See chapter 76.

$SrCrO_4$
Strontium chromate. See chapter 72.

Zn
Zinc. See chapter 74.

$ZnBr_2$
Zinc bromide. Seec hapter 74.

$ZnCl_2$
Zinc chloride. See chapter 74.

$ZnCO_3$
Zinc carbonate. See chapter 74.

$ZnCrH_2O_4$
Zinc chromate. See chapter 72.

ZnF_6S
Zinc silicofluoride. See chapter 74.

$ZnFl_2$
Zinc fluoride. See chapter 74.

$Zn(NO_3)_2$
Zinc nitrate. See chapter 74.

ZnO
Zinc oxide. See chapter 74.

ZnS
zinc sulfide. See chapter 74.

$ZnSO_4$
Zinc sulfate. See chapter 74.

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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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