ENVIRONMENTAL CONTAMINANTS ENCYCLOPEDIA

LEAD ENTRY

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Like a library or many large databases (such as EPA's national STORET water quality database), this document contains information of variable quality from very diverse sources. In compiling this document, mistakes were found in peer reviewed journal articles, as well as in databases with relatively elaborate quality control mechanisms [366,649,940]. A few of these were caught and marked with a "[sic]" notation, but undoubtedly others slipped through. The [sic] notation was inserted by the editors to indicate information or spelling that seemed wrong or misleading, but which was nevertheless cited verbatim rather than arbitrarily changing what the author said.

Most likely additional transcription errors and typos have been added in some of our efforts. Furthermore, with such complex subject matter, it is not always easy to determine what is correct and what is incorrect, especially with the "experts" often disagreeing. It is not uncommon in scientific research for two different researchers to come up with different results which lead them to different conclusions. In compiling the Encyclopedia, the editors did not try to resolve such conflicts, but rather simply reported it all.

It should be kept in mind that data comparability is a major problem in environmental toxicology since laboratory and field methods are constantly changing and since there are so many different "standard methods" published by EPA, other federal agencies, state agencies, and various private groups. What some laboratory and field investigators actually do for standard operating practice is often a unique combination of various standard protocols and impromptu "improvements." In fact, the interagency task force on water methods concluded that [1014]:

> It is the exception rather than the rule that water-quality monitoring data from different programs or time periods can be compared on a scientifically sound basis, and that...
>
> No nationally accepted standard definitions exist for water quality parameters. The different organizations may collect data using identical or standard methods, but identify them by different names, or use the same names for data collected by different methods [1014].

Differences in field and laboratory methods are also major issues related to (the lack of) data comparability from media other than water: soil, sediments, tissues, and air.

In spite of numerous problems and complexities, knowledge is often power in decisions related to chemical contamination. It is therefore often helpful to be aware of a broad universe of conflicting results or conflicting expert opinions rather than having a portion of this information arbitrarily censored by someone else. Frequently one wants to know of the existence of information, even if one later decides not to use it for a particular application. Many would like to see a high percentage of the information available and decide for themselves what to throw out, partly because they don't want to seem uniformed or be caught by surprise by potentially important information. They are in a better position if they can say: "I knew about that data, assessed it based on the following quality assurance criteria, and decided not to use it for this application." This is especially true for users near the end of long decision processes, such as hazardous site cleanups, lengthy ecological risk assessments, or complex natural resource damage assessments.

For some categories, the editors found no information and inserted the phrase "no information found." This does not necessarily mean that no information exists; it simply means that during our efforts, the editors found none. For many topics, there is probably information "out there" that is not in the Encyclopedia. The more time that passes without encyclopedia updates (none are planned at the moment), the more true this statement will become. Still, the Encyclopedia is unique in that it contains broad ecotoxicology information from more sources than many other reference documents. No updates of this document are currently planned. However, it is hoped that most of the information in the encyclopedia will be useful for some time to come even without updates, just as one can still find information in the 1972 EPA Blue Book [12] that does not seem well summarized anywhere else.

Although the editors of this document have done their best in the limited time available to insure accuracy of quotes or summaries as being "what the original author said," the proposed interagency funding of a bigger project with more elaborate peer review and quality control steps never materialized.

> The bottom line: The editors hope users find this document useful, but don't expect or depend on perfection herein. Neither the U.S. Government nor the National Park Service make any claims that this document is free of mistakes.

The following is one chemical topic entry (one file among 118). Before utilizing this entry, the reader is strongly encouraged to read the README file (in this subdirectory) for an introduction, an explanation of how to use this document in general, an explanation of how to search for power key section headings, an explanation of the organization of each entry, an information quality discussion, a discussion of copyright issues, and a listing of other entries (other topics) covered.

See the separate file entitled REFERENC for the identity of numbered references in brackets.

HOW TO CITE THIS DOCUMENT: As mentioned above, for critical applications it is better to obtain and cite the original publication after first verifying various data quality assurance concerns. For more routine applications, this document may be cited as:

> **Irwin, R.J., M. VanMouwerik, L. Stevens, M.D. Seese**, and **W. Basham.** 1997. Environmental Contaminants Encyclopedia. National Park Service, Water Resources Division, Fort Collins, Colorado. Distributed within the Federal Government as an Electronic Document (Projected public availability

on the internet or NTIS: 1998).

Lead (Pb, Lead metal, Plumbum, CAS number 7439-92-1)

Brief Introduction:

Br.Class: General Introduction and Classification Information:

Lead is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. It has no characteristic taste or smell. Metallic lead does not dissolve (much) in water and does not burn. Some natural and man-made substances contain lead, but do not look like lead in its metallic form. Some of these substances can burn [945].

Some chemicals containing lead, such as tetraethyl lead and tetramethyl lead, are used as gasoline additives. However, the use of these lead-containing chemicals in gasoline is much less than it used to be because the last producer of these additives in the United States stopped making them in early 1991 [945].

Lead behaves like many of the alkaline earth metals (Ca, Sr, and Ba) with respect to uptake, internal distribution, and secretion [488]. Lead is a bone seeking element so chemically similar to calcium that the two are processed together [488]. In fish, lead deposits in active calcification areas such as scales, fin rays, vertebrae, and opercula [488].

Lead is listed by the Environmental Protection Agency as one of 129 priority pollutants [58,446]. Lead is also listed among the 25 hazardous substances thought to pose the most significant potential threat to human health at priority superfund sites [93].

Br.Haz: General Hazard/Toxicity Summary:

Potential Hazards to Fish, Wildlife, and other Non-Human biota:

All measured effects of lead on living organisms are adverse, including those related to survival, growth, learning, reproduction, development, behavior, and metabolism [66]. Lead has no known essential biological function [383], and all lead compounds are potentially harmful or toxic, especially tetraethyl lead [83]. Lead functions as a cumulative poison [83].

Lead is a heavy metal which is very toxic to aquatic organisms, especially fish [57]. Like arsenic, lead exposure can lead to excess mucous formation [57] which can coat the gills and impact respiration.

In vertebrates, sublethal lead poisoning is characterized by neurological problems (including blockage of acetylcholine release), kidney disfunction, enzyme inhibition, and anemia [180].

In calves, solid lead is not as toxic as the more soluble salts, which are more readily absorbed. (Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1005) [940].

Animal studies indicate that relatively high levels of lead exposure interfere with resistance to infectious disease. (Gainer JH; Environ Health Perspect Exp 7: 113-9 (1974) as cited in USEPA; Ambient Water Quality Criteria Doc: Lead p.C-71, 1980, EPA 440/5-80-057) [940].

Although hardness is factored into water quality criteria equations (see W.General section below), for many metals, alkalinity is sometimes a more important co-factor for toxicity than hardness (Pat Davies, Colorado Division of Wildlife, personal communication, 1997). Some recent research has focused on the tendency of low-alkalinity (less than 50 ueq/L) waters to have a relatively high potential for acid deposition effects and increased bioaccumulation of lead in fish [383]. More research needs to be done on the toxicity, mobilization, and bioavailability of lead in low alkalinity and or/low pH waters [383].

It is doubtful whether the term "toxic dose" has any real meaning when it is applied to a substance such as/elemental lead in its ionic form, as it is affected by so many different factors. Among these are environment, nutrition, disease & age, the last of these being considerably more important, as young animals are considerably more sensitive than old ones. There is also a seasonal variation. Over half the cases of lead poisoning in cattle in Scotland occur in the spring. Similar effects have been noted for dogs. Even more important is the fact that lead is both cumulative & ubiquitous. All living creatures are continually absorbing it, & the "toxic" dose is only the amount necessary to bridge the gap between this normal intake & a potentially dangerous level. Three or four lead shots will kill a duck, 10 a goose. (Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall,

1981. 56) [940].

Lead shot poisoning of waterfowl has been widely publicized but can also occur in bald eagles and other species of fish and wildlife [29].

Elevated concentrations of lead in water are particularly toxic to many species of algae [180]. Synergistic effects of lead and cadmium and additive effects of lead, mercury, copper, zinc, and cadmium have been documented for aquatic biota [29]. The many negative effects of lead on physiology and heme formation [66] increase lead's potential for synergistic or additive effects with other contaminants and with low oxygen stress.

Populations of organisms chronically exposed to chemical pollutants may develop increased tolerance to those pollutants [177,493]. Some of the aquatic issues related to tolerance, interactions with other metals, and/or indirect impacts related to lead were summarized by Rand and Petrocelli [177]. Even metals such as lead, which do not directly induce synthesis of metallothionein, may indirectly induce it by increasing the hepatic zinc pool [177].

Potential Hazards to Humans:

Lead poisoning is particularly dangerous in young children (who may ingest lead by eating lead-containing chips of paint); it may result in anorexia and--in severe cases--permanent brain damage [335].

SYMPTOMATOLOGY: A. Acute poisoning by ingestion only. 1) An astringent and metallic taste in the mouth, dry throat, thirst. 2) Burning abdominal pain, nausea, and vomiting. The vomitus may appear milky due to the presence of lead chloride. The abdominal pain may become colicky and severe. 3) Sometimes diarrhea, less often constipation. The stools may be bloody, or black due to the presence of lead sulfide. 4) Peripheral circulatory collapse. 5) Neuromuscular symptoms include muscular weakness, pain, and cramps, especially in the legs. 6) Central nervous system manifestations include headache, insomnia, paresthesias, depression, coma, and death. 7) Though usually of secondary concern, kidney damage may result in oliguria, albuminuria, and cylindruria. The renal lesion may be due to the mildly nephrotoxic action of lead, to disturbances in kidney circulation, or to the products of intravascular hemolysis. Renal lesions may assume increased importance if edetate calcium disodium therapy is instituted. 8) An acute hemolytic crisis sometimes develops and results in anemia and hemoglobinuria. 9) Death may occur within 1 or 2 days, but recovery is the rule. Convalescence is slow and may be interrupted by episodes like those seen in typical chronic poisoning. (Gosselin, R.E., R.P. Smith, H.C. Hodge. Clinical Toxicology of Commercial Products. 5th ed. Baltimore: Williams and Wilkins, 1984.,p. III-232) [940].

SYMPTOMATOLOGY: B. Lead encephalopathy in chronic lead poisoning. 1) Headache and insomnia. 2) Persistent vomiting, which is sometimes projectile. A typical lead colic may or may not be present. 3) Visual disturbances, choked optic disks. 4) Irritability, restlessness, delirium, hallucinations. 5) Convulsions and coma. 6) The intracranial pressure is characteristically high. The cerebrospinal fluid is generally unremarkable except for and elevation of total protein. 7) Death from exhaustion and respiratory failure. The mortality rate is high; Recovery is slow and frequently incomplete. (Gosselin, R.E., R.P. Smith, H.C. Hodge. Clinical Toxicology of Commercial Products. 5th ed. Baltimore: Williams and Wilkins, 1984.,p. III-233) [940].

Although per day children ingest less lead (Pb) in their diets and inhale less Pb than do adults, on a dose per body weight basis children may have 2-3 times the exposure. Furthermore children because of their poor oral hygiene are more likely than adults to absorb Pb from extraneous sources: ingestion of foreign objects, dust, paint chips, inhalation of resuspended settled dusts (USEPA; Ambient Water Quality Criteria Doc: Lead p.C1-9, 1984, EPA 440/5-84-027) [940].

Children with pica for paint chips or for soil may experience an elevation in blood lead ranging from marginal to sufficiently high levels to cause clinical illness. Women in workplace are more likely to experience adverse effects from lead exposure than men due to the fact that their hematopoietic system is more lead sensitive than men's. (Sittig, M. Handbook of Toxic and Hazardous Chemicals and Carcinogens, 1985. 2nd ed. Park Ridge, NJ: Noyes Data Corporation, 1985. 543) [940].

Man absorbs lead in small amounts, which normally does not cause poisoning, from food, water, and air. (NIOSH; Criteria Document: Inorganic Lead p.III-3, 1978, DHEW Pub. NIOSH 78-158) [940].

Lead is associated with the following effects [940]:

1) contraction of the peripheral vascular system and impacts on blood and blood forming tissues (bone marrow).

2) inhibition of heme formation at several points, thereby altering the urinary or blood concn of enzymes and intermediates in heme synthesis or their derivatives.

3) toxic effects of inorganic lead attributed to the affinity of lead for thiol groups and other organic ligands in proteins. Low concentrations of lead ion (Pb(2+)) inhibit a select group of enzymes, including thiol-dependent enzymes involved in heme synthesis and mitochondrial energetics. The toxicologic effects of lead may result from the ability of Pb (2+) to uncouple oxidative phosphorylation and modify mitochondrial ion transport (especially for calcium ion).

4) at low concentrations of lead ion (Pb(2+)) inhibition of a select group of enzymes, including thiol-dependent enzymes involved in heme synthesis and mitochondrial energetics. The toxicologic effects of lead may result from the ability of Pb(2+) to uncouple oxidative phosphorylation and modify mitochondrial ion transport.

5) interference with synaptic transmission in the peripheral nervous system.

6) decreased glucose-6-phosphate dehydrogenase activity in humans and thus decreased the glutathione level in red blood cells.

7) inhibition of the catabolism of valine and isoleucine which are metabolized via succinyl-CoA to form delta-aminolevulinic acid. This is particularly important in the synthesis of heme for intracellular cytochrome synthesis. /Lead cmpd/ [Cavender FL; Biochem Med 5: 515-21 (1971) [940].

8) When the blood lead concentration is near 80 ug/dl or greater, basophilic stippling (the aggregation of ribonucleic acid) occurs in

erythrocytes.

9) The following signs and & symptoms of chronic lead poisoning (plumbism) related to gastrointestinal, neuromuscular, CNS, hematological, renal, & other effects, occurring separately or in combination:

> Note: The neuromuscular & CNS syndromes usually result from intense exposure, while the abdominal syndrome is a more common manifestation of a very slowly & insidiously developing intoxication. In the United States, the CNS syndrome is usually more common among children, while the GI syndrome is more prevalent in adults (Gilman, A.G., L.S.Goodman, and A. Gilman. (eds.). Goodman and Gilman's The Pharmacological Basis of Therapeutics. 7th ed. New York: Macmillan Publishing Co., Inc., 1985. 1607) [940].

The 1986 Safe Drinking Water Act (SDWA) amendments prohibit certain uses of lead materials: The Amendments forbid the use of pipe, solder, or flux that is not lead free in the installation or repair of any public water system or in any plumbing system providing water for human consumption. This does not, however, apply to leaded joints necessary for the repair of cast iron pipes. The term "lead free" means that solders and fluxes must contain not more than 0.2% lead, and pipes and fittings not more than 8% lead. Public notice is required where there is lead content in the construction materials of the public water supply and/or where the water is sufficiently corrosive to cause leaching of lead. (J.C. Thompson, Handout Personal Communication provided by Camp Dresser and McKee Inc.).

A comprehensive toxicological profile for lead and its compounds, especially as it relates to human health, is available from ATSDR [945]. Due to a lack of time, important highlights from the ATSDR document have not yet been completely incorporated into this entry. Lead issues related to fish were summarized by Sorensen in 1991 [488]. Pain provided a 1995 summary of biological effects of lead [837] (the highlights have not yet been summarized herein).

Br.Car: Brief Summary of Carcinogenicity/Cancer Information:

Lead is listed by EPA as a class B2 carcinogen, sufficient evidence to be classed as an animal carcinogen. Some salts of this element are carcinogenic [168].

EPA 1996 IRIS Database information for inorganic lead [893]:

> Human carcinogenicity weight-of-evidence classification: Classification: B2; probable human carcinogen.
>
> > BASIS: Sufficient animal evidence. Ten rat bioassays and one mouse assay have shown statistically significant increases in renal tumors with dietary and subcutaneous exposure to several soluble lead salts. Animal assays provide reproducible results in several laboratories, in multiple rat strains with some evidence of multiple tumor sites. Short term studies show that lead affects gene expression. Human evidence is inadequate.
> >
> > HUMAN CARCINOGENICITY DATA: Inadequate.
>
> ANIMAL CARCINOGENICITY DATA: Sufficient. The carcinogenic potential of lead salts, primarily phosphates and acetates, administered by the oral route, diet or by injection has been demonstrated in rats and mice by more than 10 investigators. The most characteristic cancer response is bilateral renal carcinoma [893].

Br.Dev: Brief Summary of Developmental, Reproductive, Endocrine, and Genotoxicity Information:

Adverse effects of lead on living organisms include those negatively affecting reproduction and development [66]. Effects of sublethal concentrations of lead include delayed embryonic development, suppressed reproduction, inhibition of growth, and fin erosion [57].

Evidence from human studies that included anomalies as an end point indicate no existence of an association between prenatal exposure to low levels of lead and the occurrence of major congenital anomalies. This conclusion is further supported by developmental toxicity studies conducted in rats and mice; these studies provide no evidence that lead compounds (acetate or nitrate) are teratogenic when exposure is by natural routes [945].

Eleven pregnant squirrel monkeys were perorally exposed to lead during the latter two-thirds of pregnancy at a dosing regime producing no maternal toxic symptoms. Lesions similar to lead encephalopathy and growth retardation of the fetal cerebrum were seen in some of the offspring, as well as neurological and behavioral symptoms at adult age [366]. For details, see Tis.Wildlife section below.

In birds, lead has also been implicated in decreases in eggshell thickness, growth, ovulation, and sperm formation [57].

Birds (fowls, ducks, geese & pigeons) are all susceptible to lead poisoning. They show anorexia & ataxia, followed by excitement & loss of condition. Egg production, fertility, & hatchability decrease; & mortality may be high. (Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall, 1981. 57) [940].

Chronic lead poisoning in sheep caused abortion, miscarriage & transitory sterility (IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V23 368, 1980, [366]. For details, see Tis.Wildlife section below.

There is sufficient qualitative evidence to support the conclusion that at high occupational exposure levels lead has significant adverse effects on human reproduction, including increased incidences of spontaneous abortion, miscarriages, and stillbirths [945].

The reproductive ability of men was shown to be adversely affected by moderate absorption of lead. Lead clearly has a direct toxic action on the male gonads at relatively low levels of absorption (Lancranjan I et al; Arch Environ Health 30: 396-401 (1975) as cited in NIOSH; Criteria Document: Inorganic Lead p.XI-52,1978, DHEW Pub. NIOSH 78-158) [940]. For details, see Tis.Human section below.

Exposure of a mother to lead results in the transfer of lead to the fetus and may cause preterm birth, reduced birth weight, and decreased intelligence quotient (IQ) in the infant. /Inorganic lead/ (DHHS/ATSDR; Toxicological Profile for Lead (Draft) p.3, 02/88) [940].

Results of studies with human lymphocyte cultures exposed in vitro to lead acetate were nearly equally divided between positive and negative [945]. In mammalian test systems in vitro (hamster cells), lead acetate gave conflicting results for structural chromosomal aberrations [945].

There was no significant excess of chromosome damage in cultured leukocytes obtained from 9 cows accidentally intoxicated with mixture of heavy metals & shown to have toxic levels of lead in liver & kidneys. (IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985., Multivolume work.,p. V23 376, 1980) [940].

For some history on environmental decision making vs. tetraethyl lead, see Tis.Misc. section below.

Br.Fate: Brief Summary of Key Bioconcentration, Fate, Transport, Persistence, Pathway, and Chemical/Physical Information:

The release of lead to air is now less than the release of lead to soil. Most of the lead in inner city soils comes from landfills and leaded paint. Landfills contain waste from lead ore mining, ammunition manufacturing, and from other industrial activities such as battery production. Very little lead goes directly into water [945].

Higher levels of lead from car exhausts can be measured near roadways. Very low levels of lead from car exhausts are found at distances of 25 meters (about 80 ft) from the road edge. However, once lead goes into the atmosphere, it may travel thousands of miles if the lead particles are small or if the lead compounds are volatile. Lead is removed from the air by rain as well as by particles falling to the ground or into surface water. Once lead deposits on soil, it usually sticks to soil particles. Small amounts of lead may enter rivers, lakes, and streams when soil particles are displaced by rainwater. Lead may remain stuck to soil particles in water for many years. Movement of lead from soil particles into underground water or drinking water is unlikely unless the water is acidic or "soft" [945].

Some of the chemicals that contain lead are broken down by sunlight, air, and water to other forms of lead. Lead compounds in water may combine with different chemicals depending on the acidity and temperature of the water. The lead atom cannot be broken down [945].

The levels of lead may build up in plants and animals from areas where air, water, or soil are contaminated with lead. If animals eat contaminated plants or animals, most of the lead that they eat will pass through their bodies. It is the small amount absorbed that can cause harmful effects [945].

Lead tends to bioaccumulate in mussels and clams [90,95]. Benthic fish may accumulate lead directly from the sediments [95].

Due to man's activities, lead pollution has become global [488]. Previous statements that soluble lead precipitates in natural waters are not present in concentrations likely to be harmful to fish [12] may be somewhat over-simplified and misleading [488]. Although lead can sometimes be fairly tightly bound up in sediments, biomethylation does occur, and studies of fish from lead contaminated areas warn of lead toxicity and complicated interactions [488].

The principal route of human exposure is food, but it is usually environmental & presumably controllable sources that produce excess exposure. These sources include lead in air from combustion of lead-containing auto exhausts or industrial emissions, lead-based paint, hand-to-mouth activities of young children living in polluted environments, &, less commonly, lead dust brought home by industrial workers on their clothes & shoes, & lead-glazed earthen ware. (Doull, J., C.D.Klassen, and M.D. Amdur (eds.). Casarett and Doull's Toxicology. 3rd ed., New York: Macmillan Co., Inc., 1986. 598) [940].

Lead is dissolved out of lead water supply pipes to enter the diet through the drinking water. The disposal of metallic lead & demolition debris in landfills therefore poses a potential hazard if the leachate is allowed to pass into ground water feeding a water supply system. /Inorganic lead/ (Sax, N.I. Dangerous Properties of Industrial Materials. 5th ed. New York: Van Nostrand Rheinhold, 1979. 221) [940].

Environmental Fate/Exposure Summary [940]:

> Lead is the fifth most important metal commercially in the United States and it may enter the environment during its mining, ore processing, smelting, refining use, recycling or disposal. Generally the initial means of entry is via the atmosphere. Lead may also enter the atmosphere from the weathering of soil and volcanos, but these sources are minor compared with anthropogenic ones. Generally the form of lead that enters the atmosphere is not determined. However metallic lead may be released from smelting and refining plants. If released or deposited on soil, lead will be retained in the upper 2-5 cm of soil, especially soils with at least 5% organic matter or a pH 5 or above. Leaching is not important under normal conditions although there is some evidence to suggest that Pb is taken up by some plants.

Generally, the uptake of Pb from soil into plants is not significant. It is expected to slowly undergo speciation to the more insoluble sulfate, sulfide, oxide, and phosphate salts].

Lead enters water from atmospheric fallout, runoff or wastewater; little is transferred from natural ores. Lead is a stable metal and adherent films of protective insoluble salts form that protect the metal from further corrosion. That which dissolves tends to form ligands. Lead is effectively removed from the water column to the sediment by adsorption to organic matter and clay minerals, precipitation as insoluble salt (the carbonate or sulfate, sulfide), and reaction with hydrous iron and manganese oxide. Under most circumstances, adsorption predominates].

Lead does not appear to bioconcentrate significantly in fish but does in some shellfish such as mussels. When released to the atmosphere, lead will generally be in dust or adsorbed to particulate matter and subject to gravitational settling and be transformed to the oxide and carbonate. General lead exposure occurs from ambient air especially in areas with high automotive traffic and sites near industrial sources. However, the highest intake is from food and water. Concentrations in food may be elevated due to surface contamination of fresh fruits and vegetables. Food in soldered-tin cans may contain particularly high levels of lead. Elevated levels of lead in drinking water usually result from distribution systems containing lead pipe].

Synonyms/Substance Identification:

Lead metal [940,945]
Plumbum [940,945]
Olow (Polish) [940,945]
Pigment metal [940,945]
CI pigment metal 4 [940]
CI 77575 [940]
KS-4 [940]
Lead flake [940]
Lead S2 [940]
Pb-S 100 [940]

Molecular formula [945]:
Pb

Associated Chemicals or Topics (Includes Transformation Products):

See also individual entries:

Gasoline, Leaded
Gasoline Additives

Water Data Interpretation, Concentrations and Toxicity (All Water Data Subsections Start with "W."):

W.Low (Water Concentrations Considered Low):

No information found.

W.High (Water Concentrations Considered High):

No information found.

W.Typical (Water Concentrations Considered Typical):

Typical Ocean Concentrations: EPA 1981: 0.00003 mg/l [83].

Typical Freshwater Concentrations:

EPA 1981: 0.005 mg/l [83].

Mean in U.S. (1988) surface waters, 50,000 U.S. sites: 3.9 ug/l [945].

Leland and Kuwabara, 1985: In non-polluted areas, baseline concentrations as low as 0.0002 mg/l have been recorded [177].

1971: 1.0 ug/L or more in most samples in the NE and SE U.S., 1.0 ug/L or more in about half the Midwest samples, and typically below 1.0 in most of the Western U.S. [190].

USGS 1974-1981: The 50th percentile of 292 (not especially clean) NASQWAN and NWQSS river sites in the U.S. was 4 ug/l; the 25th percentile was 3 ug/l, and the 75th percentile was 6 ug/l, with concentrations trending downward more often than upward [219]. These riverine sites in the USGS study were mostly in (or downstream of) agricultural and urban areas, and the increased use of unleaded gas is thought to be a factor in the downward trend [219].

Water Concentrations [940]:

DRINKING WATER: A survey of lead in Canadian drinking water 7.8% <1.0 ppb, 89% 1.0-29.9 ppb and 3.3% >30 ppb(1). Tap water from 969 U.S. water supplies - 1.4% >50 ppb with systems having soft water and pH <6.5 particularly high(2). In a comparison of finished and tap water in 2 U.S. cities in which the water was slightly acidic and chlorination was the only treatment, the majority of tap-water samples contained >50 ppb lead with a range of 13 to 1510 ppb and an average of 30 ppb; in all 383 households the lead concentration was higher at the tap than at the treatment plant showing that lead was picked up in the distribution system(3). Lead increases in water that remain in the distribution system overnight(4). In a Nova Scotia study the mean Pb concn in standing water was 43 ppb, a factor of 5 to 22 above that of running water(4). [(1) International Register of Potentially Toxic Chemical (IRPTC); United Nations Environment Program Geneva Switzerland p. 171-7 (1979) (2) USEPA; Ambient Water Quality Criteria for Lead; pp. B-1 to B-38, C-1 to C-5 USEPA-440/5-80-057 (1980) (3) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (4) Maessen O et al; J Amer Water Works Assoc 77: 73-80 (1985)].

SURFACE WATER: Background 0.5 ppb(1); estimate of global mean lead content of lakes and rivers 1-10 ppb(2); Canadian lakes 39-103 ppb, U.S. lakes 6-34 ppb(1). Particulate fraction of fresh water in USA northwest coast is 66 ppb(1). Lake Huron and Georgian Bay 0.022 ppb, median(3). Mean dissolved Pb concns at 5 sites in the Pb/Ag mining district of mid-Wales 0.008-0.58 ppm(4). In a 1970 study of dissolved lead in 726 rivers and lakes in the USA and Puerto Rico, 63% of the samples had levels in excess of the detection limit, 1 ppb, but only 3 samples exceeded 50 ppb(5). Positive samples were concentrated in the northeast and southeast sections of the country where the water composition is thought to be favorable for solution of lead(5). 9% of samples taken from the lower Mississippi River between 1978 to mid-1983 (435 samples) had Pb levels exceeding 50 ppb with 5 greater than 500 ppb and one exceeding 10000 ppb(1). High level occurred in acute episodes that appear to be associated with human Belle Chasse (river mile 75)(6). The fact that these high concentrations do not persist downstream suggests that mechanisms of dilution or immobilization are at work(6). [(1) International Register of Potentially Toxic Chemical (IRPTC); United Nations Environment Program Geneva Switzerland p. 171-7 (1979) (2) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (3) Dolan DM et al; Lake Huron 1980 Intensive Survey: Summary Report Windsor, Ont. (1986) (4) Jones KC et al; Water Air Soil Pollut

24: 329-38 (1985) (5) Hem JD, Durum WD; J Amer Water Works Assoc 65: 562-8 (1973) (6) Kahwa IA, Newchurch EJ; J Environ Sci Health 20: 395-417 (1985)].

SEAWATER: Coastal seawater 0.08-0.4 ppb, Central Atlantic water 0.05 ppb avg(2); Bering Sea 0.03-0.68 ppb(1). Seawater below 1000 m in the Pacific and Atlantic Oceans and Mediterranean Sea 0.03-0.04 ppb(2). The particulate fraction of seawater along the northwest coast of the U.S. 56 ppb(1). Seawater off Southern California 0.04 ppb(3). [(1) International Register of Potentially Toxic Chemical (IRPTC); United Nations Environment Program Geneva Switzerland p.171-7 (1979) (2) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (3) Morel FMM et al; Environ Sci Technol 9: 756-61 (1975)].

SNOW AND ICE: Antarctic snow before 1940 <0.001 ppb, recently 0.2 ppb(1). Glacial ice around 1870 from Norway and Poland 5.86 and 5.0 ppb avg respectively while today the mean levels are 9.88 and 148 ppb respectively (1). Pb in fresh snow particulate matter in Toronto was 140 ppb, mean while at four other sites in Ontario it ranged from 42-80 ppb(2). [(1) USEPA; Air Quality Criteria for Lead; pp.6-1 to 6-28 USEPA-600/8-77-017 (1977) (2) Brzezinska-Paudyn A et al; Water Air Soil Pollut 27: 45-56 (1986)].

RAIN: Palo Alto - freeway 0.181 ppb, residential 0.149 ppb, foothills 0.035 ppb(1). Mean levels of Pb in rural and remote precipitation reported in the literature are 3.0-15 ppb and <0.04-2.39 ppb, respectively(2). [(1) USEPA; Air Quality Criteria for Lead; pp.6-1 to 6-28 USEPA-600/8-77-017 (1977) (2) Barrie LA et al; Atmos Environ 21: 1133-5 (1987)].

A study was conducted on the distribution of manganese, iron, copper, lead, and zinc in the water and sediment of Kelang estuary in 1981. The mean total levels of manganese, iron, copper, lead, and zinc in the estuarine water were 27.1 ug/l, 106.5 g/l, 10.0 ug/l, 4.1 ug/l and 17.9 ug/l respectively. The results indicate that Kelang estuary is polluted with lead, manganese, and iron. However, levels of these heavy metals may still be considered safe for aquaculture, if the farm is located at least 10 km away from the river mouth. [Law AT, Singh A; Pertanika 9 (2): 209-18 (1986)].

W.Concern Levels, Water Quality Criteria, LC50 Values, Water Quality Standards, Screening Levels, Dose/Response Data, and Other Water Benchmarks:

W.General (General Water Quality Standards, Criteria, and Benchmarks Related to Protection of Aquatic Biota in General; Includes Water Concentrations Versus Mixed or General Aquatic Biota):

Notes on total vs. acid soluble vs. dissolved lead:

Although most of the lab tests done to develop water quality criteria and other benchmarks were originally based on "total" values rather than "dissolved" values, some regulatory authorities nevertheless recommend comparing criteria with dissolved or acid soluble lead concentrations. For detailed discussion, see the Laboratory and/or Field Analyses section (far below).

EPA National Ambient Water Quality Criteria for Aquatic Organisms (IRIS Database, 1996) [893]:

Freshwater Acute Criterion: 8.2E+1 ug/L

NOTE: 83 ug/L was the previously cited hardness dependent criterion rounded to two integers (100 mg/L CaCO3 used) [446,689]. This older citation was perhaps rounded incorrectly, since the actual value calculated on two different scientific calculators appeared to be 81.6, based on the equation: Acute = e to the power of (1.273[ln(hardness)]-1.460) [649]. Others rounded it to 82+ [649]. Further clarification:

e is the base of natural logarithms and numerically equals 2.72 (rounded), and In(hardness) equals the natural logarithm of the measured hardness (Gary Rosenlieb, National Park Service, Personal Communication, 1997).

Freshwater Chronic Criterion: 3.2E+0 ug/L [893].

Note: 3.2 is the hardness dependent criterion rounded to two integers (100 mg/L CaCO3 used) [446,889]. Note from Roy Irwin: This was rounded to 3.2, the actual calculated value is 3.18, based on the equation: Chronic = e to the power of (1.273[ln(hardness)]-4.705) [649]. Further clarification:

e is the base of natural logarithms and numerically equals 2.72 (rounded), and In(hardness) equals the natural logarithm of the measured hardness (Gary Rosenlieb, National Park Service, Personal Communication, 1997).

Marine Acute Criteria: 1.40E+2 ug/L [893].

Older criterion was the same, 140 ug/L [689].

Marine Chronic Criterion: 5.6E+0 ug/L [893].

Older criterion was the same, 5.6 ug/L [689].

Contact: Criteria and Standards Division / OWRS / (202)260-1315

Discussion: Criteria were derived from a minimum data base consisting of acute and chronic tests on a variety of species. The toxicity of this compound in freshwater is hardness dependent. The values given are for a hardness of 100 mg/L CaCO3. For a more complete discussion, see the referenced notice (50 FR 30784, 07/29/85).

Florida's water quality standard applied to some wetland sites was 30 ug/l [220].

California objective for protection of marine aquatic life: 2 ug/L 6 month median [945].

Colorado specified a hardness dependent equation as the acute general aquatic life water quality standard for lead in 1991; at a hardness of 100 mg/L, the standard is 95.85 ug/L [659].

NOTE: The above is a hardness-dependent criteria (100 mg/L CaCO3 was used to calculate the above concentration). For sites with different water hardness, site-specific criteria should be calculated with the following formula:

Acute = 0.5 e(1.6148[ln(hardness)]-

2.1805) where "e" = exponential [659].

Colorado specified a separate hardness dependent equation as the chronic water quality standard for general aquatic life for lead in 1991; at a hardness of 100 mg/L, the standard is 3.89 ug/L [659].

> NOTE: The above is a hardness-dependent criteria (100 mg/L CaCO3 was used to calculate the above concentration). For sites with different water hardness, site-specific criteria should be calculated with the following formula:
>
> > Chronic = e(1.417[ln(hardness)]-5.167) [659] where "e" = exponential [659].

Colorado specified an agricultural water quality standard of 100 ug/L lead in 1991 [659].

Oak Ridge National Lab, 1994: Ecological Risk Assessment Freshwater Screening Benchmarks for concentrations of contaminants in water [649]. To be considered unlikely to represent an ecological risk, field concentrations should be below all of the following benchmarks [649]:

CAS 7439-92-1, LEAD (ug/L):

NATIONAL AMBIENT WATER QUALITY CRITERION - ACUTE: 82

> NOTE: The above is a hardness-dependent criteria (100 mg/L CaCO3 was used to calculate the above concentration). For sites with different water hardness, site-specific criteria should be calculated with the following formula:
>
> Acute = e to the power of (1.273[ln(hardness)]-1.460) where "e" = exponential [649]. Note: Same as IRIS 1996 EPA equation given above [893]. Further clarification:
>
> > e is the base of natural logarithms and numerically equals 2.72 (rounded), and In(hardness) equals the natural logarithm of the measured hardness (Gary Rosenlieb,

National Park Service, Personal Communication, 1997).

NATIONAL AMBIENT WATER QUALITY CRITERION - CHRONIC: 3.2

NOTE: The above is a hardness dependent criterion (100 mg/L CaCO3 was used to calculate the above concentration). For sites with different water hardness, site-specific criteria should be calculated with the following formula:

Chronic = e to the power of (1.273[ln(hardness)]-4.705) where "e" = exponential [649]. Note: Same as IRIS 1996 EPA equation given above [893]. Further clarification:

e is the base of natural logarithms and numerically equals 2.72 (rounded), and In(hardness) equals the natural logarithm of the measured hardness (Gary Rosenlieb, National Park Service, Personal Communication, 1997).

SECONDARY ACUTE VALUE: No information found.

SECONDARY CHRONIC VALUE: No information found.

LOWEST CHRONIC VALUE - FISH: 18.88

LOWEST CHRONIC VALUE - DAPHNIDS: 12.26

LOWEST CHRONIC VALUE - NON-DAPHNID INVERTEBRATES: 25.46

LOWEST CHRONIC VALUE - AQUATIC PLANTS: 500

LOWEST TEST EC20 - FISH: 22

LOWEST TEST EC20 - DAPHNIDS: No information found.

SENSITIVE SPECIES TEST EC20: 0.35

POPULATION EC20: 71

W.Plants (Water Concentrations vs. Plants):

Shallow Groundwater Ecological Risk Assessment Screening Benchmark for Terrestrial Plants Listed by Oak Ridge National Lab, 1994 [651]:

To be considered unlikely to represent an ecological risk, field concentrations in shallow groundwater or porewater should be below the following benchmark for any aqueous solution in contact with terrestrial plants. Toxicity of groundwater to plants may be affected by many variables (pH, Eh, cation exchange capacity, moisture content, organic content of soil, clay content of soil, differing sensitivities of various plants, and various other factors). Thus, the following solution benchmark is a rough screening benchmark only, and site specific tests would be necessary to develop a more rigorous benchmark for various combinations of specific soils and plant species [651]:

For CAS 7439-92-1, LEAD, the benchmark is 0.02 mg/L (groundwater or porewater).

LC50 for Chlorella algae 0.50 mg/L [970].

W.Invertebrates (Water Concentrations vs. Invertebrates):

LC50 for Daphnia magna 0.45 mg/L [970].

LC50s for Artemia salina (brine shrimp) were 10.0 mg/L (ppm) for a 24-hr exposure, and 5.01 mg/L for a 48-hr exposure [998].

LC50 for Brachionus calyciflorus (rotifer) was >4.0 mg/L for a 24-hr exposure [998].

LC50 for Ceriodaphnia reticulata (water flea) was 0.53 mg/L for a 48-hr exposure [998].

LC50 for Daphnia pulex (water flea) was 5.1 mg/L for a 48-hr exposure [998].

LC50 for Dugesia tigrina (Turbellarian, flatworm) was 160 mg/L for a 96-hr exposure [998].

LC50s for Perna viridis (green mussel) were 6.2 mg/L for a 24-hr exposure, and 10.0 mg/L for a 48-hr exposure [998].

LC50 for Mysidopsis bahia (Opossum shrimp) was 3.13

mg/L for a 96-hr exposure [998].

W.Fish (Water Concentrations vs. Fish):

LC50s for various fish 1.17 mg/L (rainbow trout) to 4.61 mg/L (fathead minnow) [970].

LC50 for Channa striata (Snake-head catfish) was 58.4 mg/L (ppm) for a 72-hr exposure [998].

LC50s for Micropterus dolomieui (smallmouth bass) were 2.2, 2.8 and 29.0 mg/L for 96-hr exposures [998].

Levels of lead above the allowable drinking water standard of 50 ug/l (ppb) are toxic, or result in morphological changes in aquatic vertebrates. ... Embryo and fingerling stages of fish are more susceptible to lead poisoning than adults. Fish are more susceptible to poisoning in soft water than in hard water (USEPA; The Health and Environmental Impacts of Lead: p.152, 1979, EPA 560/2-79-001) [940].

W.Wildlife (Water Concentrations vs. Wildlife or Domestic Animals):

To protect Nevada livestock/wildife use, lead levels should be less than or equal to 0.1 mg/L [671].

To protect livestock/cattle use, lead levels should be less than 0.05 mg/L [671].

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Wildlife derived for No-Observed-Adverse-Effect (NOAEL) levels (see Tis.Wildlife, B) section below for these). To be considered unlikely to represent an ecological risk, water concentrations should be below the following benchmarks for each species present at the site [650]:

CAS 7439-92-1, LEAD (AS LEAD ACETATE)

SPECIES	WATER CONCENTRATION (ppm)
Rat (test species)	0.00000
Short-tailed Shrew	102.82500
Little Brown Bat	177.72300
White-footed Mouse	66.45300
Meadow Vole	116.30400
Cottontail Rabbit	55.11000

Mink	57.14700
Red Fox	40.78500
Whitetail Deer	22.82000

Comment: Actually, the number of significant figures for a benchmark value should never be more than one; even if these values have been taken directly from another report, they should be rounded; otherwise the impression is given of a level of accuracy that is simply unwarranted. The uncertainties are too large to justify such a fine distinction (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

W.Human (Drinking Water and Other Human Concern Levels):

Notes on total vs. acid soluble vs. dissolved lead:

Although most of the lab tests done to develop water quality criteria and other benchmarks were originally based on "total" values rather than "dissolved" values, some regulatory authorities nevertheless recommend comparing criteria with dissolved or acid soluble lead concentrations. For detailed discussion, see the Laboratory and/or Field Analyses section (far below).

EPA 1995 Region IX Preliminary Remediation Goal (PRG) for lead in tap water: 4.0 ug/L [868].

Information from EPA 1996, IRIS database [893]:

Ambient Water Quality Criteria for Human Health for Water & Fish (routes of exposure): 5.0E+1 ug/liter [893].

Older Human Health Risk Level for Carcinogens (risk of one additional case in 1 million, 1E-06):

Published Criteria for Water and Organisms was the same: 50 ug/L [689].

IRIS Recalculated (9/90) Criteria for Water and Organisms: None Published [689].

Published Criteria for Organisms Only: None Given [689,893].

Older IRIS Recalculated (9/90) Criteria for Organisms Only: None Published [689].

NOTE: In critical applications, before citing a concentration as EPA's water quality criteria, it is prudent to make sure you have the latest one. Work on the replacement for the Gold Book [302] was underway in March of 1996, and IRIS database is updated monthly.

Maximum Contaminant Level Goal [893]:

Value: 0 mg/L Status/Year: Final 1991 Econ/Tech?: No, does not consider economic or technical feasibility Reference: 56 FR 26460 (06/07/91); 56 FR 32112 (07/15/91) [893].

Contact: Health and Ecological Criteria Division / (202)260-7571 Safe Drinking Water Hotline / (800)426-4791 [893].

Discussion: The MCLG for lead is zero based on (1) occurrence of low level effects and difficulties in identifying clear threshold levels, (2) the overall Agency goal of reducing total lead exposures, and (3) the classification of lead as a group B2 carcinogen [893].

Maximum Contaminant Level (MCL) [893]:

Value: none given. Status/Year: Final 1991 Econ/Tech?: Yes, does consider economic or technical feasibility Reference: 45 FR 57332 (08/27/80); 53 FR 31517 (08/18/88); 56 FR 26460 (06/07/91); 56 FR 32112 (07/15/91) [893].

Contact: Drinking Water Standards Division / OGWDW / (202)260-7575 Safe Drinking Water Hotline / (800)426-4791 [893].

Discussion: EPA concluded that setting an MCL for lead is not feasible and believes that the treatment approach contained in the final rule (corrosion control, source water reduction, public education and lead service line replacement) will achieve the public health goals of the SDWA without the problems associated with establishing MCL's [893].

> Earlier Drinking Water MCL: Proposed Criterion 5.0 ug/L (Criteria Federal Register Notice Number: 50 FR 30791) [446].

EPA reference dose for chronic oral exposure (RfD) IRIS 1996 Note from EPA [893]:

> A great deal of information on the health effects of lead has been obtained through decades of medical observation and scientific research. This information has been assessed in the development of air and water quality criteria by the Agency's Office of Health and Environmental Assessment (OHEA) in support of regulatory decision-making by the Office of Air Quality Planning and Standards (OAQPS) and by the Office of Drinking Water (ODW). By comparison to most other environmental toxicants, the degree of uncertainty about the health effects of lead is quite low. It appears that some of these effects, particularly changes in the levels of certain blood enzymes and in aspects of children's neurobehavioral development, may occur at blood lead levels so low as to be essentially without a threshold [893].

Bureau of Land Management RMC Benchmarks, 1995: Risk Management Criteria (RMC) were developed for the mostly dry BLM lands in the western U.S. These risk management criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are needed [715]. Exceedances of the criteria should be interpreted as follows [715]:

Less than criteria: low risk
1-10 times the criteria: moderate risk
10-100 times the criteria: high risk
>100 times the criteria: extremely high risk

Human RMC criteria for lead in surface waters. These categories of humans not exposed to surface waters with concentrations of lead exceeding the below RMCs are not expected to experience adverse toxic effects [715]:

Camp host: 50 ug/L

Child Camper: 50 ug/L
Boater: 50 ug/L
Swimmer: 50 ug/L

Human RMC criteria for lead in ground water. These categories of humans not exposed to ground waters with concentrations of lead exceeding the below RMCs are not expected to experience adverse toxic effects [715]:

Child resident (living on properties adjacent to BLM lands): 15 ug/L
Camp host: 15 ug/L
Child Camper: 15 ug/L
Worker: 15 ug/L
Surveyor: 15 ug/L

In rural Scotland, four people developed clinical lead poisoning and others showed biochemical evidence of grossly elevated lead exposure. Lead concn in the domestic water supply was 2-3 mg/l. In this case the reason for the extreme contamination was that the water was stored in lead tanks. /Inorganic lead/ [Goldberg A; Environ Health Perspect Exp 7: 103-07 (1974) as cited in WHO; Environ Health Criteria: Lead p.49 (1977)] [940].

Older Federal Drinking Water Standard (1993) [940]:

> EPA has a drinking water action level of 15 ug/l (USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee, FSTRAC. Summary of State and Federal Drinking Water Standards and Guidelines, 11/93).
>
> Note from USGS on 1993 action level of 15 ug/L:
>
>> Reference: The Branch of Technical Development and Quality Systems (BTD&QS) of the USGS released a Quality Assurance Summary report in September of 1995 for NWQL data which indicated that lead by Inductively Coupled Plasma (ICP) has been displaying extreme variability. A recommendation was made to use alternate methods for lead such as graphite furnace (GFAA) and ICP-mass spectrometry (ICP-MS). Alternate methods should especially be considered for studies assessing concentrations of lead below the

action level set by EPA for drinking water, 15 micrograms per liter. The relative standard deviation (RSD) data for lead ICP standard ICP) quality control samples has historically not supported a 10 microgram per liter Method Reporting Limit (MRL) for lead (Alert issued by Thomas J Maloney, Supervisory Hydrologist, Denver, CO).

Some state drinking water standards are quite low, for example [945]:

Iowa:	0.05 ug/L (sic, possibly a typo since some other states use 0.05 mg/L)
Wisconsin	5 ug/L preventative action limit

Colorado specified a drinking water quality standard of 50 ug/L lead in 1991 [659].

Other State Drinking Water Standards [940]:

(AL) ALABAMA 20 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

(AZ) ARIZONA 50 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93) Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

State Drinking Water Guidelines [940]:

(AZ) ARIZONA 20 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

(ME) MAINE 20 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

(MN) MINNESOTA 20 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

W.Misc. (Other Non-concentration Water Information):

A potential complication in comparing contaminants data is that different investigators have sometimes meant different things when they put the words "dissolved" or "total" in front of a reported measurement. In the case of nutrients, the "dissolved" portion is usually simply that portion which has passed through a 0.45-micrometer membrane filter and the "total" measurements implies that it was not filtered and includes both dissolved and other forms of the nutrient [141]. However, usage of the words dissolved and total has not been uniform in the past and there is still considerable debate about which methods should truly be considered "dissolved" or "total" (Merle Schlockey, USGS, personal communication).

Water bodies are often marked by heterogeneity of the distribution of undissolved materials [691]. The size of any effects depends on the difference in density of the undissolved materials and the water, the size of the particles or bubbles of the materials, and various hydrodynamic factors such as the degree of turbulence in the water. Thus, undissolved inorganic materials in rivers and other natural water-bodies tend to increase in concentration with increasing depth because the particles tend to settle [691]. On the other hand, certain biological detritus may tend to rise towards the surface of the water because its density is less than that of water; oils also commonly demonstrate this effect markedly [691]. The surface microlayer is usually higher in concentration of many metallic and organic contaminants than the water column further down.

If the only change one makes is to use the prefix "dissolved" rather than the prefix "total" in an otherwise identical water quality standard, the effect can be a weakening of the standard related to total loading of a system. Many contaminants which are not currently dissolved can become dissolved at a later time, when encountering different conditions (perhaps downstream), such as changes in pH, additions of surfactants or humic substances, bioturbation, methylating organisms, and various other physical, chemical, or biological changes.

One problem with relying too heavily on dissolved fractions of metals is that the dissolved fraction misses the metals carried by colloids. Colloids were found to carry toxic metals 140 miles downstream of mining sources in Leadville, Colorado, to be repeatedly washed from flood deposited lowlands back into the river year after year in spring runoff (Briant Kimball, USGS Salt Lake City, as quoted in U.S. Water News, April 5th, 1995).

See Laboratory section below for EPA generic (guesstimate) conversion factors to convert total to dissolved concentrations.

Some environmental toxicologists make the argument that dissolved metals in surface water and porewaters represent most of what is bioavailable and thus "total" metals parameters are not good as a measure of potential biological effects. This is mostly true in many situations, but it should be kept in mind that fish and other aquatic organisms do not typically live in filtered water and that many fish and other aquatic organisms live in the sediments and in other situations in which they come in contact with toxic or otherwise harmful compounds (as certain colloids, precipitates, oxides, adsorbed metals), etc. Sometimes the effect of total metals is partially related to physical or chemical aspects, such as when ferric oxide coats or covers benthic organisms. Another factor to consider: contaminants carried downstream by erosion of bottom sediments or colloids can be mobilized when they come in contact with different physical/chemical environments downstream (for example, a tributary bringing low pH into the system).

> Misc. Notes on colloids (Briant Kimball, USGS, Salt Lake City Office, Personal Communication, 1995):
>
> > There is no question that dissolved metals are critical to fish and invertebrates, but less well recognized is the potential impact and movement of metals in colloids. The possibility of having colloidal material present means there is a readily available supply of metals in a state in which the metals can quickly be reduced and mobilized. In

river banks, reducing environments form just under the surface quickly. Toxic metals of concern would include zinc, lead, copper, and cadmium.

Colloids do move in surface water (for example, transport of metal in colloids 140 miles downstream of Leadville, CO), but also in groundwater, especially related to radionuclides.

Colloidal metals may effect biota more than is widely recognized. Brown trout are effected by colloids which travel kind of like dissolved fractions, don't settle out. There may be little understood colloidal pathways of metals to fish, for example. Colloidal metals become part of the caddis cast which are ingested, once part of acid gut, metals can be released. On the Arkansas River of Colorado below Leadville, the dissolved metals have gone down with treatment, but Will Clements of CSU has discovered the toxicity has not been reduced to the same extent as have the dissolved metals. Treatment has not eliminated colloidal fractions loaded with cadmium and copper, and this is possibly impacting the fish.

In rivers, there is annual flushing of the colloids, loads are much greater during runoff.

Sediment Data Interpretation, Concentrations and Toxicity (All Sediment Data Subsections Start with "Sed."):

Sed.Low (Sediment Concentrations Considered Low):

No information found.

Sed.High (Sediment Concentrations Considered High):

NOAA National Status and Trends Program (1984-1990) [698]: High concentration for lead in fine-grained sediment (n=233) = 89 ug/g dry weight at 4.6% TOC dry weight. The above concentration was adjusted for sediment grain-size in the following way: the raw concentrations were divided by the fraction of particles less than or equal to 64 um. "High" NOAA concentrations are equal to the geometric mean plus one standard deviation on the log normal distribution [696].

NOTE: Fine-grained sediment would typically contain more lead than course-grained sediment, and sediments higher in total organic carbon (TOC) would typically have more lead than sediments which are similar except for being lower in TOC, which is why NOAA and many others are now normalizing sediment values for grain size, and reporting TOC.

Texas: The statewide 90th percentile value was 63 mg/kg dry weight [7]. Sediment concentrations of lead from certain Trinity River sites below Dallas exceeded statewide 90th percentiles in at least 50% of the historical records from 1974 to 1985 [7]. These highly elevated levels were still present at one site as late as October of 1985 [91].

Great Lakes Harbors, EPA 1977: Sediments having concentrations higher than 60 mg/kg dry weight were classified as "heavily polluted [145,347]."

Illinois EPA, 1984: Sediments having concentrations higher than 38.0 mg/kg dry weight were classified as "elevated" [145].

Leland and Kuwabara, 1985: In polluted areas, concentrations as high as 20,000 mg/kg have been recorded [177].

Highway Runoff, 1989: Detention pond sediments receiving runoff from highways averaged 620 mg/kg dry weight of lead; the cypress wetlands the detention pond effluent was routed to, by contrast, had a median value of 20 mg/kg lead, indicating most was removed by the detention pond [220].

Analyses of sewage sludges from 50 publicly owned treatment works by the U.S. Environmental Protection Agency (1985): The mean concentration of lead was 378 ppm (dry weight) [347].

Analyses of 74 Missouri sewage sludges (1985): The median weight for lead was 145 ppm, the range was 42-960 ppm (dry weight) [347].

Sed.Typical (Sediment Concentrations Considered Typical):

Great Lakes Harbors, EPA 1977: Sediments having sediment concentrations lower than 40.0 mg/kg dry weight were classified as "non polluted [145]."

Average lead in river sediments (1982): 20,000 ug/g [945].

Average lead in coastal sediments (1982): 100,000 ug/g [945].

International Joint Commission, 1988: The International Joint Commission considered <27.5 mg/kg dry weight as a background sediment level [145]. The control site in one Great Lakes study had a sediment concentration of <32.4 mg/kg dry weight [145].

Leland and Kuwabara, 1985: In non-polluted areas, baseline concentrations as low as 3 mg/kg dry weight have been recorded [177].

NOAA National Status and Trends Program (1984-1990) [698]: Geometric mean for lead in fine-grained sediment (n=233) = 43 ug/g dry weight at 1.4% TOC dry weight. The above concentration was adjusted for sediment grain-size in the following way: the raw concentrations were divided by the fraction of particles less than or equal to 64 um.

> Note: Fine-grained sediment would typically contain more lead than course-grained sediment, and sediments higher in total organic carbon (TOC) would typically have more lead than sediments which are similar except for being lower in TOC, which is why NOAA and many others are now normalizing sediment values for grain size, and reporting TOC.

Typical Sediment/Soil Concentrations [940]:

> Big River (Old Lead Belt, MO) sediment and organic detritus contain 1400-2200 and 800-7000 ppm of lead, respectively(1). Soil samples collected 0.3 km from an industrial park containing a battery manufacturing plant and a Missouri ore processing plant contained elevated Pb levels 945 and 983 ppm, mean 0-5 cm depth, and 257 and 204, mean 5-15 cm depth, in 1982 and 1983, respectively(2). The extractable Pb levels were 117 and 1 ppm, mean 0-5 cm depth, and 36 ppm and not detected mean 5-15 cm depth in 1982 and 1983, respectively. The battery manufacturing plant closed after testing in 1982, suggesting that the extractable Pb in these soils reflected recent additions and that reversion to nonextractible forms were rapid. All other sites tested had essentially the same Pb levels, 47-106 ppm, and <1 ppm or non detectible amounts of extractable Pb in 1983. Soil and dust sampling downwind of battery manufacturing and secondary smelter/battery manufacturing plants in Houston indicate that the smelters, but not the battery manufacturing facilities result in significantly elevated Pb levels that correlated with distance(3). Soil lead levels near battery

manufacturing plants are slightly elevated compared with reference areas(3). [(1) Czarnezki JM; Bull Environ Contam Toxicol 34: 736-45 (1985) (2) Schalscha EB et a; J Environ Qual 16: 313-5 (1987) (3) Crosby EC, Agento VK; Ind Pollut Control Symp pp. 85-92 (1985)].

Mean lead concn in peat soil and sediment from the Pungo River peatland area of coastal North Carolina: surface soil 12.8 ppm, soil (20 cm depth) 2.7 ppm, soil (1 m depth) 3.6 ppm, surface sediment 0.1 - 7.0 ppm(1). Most of the lead is associated with the residual fraction with less amounts organically bound and negligible amounts in the water-soluble fraction(1). Concns of lead in a polluted sediment in the Rhine River near Mainz ranged from 32 ppb to 4 ppm and are primarily bound to organic matter in an extremely reducing environment(2). In polluted and unpolluted estuarine sediment in England 18-22% of the lead is organically bound, 4-11% is easily leachable and exchangeable, <4% tied up with hydroxides or possibly carbonates, and the remainder resistant (possibly derived from rock)(3). Mean lead levels in West Midlands England soil for four land-use types were: agricultural 49 ppm, suburban/residential 109 ppm, mixed industrial/residential 140 ppm, industrial/inner urban 260 ppm(4). [(1) Pace CB, DiGiulio RT; Environ Pollut 43: 301-11 (1987) (2) Dissanayake CB et al; Intern J Environ Studies 22: 109-19 (1984) (3) Badri MA, Aston SR; Environ Pollut B 6: 181-93 (1983) (4) Haines RC; Trace Substances Environ Health 18: 450-60 (1984)].

Sed.Concern Levels, Sediment Quality Criteria, LC50 Values, Sediment Quality Standards, Screening Levels, Dose/Response Data and Other Sediment Benchmarks:

Sed.General (General Sediment Quality Standards, Criteria, and Benchmarks Related to Protection of Aquatic Biota in General; Includes Sediment Concentrations Versus Mixed or General Aquatic Biota):

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Sediment Concentrations. To be considered unlikely to represent an ecological risk, field concentrations should be below all of the following benchmarks in mg/kg (ppm) dry weight [652]:

CAS 7439-92-1, LEAD:

EFFECTS RANGE - MEDIAN (NOAA): 218 mg/kg dry wt.

EFFECTS RANGE - LOW (NOAA): 46.7 mg/kg dry wt.

St. Lawrence River Interim Freshwater Sediment Criteria, 1992. No effect level: 23 mg/kg dry weight. Minimal effect level: 42 mg/kg dry weight. Toxic effect level: 170 mg/kg dry weight [761].

Environment Canada Interim Sediment Quality Assessment Values, 1994. Threshold effect level: 35.0 mg/kg dry weight. Probable effect level: 91.3 mg/kg dry weight [761].

Ontario Ministry of the Environment Freshwater Sediment Guidelines, 1993. Lowest effect level: 31 mg/kg dry weight. Severe effect level: 250 mg/kg dry weight [761].

Older Benchmarks: Ontario Ministry of the Environment guidelines for open lake disposal of sediments. The guideline for lead is 50 ppm [347]. Ontario, 1978: The concentration proposed by the Ontario Ministry of the Environment as a threshold for evaluations of dredging projects was 50.0 mg/kg dry weight [145].

International Joint Commission, 1988: The IJC suggested sediment concentrations not exceed background levels of 27.5 mg/kg dry weight [145].

AET 1988: The apparent effects threshold concentrations for lead in sediments proposed for Puget Sound ranged from 450 mg/kg dry weight (Benthic Species) to 660 mg/kg dry weight (amphipods) [416].

NOTE: Although the authors of the Puget Sound AETs have cautioned that Puget Sound AETs may not be appropriate for comparison with data from other geographic areas, so few concern levels for this chemical have been published that the proposed Puget Sound concern level is included in this text as an item of interest.

NOAA 1995 Concern Levels for Coastal and Estuarine Environments: After studying its own data from the National Status and Trends Program as well as many literature references concerning different approaches to determining sediment criteria, NOAA suggested that the potential for biological effects of this contaminant sorbed to sediments was highest in sediments where its concentration exceeded the 218 ppm dry weight Effects Range-Median (ERM) concentration and was lowest in sediments where its concentration was less than the 46.7 ppm dry weight Effects Range-Low (ERL) concentration [664]. To improve the original 1990 guidelines [233], the 1995 report included percent (ratios) incidence of effects for ranges below, above, and between the ERL and ERM values. These numbers represent the number of data entries within each concentration range in which biological effects were observed divided by the total number of entries within each range [664]:

<ERL	8.0
ERL-ERM	35.8
>ERM	90.2

Guidance for freshwater dredging, N.Y. 1994: No appreciable contamination is less than 30 ppm of lead, moderately polluted between 30 and 100 ppm, and heavily polluted greater than 100 ppm [761].

Wisconsin Interim Criteria for Lead in Sediments from Great Lakes Harbors for Disposal in Water [347]: 50 ppm dry weight (same as the open water disposal guideline for Ontario).

Guidelines for the pollutional classification of Great Lakes harbor sediments (1977): Nonpolluted less than 40 ppm of lead, moderately polluted between 40 and 60 ppm, and heavily polluted greater than 60 ppm [347].

EPA Region 6, 1973: The concentration proposed by EPA Region 6 as a guideline for determining acceptability of dredged sediment disposal was 50 mg/kg dry weight [143].

Sed.Plants (Sediment Concentrations vs. Plants):

No information found.

Sed.Invertebrates (Sediment Concentrations vs. Invertebrates):

No information found.

Sed.Fish (Sediment Concentrations vs. Fish):

No information found.

Sed.Wildlife (Sediment Concentrations vs. Wildlife or Domestic Animals):

Bureau of Land Management RMC Benchmarks, 1995: Risk Management Criteria (RMC) were developed for the mostly dry BLM lands in the western U.S. These risk management criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are needed [715]. Exceedances of the criteria should be interpreted as follows [715]:

Less than criteria: low risk
1-10 times the criteria: moderate risk
10-100 times the criteria: high risk
>100 times the criteria: extremely high risk

Wildlife criteria for lead in soils and sediments. Wildlife not exposed to soils/sediments with concentrations of lead exceeding the below RMCs are not expected to experience adverse toxic effects [715]:

Deer/Mouse: 302 mg/kg
Rabbit: 44 mg/kg
Bighorn Sheep: 425 mg/kg
Whitetailed Deer: 354 mg/kg
Mule Deer: 438 mg/kg
Elk: 361 mg/kg
Mallard: 152 mg/kg
Canada Goose: 55 mg/kg
Trumpeter Swan: 59 mg/kg

Sed.Human (Sediment Concentrations vs. Human):

Bureau of Land Management RMC Benchmarks, 1995: Risk Management Criteria (RMC) were developed for the mostly dry BLM lands in the western U.S. These risk management criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are needed [715]. Exceedances of the criteria should be interpreted as follows [715]:

Less than criteria: low risk
1-10 times the criteria: moderate risk
10-100 times the criteria: high risk
>100 times the criteria: extremely high risk

Human RMC criteria for lead in sediments. These categories of humans not exposed to sediments with concentrations of lead exceeding the below RMCs are not expected to experience adverse toxic effects [715]:

Camp host: 1000 mg/kg
Child Camper: 1000 mg/kg
Boater: 1000 mg/kg
Swimmer: 1000 mg/kg

Sed.Misc. (Other Non-concentration Sediment Information):

No information found.

Soil Data Interpretation, Concentrations and Toxicity (All Soil Data Subsections Start with "Soil."):

NOTE: Concentrations in soil are usually assumed to be dry weight unless otherwise stated [347]. However, there are exceptions to every rule, so for critical applications, check with the source.

Soil.Low (Soil Concentrations Considered Low):

No information found.

Soil.High (Soil Concentrations Considered High):

An upper limit for lead content of normal soils has been suggested as 70 ppm; higher values reflect anthropogenic inputs (Kabata-Pendias and Pendias, 1992) [699].

Lead in German Gulch (Upper Clark Fork Superfund Site Area, Montana) samples ranged from 31.1 to 119.7 ppm and averaged 68.1 ppm.

Analyses of sewage sludges from 50 publicly owned treatment works by the U.S. Environmental Protection Agency (1985): The mean concentration of lead was 378 ppm (dry weight) [347].

Analyses of 74 Missouri sewage sludges (1985): The median weight for lead was 145 ppm, the range was 42-960 ppm (dry weight) [347].

Soil.Typical (Soil Concentrations Considered Typical):

Typical Igneous Rocks (Earth's Crust) Concentrations from EPA 1981: 12.5 mg/kg dry weight [83].

Western U.S. Soil Median Concentrations [715]: 20 mg/kg

Mean soil concentration of lead in U.S. soils is approximately 32 ppm (range 10-70 ppm) [699].

The median lead concentration in the soil (to a depth of 20 cm) is 5-16 ug Pb/g (ppm) soil with 95% of samples being <30 ppm [940].

Background values for lead in soils overlying granitic rock are typically between 10 and 50 ppm (Kabata-Pendias and Pendias, 1984, as cited in Morrison Knudsen, 1991) [699].

EPA 1981: 10 mg/kg dry weight is typical [83].

The national average concentration for lead in U.S. soils is 10 mg/kg [98], but much higher concentrations are common near busy highways [43].

Uncontaminated soils can have as much as 40-120 ppm lead, and lawn and garden soils often have as much as 200-500 ppm lead.

Averages and ranges of concentrations of elements in soils and other surficial materials in the United States (1971): The mean for lead is 20 ppm the range is <10-700 ppm [347].

Typical Sediment/Soil Concentrations [940]:

> Big River (Old Lead Belt, MO) sediment and organic detritus contain 1400-2200 and 800-7000 ppm of lead, respectively(1). Soil samples collected 0.3 km from an industrial park containing a battery manufacturing plant and a Missouri ore processing plant contained elevated Pb levels 945 and 983 ppm, mean 0-5 cm depth, and 257 and 204, mean 5-15 cm depth, in 1982 and 1983, respectively(2). The extractable Pb levels were 117 and 1 ppm, mean 0-5 cm depth, and 36 ppm and not detected mean 5-15 cm depth in 1982 and 1983, respectively. The battery manufacturing plant closed after testing in 1982, suggesting that the extractable Pb in these soils reflected recent additions and that reversion to nonextractible forms were rapid. All other sites tested had essentially the same Pb levels, 47-106 ppm, and <1 ppm or non detectible amounts of extractable Pb in 1983. Soil and dust sampling downwind of battery manufacturing and secondary smelter/battery manufacturing plants in Houston indicate that the smelters, but not the battery manufacturing facilities result in significantly elevated Pb levels that correlated with distance(3). Soil lead levels near battery manufacturing plants are slightly elevated compared

with reference areas(3). [(1) Czarnezki JM; Bull Environ Contam Toxicol 34: 736-45 (1985) (2) Schalscha EB et a; J Environ Qual 16: 313-5 (1987) (3) Crosby EC, Agento VK; Ind Pollut Control Symp pp. 85-92 (1985)].

Mean lead concn in peat soil and sediment from the Pungo River peatland area of coastal North Carolina: surface soil 12.8 ppm, soil (20 cm depth) 2.7 ppm, soil (1 m depth) 3.6 ppm, surface sediment 0.1 - 7.0 ppm(1). Most of the lead is associated with the residual fraction with less amounts organically bound and negligible amounts in the water-soluble fraction(1). Concns of lead in a polluted sediment in the Rhine River near Mainz ranged from 32 ppb to 4 ppm and are primarily bound to organic matter in an extremely reducing environment(2). In polluted and unpolluted estuarine sediment in England 18-22% of the lead is organically bound, 4-11% is easily leachable and exchangeable, <4% tied up with hydroxides or possibly carbonates, and the remainder resistant (possibly derived from rock)(3). Mean lead levels in West Midlands England soil for four land-use types were: agricultural 49 ppm, suburban/residential 109 ppm, mixed industrial/residential 140 ppm, industrial/inner urban 260 ppm(4). [(1) Pace CB, DiGiulio RT; Environ Pollut 43: 301-11 (1987) (2) Dissanayake CB et al; Intern J Environ Studies 22: 109-19 (1984) (3) Badri MA, Aston SR; Environ Pollut B 6: 181-93 (1983) (4) Haines RC; Trace Substances Environ Health 18: 450-60 (1984)].

Soil.Concern Levels, Soil Quality Criteria, LC50 Values, Soil Quality Standards, Screening Levels, Dose/Response Data and Other Soil Benchmarks:

Soil.General (General Soil Quality Standards, Criteria, and Benchmarks Related to Protection of Soil-dwelling Biota in General; Includes Soil Concentrations Versus Mixed or General Soil-dwelling Biota):

Other Maximum Allowable Concentration (MAC) levels (ppm dry weight): 100 (Stuttgart), 500 (London) [719].

Proposal of European Economic Commission for Maximum Allowable Concentration (MAC) in soils treated with sewage sludge: 50 (100) ppm dry weight (London). The value in parentheses is for mandatory concentrations [719].

Proposal of Ontario Ministry of Agriculture and Food for Maximum Allowable Concentration (MAC) in soils treated with sewage sludge: 60 ppm dry weight (published in Tokyo; work done for Ontario) [719].

The 1987 soil (clean up) criteria given by the New Jersey Department of Environmental Protection for lead is 250 to 1,000 mg/kg dry weight [347,386]. Other authors have also suggested 1,000 ppm lead as a prudent critical regulatory limit for soil in lead [347].

Dutch soil (clean up) Act levels for lead [347]:

> 50 ppm background levels (same as Quebec)
>
> 150 ppm moderate soil contamination (200 ppm in Quebec)
>
> 600 ppm threshold values that require immediate cleanup.
>
> > NOTE: 600 is also the cleanup criteria in Japan and Quebec.

Ontario clean up criteria [347]:

> 60 ppm for agriculture land
>
> 500 ppm for residential/park-land
>
> 1,000 ppm for commercial, industrial.

Acceptable level of lead in acidic soils of Alberta [347]:

> 800 ppm for soil with pH of less than 6.5

Soviet Union Maximum Allowable Concentration in Soils, 1984: 20 mg/kg [347].

In 1981 the U.S. Environmental Protection Agency proposed 1000 ppm as an upper limit for lead for sewage sludges suitable for land application [391].

Maximum cumulative addition of metals (kg/ha) from sewage sludge to Maryland agricultural soil (1986): For a soil with a cation exchange capacity (CEC) of less than 5 meq/100 g lead should not be added at more than 560 ppm. For a soil with a CEC of equal to or more than 5 lead should not be added at greater than 1,120 ppm [347].

Maximum cumulative addition of metals from sewage sludge that may be added to Minnesota soils used for growing food crops (1987): For a soil cation exchange capacity (CEC) of less than 5 meq/100 g lead should not be added at greater than 560 ppm, for a CEC between 5 and 15 lead should not be added at greater than 1,120 ppm, and for a soil with a CEC greater than 15 lead should not be added at greater than 2,240 ppm [347].

Maximum cumulative addition of metals (kg/ha) from sewage sludge recommended for privately owned Missouri farmland (1988): For a soil with a cation exchange capacity (CEC) of less than 5 meq/100 g lead should not be added at greater than 560 ppm, for a soil with a CEC between 5 and 15 lead should not be added at greater than 1,120 ppm, and for a soil with a CEC greater than 5 lead should not be added at greater than 2,240 ppm [347].

Cumulative amounts of metals per hectare that may be added to New York State soils with sewage sludge (1988): For productive soils lead may be added at 336 ppm, for less productive soils lead may be added at 500 ppm, for forests lead may be added at 1,120 ppm [347].

Maximum heavy metal loading (kg/ha) recommended for sludge applications to privately owned Oregon farmland (1984): For a soil with a cation exchange capacity (CEC) of less than 5 meq/100 g lead should not be added at greater than 500 ppm, for a soil with a CEC between 5 and 15 lead should not be added at greater than 1,000 ppm, and for a soil with a CEC greater than 15 lead should not be added at greater than 2,000 ppm [347].

Maximum cumulative additions (kg/ha) of metals from sewage sludge that may be added to Vermont soils, by soil texture (1984): For loamy sand lead should not be added at greater than 200 ppm, for a fine sandy loam lead should not be added at greater than 400 ppm, and for clay loam lead should not be added at greater than 800 ppm [347].

Maximum cumulative applications (kg/ha) of lead from sewage sludge that may be added to Wisconsin soils (1985): For a soil with a cation exchange capacity (CEC) less than 5 meq/100 g lead should not be added at greater than 500 ppm, for a soil with a CEC between 5 and 10 lead should not be added at greater than 1,000 ppm, for a soil with a CEC between 11 and 15 lead should not be added above 1,500 ppm, and if there is a soil with a CEC above 15 lead should not be added above 2,000 ppm [347].

Soil limit values determined by the Council of European Communities for the addition of heavy metals from sewage sludge to soil with a pH of 6.0-7.0 (1986): The limit value of lead is 50-300 ppm [347].

Soil.Plants (Soil Concentrations vs. Plants):

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Terrestrial Plants. To be considered unlikely to represent an ecological risk to terrestrial plants, field concentrations in soil should be below the following dry weight benchmark for soil [651]:

> For CAS 007439-92-1 (LEAD), the benchmark is 50 mg/kg in soil (WILL and SUTER, 1994)

Levels of lead (ppm dry weight) considered phytotoxic: 100 (Vienna), 100 (Warsaw), 400 (Tokyo), 100 (Warsaw), 200 (Ontario) [719].

Minimum soil concentration causing phytotoxicity: 100-400 [699].

Plants can absorb and translocate available lead (Pb) level from nutrient solution, and to a lesser degree from soil. Most of the absorbed Pb remains in the roots, but cessation of growth in late summer and fall is often accompanied by mobilization of Pb from roots into the plant tops. Pasture herbage growing in an abandoned Pb mining area (soil pH 4, soil Pb 3600 ppm) accumulated up to 74 ppm Pb (dry weight basis) in their leaves. Corn accumulated 37.8 ppm in tops from a soil treated with 3200 kg Pb/ha, but the kernels did not contain significantly more Pb than controls (0.3-0.5 ppm Pb at 15.5% moisture). Lettuce and radishes were two plants shown to accumulate Pb from soil. Pb chelates were taken up by plants more readily than Pb(2+) and exhibited a high degree of translocation to the plant tops [940].

Some trees have the capacity to accumulate large amounts of lead from contaminated soil - the tips of larch, pine, and fir contained 100 ppm lead when grown in lead mining areas with soil concentration appreciably different from the usual concentration (80,000 ppm) in most soils. However, in most cases this indicates that there is no significant bioconcentration of lead from soil into plants(1) [940].

Soil.Invertebrates (Soil Concentrations vs. Invertebrates):

It takes quite a bit (5,941 to 12,800 ppm) of lead in soils to kill earthworms in acute (short term) tests [347]. This is relevant to the ability of earthworms to live in lead contaminated soils and accumulate levels potentially harmful to predators. A typical concentration factor for lead in soil to earthworms is 0.66, so part of the hazard to predators would be from lead gut-contents [347].

Soil.Wildlife (Soil Concentrations vs. Wildlife or Domestic Animals):

See Sed.Wildlife section above.

Soil.Human (Soil Concentrations vs. Human):

EPA 1996 National Generic Soil Screening Level (SSL) designed to be conservative and protective at the majority of sites in the U.S. but not necessarily protective of all known human exposure pathways, land uses, or ecological threats [952]:

SSL = 400 mg/kg for ingestion pathway [952].

SSL = none given for inhalation pathway [952].

EPA 1995 Region IX Preliminary Remediation Goal (PRG) for lead in residential soil: 400 mg/kg [868].

EPA 1995 Region IX Preliminary Remediation Goal (PRG) for lead in industrial soil: 1000 mg/kg [868].

Bureau of Land Management RMC Benchmarks, 1995: Risk Management Criteria (RMC) were developed for the mostly dry BLM lands in the western U.S. These risk management criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are needed [715]. Exceedances of the criteria should be interpreted as follows [715]:

Less than criteria: low risk
1-10 times the criteria: moderate risk
10-100 times the criteria: high risk

>100 times the criteria: extremely high risk

Human RMC criteria for lead in soil. These categories of humans not exposed to soil with concentrations of lead exceeding the below RMCs are not expected to experience adverse toxic effects [715]:

Child resident (living on properties adjacent to BLM lands): 400 mg/kg
Camp host: 1000 mg/kg
Child Camper: 1000 mg/kg
ATV Driver: 1000 mg/kg
Worker: 2000 mg/kg
Surveyor: 2000 mg/kg

Acceptable level of lead for production of healthy food: 20 ppm dry weight (Moscow) [719]

Maximum Allowable Concentration (MAC) trigger (of concern) concentration for domestic gardens and playing fields: 500-2000 ppm dry weight (London) [719].

Soil.Misc. (Other Non-concentration Soil Information):

In Minnesota, there was more lead in the soil of inner cities, especially big ones [945].

If released or deposited on soil, lead will be retained in the upper 2-5 cm of soil, especially soils with at least 5% organic matter or a pH 5 or above. Leaching is not important under normal conditions although there is some evidence to suggest that Pb is taken up by some plants. Generally, the uptake of Pb from soil into plants is not significant. It is expected to slowly undergo speciation to the more insoluble sulfate, sulfide, oxide, and phosphate salts.

News reports have indicated that plants such as common ragweed and hemp dogbane are being considered as candidates for the phytoremediation of lead contaminated soils [Unconfirmed Wire Service Reports from April 2, 1993, attributed to Scott Cunningham, Dupont Central Research and Development at the ACS meeting in Denver on April 1, 1993].

Phytoremediation; Compared to the radionuclides, lead presents a particularly sticky problem for the environment and for phytoremediation researchers [1023]. It forms strong bonds with minerals and organic matter in the soil [1023]. Plants absorb only a little lead, and it doesn't move beyond the roots [1023]. Phytotech has applied for a patent on the use of chelators for lead removal [1023]. Cunningham reports that ethylenediaminetetraacetic (EDTA) salt is one of the most promising chelators [1023]. Manufacturers use EDTA salt and closely related compounds as food preservatives [1023].

Tissue and Food Concentrations (All Tissue Data Interpretation Subsections Start with "Tis."):

Tis.Plants:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Plants:

No information found.

B) Body Burden Residues in Plants: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

See Br.Fate, Soil.Misc, and Bio.Detail sections for general information on plant uptake of lead.

Lead plant tissue concentrations across the (highly polluted) Smelter Hill (Upper Clark Fork Superfund Site Area, Montana) site averaged 15.43 ppm [699].

Nationwide lead levels in a variety of plant tissues generally range from 0.5 to 4 ppm (Kabata-Pendias and Pendias, 1984, as cited in PTI, 1991a) [699].

Results for the FDA's Total Diet Study including data for adult diet market basket samples collected from Oct 1977 through Sept 1978 in 20 cities throughout 4 geographical areas (240 composites): 64% had residues of lead ranging from 0.01-0.40 ppm contributing to a daily intake of 79.3 and 95.1 ug of lead in FY77 and FY78 respectively(1). Lead was found in all 12 food classes including: dairy products 0.01-0.20 ppm, 0.014 ppm avg; meat fish and poultry 0.02-0.10 ppm, 0.031 ppm avg; grain and cereal products 0.02-0.18 ppm, 0.055 ppm avg; potatoes 0.01-0.29 ppm, 0.046 ppm avg; leafy vegetables 0.01-0.08 ppm, 0.020 ppm avg; legume vegetables 0.05-0.40 ppm, 0.162 ppm avg; root vegetables 0.02-0.11 ppm, 0.027 ppm avg; garden fruit 0.03-0.34 ppm, 0.089 ppm avg; fruits 0.02-0.21 ppm, 0.045 ppm avg; oils, fats, and shortening 0.02-0.16 ppm, 0.020 ppm avg; sugar and adjuncts 0.02-0.15 ppm, 0.051 ppm avg; beverages 0.02-0.08

ppm, 0.018 ppm avg [940].

Willows and grasses downstream of Montana mining areas tended to uptake some heavy metals (copper, lead) in polluted areas to a greater degree than farther downstream: results for zinc were inconclusive, and levels of various metals in moss and lichens tended to be much higher than willow and grass (Daniel Norton, USGS, personal communication, 1995).

Both tree lichens and mosses are capable of absorbing large quantities of metals and have been used to map zones of impact from air pollution, so the USGS has been developing baseline levels for these plants [739].

Plant Concentrations [940]:

Natural constituent in all plants with normal concentration in leaves and twigs of woody plants 2.5 ppm, pasture grass 1.0 ppm; cereals 0.1-1.0 ppm(1). Some trees have the capacity to accumulate large amounts of lead from contaminated soil - the tips of larch, pine, and fir contained 100 ppm lead when grown in lead mining areas with soil concentration appreciably different from the usual concentration (80,000 ppm) in most soils. However, in most cases this indicates that there is no significant bioconcentration of lead from soil into plants(1). Lead on leafy parts of plants result from deposition of Pb from air(1). An experiment performed with hydroponically grown corn showed that lead was taken up and precipitates in the cell walls(3). Aquatic plants from the Chesapeake Bay region 2.2-18.9 ppm dry weight(4). Aquatic bryophytes from the Pb/Ag mining district of mid-Wales contained 34-49,400 ppm dry weight which correlated well with the concn of dissolved Pb in the streams(2). [(1) IARC; Monograph Some Metal and Metallic Compounds 23: 325-415 (1980) (2) James KC et al; Water Air Soil Pollut 24: 329-38 (1985) (3) USEPA; Air Quality Criteria for Lead; p. 6-1 to 6-28 USEPA-600/8-77-017 (1977) (4) DiGiulio RT, Scanlon PF; Sci Tot Environ 41: 259-74 (1985)].

Plants can absorb and translocate available lead (Pb) level from nutrient solution, and to a lesser degree from soil [940]. Most of the absorbed Pb remains in the roots, but cessation of growth in late summer and fall is often accompanied by mobilization of Pb from roots into the plant tops. Pasture herbage growing in an abandoned Pb mining area (soil pH 4, soil Pb 3600 ppm) accumulated up to 74 ppm Pb (dry weight basis) in their leaves. Corn accumulated 37.8 ppm in tops from a soil treated with 3200 kg Pb/ha, but the kernels did not contain significantly more Pb than controls (0.3-0.5 ppm Pb at 15.5% moisture). Lettuce and radishes were two plants shown to accumulate Pb from soil. Pb chelates were taken up by plants more readily than Pb(2+) and exhibited a high degree of translocation to the plant tops [940].

Tis.Invertebrates:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Invertebrates:

No information found.

B) Concentrations or Doses of Concern in Food Items Eaten by Invertebrates:

No information found.

C) Body Burden Residues in Invertebrates: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

See also [940] information in Tis.Fish, C) below.

Lead does not accumulate to the same extent in both oysters and mussels. Therefore, the following information summarizes data gathered on both oysters and mussels from the NOAA National Status and Trends (NS&T) Program for the year 1990 [697]:

> For lead in oysters (n=107), the Geometric Mean was 0.52 ug/g dry and the "high" concentration was 0.94 ug/g dry weight [697]. For lead in mussels (n=107), the Geometric Mean was 1.8 ug/g dry and the "high" concentration was 4.3 ug/g dry weight [697]. NOAA "high" concentrations are equal to the geometric mean plus one standard deviation on the log normal distribution [696].

Tis.Fish:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Fish (Includes FDA Action Levels for Fish and Similar Benchmark Levels From Other Countries):

Legal Limits for Concentrations in Fish and Fishery Products:

The lowest legal limit was 0.5 mg/kg (Zambia and the Netherlands) [216,418]. Nine countries have limits less than or equal to 1.0 mg/kg, but the U.S. apparently has no official limit [216,418].

Other Concern Level Related to Human Consumption:

In the U.S., there is no FDA action level for lead in fish, but an edible tissue guideline often cited as an upper limit for lead in foods is 0.3 mg/kg [27,66].

Bureau of Land Management RMC Benchmarks, 1995: Risk Management Criteria (RMC) were developed for the mostly dry BLM lands in the western U.S. These risk management criteria should be used by the land manager as a cautionary signal that potential health hazards are present and that natural resource management or remedial actions are needed [715]. Exceedances of the criteria should be interpreted as follows [715]:

Less than criteria: low risk
1-10 times the criteria: moderate risk
10-100 times the criteria: high risk
>100 times the criteria: extremely high risk

Human RMC criteria for lead in fish consumed by humans. These categories of humans not exposed to fish with concentrations of lead exceeding the below RMCs are not expected to experience adverse toxic effects [715]:

Child resident (living on properties adjacent to BLM lands): 200 ug/kg
Camp host: 200 ug/kg
Child Camper: 200 ug/kg

RBC: no Risk Based Values were given for lead [903].

B) Concentrations or Doses of Concern in Food Items Eaten by Fish:

No information found.

C) Body Burden Residues in Fish: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

Mean NCBP Levels (Tissue Concentrations): The nationwide wet-weight geometric means of whole-body concentrations of lead in fish were 0.17 mg/kg (1981-1982) [23] and 0.11 mg/kg (1976-1984) [384]. The recent (1976-1984) NCBP survey report gave the nationwide maximum level as 4.88 mg/kg wet weight lead, and the 85th percentile level as 0.22 mg/kg [384].

The highest concentrations of lead in 5 studies of edible fish tissues in several states (mostly eastern states and the studies included sites which were not especially clean) ranged from 0.9 to 15.86 mg/kg wwt [57].

The three highest levels (2.7 to 3.7 mg/kg) in Trinity River fish were all samples of mosquitofish from storm drains in downtown Fort Worth [201].

Gradient Monitoring Levels: A river mile plot of mosquitofish whole-body values for lead showed peaks just downstream of Fort Worth and just downstream of Dallas [201]. An analysis of all Trinity River sites showed that 17 of 23 mosquitofish samples had concentrations equaling or exceeding 0.1 mg/kg lead [201]. Concentrations of lead in 3 samples of mosquitofish from the Rio Grande River at Big Bend National Park were all less than 0.1 mg/kg lead [65]. A group of mosquitofish samples from sites 1, 16, and 27 (upstream sites on the Trinity River) had significantly lower concentrations of lead than a group of mosquitofish samples from all other Trinity River sites [201]. A group of mosquitofish samples from sites 9, 10, 11, and 12 just downstream of Dallas had significantly higher concentrations of lead than a group of mosquitofish samples from sites (1, 16, and 27) upstream of Fort Worth or Dallas [201].

Like manganese, lead tends to be deposited in bone, skin, and scales to a much greater extent than in muscle tissue. Therefore fillets can be contaminated by common fish-cleaning techniques [27]. However, fish from polluted areas do build up substantial concentrations of lead in muscle tissue and whole-body analysis of fish for lead is still recommended for general environmental monitoring [27].

Fish/Seafood Concentrations [940]:

Concn of lead in freshwater fish 0.16-0.24 mg/kg, with 12 mg/kg in liver, 5.7 mg/kg in gills and 1.4 ppm in muscle. ... Lead /was found/ in the soft tissue of freshwater mussels in the Thames River, with mean concn ranging from 9.8-42.5 mg/kg (dry weight). The higher concentrations were found in mussels taken from urban sites. ... Shellfish in general have been reported to contain 0.31 mg/kg, soft shell clam an avg of 0.7 mg/kg & northern quahog clam an avg of 0.52 mg/kg lead on a wet wt basis. Oysters have been found to contain 0.47 mg/kg. ... Fresh tuna fish muscle was reported to contain 0.3 mg/kg lead. /Inorganic lead/ [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V23 351 (1980)].

As part of the National Contaminant Biomonitoring Program, freshwater fish were collected from 112 stations located throughout the US. The geometric mean and range of Pb in 1978-79 (ppm wet weight) was 0.19, 0.10-6.73 and for 1980-81 was 0.17, 0.10-1.94(1). The specimen with the highest Pb concn in 1978-79 came from a stream near Honolulu, HA; no specimens were analyzed from this station in 1980-81(1). In the Big River, MO (inactive Old Lead Belt), average lead levels in edible tissue in 3 species of suckers at 9 stations (157 samples) ranged from 0.13 to 0.88 ppm wet weight compared with 0.06-0.12 at a background station(2). 61% of these fish had levels in excess of the 0.3 ppm standard and the highest concentration measured was 1.30 ppm, from a site below a ruptured tailings pond dam(2). Average values in sunfish and smallmouth bass ranged from not detected to 0.39 ppm(2). Mean lead concentrations of fish from streams in the New Lead Belt (71 samples) and the defunct Tri-State Mining District (100 samples) ranged from 0.03 to 0.4 ppm and 0.03-0.11 ppm, respectively(2). Mean controls in these two regions ranged from not detected to 0.04 ppm. The normal pH and hardness of all streams sampled was 7.0-8.4 and 100-300 mg/l CaCO3(2). Lead concn in clams (R cuneata) from the Pungo River peatland area of coastal North Carolina contained 0.2-0.5 ppm dry weight Pb(3). Clams from the Chesapeake Bay region contained 0.8-20.4 ppm dry weight Pb(4). [(1) Lowe TP; Arch Environ Contam Toxicol 14: 363-88 (1985) (2) Czarnezki JM; Bull Environ Contam Toxicol 34:

736-45 (1985) (3) Pace CB, DiGiulio RT; Environ Pollut 43: 301-11 (1987) (4) DiGiulio RT, Scanlon PF; Sci Tot Environ 41: 259-7 (1985)].

Tis.Wildlife: Terrestrial and Aquatic Wildlife, Domestic Animals and all Birds Whether Aquatic or not:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Wildlife, Domestic Animals, or Birds:

No information found.

B) Concentrations or Doses of Concern in Food Items Eaten by Wildlife, Birds, or Domestic Animals (Includes LD50 Values Which do not Fit Well into Other Categories, Includes Oral Doses Administered in Laboratory Experiments):

See also Tis.Plant, C) section above.

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Wildlife derived from No-Observed-Adverse-Effect (NOAEL) levels (mg contaminant per kg body weight per day). To be considered unlikely to represent an ecological risk, wet-weight field concentrations should be below the following (right column) benchmarks for each species present at the site [650]:

CAS 7439-92-1, LEAD (AS LEAD ACETATE):

SPECIES	NOAEL (mg/kg/day)	FOOD CONCENTRATION (ppm)
Rat (test species)	8.00000	0.00000
Short-tailed Shrew	22.62200	37.70300
Little Brown Bat	28.43600	85.30700
White-footed Mouse	19.93600	128.99600
Meadow Vole	15.86000	139.56400
Cottontail Rabbit	5.32700	26.97400
Mink	5.65800	41.29600
Red Fox	3.44400	34.44100
Whitetail Deer	1.49400	48.52500

Comment: Actually, the number of significant figures for a benchmark value should never be more than one; even if these values have been taken directly from another report, they should be rounded; otherwise the impression is given of a level of accuracy that is simply unwarranted. The uncertainties are too large to justify such a fine distinction (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

The concentration of this metallic element in earthworms is correlated with soil concentrations, which is a consideration relative to birds feeding on sewage sludge amended soils [179].

It takes quite a bit (5,941 to 12,800 ppm) of lead in soils to kill earthworms in acute (short term) tests [347]. This is relevant to the ability of earthworms to live in lead contaminated soils and accumulate levels potentially harmful to predators. A typical concentration factor for lead in soil to earthworms is 0.66, so part of the hazard to predators would be from lead gut-contents [347].

Initial short-term tests (acute oral toxicity) indicate several lead compounds (except for lead arsenate) were relatively nontoxic to at least one bird species [185]. Of course these short term toxicity tests do not address the chronic (long-term) impacts (as mentioned elsewhere in this discussion) of lead on fish and wildlife.

LC50 Japanese quail (Coturnix japonica), males or females, 14 days old, oral (5-day ad libitum in diet) >5,000 ppm; at 1000, 2236 & 5000 onset of toxic signs began at 7, 7 & 7 days and remissed at 11, 11 & 12 days, respectively, no mortality was observed; control references were dieldrin & dicrotophos; corn oil diluent was added to diet at ratio of 2:98 by wt; (extreme concentrations: 1,000-5,000 ppm) /Lead metal, 100%/ (Hill, E.F. and Camardese, M.B. Lethal Dietary Toxicities of Environmental Contaminants and Pesticides to Coturnix. Fish and Wildlife Technical Report 2.Washington, DC: United States Department of Interior Fish and Wildlife Service, 1986. 86) [940].

Waterfowl can become poisoned by ingesting 6-8 buckshot from frequently hunted shorelines. Natural sources of lead such as galena or soils are not particularly toxic but can add to the total body burden. (Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1005) [940].

In waterfowl, lead shot ingestion causes anorexia, loss of wt, weakness, lethargy, diarrhea, coma, & quiet death. ... Progressive tachycardia /has been observed/ in geese as the birds became more & more ill. Some geese developed ECG abnormalities (Booth, N.H., L.E. McDonald, eds., Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1008) [940].

In geese chronically poisoned with lead shot, microscopic degenerative lesions appear in the myocardium before any ECG abnormalities are manifested. Lesions include upper GI impaction with plant materials, emaciation, distended gallbladder, flabby hemorrhagic heart, discolored friable liver, & enteritis. Lesions in mallard ducks given lead shot include destruction of proventricular epithelium, bone medullary osteocytes, & pectoral muscle cells. Renal proximal tubules contain intranuclear inclusions. Mallard ducks also may develop encephalopathy & peripheral neuropathy (Booth, N.H., L.E. McDonald, eds., Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1009) [940].

Metallic lead in the form of weights or foil can cause poisoning, as also can shot; duck frequently dredge up shot from the mud at the bottom of ponds. Lead shot in muscle is usually encapsulated, & systemic poisoning from it is unlikely. Nevertheless, lead shot dropped by anglers on river banks is a serious cause of poisoning in swans. ... Vegetation in the neighborhood of a smelter engaged in melting down old battery plates had a lead content of up to 3200 ppm. ... Vegetation near a busy highway may contain 500 ppm of lead due to contamination by exhaust fumes. It should be noted that in these cases the lead is only a surface contaminant; significant quantities of the element cannot be taken up by vegetation from lead-bearing soil, although the latter has itself caused poisoning in small animals. (Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall, 1981. 55) [940].

Birds (fowls, ducks, geese & pigeons) are all susceptible to lead poisoning. They show anorexia & ataxia, followed by excitement & loss of condition. Egg production, fertility, & hatchability decrease; & mortality may be high. (Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall, 1981. 57) [940].

In rats, the absorption of a 10 mg/kg oral lead (Pb) dose was reduced by the presence of food in the intestine. ... No circadian rhythm was apparent in Pb absorption or transport across everted intestines in vitro. ... Pretreatment of rats with propantheline (5 mg/kg, ip) delayed and decreased Pb absorption ... Pb absorption in undernourished rats ... was similar to control but the distribution of systemically administered Pb was altered. /Lead and inorganic compounds/ (Aungst BJ, Fung HL; Res Commun Chem Pathol Pharmacol 34 (3): 515-30 (1981)) [940].

Lead poisoning can result when curious animals ingest lead based paints (either old dry paint or paint from "empty" paint cans), glazier's putty or other caulking materials, used crankcase oil, greases, linoleum, leaded gasoline ... solder, roofing materials, asphalt, or industrial effluents in streams or on forage. Grass near busy highways may contain toxic amounts of lead from auto exhausts. Licking of discarded storage batteries can also result in lead poisoning. Water from lead plumbing or glazed crockery pots may contain toxic amounts. ... Natural sources of lead such as galena or soils are not particularly toxic but can add to the total body burden. Milk secreted from lead poisoned animals can be dangerous for the young animal. Paint seems to be a common source of lead in poisoned animals. In addition, cattle & calves are often poisoned by ingesting crankcase oil drained from internal combustion engines. The farm dump is often a smorgasbord of poisons for animals that gain access to it. /Lead and inorganic lead compounds/ (Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1005) [940].

The acute oral lethal single dose of lead in various species is: calves, 50-600 mg/kg as lead or lead salts; cattle ... 600-800 mg/kg from lead salts ... sheep & goats, 600-800 mg Pb/kg from lead salts ... fowl, 160-600 mg/kg absorbed from lead salts. Chronic toxicosis can arise when lead is ingested over a period of days, weeks, or months. The chronic oral lethal dose in different species is: calves, 1-3 g total/day; cattle ... may not get ill with 6 mg/kg/day for 60 weeks from lead paint. ... Prolonged ingestion of small amounts of lead can eventually cause mild to severe illness in animals, although the definition of "small amounts" may vary with species. ... The no effect level of lead intake for sheep is about 0.1 mg/kg/day; biochemical aberrations occur in this species when the intake is 0.3 to 3 mg/kg/day. In mammals (rats), the no effect level for prenatal exposure is about 1 ppm in the diet. Some pet foods contain more lead than this. ... Cats are not poisoned by lead very often because they do not chew on foreign objects, lick painted surfaces, or eat materials that are not foodstuffs. Cats can be poisoned if their food or water is contaminated or if they lick lead containing matter such as grease or oil from their fur. /Lead and inorganic lead compounds/ (Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1005) [940].

Onset of clinical signs of lead poisoning /in cattle/ may take a few hours, days, or weeks, depending on the amount ingested, species, & other factors. ... Chronic poisoning may take weeks or months to develop. Clinical signs manifested by different species do have some differences, but the overall impression is of an encephalopathy preceded & accompanied by GI malfunction. ... When signs are classified /in the literature/, the classification looks very much like that of chlorinated hydrocarbon insecticides & urea, which also produce encephalopathy and GI signs. /Lead and inorganic lead compounds/ (Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1008) [940].

Behavioral aberrations are manifested, beginning with apparent anxiety or apprehension & proceeding to such things as hyperexcitability, bellowing or other vocalization, rolling of eyes & apparent fear or terror, possible belligerence, pressing of the head against a wall or post, attempts to climb the wall, sudden jumping into the air, & frenzied or manical behavior. One fascinating aspect of this category is the effect of small amounts of lead in exptl animals. Lead can disrupt conditioned (learned) behavior in adult rats, rabbits & sheep. It can also disrupt learning & memory in young & adult rats & in lambs born of lead treated ewes. /Lead and inorganic lead compounds/ (Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1008) [940].

Chronic exposure through ingestion of 6 to 7 milligrams of lead per kg of body weight, can result in poisoning in cattle. /Lead and inorganic lead compounds/ (USEPA; The Health and Environmental Impacts of Lead: 152 (1979) EPA 560/2-79-001) [940].

Over half the cases of lead poisoning in cattle in

Scotland occur in the spring. Similar effects have been noted for dogs. ... Even more important is the fact that lead is both cumulative & ubiquitous. All living creatures are continually absorbing it, & the "toxic" dose is only the amount necessary to bridge the gap between this normal intake & a potentially dangerous level. ... Three or four lead shots will kill a duck, 10 a goose. (Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall, 1981. 56) [366].

C) Body Burden Residues in Wildlife, Birds, or Domestic Animals: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

The highest lead concentration in Trinity River tissue samples, 7.2 mg/kg, was from a shell composite sample dissected from five red-eared turtles from site 18 (which was a storm drain in downtown Fort Worth) [201].

Lead was one of the few contaminants for which turtle shells appeared to be efficient accumulators, a reflection of the fact that lead tends to be deposited in bone as a cumulative poison [26].

Eleven pregnant squirrel monkeys were perorally exposed to lead during the latter two-thirds of pregnancy (mean blood lead 0.54 ug/ml (2.61 umol/l), range 0.39-0.82 ug/ml (1.88-3.96 umol/l), at a dosing regime producing no maternal toxic symptoms. Lesions similar to lead encephalopathy and growth retardation of the fetal cerebrum were seen in some of the offspring, as well as neurological and behavioral symptoms at adult age. Cerebral lead levels in offspring (an abortion, stillborns, a sacrificed full-term fetus, and a neonatal death) were between 0.1-0.7 ug/g. Pre- and perinatal mortality, and prematurity, was increased, and the size of the offspring at birth was reduced. The head circumference tended to be reduced postnatally (Logdberg MD et al; Scand J Work Environ Health 13: 135-45, 1987) [366].

Twelve sheep were exposed to finely powdered metallic lead in their diet (doses, 0.5 To 16 mg/kg body wt) during entire pregnancy; blood levels were about 0.4 Mg/l, without resulting in death. Nine animals served as controls. Rate of lambing was 18% in exposed (27% abortions) & 100% in unexposed sheep (no abortions). No malformations were reported. It was concluded that/ chronic lead poisoning in sheep caused abortion, miscarriage & transitory sterility (Sharma & Buck 1976). (IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V23 368, 1980, [366].

Animal Concentrations [940]:

> Principal source of exposure to ducks and waterfowl is from lead shot which is ingested by the birds in search of gravel. Livers of 28 species of birds with no known lead exposure 0.3-7 ppm(2). Small mammals within 10 m of road 2.6-15.2 ppm with the contents higher along high traffic road and among insectivores(3); urban biota 11-367 ppm, rural biota 4.7-16 ppm(4). Riparian wildlife from sites in the active New Lead Belt mining district of southeastern Missouri (species - geometric mean in ppm wet weight (range in ppm)): Bullfrog carcasses - 1.22-1.47 (not detected - 7.40), Northern water snake carcasses 0.15-1.21 (not detected - 3.90), Rough-winged swallow carcasses - 0.23-2.39 (not detected - 61.2), Muskrat livers - 0.07-0.26 (not detected - 0.53)(1). [(1) Niethammer KR et al; Arch Environ Contam Toxicol 14: 213-23 (1985) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (3) National Science Foundation; Lead in the Environment; Boggers WR ed NSF/RA-770214 (1977) (4) International Register of Potentially Toxic Chemicals; p. 171-77 United Nations Environment Program Geneva Switzerland (1979)].
>
> Data from the Old Lead Belt mining district in southeastern Missouri (species-geometric mean in ppm wet weight (range in ppm) Bullfrog carcasses - 12.6-109.0 (2.90-300.0), Northern water snake carcasses 0.15-1.21 (not detected - 3.90), Rough-winged swallow carcasses - 0.44-1.86 (not detected - 14.7), Muskrat livers - 0.64-0.69 (0.29-1.60)(1). Site upstream from the old lead belt: Bullfrog carcasses - 0.97 (0.11-6.10), Northern water snake carcasses 6.07- 7.52 (1.60-14.1), Rough-winged swallow carcasses - 0.51 (not detected - 5.40), Muskrat livers - 0.16 (not detected - 0.32)(1). While mining in the Old Lead Belt ceased in 1972, this district contains huge tailing piles from which lead enters the river

by erosion and seepage. Herring gulls feeding on refuge from a dump receiving large quantities of industrial residues from leather, ceramics, and glass manufacturing in addition to domestic refuge contained an average of 13.25 ppm of Pb in their kidneys compared with <0.10 to 3.78 ppm for gulls feeding from 3 other dumps(2). [(1) Niethammer KR et al; Arch Environ Contam Toxicol 14: 213-23 (1985) (2) Leonzio C et al; Sci Tot Environ 57: 121-7 (1986)].

Baseline data on Pb accumulation in organs and tissues, and their variations with age, sex, and habitat in Japanese serows (Capricornus crispus) were determined. The animals were killed during the winter 1981-82 in the Gifu and Nagano Prefectures, Japan. The Pb concentrations were measured by flame absorption spectrometry. On a wet wt basis, the mean Pb concentration in muscle, liver, kidneys, and the whole body of fetuses (gestation age 0.3-0.7 yr, N= 13) was 0.01, 0.13, 0.01, and 0.04 ug/g, respectively; in fawns (age 0.0-0.5 yr, N= 12) was 0.05, 0.07, 0.06, and 0.06 ug/g, respectively; in yearlings (age 0.5-2.5 yr, N= 6) was 0.06, 0.07, 0.09, and 0.06 ug/g; in adults (age 2.5 to 10 yr, N= 42), 0.06, 0.12, 0.09, and 0.08 ug/g; and in adults (age 10 to 17.5 yr, N= 17), 0.06, 0.11, 0.11, and 0.11 ug/g, respectively. The mean Pb concentration in fleece of fawns, yearlings, and adults (age 2.5 to 10 yr) was 0.72, 0.50, and 0.43 ug/g, respectively. Bone samples of two adult serows contained 0.22 to 0.26 ug/g. The body burden of fetuses was low (<1%) compared with that of their mothers. There was no significant difference in Pb concentration between collection locations. The body burden of Pb agreed well with the concentration found in food plants. [Honda K et al; Arch Environ Contam Toxicol 16: 551-61 (1987)].

Tis.Human:

A) Typical Concentrations in Human Food Survey Items:

See also Tis.Fish, C) and Tis.Wildlife, C) sections above.

Milk Concentrations [940]:

Milk directly from cows 9 ppb; whole bulk milk 40 ppb avg; local milk from U.S. markets 20-40 ppb(1); canned milk 0.05-0.2 ppm(1). Results of a 1982 survey of lead in Canadian milk (68 samples) ranged from 0.01-2.48 ppb, 1.12 ppb, mean, 1.19 ppb median(1). Canned evaporated milk and infant formula ranged from 27-106 and 1.1-122 ppb, respectively(2). The mean lead level in the breast milk of occupationally unexposed women in Malaysia was 43.5 ug/l(3). Human milk in two previous studies contained 12 ug/l and <5 ug/l(1). [(1) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (2) Dabeka,RW, McKenzie AD; J Assoc Anal Chem 70: 754-7 (1987) (3) Ong CN et al; Arch Disease Childhood 60: 756-9 (1985)].

Food Survey Results [940]:

10 mg/l lead found in illicitly distilled whiskey. /Inorganic lead/ [WHO; Environ Health Criteria: Lead p.54 (1977)].

As a general rule, foods which are apt to have elevated lead concentrations are dried foods, liver, canned food, and vegetable that have a high area to mass ratio(2). The effect of soldered cans on the lead concentration in food is illustrated by the fact that the mean lead content of ravioli in a 98% Pb/2% Sn soldered can was 150 ppb while the same food in a welded (no lead) can was 30 ppb(2). Condiments 0-1.5 ppm; fish and seafood 0.2-2.5 ppm; meats and eggs 0-0.37 ppm; grains 0-1.39 ppm; vegetables 0-1.3 ppm; wine 60-255 ppb, 130-190 ppb avg(1). Another value for wine of 299 ppb, avg has been reported(1). Moonshine whiskey commonly exceeds 10 ppm(1). Lead in canned food: fruit 0.01-14.0 ppm, fruit juice 0.01-3.1 ppm, vegetables 0.01-38.6 ppm, tunafish 0.08 ppm avg(1). Dietary exposure to lead ranges from 100-500 ug/day(1), however people living near a smelter have intakes of 670-2640 ug/day(1). [(1) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (2) Sherlock JC; Environ Geochem Health 9: 43-7 (1987)].

Results for the FDA's Total Diet Study including data for adult diet market basket samples collected from Oct 1977 through Sept 1978 in 20 cities throughout 4 geographical areas (240 composites): 64% had residues of lead ranging from 0.01-0.40 ppm contributing to a daily intake of 79.3 and 95.1 ug of lead in FY77 and FY78 respectively(1). Lead was found in all 12 food classes including: dairy products 0.01-0.20 ppm, 0.014 ppm avg; meat fish and poultry 0.02-0.10 ppm, 0.031 ppm avg; grain and cereal products 0.02-0.18 ppm, 0.055 ppm avg; potatoes 0.01-0.29 ppm, 0.046 ppm avg; leafy vegetables 0.01-0.08 ppm, 0.020 ppm avg; legume vegetables 0.05-0.40 ppm, 0.162 ppm avg; root vegetables 0.02-0.11 ppm, 0.027 ppm avg; garden fruit 0.03-0.34 ppm, 0.089 ppm avg; fruits 0.02-0.21 ppm, 0.045 ppm avg; oils, fats, and shortening 0.02-0.16 ppm, 0.020 ppm avg; sugar and adjuncts 0.02-0.15 ppm, 0.051 ppm avg; beverages 0.02-0.08 ppm, 0.018 ppm avg(1). [(1) Podrebaric DS; J Assoc Off Anal Chem 67: 176-85 (1984)].

Lead was found in 52% and 58% of the 98 and 110 composites sampled in the infant and toddler total diet study respectively, with lead concentrations ranging from 0.003-0.51 ppm. The dietary intake, including water, for infants and toddlers was 25 and 35 ug respectively for FY78(1). Lead is frequently found as an impurity in calcium nutritional supplements derived from limestone and dolomite(SRC). This lead is probably in the form of lead sulfide since lead deposits of the "replacement type" are deposited in susceptible sedimentary rock, usually limestone and dolomite(2). [(1) Podrebaric DS; J Assoc Off Anal Chem 67: 166-75 (1984) (2) Howe HE; Kirk-Othmer Encycl Chem Tech 3rd ed. NY,NY: Wiley 14: 98-139 (1981)].

For more inforation on food survey items, see ATSDR [945].

B) Concentrations or Doses of Concern in Food Items Eaten by Humans (Includes Allowable Tolerances in Human Food, FDA, State and Standards of Other Countries):

See also Tis.Fish, A) section above.

EPA REFERENCE DOSE (RfD, a "safe" dose) for chronic oral exposure from EPA 1996 IRIS database, Note from EPA [893]:

A great deal of information on the health effects of lead has been obtained through decades of medical observation and scientific research. This information has been assessed in the development of air and water quality criteria by the Agency's Office of Health and Environmental Assessment (OHEA) in support of regulatory decision-making by the Office of Air Quality Planning and Standards (OAQPS) and by the Office of Drinking Water (ODW). By comparison to most other environmental toxicants, the degree of uncertainty about the health effects of lead is quite low. It appears that some of these effects, particularly changes in the levels of certain blood enzymes and in aspects of children's neurobehavioral development, may occur at blood lead levels so low as to be essentially without a threshold.

There is no FDA action level for lead in fish, but an edible tissue guideline previously often cited as an upper limit for lead in foods was 0.3 mg/kg [27,66].

The FDA action level of lead is 7.0 ug/ml of leaching soln for pottery (ceramics) flatware (avg of 6 units); 5.0 ug/ml of leaching soln for small hollowware (any one of 6 units); 2.5 ug/ml of leaching soln for large hollowware (any one of 6 units); 7.0 ug/ml of leaching soln if product intended for use by adults for silver-plated hollowware (avg of 6 units); and 0.5 ug/ml of leaching soln if product intended for use by infants and children for silver-plated hollowware (one or more of 6 units). /Inorganic lead/ [FDA; Action Levels for Poisonous or Deleterious Substances in Human Food and Animal Feed p.9 (1982)] [366].

Acceptable Daily Intake [366]:

Tolerable intake of lead for preschool children should be less than the 3 mg/wk recommended provisionally for adults ... . /Inorganic lead/ [WHO; Environ Health Criteria: Lead p.127 (1977)].

Average Daily Intake [940]:

AIR INTAKE: (Assume 1 ug/cu m) 20 ug, 40 ug adult(4), 6 ug child(4); WATER INTAKE: (Assume 15 ug/l) 30 ug, 12 ug adult(4), 13 ug child(4); FOOD INTAKE: (Assume 100-500 surface contamination(4), 170 ug child which includes 40 ug from surface contamination and 48 ug from dirt on hands(4). It has been estimated that adult Americans absorb 29 ug of Pb daily from atmospheric and dietary sources with approximately 9% of one's Pb intake being absorbed(3). Results of a study of lead in two low income groups, rural black and urban Hispanics of Mexican-American ancestry showed that Pb ingestion by these groups (means of subgroups 16.4-82.1 ug/day) were no greater than and is probably less than that of the general population(3). The average dietary intake in the U.K. is about 30 ug(2). Fruits and vegetables exposed to source emissions of lead may be appreciably contaminated. One researcher determined that the daily ingestion of lead in the food of peasants living near a smelter was 670-2640 ug(1). [(1) World Health Organization; Envrionmental Health Criteria 3. Lead. Geneva, Switzerland: World Health Organization (1977) (2) Sherlock JC; Environ Geochem Health 9: 43-7 (1987) (3) Prevost RJ et al; Measurement of Cadmium, Lead. Zinc, and Calcium in selected polulations in the United States USEPA-600/S1-84-021 (1985) (4) Bennett BG; IARC 71: 115-28 (1986)] [940].

Calculated daily intake of lead from food in diet of 18 yr old male is 233 ug. [WHO; Environ Health Criteria: Lead p.52 (1977)] [940].

C) Body Burden Residues in Humans: Typical, Elevated, or of Concern Related to the Well-being of Humans:

At present the average blood-lead levels in an urban adult are estimated at 75 to 100 times the natural level [335].

Lead concentrations (ug/g wet weight) in human bone (tibia) were measured noninvasively in vivo employing an x-ray fluorescence technique. Forty-five workers who had been chronically exposed to lead (mean duration of employment 20.9 yr) were found to have a mean bone lead content of 52.9 ug/g wet weight (range 0-198 ug/g) [940].

The reproductive ability of men was ... shown to be adversely affected by moderate absorption of lead. Concn of lead in blood greater than 52 ug/100 ml were associated with a high frequency of altered spermatogenesis. Disorders of sexual dynamics were evident with blood lead values greater than 41 ug/100 ml. Among the workers with the highest concn of lead in blood (mean 74.50 + or - 26 ug/100 ml), 75% were judged to be hypofertile, 50% being even infertile. It was not possible, however, to demonstrate a reliable association between lead absorption in these men and the number of normal pregnancies per couple, or the frequency of miscarriages, ectopic pregnancies, or premature births. Nevertheless, these results were interpreted to indicate that lead clearly has a direct toxic action on the male gonads at relatively low levels of absorption. /Inorganic lead/ (Lancranjan I et al; Arch Environ Health 30: 396-401 (1975) as cited in NIOSH; Criteria Document: Inorganic Lead p.XI-52,1978, DHEW Pub. NIOSH 78-158) [940].

Body Burdens [940]:

A cross-sectional study of blood lead levels in 100 inner city residents of Stockholm for the period of 1980-1984 was conducted to investigate whether recent measures undertaken in Sweden to decrease environmental exposure to lead have had any effect. Measures include replacement of lead soldered food cans and a decrease in allowable gasoline levels from 1.9 to 0.7 mmol lead/l gasoline. The average blood lead levels of all the subjects examined were 0.37, 0.26, and 0.25 umol/l for 1980, 1983, and 1984, respectively. The mean change in individual levels between 1980 and 1984 was 0.12 umol/l, which corresponds to an average individual decrease in blood lead of 34%. The decrease occurred mainly during the period 1980-1983 (0.11 umol/l) and was statistically significant for this period ($p<0.01$). Age, sex, and change of residence during the observation period did not influence the results. [Elinder CG et al; Scand J Work Environ Health 12: 114-20 (1986)].

The body burden of the average adult in the USA is reported to be not less than 100 mg and not more than 300 mg. Ninety-five percent of the total body burden is stored in bone. /Inorganic lead/ [Committee on Biological Effects of Atmospheric Pollutants, Lead, National Academy of Sciences, Washington, DC (1972)].

There is fairly good correlation between degree of lead intoxication & body burden of lead, main exception being where there has been high exposure over short period. /INORGANIC LEAD/ [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer, 1972-1985. (Multivolume work).,p. V1 47 (1972)].

Body burden of lead increases from birth to old age. /Inorganic lead/ [Barry PSI; Brit J Ind Med 32: 119-39 (1975) as cited in WHO; Environ Health Criteria: Lead p.81 (1977)].

Total lead content in 60-70 year old men may reach more than 200 mg with about 95% residing in the bone(1). The mean lead level in the milk of occupationally unexposed women in Malaysia was 43.5 ug/l(5). Human milk 12 ug/l and <5 ug/l in 2 studies(1). Blood lead 100-250 ug/l in occupationally unexposed rural and urban populations in the majority of studies(1). Blood levels of German children 0-1 yr 33 ug/l, 6-8 yr 115 ug/l. Children aged 1-5 in rural U.S. counties 228 ug/l avg(1). Urban children may display blood lead levels >590 ug/l(1). Blood levels in children in a Texas city with smelter >400 ug/l(1). Human tissue from an industrial city and rural area in northwest Germany 4.53 ppm avg and 2.74 ppm avg respectively(2). Average blood levels in the EPA sponsored NHANES II survey from Feb 1976 to Feb 1980 fell from 158 to 98 ug/l, during which time the semiannual use of lead in gasoline dropped from 105 to 48 thousand tons(3). Mean lead levels in whole blood and urine of subgroups of low income rural black and urban Hispanics of Mexican-American ancestry ranged from 39.2-138.8 ug/l and 1.9-8,5 ug/l(4). Levels were highest for male rural blacks and lowest from urban female Hispanics. [(1) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1977) (2) International Register of Potentially Toxic Chemicals; p. 171-77 United Nations Environment Program Geneva Switzerland (1979) (3) Schwartz J et al; Cost and Benefits of Reducing Lead in Gasoline USEPA-230-03-84-005 (1984) (4) Prevost RJ et al; Measurement of Cadmium, Lead. Zinc, and Calcium in selected populations in the United States USEPA-600/S1-84-021 (1985) (5) Ong CN et al; Arch Disease Childhood 60: 756-9 (1985)].

Lead is also excreted in human milk in concentrations ... up to 12 ug/l. /Inorganic lead/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 314].

Seventy-five workers in 27 radiator repair shops were interviewed and tested for blood Pb and free erythrocyte protoporphyrin levels. Fifty-six of the workers were actual radiator mechanics (repairing and soldering radiators) and 19 workers performed other jobs, such as trucking and delivery. No totally unexposed controls were tested. The mean blood Pb level found in the radiator mechanics was 37.1 +/- 13.8 ug/dl (range 16-73 ug/dl), (39% had blood Pb levels >40 ug/dl and 16% had levels >50 ug/dl). The mean blood Pb level for the other workers was 21.6 +/- 11.2 ug/dl (range 7-51 ug/dl). Multiple regression analysis showed that the most significant variable contributing to an increase in the blood Pb level was the number of radiator repair stations within the shop. Mean zinc protoporphyrin levels (used as a screen for lead intoxication) was 40.6 ug/dl for the radiator mechanics and 15.6 ug/dl for the other workers. One 32 yr-old radiator mechanic whose Pb level was 72 ug/dl, reported with symptoms of fatigue, headache, dizziness, nausea, and abdominal and back pains. [Goldman RH et al; N E J Med 317 (4): 214-8 (1987)].

A group of 109 male workers occupationally exposed to both antimony (as Sb_2O_3) and lead in the glass-producing industry were examined for levels of these metals in whole blood and urine. The workers were divided into four groups based on specific work activities: melter (n= 32), batch mixer (n= 45), craftsman (n= 8), and glass washer (n= 24). Blood and urine samples were collected at the end of a shift. Concentrations of lead in the blood ranged from 70 to 680 ug/l. Median values for melters, batch mixers, craftsmen, and glass washers were 220, 340, 275, and 170 ug/l, respectively. A significant difference ($p< 0.05$) was found only between the batch mixers and glass washers. The urinary lead values ranged from 7 to 110 ug/l with median values for melters, batch mixers, craftsmen, and glass washers of 35, 43, 24, and 42 ug/l, respectively. A significant difference was found between only the batch mixers and craftsmen ($p< 0.05$). Exposure rates for lead were not given. [Ludersdorf R et al; Int Arch Occupat Environ Health 59 (5): 469-74 (1987)].

The portions of the Pb body burden found in soft tissues of children and adults are 27.5% and 5% respectively. Hence, a higher fraction of a child's body burden of Pb is available to produce toxic effects in soft tissues. (USEPA; Ambient Water Quality Criteria Doc: Lead p.C1-9, 1984, EPA 440/5-84-027) [940].

Tis.Misc. (Other Tissue Information):

Lead contamination of livestock and poultry is primarily derived from atmospheric lead [963]. Grazing animals take up lead from feed. Lead concentrations in feed are related to the atmospheric deposition rate. Therefore, if the concentration of lead in the atmosphere is high the concentration of lead in the feed will be high.

Other factors that may contribute to the accumulation of lead in domesticated animals from both atmospheric and nonatmospheric sources include direct soil ingestion, ingestion of processed food, and lead added to the meat during processing. However, the transfer of soil lead is generally quite small relative to the later two sources [963].

For a couple of species of New Zealand plants, concentration of lead is soils correlated with concentrations in twigs [951].

Interesting newsmedia commentary on environmental decision making vs. historical deliberations on tetraethyl lead (statments neither confirmed nor repudiated independently, source: RACHEL'S ENVIRONMENT & HEALTH WEEKLY #539, March 27, 1997, http://www.monitor.net/rachel):

> An issue 70 years ago was whether General Motors (GM), Standard Oil of New Jersey, and the DuPont corporation should begin putting tetraethyl lead into gasoline. At that time, the toxicity of lead had been well-established for 100 years,[4,pg.76] but a new gasoline additive was needed by the automobile and petroleum corporations and lead suited their purposes.[4,pg.6]
>
> In 1923, the automobile industry was booming. In 1916, 3.6 million cars were registered; in 1920 the number was 9.2 million and by 1925 it would be 17.5 million.[5] Prior to 1920, Ford had grabbed the lion's share of the market by mass producing the standardized Model T but General Motors developed a successful strategy for overtaking Ford. In the words of GM chairman Alfred Sloan, GM created demand "not for basic transportation but for progress in new cars for comfort, convenience, power and style."[6,pg.344] In the search for greater horsepower, GM developed higher-compression engines. However, with ordinary gasoline, high-compression engines developed an annoying "knock" because the gasoline burned explosively. So GM chemists searched systematically for a gasoline additive that would make gasoline burn evenly in high-compression engines, eliminating "knock." On February 1, 1923, in Dayton, Ohio, leaded gasoline went on sale for the first time.[4,pg.90]
>
> Leaded gasoline was produced by the Ethyl Corporation --a joint venture of GM, Standard Oil of New Jersey, and DuPont.[4,pg.105] Tetraethyl lead is at least as toxic as normal metallic lead,

but with this difference: tetraethyl lead is a volatile liquid, readily absorbed through the lungs and skin. Almost immediately, workers began to be poisoned. At Standard Oil's Bayway, N.J., facility, 5 workers died and 35 suffered severe palsy, tremors, hallucinations and other serious symptoms of nerve damage. Several of these workers spent the rest of their lives confined in insane asylums. One of the supervisors at the Bayway facility told the NEW YORK TIMES that "these men probably went insane because they worked too hard."[6,pg.345] At DuPont's Deepwater, N.J., plant, more than 300 workers were poisoned by tetraethyl lead. DuPont workers dubbed the plant "The House of Butterflies" because so many workers had hallucinations of insects. The NEW YORK TIMES reported that 80% of the workers at DuPont's lead plant were poisoned.[6,pg.347]

These industrial poisonings created headlines nationwide and public health officials became apprehensive about the prospect of treating billions of gallons of gasoline with tons of tetraethyl lead, which would be released into the air along with the exhaust fumes.

In 1924, General Motors and DuPont paid the federal Bureau of Mines to investigate the hazards of lead from automobile exhausts. [4,pg.25] The Bureau of Mines agreed to investigate and accepted a stipulation by Charles Kettering, president of the Ethyl Corporation: "...the Bureau [shall] refrain from giving out the usual press and progress reports during the course of the work, as [Ethyl Corporation] feels that the newspapers are apt to give scare headlines and false impressions before we definitely know what the influence of the material will be."[6,pg.345] Further, the Bureau agreed never to mention the word "lead" in its reports but to use only the trade name "Ethyl." Further, Ethyl Corporation insisted that "all manuscripts, before publication, will be submitted to the Company for comment, criticism, and approval."[6,pg.345] The Bureau of Mines agreed. During an 8-month period, the Bureau exposed monkeys, dogs, rabbits, guinea pigs, and pigeons to automobile exhaust on 188 occasions, half for 3 hours at a time and half for 6.

The Bureau reported finding no evidence of lead poisoning, and no accumulation of lead, in any of the animals.[4,pg.27] The NEW YORK TIMES reported the Bureau's results November 1, 1924, with this headline: "No Peril to Public Seen in Ethyl Gas/

Bureau of >Mines Reports After Long Experiments with Motor Exhausts/ More Deaths Unlikely."[6,pg.346] The TIMES also reported that "the investigation carried out indicates the danger of sufficient lead accumulation in the streets through the discharging of scale from automobile motors to be seemingly remote."[6,pg.346]

Despite this reassuring news, public health authorities remained concerned about the prospect of putting millions of pounds of toxic lead in the form of a fine dust into the streets of every American city and town.

Therefore, the U.S. Public Health Service convened a conference May 20, 1925 to discuss the issue. Just before the conference, Standard Oil announced it was temporarily suspending the sale of leaded gasoline.

Here in summary is what the conference revealed: ** Charles F. Kettering, president of the Ethyl Corporation, pointed to the unique properties of tetraethyl lead as an anti-knock additive. Other additives gummed up the engine, but the lead compounds passed out through the exhaust, leaving the engine clean, he said.[4,pg.8]

** Mr. Kettering said American automobiles would burn 15 billion gallons of gasoline in 1926.[4,pg.9]

** Lt. Col. E.B. Vedder, chief of the U.S. Chemical War Service, said lead is a cumulative poison.[4,pg.31]

** Robert Kehoe, a medical consultant to GM and to the Ethyl Corporation, confirmed that "in sublethal dose, lead is cumulative."[4,pg.50]

** Joseph C. Aub of Harvard University emphasized that "lead is an accumulative poison".[4,pg.72]

** Robert Kehoe established that lead passed through the placenta of a rabbit, contaminating unborn rabbits with lead if the pregnant mother were exposed.[4,pg.52]

** Robert Kehoe established that pregnant rabbits exposed to lead had abortions, miscarriages, and premature births.[4,pg.54]

** Robert Kehoe, the industry's consultant, acknowledged that poisoning by tetraethyl lead is the same as other lead poisoning: "In those cases in which absorption is present over a long period of time the symptoms do not differ strikingly from the symptoms >in chronic lead poisoning....," Kehoe said.[4,pg.80]

** Alice Hamilton of Harvard University --one of the country's acknowledged experts on lead poisoning --said, "...lead is a slow and cumulative poison and... it does not usually produce striking symptoms that are easily recognized."[4,pg.98]

** E.R. Hayhurst from Ohio State University made the point that serious lead poisoning "is most apt to occur in cases using lead in the form of a dust."[4,pg.89]

** R.R. Sayers of the U.S. Bureau of Mines described experiments in which 5 times the normal amount of tetraethyl lead was added to gasoline and animals were forced to breathe the exhaust fumes. "The dust from the floor of the test chamber contained 10.5% of lead within six months without cleaning," Sayers said.[4,pg.27]

** Joseph Aub of Harvard calculated that 15 billion gallons of leaded gasoline would release 50 thousand tons of lead dust each year.[4,pg.72]

** David Edsall, dean of the Harvard School of Public Health, summarized as follows:

"The only conclusion that I can draw from the data presented here to-day is that in the question of the exhaust... I can not escape feeling that a hazard is perfectly clearly shown thus far by what has been reported here to-day, that it appears to be a hazard of considerable moment, and that the only way that it could be said that it is a safe thing to continue with that hazard would be after very careful and prolonged and devoted study as to how great the hazard is."[4,pg.77]

The conference resolved unanimously that the Surgeon General should appoint a seven-member panel to determine the dangers of leaded gasoline by January 1, 1926, and, until then, the sale of leaded gasoline should remain suspended. At the time, it seemed like a great victory for the principle of precautionary action. But it was not to be.

[To be continued] --Peter Montague
(National Writers Union, UAW Local 1981/AFL-CIO)

=============== [1] Thomas M. Crisp and others, SPECIAL REPORT ON ENVIRONMENTAL ENDOCRINE DISRUPTION: AN EFFECTS ASSESSMENT AND ANALYSIS [EPA/630/R-96/012] (Washington, D.C.: Environmental Protection Agency, Risk Assessment Forum, February, 1997). Available via the internet: http://www.epa.gov/ORD/webpubs/endocrine/ .

[2] See RACHEL'S #249, #263, #264, #279, #323, #334, #372, #377, #380, #390, #393, #405, #438, #441, #446, #447, #448, #453, #457, #462, #471, #475, #477, #485, #486, #487, #490, #491, #498, #499, #512, #536.

[3] Associated Press, "Hormone Disruptors Require Additional Study, EPA Says," NEW YORK TIMES March 14, 1997, pg. A26.

[4] Treasury Department, United States Public Health Service, PROCEEDINGS OF A CONFERENCE TO DETERMINE WHETHER OR NOT THERE IS A PUBLIC HEALTH QUESTION IN THE MANUFACTURE, DISTRIBUTION OR USE OF TETRAETHYL LEAD GASOLINE [PUBLIC HEALTH BULLETIN NO. 158] (Washington, D.C.: Treasury Department, United States Public Health Service, 1925). Available from William Davis at the National Archives in Washington, D.C.: (202) 501-5350. [National Archives Record Group No. 287; T27.12:158/3S1 [possibly 351?] 24/2316 Box T777. RG 287.]

[5] U.S. Bureau of the Census, HISTORICAL STATISTICS OF THE UNITED STATES, COLONIAL TIMES TO 1970, BICENTENNIAL EDITION, PART 2 (Washington, D.C.: U.S. Government Printing Office, 1975), Series Q-153, pg. 716.

[6] David Rosner and Gerald Markowitz, "A 'Gift of God'?: The Public Health Controversy over Leaded Gasoline during the 1920s," AMERICAN JOURNAL OF PUBLIC HEALTH Vol. 75, No. 4 (April 1985), pgs. 344-352.

Bio.Detail: Detailed Information on Bioconcentration, Biomagnification, or Bioavailability:

Airborne lead from automobile and industrial emissions is absorbed into the body through the lungs [335].

The concentration of lead in earthworms is correlated with soil concentrations, which is a consideration relative to birds feeding on sewage sludge amended soils [179]. A typical concentration factor for lead in soil to earthworms is 0.66, so part of the hazard to predators would be from lead gut-contents

[347].

Lead behaves like many of the alkaline earth metals (Ca, Sr, and Ba) with respect to uptake, internal distribution, and secretion [488]. Lead is a bone seeking element so chemically similar to calcium that the two are processed together [488]. In fish, lead deposits in active calcification areas such as scales, fin rays, vertebrae, and opercula [488].

Lead was one of the few contaminants for which turtle shells appeared to be efficient accumulators, a reflection of the fact that lead tends to be deposited in bone as a cumulative poison [26].

Preliminary data suggests the potential for bioaccumulation or bioconcentration of lead is high to very high for the following biota: mammals, birds, fish, mosses, lichens, algae, mollusks, crustacea, lower animals, and higher plants [83]. The best potential mediums for biological monitoring (including gradient monitoring) appear to include animal hair, mammal kidneys, mammal bones, bird feathers, bird bones, clams, lichens, mosses, algae, and higher plants [83]. Calcium deficiencies can lead to lead redistributing from bone to kidney tissues [180].

Previous reports have downplayed the ability of lead to biomagnify or bioaccumulate to high levels in biota other than bivalves such as clams [30,66]. However, Trinity River data shows that mosquitofish, softshell turtles, Texas cooter turtles, bullhead minnows, crayfish, and red-eared turtles accumulated significant amounts (>1.0 mg/kg) of lead in the Trinity River [201]. Nevertheless, lead concentrations were not higher in top of the food-chain predators like gar than they were in mosquitofish [201]. Irwin found mosquitofish to be acceptable for gradient monitoring of lead in biota of an urban river [201].

Another recent report documented that lead concentrations in crayfish and midges correlated with lead in effluent water and that exclusion of crayfish gut concentrations did not appreciably change the correlation [53].

Some trees have the capacity to accumulate large amounts of lead from contaminated soil - the tips of larch, pine, and fir contained 100 ppm lead when grown in lead mining areas with soil concentration appreciably different from the usual concentration (80,000 ppm) in most soils. However, in most cases this indicates that there is no significant bioconcentration of lead from soil into plants(1) [940].

Bioconcentration [940]:

Lead was absorbed /by fresh water field crab, Barytelphusa guerini/ through the gills and distributed by the haemolymph to hepatopancreas, muscle, and exoskeleton. Haemoymph was found to contain the highest amount of lead followed by gill, hepatopancreas, muscle, and exoskeleton. Lead bioaccumulated over the course of the study showed a high degree of organ specificity. [Tulasi SJ et al; Bull Environ Contam Toxicol 39 (1): 63-8 (1987)].

Log BCF on a wet weight basis in freshwater fish 1.38-

1.65(1.2); 4 freshwater invertebrate species 2.70-3.23(1); various saltwater bivalves, molluscs, diatoms and phytoplankton range from 1.24 after 56 days in hard clam to 3.40 in 130 days for mussels(1). Evidence suggests that lead uptake in fish is localized in the mucous on the epidermis, the dermis, and scales so that the availability in edible portions do not pose a human health danger(3). In a 38-day intertidal benthic mesocosm experiment in which there were daily additions of lead to a caisson containing sediment, seawater and fauna placed on an intertidal sand flat in the German Bight, lead uptake rates of 15 species and 2 taxa were ordered according to feeding pattern with filter feeder > deposit feeder (surface) > opportunistic feeder (deposit feeder or predator) > deposit feeder (depth)(4). Mylitis edulus in the sediment had the highest 20-day BCF of 100(4). The lead is quickly released and the rates of loss are uniformly one third the uptake rate(4). [(1) USEPA; Ambient Water Quality Criteria for Lead; pp. B-1 to B-38, C-1 to C-5 USEPA-440/5-80-057 (1980) (2) International Register of Potentially Toxic Chemicals(IRPTC); p. 171-77 United Nations Environment Program Geneva Switzerland (1979) (3) Biddinger GR, Glass SP; Res Rev 91: 103-45 (1984) (4) Schulz-Baldes M et al; Marine Biology 75: 307-18 (1983)].

Biological Half-Life [940]:

Biological half-life for lead in the bones of humans is 10 yr. /Inorganic lead/ [USEPA; The Health and Environmental Impacts of Lead: p.211 (1979) EPA 560/2-79-001].

The half-life of lead in blood is about 1 mo, and a steady state is thus achieved in about 5 mo. /Inorganic lead/ [Gilman, A.G., L.S.Goodman, and A. Gilman. (eds.). Goodman and Gilman's The Pharmacological Basis of Therapeutics. 7th ed. New York: Macmillan Publishing Co., Inc., 1985. 1606].

In humans/ with a constant daily oral input of (204)lead (Pb), a virtually constant concn of the tracer in the blood was achieved after 110 days. Upon withdrawal of the tracer from the diet, the (204)Pb concn in the blood disappeared with a half-time of approx 19 days. ... /Lead cmpd/ [Rabinowitz MB et al; Environ Health Perspect 7: 145 (1974) as cited in WHO; Environ Health Criteria: Lead p.81 (1977)].

The half-life of lead in human blood is 28 to 36 days; thus, levels of lead in blood reflect relatively recent exposure compared with levels of lead in teeth, which continue to accumulate lead over time. /Organic lead/ [DHHS/ATSDR; Toxicological Profile for Lead (Draft) p.25 (1988)].

Interactions:

Synergistic effects of lead and cadmium and additive effects of lead, mercury, copper, zinc, and cadmium have been documented for aquatic biota [29]. The many negative effects of lead on physiology and heme formation [66] increase lead's potential for synergistic or additive effects with other contaminants and with low oxygen stress.

Interactions [940]:

1. Alcohol ingestion ... may precipitate ... /intense periodic abdominal cramping symptoms as a result of its interaction with lead/. /Inorganic lead/ [Sittig, M. Handbook of Toxic and Hazardous Chemicals and Carcinogens, 1985. 2nd ed. Park Ridge, NJ: Noyes Data Corporation, 1985. 544 [940].

2. A high intake of phosphate favors skeletal storage of lead & a lower concentration in soft tissues. Conversely, a low phosphate intake mobilizes lead in bone & elevates its content in soft tissues. High intake of calcium in the absence of elevated intake of phosphate has a similar effect, owing to competition with lead for avail phosphate. Vitamin d tends to promote the deposition of lead in bone if sufficient amt of phosphate is avail; otherwise, deposition of calcium preempts that of lead. Parathyroid hormone & dihydrotachysterol mobilize lead from skeleton & augment the concn of lead in blood & its rate of urinary excretion. /INORGANIC LEAD/ [Gilman, A.G., L.S.Goodman, and A. Gilman. (eds.). Goodman and Gilman's The Pharmacological Basis of Therapeutics. 7th ed. New York: Macmillan Publishing Co., Inc., 1985. 1607 [940].

3. Lead exposure during the development of folate deficiency in male Sprague-Dawley rats resulted in alterations in 2 of the parameters diagnostic of the individual conditions. Decreases in erythrocyte mean corpuscular volume occur during lead poisoning, while increases occur during the development of folate deficiency. Significant reductions in mean corpuscular volume were observed in both the control + lead and in the low folate + lead groups. The increased mean corpuscular volume characteristic of folate deficiency was prevented by the concomitant lead exposure. Elevations in free erythrocyte protoporphyrin levels are characteristic of lead intoxication; free erythrocyte protoporphyrin levels decline during folate deficiency. Free erythrocyte protoporphyrin levels were significantly elevated only in the control + lead group. /Inorganic lead/ [Rader JI et al; Drug-Nutr Interact 1 (2): 131-42 (1983) [940].

4. Administration of ethanol (10% ad libitum in drinking water) had no effect on the toxicity of lead to rats as measured by urinary ALA excretion, renal weight, or lead concn in the kidneys, liver, or bones. /Lead cmpd/ [Mchaffey K; Environ Health Perspect 7: 107-13 (1974) as cited in WHO; Environ Health Criteria: Lead p.97 (1977) [940].

5. Minerals such as calcium, iron, zinc, & phosphorus interact

with lead & influence its lead metabolism & toxicity in mammals. ... Susceptibility of rats to lead intoxication is incr ... By low intake of calcium ... Transfer ... To newborn & weanling pups incr in calcium deficient rats ... Iron deficiency markedly incr adverse effects of lead ... . /INORGANIC LEAD/ [Venugopal, B. and T.D. Luckey. Metal Toxicity in Mammals, 2. New York: Plenum Press, 1978. 194 [940].

6. Lactose hydrolyzed milk consumption by rats fed less than 20 ug pb/g diet over 8 wk showed tissue lead concn incr in rats fed low concn of lead & milk simultaneous. Lactose was apparently the factor in milk responsible for this incr. /INORGANIC LEAD/ [BELL RR ET AL; FOOD COSMET TOXICOL 19 (4): 429-36 (1981) [940].

7. Zinc given in diet with lead protected horses against toxic effects. ... Probably, this effect was not due to inhibition of lead absorption. Zinc supplementation actually caused an incr in the lead content of liver and kidney, but a decr in the lead content of brain and bone. /Inorganic lead/ [Willoughby RA et al; Vet Rec 91: 382-83 (1972) as cited in WHO; Environ Health Criteria: Lead p.97 (1977) [940].

8. ... lead interferes ... with synaptic transmission in the peripheral nervous system and ... the effects can be reversed by calcium. /Lead cmpd/ [Kostial K, Vorik VB; Brit J Pharmacol, Chemother 12: 219-22 (1957) as cited in WHO; Environ Health Criteria: Lead p.89 (1977) [940].

9. Female Swiss mice were exposed to lead in the drinking water at concentrations ranging from 0 to 1000 ppm for 105 or 280 day periods of time. The effect of lead on urethane induced pulmonary adenoma formation was evaluated in the 105 day study. Urethane induced sleeping times observed following ip injection of urethane (1.5 mg/g) after 3 weeks of lead exposure were not altered by lead indicating that lead did not affect the rate of urethane elimination. Pulmonary adenoma formation was evaluated 84 days later. Lead exposure did not affect the number of tumors produced, nor did it alter the mean tumor diameter in the lead treatment groups. Immunosuppressive activity of lead did not enhance urethane induced adenoma formation. In the 280 day study, leukemia was observed in all treatment groups. Mortality was greater in the lead exposed mice. Mice exposed to 50 or 1000 ppm lead had 41.6% and 58.3% more deaths associated with the virus. The median survival time was also reduced in the lead exposed mice. Immunosuppressive effects of lead increased expression of the murine lymphocytic leukemia virus. [Blakley BR; J Appl Toxicol 7 (3): 167-72 (1987) [940].

10. Cultured C6 rat glioma cells were exposed to lead acetate (0, 1, 10, or 100 uM) for 3-4 days. Cells were analyzed for changes in viability and intracellular lead, iron, and copper

concentrations after lead treatment was discontinued. Lead uptake did not affect intracellular iron or copper concentrations. Unlike C6 cells, however, astroglia showed elevations of intracellular iron or copper after lead treatment. C6 cells appear to be an adequate model for selected events in glial toxicosis, such as lead stimulated protein synthesis in oligodendroglia and lead uptake in astroglia, but not lead induced alterations of intracellular copper and iron in astroglia. [Bratton GR; J Toxicol Environ Health 23 (2): 267-80 (1988) [940].

11. The distribution of iv admin lead (50 nmol/kg) was studied by means of autoradiography and impulse counting in pregnant C57BL mice (day 18 of gestation) treated orally with dithiocarbamates. Diethyldithiocarbamate, disulfiram or thiram (2X1 mmol/kg) or vehicle (gelatin) alone, was given by gavage 2 hr before & immediately after injection of lead. All the dithiocarbamates changed the distribution pattern of lead. Disulfiram had the greatest effect at 24 hr after lead. The pattern of changes in lead distribution is consistent with the formation in the body of lipid sol. Lead-dithiocarbamate complexes that pass biological barriers more easily than inorganic lead (to brain, fetus, melanocytes, etc), probably are followed by a dissociation of the complexes in the tissues. (Danielsson BR G et al; Arch Toxicol 55 (1): 27-33 , 1984) [940].

Uses/Sources:

Lead has many different uses [945]. Its most important use is in the production of some types of batteries. Other uses include the production of ammunition, various metal products (such as sheet lead, solder, and pipes), and ceramic glazes. Some chemicals containing lead, such as tetraethyl lead and tetramethyl lead, are used as gasoline additives. However, the use of these lead-containing is much less than it used to be because the last producer of these additives in the United States stopped making them in early 1991. Other chemicals containing lead are used in paint. Lead is also used for radiation shields for protection against X-rays and in a large variety of medical, scientific, and military equipment [945].

Plants take up lead from soil, groundwater, sewage sludge, biocides, and air pollution [83]. Animals take up lead from industrial sources, contaminated water, licking or preening fur or feathers, lead shot, and contaminated food [83].

Typical sources of lead in rivers include atmospheric fallout from motor vehicle and smelter emissions as well as sewage sludge, batteries, pipes, lead shot, glazes, paints, and alloys. Significant amounts of lead are also known to leach from municipal landfills [46,80]. Lead is also a common contaminant in used motor oil [75] and in sludges generated by sewage treatment plants [94]. Airborne lead is deposited on vegetation and wildlife living near highways, and some urban zoos have experienced lead poisoning [28].

Sediments can act as a sink for lead and a continuing source of lead after the original source has subsided [66]. In some areas, lead shot also ends up in sediment, and may be ingested by bottom feeding biota. Lead removals by wetlands and detention ponds receiving highway runoff is high [220]. Galena (PbS) is a common lead (ore) compound [495].

Major Uses [940]:

Construction material for tank linings, piping, equipment handling corrosive gases & liquids used in mfr of sulfuric acid, petroleum refining, halogenation, sulfonation, extraction, condensation; in mfr of tetraethyllead; for x-ray & atomic radiation protection; bearing metal & alloys; building construction; metallurgy; mfr of pigments for paints, org & inorg lead cmpd, in ceramics, plastics, electronic devices [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Used in weights & as ballast [IARC. Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man. Geneva: World Health Organization, International Agency for Research on Cancer,1972-PRESENT. (Multivolume work).,p. V23 332 (1980)].

Component of lead oxide & antimonial lead storage batteries; chem int for lead alkyls & pigments; prodn of ammunition, solder, cable covering & sheet lead; prodn of other metal products (eg, brass, pipes, caulking); other uses (eg, ballast, plating, galvanizing & annealing) [SRI].

Natural Sources [940]:

Extent of occurrence in earth's crust /is/ about 15 g/ton, also expressed as 0.002% (Depth of crust: 16 km). Occurs chiefly as sulfide in galena, other minerals /which contain lead cmpd/ include anglesite ... Cerussite ... Mimetite ... & Pyromorphite ... . [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 766].

Lead rarely occurs in the elemental state, but exists ... In a number of ores ... Also occurs in various uranium & thorium minerals, arising from radioactive decay. [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1687].

Sources contributing to airborne lead are silicate dusts, volcanic halogen aerosols, forest fires, sea salt aerosols, meteoric and meteoritic smoke, and Pb derived from the decay of radon. /Inorganic lead/ [WHO; Environ Health Criteria: Lead p.32 (1977)].

Lead enters the environment from lead-bearing minerals. The median lead concentration in the soil (to a depth of 20 cm) is 15-16 ug Pb/g soil with 95% of samples being <30 ppm(3). It is estimated that 10X10+9 kg of lead is produced in volcanic dust with an average concn of 640 ppm(3). Through erosion and leaching, lead may be transferred from the soil into surface waters and the atmosphere. However calculations indicate that the contribution of these natural sources to lead in the atmosphere is relatively small(3). The amount of lead that enters the ocean from river discharges from natural sources has been set at 17000 tons annually(2), also a relatively small contribution to lead in the aqueous environment(2). The form of lead is generally unspecified. Metallic lead is naturally occurring and is the end product of three natural radioactive elements uranium (206), thorium (208), and actinium (207)(1). [(1) Hawley GG; Condensed Chem Dictionary 10th ed pp.604-5 Von Nostrand Reinhold NY (1981) (2) World Health Organization; Envrionmental Health Criteria 3. Lead. Geneva, Switzerland. (1977) (3) USEPA; Air Quality Criteria for Lead USEPA-600-8-83-028bF (1986)].

Artificial Sources [940]:

During 1973-4 ... NIOSH conducted environmental surveys of 9 indoor firing ranges. Several sources of lead dust and fume generation were found; one, from the bullet primer, produced 25-30 mg of ... lead styphnate and lead peroxide. Another source is lead vaporization, resulting from the 2000 deg F temperature generated upon firing and fragmentation of the lead bullet. Of a total of 331 samples for airborne inorganic lead ... concentrations of lead range from 0.10 to 13.17 mg/cu m for general air samples, and from 0.01 to 34.50 mg/cu m for personal samples. ... Investigators concluded that indoor firing ranges constitute "present health hazards from lead poisoning" (due to improper ventilation control ...). /Inorganic lead/ [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1718].

Ceramic artists can be exposed to many hazardous materials, generally related to dry clays, glazes and kiln use. Glazes can contain lead, antimony, arsenic, barium, beryllium, boron, chromium, cobalt, cadmium, copper, vanadium and other materials which all have potential toxic effects. [Hart C; Journal of Environmental Health 49 (5): 282-86 (1987)].

Electric arc welding produced an average concn of 5.63 mg/cu m and oxy-acetylene welding produced 1.96 mg/cu m of lead. [NIOSH; Criteria Document: Inorganic Lead p.IV-3 (1978) DHEW Pub. NIOSH 78-158].

Lead is emitted ... from various types of melting furnaces (basic oxygen, open hearth, and electric) in the steel and grey iron (cupola and electric) industries. /Inorganic lead/

[USEPA; The Health and Environmental Impacts of Lead: p.152 (1979) EPA 560/2-79-001].

Mining, smelting, and refining as well as the manufacture of lead containing cmpd and goods, give rise to lead pollution. /Inorganic lead/ [WHO; Environ Health Criteria: Lead p.34-5 (1977)].

Lead (Pb) emissions from stacks and slag heaps of primary and secondary Pb smelters. /Inorganic lead/ [Nat'l Research Council Canada: Effects of Lead in the Canadian Envir p.75 (1978) NRCC No.0316-0114].

Coal fired power plants, ceramic manufacturing, and mine seepage. [Nat'l Research Council Canada: Effects of Lead in the Canadian Envir p.76 (1978) NRCC No.0316-0114].

Lead is the fifth most important metal in the USA economy in terms of consumption. Of this approximately 85% of the primary lead is produced domestically and 40-50% is recovered and recycled(1). Eighty eight percent of the lead mined in the US comes from seven mines in the New Lead Belt in southeastern Missouri; the rest coming from eight mines in Colorado, Idaho, and Utah(2,3). Three of the six USA lead smelters are from this region, the others are located in Idaho, Montana, and Texas(2). Metallic lead is produced by smelting ore concentrates or scrap metal; lead or its compounds can enter the environment during its mining, ore processing, smelting, refining, use, recycling or disposal. In the USA in 1984, 71.7% of the 1.2 million metric tons of lead metal consumed was used for batteries, 6.5% was used as an intermediate for gasoline antiknock additives, 6.4% for pigments and ceramics, 4.0% for ammunition, 2.0% for solder, 1.0% for cable covering, 0.3% for caulking, 2.3% for pipe and sheet, 0.18% for type metal, 0.6% for brass and bronze, 0.4% for bearings, 4.6% for miscellaneous uses(1). Estimates of lead dispersal into the environment indicate that the atmosphere is the major initial recipient(1). [(1) USEPA; Air Quality Criteria for Lead USEPA-600-8-83-028bF (1986) (2) USEPA; Industrial Process Profiles for Environmental Use. Chpt 27. USEPA-600/2-80-168 (1980) (3) Howe HE; Kirk-Othmer Encycl Chem Tech 3rd ed. NY, NY: Wiley 14: 98-139 (1981)].

Of the 39 million tons of estimated total US emissions in 1984, the estimated allocation between sources is (source category, %): gasoline combustion, 89.4; waste oil combustion 2.0; solid waste disposal 0.9; coal combustion 0.7; oil combustion, 0.3; gray iron production, 0.1; iron and steel production, 1.1; secondary lead smelting, 0.7; primary copper smelting, 0.1; ore crushing and grinding, 0.3; primary lead smelting, 2.8; zinc smelting, 0.3; other metallurgical, 0.1; lead alkyl manufacturing, 0.6; lead acid battery manufacture, 0.3; portland cement production, 0.2; miscellaneous, 0.1(1). The form of lead released into the environment during the production and use of elemental lead is generally not reported in monitoring studies. However the chemical composition of baghouse effluent from smelting and refining operations has been examined in one study which found that elemental Pb composed 15-20% of the emissions in some cases; with PbS, PbSO4, and PbO.PbSO4 also being present(2). The median particle size of Pb emissions was 1.5 um with a geometric standard deviation of 5 um(2). Because 86% of lead-containing aerosols are <10 mu distribution, their fallout rate is low and long-range transport should occur. [(1) USEPA; Air Quality Criteria for Lead USEPA-600-8-83-028bF (1986) (2) Corrin ML, Natusch DFS; pp.7-31 in Lead in the Environment; Boggess WR ed National Science Foundation NSF/RA-770214 (1977)].

In addition to air emissions from smelters and refineries, lead may also be discharged in wastewater and runoff from production and use facilities. An analysis of sediment cores of lakes in Ontario and Quebec that are remote from point sources of Pb indicate that the lead burden is primarily due to long-term atmospheric deposition beginning around 1850(1). The deposition is highest in South-Central Ontario where the lake burdens ranged from 312-432 mg/sq m and decreased in an eastward direction and to the north where the lowest deposition occurred, 31-42 mg/sq m. Because of its good corrosion resistance, the use of metallic lead should not lead to large release of lead into the environment. However, some dissolution occurs from lead water pipe or soldered cans especially where the water is soft or acidic. Wear of lead-containing components will also contribute to lead releases(SRC). [(1) Evans RD, Rigler FH; Water Air Soil Pollut 24: 141-51 (1985)].

Lead producing industry (est releases to the environment): primary lead: 893 ton/yr (atmosphere), 200-500 ton/yr (waste water), 21,000 ton/yr (land); secondary lead: 750 ton/yr (atmosphere), 3,260 ton/yr (land); secondary brass and bronze: 47 ton/yr (atmosphere), 10 ton/yr (waste water), 460 ton/yr (land). Lead consuming industries (est releases to the environment): battery manufacture: 82 ton/yr (atmosphere), 1-340 ton/yr (waste water), 40 ton/yr (land) lead alkyl manufacture: 1000 ton/yr (atmosphere), 60 ton/yr (waste water); lead oxides and pigments: 112 ton/yr (atmosphere), 200 ton/yr (land); lead stabilizers: 40 ton/yr (atmosphere), 40 ton/yr (land); cable covering: 113 ton/yr (atmosphere); type metal: 435 ton/yr (atmosphere); can soldering: 60 ton/yr (atmosphere); ceramics: 600 ton/yr (atmosphere). Indirect sources (est releases of lead to the environment); gasoline distribution: 420 ton/yr (atmosphere); gasoline combustion: 122,000 ton/yr (atmosphere); waste oil disposal: 3,400 ton/yr (atmosphere), 4,600 ton/yr (land); coal combustion: 225 ton/yr (atmosphere), 4,275 ton/yr (land); oil combustion: 100 ton/yr (atmosphere); cement manufacture: 312 ton/yr (atmosphere); iron and steel manufacture: 605 ton/yr (atmosphere); grey iron products: 1,080 ton/yr (atmosphere); ferro alloy production; 30 ton/yr; solid waste incineration: 1,170 ton/yr (atmosphere); sludge disposal: 5 ton/yr (atmosphere), 2,400 ton/yr (land). /Lead and lead cmpd/ [USEPA; The Health and Environmental Impacts of Lead: p.122 (1979) EPA 560/2-79-001].

Lead poisoning can result when curious animals ingest lead based paints (either old dry paint or paint from "empty" paint cans), glazier's putty or other caulking materials, used crankcase oil, greases, linoleum, leaded gasoline ... solder, roofing materials, asphalt, or industrial effluents in streams or on forage. Grass near busy highways may contain toxic amounts of lead from auto exhausts. Licking of discarded storage batteries can also result in lead poisoning. Water from lead plumbing or glazed crockery pots may contain toxic amounts. ... Natural sources of lead such as galena or soils are not particularly toxic but can add to the total body burden. Milk secreted from lead poisoned animals can be dangerous for the young animal. Paint seems to be a common source of lead in poisoned animals. In addn, cattle & calves are often poisoned by ingesting crankcase oil drained from internal combustion engines. The farm dump is often a smorgasbord of poisons for animals that gain access to it. /Lead and inorganic lead compounds/ [Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1005].

Lead Concentrations in other sources [366]:

1. Cigarettes 21-84 ug/cigarette of which 1.0-3.3 ug/cigarette is inhaled(1). Food wrappings 1400 to 28,700 ppm(1) 8% of oil- based paints and 1% of water-based paints contain > 0.5% lead(2). Dry fallout in Palo Alto, CA - freeway, residential, and foothills is 0.92, 0.24 and 0.153 mg/wk sq-ft respectively(3). Avg lead content of gasoline: premium grade 600 ug/ml, regular grade 494 ug/ml, low-lead grade 134 ug/ml(4). Dust and backdrop sand from an indoor shooting range contained 57 and 13% lead, respectively(5). Typical southeastern Missouri lead concentrate contains 75.5% Pb, while western concentrate contains 45-6% lead(5). Ten percent of homes in a national survey (5228 homes) in the United Kingdom had floor dust containing >200 ppm of lead(6). National Municipal Sewage Sludge Survey (30 sludges in 23 US cities): 80.0-676 ppm dry wt(7). [(1) IARC; Monograph Some Metals and Metallic Compounds 23: 325-415 (1980) (2) USEPA; Air Quality Criteria for Lead; p. 7-1 to 7-17 USEPA-600/8-77-017 (1977) (3) USEPA; Air Quality Criteria for Lead; p. 6-1 to 6-28 USEPA-600/8-77-017 (1977) (4) Piver WT; Environ Health Perspect 19: 247-59 (1977) (5) Olmez I et al; Environ Toxicol Chem 4:447-52 (1985) (6) Thomas JFA et al; Heavy Met Environ, 5th Int Conf 1: 317-20 (1985) (7) Mumma RO et al; Arch Environ Contam Toxicol

13: 75-83 (1984)].

Forms/Preparations/Formulations:

Radionuclides:

The symbol for Lead-210 is 210Pb, the atomic number is 82, the half-life is 22.3 years, and beta emission is the major form of decay [674].

The symbol for Lead-211 is 211Pb, the atomic number is 82, the half-life is 36.1 minutes, and beta emission is the major form of decay [674].

The symbol for Lead-212 is 212Pb, the atomic number is 82, the half-life is 10.6 hours, and beta emission is the major form of decay [674].

The symbol for Lead-214 is 214Pb, the atomic number is 82, the half-life is 26.8 minutes, and beta emission is the major form of decay [674].

Formulations/Preparations [940]:

Grade: high purity (less than 10 ppm impurity); pure (99.9+); Powdered (99% pure); pig lead; paste. Forms available: ingots, sheet, pipe, shot, buckles or straps, grids, rod, wire, etc; paste; powder; singel crystals. [Sax, N.I. and R.J. Lewis, Sr. (eds.). Hawley's Condensed Chemical Dictionary. 11th ed. New York: Van Nostrand Reinhold Co., 1987. 687].

See also: Laboratory Section below for discussion of total vs. Acid Soluble Metals.

Chem.Detail: Detailed Information on Chemical/Physical Properties:

Solubilities [940]:

Insol (sic, actually "relatively insoluble") in hot or cold water; sol in nitric acid, hot concn sulfuric acid [Weast, R.C. (ed.) Handbook of Chemistry and Physics, 68th ed. Boca Raton, Florida: CRC Press Inc., 1987-1988.,p. B-99].

Solubilities [945]:

Water: Insoluble (sic, actually "relatively insoluble")
Nitric acid: Soluble
Hot concentrated sulfuric acid: Soluble
Organic solvent(s): Insoluble (sic, actually "relatively insoluble")

Boiling Point [940]:

1740 DEG C [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Melting Point [940]:

327.4 DEG C [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Molecular Weight [940]:

207.20 [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Density/Specific Gravity [940]:

11.34 AT 20 DEG C/4 DEG C [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Heat of Vaporization [940]:

206 CAL/G AT 1740 DEG C [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Color/Form [940]:

BLUISH-WHITE, SILVERY, GRAY METAL, LUSTROUS WHEN FRESHLY CUT; CUBIC, CRYSTAL STRUCTURE [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Spectral Properties [940]:

INDEX OF REFRACTION: 2.01 [Weast, R.C. (ed.) Handbook of Chemistry and Physics, 68th ed. Boca Raton, Florida: CRC Press Inc., 1987-1988.,p. B-99].

Vapor Pressure [940]:

1.77 MM HG AT 1000 DEG C [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Viscosity [940]:

VISCOSITY OF MOLTEN LEAD 3.2 CENTIPOISES AT 327.4 DEG C, 2.32 AT 400 DEG C, 1.54 AT 600 DEG C) & 1.23 AT 800 DEG C [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

Other Chemical/Physical Properties [940]:

Very soft & malleable, easily melted, cast, rolled, extruded; density at melting point: 10.65; Resistivity (uohm/cm) 20.65 At 20 deg c, 27.02 At 100 deg c, 54.76 At 320 deg c, & 96.74 At 330 deg c; thermal conductivity from 0.083 At 50 deg c to 0.077 At 225 deg c; 4 natural isotopes: 204 (1.4%), 206

(25.2%), 207 (21.7%), & 208 (51.7%); Heat of capacity: 0.031 Cal/g @ 20 deg c; hardness 1 on mohs's scale; brinell hardness (high purity lead) 4.0; Attack by pure water, weak organic acids in presence of oxygen [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 776].

VAPOR PRESSURE: 10 MM HG AT 1162 DEG C; 100 MM HG AT 1421 DEG C; 400 MM HG AT 1630 DEG C [Sunshine, I. (ed.). CRC Handbook of Analytical Toxicology. Cleveland: The Chemical Rubber Co., 1969. 706

Fate.Detail: Detailed Information on Fate, Transport, Persistence, and/or Pathways:

Environmental Fate [940]:

TERRESTRIAL FATE: Lead is a extremely stable metal, although it dissolves in acid. While some corrosion may be expected in soil, generally an inert coat of an insoluble salt will form and limit further corrosion. It is expected to convert to more insoluble forms such as $PbSO_4$, $Pb_3(PO_4)_2$, PbS, and PbO(1). It also forms complexes with organic matter and clay minerals that limits its mobility. Concentrations of Pb in soil solution reach a minimum between pH 5 and 6 and increase below pH 4 to 5 and above pH 6 to 7, because metal-organic complexes form in this pH range(2). Only a small fraction of lead in lead contaminated soil appears to be in water-soluble form, 0.2-1% according to one report, although the fraction soluble in EDTA ranged from 43-67% of the total lead in soil(3). The EDTA extractable material should include largely the chelated metal ions held in the soil organic and organomineral complexes although there is some evidence that the metal adsorbed on colloidal surfaces such as insoluble inorganic compounds may also be extracted(3). When 500 ppm Pb was added to soil as the soluble chloride, it became insoluble within an hour of contact with the soil, this insolubility lasted the duration of a 42-day experiment. After 42 days 0.7 and 70% were in the water-soluble and EDTA-soluble fractions, respectively(3). The percentage of lead in the water-soluble and EDTA-extractable fraction was similar when the insoluble PbO oxide was added to soil rather than the soluble chloride(3). [(1) USEPA; Health Effects Assessment for Lead. USEPA 540/1-86-055 (1984) (2) Bruemmer GW et al; Z Pflanzenernaehr Bodenk 149: 382-98 (1986) (3) Khan DH, Frankland B; Environ Pollut (B) 6: 15-31 (1983)].

AQUATIC FATE: If released into water, metallic lead will simply sink into the sediment. Surface layers of insoluble salts may form and protect the surface from further corrosion. In the dissolved state, it will form ligands, the dominant ones varying with pH(2). In freshwater systems, the most important ligands are HCO_3, CO_3, OH and $(OH)_2$, whereas in seawater they are Cl, CO3, (OH), (OH)2, Cl2, and Cl3(2). A characteristic of lead is its tendency to form compounds of low solubility with the major anions of natural water. As a result natural concentrations of lead in lead-ore deposits do not move appreciably in ground or surface water but rather any dissolved lead will tend to combine with carbonate or sulfate ions to form insoluble lead carbonates or sulfates or be absorbed by ferric hydroxide(1). [(1) USEPA; Air Quality Criteria for Lead; pp. 6-1 to 6-28 USEPA-600/8-77-017 (1977) (2) Long DT, Angino EE; Geochim Cosmochim Acta 41: 1183-91 (1977)].

AQUATIC FATE: Precipitation has been shown to be important(2), at relatively high pH. The amount of lead that can remain in solution in water is a function of the pH of the water and the dissolved salt content which is about 30 ug/l in hard water (pH > 5.4) and about 500 ug/l in soft water (pH <5.4)(1). Much of the lead carried by river water is in the form of suspended solids. One study of the distribution of lead between filtrate and solids in stream water from urban and rural areas reported the ratio of lead in suspended solids to that in filtrate varied from 4% in rural areas to 27% in urban areas(1). [(1) USEPA; Air Quality Criteria for Lead; pp. 6-1 to 6-28 USEPA-600/8-77-017 (1977) (2) Callahan MA et al; Water-related Environmental Fate of 129 Priority Pollutants Vol 1. USEPA-440/4-79-029a 13-1 to 13-19 (1979)].

AQUATIC FATE: Sorption also appears to be an important process in removing lead from both fresh and estuarine natural waters into sediment(1). The amount adsorbed depends on parameters such as the availability of ligands, pH, redox conditions, salinity, iron concentration, composition of dissolved particulate matter and sediment, and lead concentration(1). Lead is adsorbed by polar particulate matter as is evidenced by its dominance in sediment of specific gravity 2.0-2.9, where the clay fraction is found. It is almost absent from less dense sediment, characterized by organic matter not active in complex formation or denser fractions, characterized by precipitation(1). Another study showed that the organic content of the bottom mud was the most significant factor affecting adsorptivity(2). [(1) Callahan MA et al; Water-related Environmental Fate of 129 Priority Pollutants Vol 1. USEPA-440/4-79-029a p. 13-1 to 13-19 (1979) (2) Tada F, Suzuki S; Water Res 16: 1489-94 (1982)].

AQUATIC FATE: Biomethylation of lead by benthic microorganisms can lead to its remobilization and reintroduction into the aqueous environment compartment. In a 38-day intertidal benthic mesocosm experiment in which there were daily additions of lead to a caisson containing sediment, seawater and fauna placed on an intertidal sand flat in the German Bight, the lead equally distributes between the dissolved and particulate matter in the water column during high tide with the levels decreasing during ebb tide due to exchange with the sediment, porewater and infauna(1). The lead accumulated primarily in the uppermost cm of sediment(1). [(1) Schulz-Baldes M et al; Marine Biology 75: 307-18 (1983)].

AQUATIC FATE: Cycling of Pb in estuaries involves a complex exchange between dissolved and particulate phases. Particulate speciation studies of Pb flowing from a French river to the sea showed that the carbonate-bound and exchangeable Pb decreased while bound Fe- Mn oxides and organic Pb increased(2). Mobilization of Pb occurred in the lower estuary where particles are depleted in Pb, transported above the salt intrusion and recycled to the tidal estuary by tidal currents(1). When lead sulfide in sewage effluent is discharged into seawater, the lead will be diluted and oxidized leading to the dissolution of the sulfide solid(1). [(1) Morel FMM et al; Environ Sci Technol 9: 756-61 (1975) (2) Elbaz-Poulichet F et al; Nature 308: 409-14 (1984)].

ATMOSPHERIC FATE: Lead released to the atmosphere will be in particulate matter and be subject to washout and gravitational settling. Transformations in the atmosphere to the carbonate and oxide may be expected. Estimates of the annual net Pb deposition to the tropical North Pacific Ocean is 2.0 and 5.0 ng/sq cm, respectively and is predominately from noncrustal sources(2). Recycled sea spray represents a significant but variable component of the deposition. The average annual scavenging ratio (concn in precipitation (mg/l) to air concn (ug/cu m)) for Pb is 0.18X10+6, the lowest value of the 7 trace metals studied(1). The mean ratio of wet to dry deposition of lead in southern, central and northern Ontario is 1.63, 1.99, and 2.50, respectively(1). [(1) Chan WH et al; Water Air Soil Pollut 29: 373-89 (1986) (2) Arimoto R et al; J Geophys Res 90: 2391-408 (1985)].

Biodegradation [940]:

Lake sediment microorganisms are able to directly methylate certain inorganic lead compounds(1). While all lake sediments tested in one study were able to transform trimethyllead to tetramethyllead, only some could transform lead nitrate and chloride to tetramethyllead and no biotransformation occurred with lead oxide, hydroxide, bromide, cyanide, or palmitate(1). Under appropriate conditions, dissolution due to anaerobic microbial action may be significant in subsurface environments(2). In one investigation, half of 40 intertidal sediments were found to release spasmodic and variable amounts of gaseous alkyllead over periods of 5-120 days with a maximum release rate of 0.085 ng Pb/kg-hr(5). Indeed the further from source areas, the more dominant the fraction of alkyllead relative to total lead in air (up to 20%)(5). It is not known what forms of Pb in sediment may be amenable to alkylation(SRC). The mean percentage removal of lead during the activated sludge process was 82% and was almost entirely due to the removal of the insoluble fraction by adsorption onto the sludge floc and to a much lesser extent, precipitation(3,4). [(1) USEPA; Air Quality Criteria for Lead; pp. 6-1 to 6-2 USEPA-600/8-77-017 (1977) (2) Frances AJ; Anaerobic microbial dissolution of toxic metals in subsurface environments. BLN-36571, CONF-8540521-1 Upton, NY: Brookhaven National Lab (1985) (3) Stephenson T, Lester JN; Sci Tot Environ 63: 199-214 (1987) (4) Stephenson T, Lester JN; Sci Tot Environ 63: 215-30 (1987) (5) Hewitt CN, Harrison RM; Environ Sci Technol 21: 260-66 (1987)].

Abiotic Degradation [940]:

Lead is one of the most stable of metals because of its excellent corrosion resistance to air, water, and soil(1). Reactions initially take place leading to tarnishing in air, for example. However, protective coatings of insoluble lead compounds can protect the metal from further attack(1). Metallic lead is attacked by pure water in the presence of oxygen, but if the water contains carbonates and silicates, protective films are formed preventing further attack(1). Similarly, tap water or brine do not corrode the metal(2). Lead dissolves in nitric and acetic acids, but dissolution is slow in hydrochloric acid because of the low solubility of the chloride; and in dilute sulfuric acid, an adherent film of lead sulphate protects the metal from further attack(1). [(1) Howe HE; Kirk-Othmer Encycl Chem Tech 3rd ed. NY,NY: Wiley 14: 98-139 (1981) (2) Merck Index; 10th ed pp. 776-7 (1983) (30 Hem JD, Durum WD; J Amer Water Works Assoc 65: 562-8 (1973)].

The most stable form of lead in natural water is a function of the ions present, the pH, and the redox potential(2). In oxidizing systems, the least soluble common forms are probably the carbonate, hydroxide, and hydroxycarbonate(2). While the hydroxide is converted to PbO with loss of water under some conditions, the hydroxide is the more stable solid form when water is present. In reduced systems where sulfur is present, PbS is the stable solid(2). From solubility diagrams using relevant ionic strengths and dissolved CO2, it is evident that the solubility of Pb is 10 ppb above pH 8, while near pH 6.5 the solubility can approach or exceed 100 ppb(2). It has been demonstrated that Pb(0) and Pb(+2) can be oxidatively methylated by naturally occurring compounds such as methyl iodide and glycine betaine(1). This can result in the dissolution of lead already bound to sediment or particulate matter(1). [(1) Craig PJ, Rapsomanikis S; Environ Sci Tecnol 19; 726-30 (1985) (2) Hem JD, Durum WD; J Amer Water Works Assoc 65: 562-8 (1973)].

Some information is available on the photodegradation of lead compounds. Tetraethyllead undergoes photodegradation principally by reaction with hydroxyl radicals resulting in 93% degradation per hour on a sunny summer day(1). The degradation rate of tetramethyllead is somewhat slower(2). Lead halides are readily photolyzed with PbO presumably being formed(3). Lead particulate matter emitted by motor vehicles which is largely lead bromochloride and lead oxide with lesser amounts of the sulfate and phosphate salt, nonphotolytically degrade in the atmosphere. In particular, 75% of the bromine and 30-40% of the chlorine contained in the particulate matter is lost within 18 hrs while the proportions of carbonate and oxide increases(2). The sulfate concentration and water solubilities of the particulates is increased by irradiation(2). It has been suggested that sulfuric acid formed from the SO2 in the atmosphere or at the soil interface reacts with the lead particulate to form lead sulfate. This can also occur in soil in contact with groundwater(2). [(1) Harrison RM, Laxen DPH; Environ Sci Technol 12: 1384-92 (1978) (2) USEPA; Air Quality Criteria for Lead; pp. 6-1 to 6-28 USEPA-600/8-77-017 (1977) (3) Pierrard JM; Environ Sci Technol 3: 48-51 (1969)].

Soil Adsorption/Mobility [940]:

Lead is tightly bound to most soils with virtually no leaching under natural conditions(1). The soil's capacity to remove lead from solution is correlated with the soil pH, cation exchange capacity, organic matter and the available phosphorous level(1). 24, 35 and 3 mg of lead adsorbed by 1 g of montmorillonite clay at pH 8, 7, and 4 respectively, whereas 8 and 2 mg/g are adsorbed by kaolinite at pH 8 and 4, and 116 and 12 mg/g are adsorbed by humus at pH 8 and 2(3). The Freundlich's K and 1/N for lead in bottom mud from three sections of Japanese rivers ranged from 159 to 1436 and 0.04 to 0.27, respectively(5). The organic carbon content of the mud was the key factor affecting adsorptivity(5). It has been demonstrated that there are a number of binding sites per gram of dissolved organic matter from natural waters and the amount of a particular cation bound will depend on the presence and nature of competing cations(4). In particular, trivalent cations are very effective at blocking lead adsorption whereas Ca(+2) has little influence(4). [(1) Zimdane RL, Hassett JJ; pp. 93-8 in Lead in the Environment; Boggess WR ed National Science Foundation NSF/RA-770214 (1977) (2) USEPA; Air Quality Criteria for Lead; pp. 6-1 to 6-28 USEPA-600/8-77-017 (1977) (3) International Register of Potentially Toxic Chemicals(IRPTC); United Nations Environment Program Geneva Switzerland pp. 171-7 (1979) (4) Alberts JJ, Giesy JP; pp 333-47 in Aquatic and Terrestrial Humic Materials, RF Christman, ET Gjessing eds. Vol 16. Ann Arbor, MI: Ann Arbor Science (1983) (5) Tada F, Suzuki S; Water Res 16: 1489-94 (1982)].

Volatilization from Water/Soil [940]:

Due to its very low vapor pressure and insolubility, volatilization of lead from soil or water will be negligible. However relatively volatile tetramethyllead can be formed in anaerobic lake sediment and loss of lead via volatilization can subsequently occur(1). [(1) Callahan MA et al. Water-related environmental fate of 129 priority pollutants. USEPA-440/4-79-029a pp. 13-19 (1979)].

Absorption, Distribution and Excretion [940]:

1. Only 1 to 2% of ingested lead is absorbed from the GI tract because it can form rather insoluble compounds, even within the gut. Acid conditions favor dissolution of lead & its compounds. [Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1005].

2. Metallic lead shot or bullets lodged in tissues do not dissolve readily because tissue pH is not low enough. [Booth, N.H., L.E. McDonald (eds.). Veterinary Pharmacology and Therapeutics. 5th ed. Ames, Iowa: Iowa State University Press, 1982. 1006].

3. The proportion absorbed is much the same whether the lead is present as a sol or an insol salt such as the carbonate ... Which, although insol in water ... /Is/ appreciably sol in body fluids. /Inorganic lead/ [Clarke, M. L., D. G. Harvey and D. J. Humphreys. Veterinary Toxicology. 2nd ed. London: Bailliere Tindall, 1981. 56].

4. The absorption rate of deposited lead depends on various factors, particularly on the physiochemical form of lead in particles. There is ... no evidence of lead accumulation in the lung, & any lead compound once deposited is eventually absorbed or transferred to the gastrointestinal tract. [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 312].

5. Only a very minor fraction of particles over 0.5 um in mean maximal external diameter are retained in the lung but are cleared from the respiratory tract & swallowed. ... The percentage of particles less than 0.5 um retained in the lung increases with reduction in particle size. About 90% of lead particles in ambient air that are deposited in lung are small enough to be retained. Absorption of retained lead through alveoli is relatively efficient & complete. [Doull, J., C.D.Klassen, and M.D. Amdur (eds.). Casarett and Doull's Toxicology. 3rd ed., New York: Macmillan Co., Inc., 1986. 599].

6. Absorbed lead is transported by blood & initially distributed in various organs & tissues. It is then gradually redistributed to form an exchangeable compartment (blood & soft tissues) & a storage compartment, essentially bone. In human subjects with low lead exposure, about 90% of the total body burden is found in bone. ... Lead in blood is mainly bound to erythrocytes where its concentration is about 16

times higher than in plasma. The manner in which lead combines with erythrocytes is not clear, but it is probably assoc with hemoglobin. Lead also has an affinity for cell membrane & mitochondria, but not for lysosomes. Lead in bone builds up throughout life; this does not apply to soft tissues where it stabilizes early in adult life; in some tissues it may even decrease with age. /Inorganic lead/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 313].

7. After absorption, inorganic lead is distributed initially in soft tissues, particularly the tubular epithelium of the kidney & in the liver. In time ... /it/ is redistributed & deposited in bone, teeth, & hair. ... Only small quantities of inorganic lead accumulate in the brain, with most of that in gray matter & the basal ganglia. Nearly all circulating inorganic lead is assoc with erythrocytes; only when lead is present in relatively high concn does a significant portion remain in the plasma. /Inorganic lead/ [Gilman, A.G., L.S.Goodman, and A. Gilman. (eds.). Goodman and Gilman's The Pharmacological Basis of Therapeutics. 7th ed. New York: Macmillan Publishing Co., Inc., 1985. 1606].

8. Blood lead levels are a good indicator of recent exposure to lead & are influenced by inhalation & ingestion. A number of recent studies suggest that inhalation of air containing 1 ug/cu m in respirable particles will increase blood lead concentrations by about 1 ug/dl when air lead concn are in the range of 1-5 ug/cu m. Lead in blood varies with age. Children under 7 yr of age have significantly higher blood lead levels than older children, & there is no difference between boys & girls under age 12. Blood lead levels decline during adolescence /& is/ probably related to bone growth & deposition of lead in bone with calcium. Blood lead levels are lower in adult females than adult males. /Inorganic lead/ [Doull, J., C.D.Klassen, and M.D. Amdur (eds.). Casarett and Doull's Toxicology. 3rd ed., New York: Macmillan Co., Inc., 1986. 599].

9. The deposition of lead in bone closely resembles that of calcium, but it is deposited as tertiary lead phosphate. Lead in the bone salts does not contribute to toxicity. After a recent exposure, the concn of lead is often higher in the flat bones than in the long bones, although, as general rule, the long bones contain more lead. In the early period of deposition, the concentration of lead is highest in the epiphyseal portion of the long bones. This is esp true in growing bones, where deposits may be detected by X-ray examination as rings of increased density in the ossification centers of the epiphyseal cartilage & as a series of tranverse lines in the diaphyses, so called lead lines. Such findings are of diagnostic significance in children. /Inorganic lead/ [Gilman, A.G., L.S.Goodman, and A. Gilman. (eds.). Goodman and

Gilman's The Pharmacological Basis of Therapeutics. 7th ed. New York: Macmillan Publishing Co., Inc., 1985. 1606].

10. About 90% of ingested lead is eliminated unabsorbed through feces. Absorbed lead is excreted primarily in urine (about 76%); other ... routes are gastrointestinal secretions (about 16%) & hair, nails & sweat (< 8%). The rate of biliary excretion in man is not known. The mechanism of excretion appears to be essentially glomerular filtration. Lead is also excreted in human milk in concentrations ... up to 12 ug/l. There is considerable species variation for lead excretion in animals. In baboons, the main route of excretion is urine, but in rat & sheep, biliary & transmucosal excretion may be higher than urinary excretion. /Inorganic lead/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 314].

11. Placental transfer of lead has been demonstrated ... . There is fairly good correlation between lead concentrations in the blood of mothers & newborn infants, & the distribution in fetal tissues is similar to the distribution in the adult ... . /Inorganic lead/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 314].

12. Maternal blood lead decreases during pregnancy, suggesting that maternal lead is transferred to the fetus or excreted in some way. /Inorganic lead/ [Doull, J., C.D.Klassen, and M.D. Amdur (eds.). Casarett and Doull's Toxicology. 3rd ed., New York: Macmillan Co., Inc., 1986. 599].

13. Absorption is ... Influenced by concurrent dietary levels of ... Calcium, iron, fats, & proteins ... /It/ ... Is ... Greater in infants than in adults & during fasting state than with meals. [Doull, J., C.D. Klaassen, and M. D. Amdur (eds.). Casarett and Doull's Toxicology. 2nd ed. New York: Macmillan Publishing Co., 1980. 416].

14. Plants can absorb and translocate available lead (Pb) level from nutrient solution, and to a lesser degree from soil. Most of the absorbed Pb remains in the roots, but cessation of growth in late summer and fall is often accompanied by mobilization of Pb from roots into the plant tops. Pasture herbage growing in an abandoned Pb mining area (soil pH 4, soil Pb 3600 ppm) accumulated up to 74 ppm Pb (dry weight basis) in their leaves. Corn accumulated 37.8 ppm in tops from a soil treated with 3200 kg Pb/ha, but the kernals did not contain significantly more Pb than controls (0.3-0.5 ppm Pb at 15.5% moisture). Lettuce and radishes were two plants shown to accumulate Pb from soil. Pb chelates were taken up by plants more readily than Pb(2+) and exhibited a high degree of translocation to the plant tops. /Inorganic

lead/ [Nat'l Research Council Canada; Effects of Lead in the Canadian Environment p.48 (1978) NRCC No. 16736].

15. Excretion of lead in /one non-occupationally exposed man/ was: urine (76%); gastrointestinal secretions (16%); hair, nails, sweat, other (8%). /Inorganic lead/ [Rabinowitz MB et al; Science 182: 725-27 (1973) as cited in WHO; Environ Health Criteria: Lead p.84 (1977)].

16. Using radioactive tracers /an estimated/ 70% of the lead absorbed from the lung of a human remained present in blood while 30% was almost immediately absorbed by the soft tissues ... after 24 hr. /Inorganic lead/ [Hursh JB, Mercer TT; J Appl Physiol 28: 268 (1970) as cited in Nat'l Research Council Canada; Effects of Lead in the Canadian Envir p.271 (1978) NRCC No.16736].

17. Body burden of lead (Pb), as assessed by lead excretion 24 hr after Ca-EDTA administration, was increased in 37% of the workers with a mean value of 607 + or - 425 ug. Mean blood Pb was 32 + or - 14 ug/dl. Creatinine clearance was normal in all workers. Maximal urinary concentrating ability was abnormal in a significant fraction (52%) of the men. /Inorganic lead/ [Greenberg A et al; Arch Environ Health 41 (2): 69-76 (1986)].

18. For all practical purposes, there are two forms of lead. The first is inorganic lead, in which the various salts & oxides are considered to act identically once absorbed into the systemic circulation. The second is alkyl lead ... Clearly different from inorganic forms of lead, as to ... Absorption & disposition in the body. ... Distinctions are not generally made regarding the disposition of the various inorganic compounds. It is assumed that lead ions /of various inorg compounds/ dissociate to some degree & are absorbed & distributed in the body in the same manner, regardless of environmental origin. The validity of this assumption has not been tested. [Doull, J., C.D. Klaassen, and M. D. Amdur (eds.). Casarett and Doull's Toxicology. 2nd ed. New York: Macmillan Publishing Co., 1980. 415].

19. Nonradioactive and radioactive metal salts were administered intravenously to Sprague Dawley rats. The highest amount of each metal approached the maximum tolerated dose. Cobalt (Co), silver (Ag), and manganese (Mn) were eliminated rapidly. The elimination of 20 to 50% of the dosage was observed for copper (Cu), thallium (Tl), bismuth (Bi), lead (Pb), cesium (Cs), gold (Au), zinc (Zn), mercury (Hg), selenium (Se), and chromium (Cr). The slowest excretion rate was measured for arsenic (As), cadmium (Cd), iron (Fe), methyl mercury (MeHg), and tin (Sn). No substantial elimination rate decline was observed for MeHg and Fe, and the decline was small for Tl, Cs, Hg, Sn, Co, Ag, Zn, Cr, and As. Elimination of Ag and Mn via feces was fast, with more than 70% eliminated on the first day. Cu, Tl, Pb, and Zn were excreted at a slower

rate, with 30.6 to 38.3% excreted on the first day. The rest of the metals were eliminated slowly by the intestinal route. Co was removed rapidly via urine, while Pb, Sn, Zn, MeHg, Ag, Fe, Mn, and Cd were eliminated slowly. The biliary excretion of Ag, As, and Mn was fast, with 25.5, 30.2 and 16.2% eliminated in two hours. Cu, Se, Cd, Pb, Bi, and Co were eliminated at an intermediate rate via the biliary route. Ag, As, Mn, Cu, Se, Cd, Pb, Bi, and MeHg were highly concentrated in bile relative to plasma. Liver and kidney contained the highest concentrations of most metals. The intestinal route was the major path of elimination for Ag, Mn, Cu, Tl, Pb, Zn, Cd, Fe, and MeHg. Co, Cs, Au, Se, and Cr, were removed predominantly by urine. For Bi, Hg, As, and Sn the two routes were similar. [Gregus Z, Klaassen CO; Toxicol Appl Pharm 85 (1): 24-38 (1986)].

Fate-related Abstract from Compact Cambridge CD-ROM: Life Sciences 1982 - 1983: Subject: Lead:

TITLE: Settleability of Urban Runoff Pollution.
AUTHOR:Whipple W Jr; Hunter JV
SOURCE: J. WATER POLLUT. CONTROL FED.; vol. 53, no. 12, pp. 1726-1731; 1981
ABSTRACT: With the growing interest in stormwater management, and particularly of the possibility of using detention basins for removing particulate pollution, it is important to determine the effectiveness of such basins for removal of various polluting substances. In the study, samples of urban runoff were allowed to settle in a large tube, and the quantity of each pollutant settling in a given period was determined. There was more variability in rate of settlement of specific pollutants than for total suspended solids. Lead and hydrocarbons settled out 60 to 65% in 32 hours, only slightly slower than total suspended solids. Biochemical oxygen demand and copper were removed at somewhat lower rates, and zinc even lower. Coliform counts were reduced by an order of magnitude. These results indicate the probable effectiveness of retention of storm waters in removing particulate pollutants.

Laboratory and/or Field Analyses:

Many methods have been used to monitor for lead [861,1001,1003,1004,1005,1006]. EPA methods recommended depend on the application: whether for drinking water [40 CFR Part 141 and 1005,1006,1008], NPDES discharge permits [40 CFR 136 and 1005,1006], CERCLA [861,1005,1006], RCRA [861,1005,1006], or low-detection-limit water-quality based permitting [1001,1003,1004]. Other agencies (USGS, APHA, ASTM, NOAA, etc. also publish different "standard methods."

If one simply wants to know whether or not the concentration exceeds EPA criteria or various low concentration benchmarks for humans, fish, or wildlife, it is not always too clear which "standard method" is optimum, although some might argue that for water, the 1996 EPA methods 1640 and 1669 (see details below) should apply.

Historically, methods which have been used for drinking water include Atomic absorption/furnace technique (EPA239.2; ASTM D-3559-85D; SM 3113); inductively-coupled plasma/mass spectrometry(EPA 200.8); atomic absorption/platform furnace technique (EPA 200.9) [861,893]. One of the most recent water methods for lead is EPA lab method 1640, accompanied by EPA field method 1669 (see details below).

> Recommended Detection Limits for Lead: 0.5 ppm dry weight in tissues, 5.0 ppm in sediments and soils. If required, better methods can go as low as 0.025 ppm for tissues and 0.01 ppm for sediments [945]. In the past, many methods have been used to analyze for lead in water [861,945]. However, the historic detection limit of 0.01 ppm in water is becoming obsolete since lower benchmarks are often used:
>
> > EPA water quality criteria for lead are as low as 0.14 ug/L [1001,1003].
> >
> > A proposed MCL for lead was 5 ug/L [446].
> >
> > The Maximum Contaminant Level Goal from EPA 1996 IRIS database [893] is zero based on (1) occurrence of low level effects and difficulties in identifying clear threshold levels, (2) the overall Agency goal of reducing total lead exposures, and (3) the classification of lead as a group B2 carcinogen [893].
> >
> > The 1996 EPA freshwater chronic criteria is 3.2 ug/L [893].
> >
> > EPA 1995 Region IX Preliminary Remediation Goal (PRG) for lead in tap water: 4.0 ug/L [868].
> >
> > Some state drinking water standards are quite low, for example [945]:
>
> | | |
> |---|---|
> | Iowa: | 0.05 ug/L (sic) |
> | Wisconsin | 5 ug/L preventative action limit |
>
> Therefore, in some situations (as when background concentrations or comparison criteria are low), water lead detection limits as low as 0.0081 ug/L may be necessary, using EPA method 1640 [1001]. For Lead, EPA method 1637 allows a (slightly higher) water MDL detection limit of 0.036 ug/L [1003].
>
> > NOTE: The Branch of Technical Development and Quality Systems (BTD&QS) of the USGS released a Quality Assurance Summary report in September of 1995 for NWQL data which indicated that lead by Inductively Coupled

> Plasma (ICP) has been displaying extreme variability. A recommendation was made to use alternate methods for lead such as graphite furnace (GFAA) and ICP-mass spectrometry (ICP-MS). Alternate methods should especially be considered for studies assessing concentrations of lead below the action level set by EPA for drinking water. The relative standard deviation (RSD) data for lead ICP standard ICP) quality control samples has historically not supported a 10 microgram per liter Method Reporting Limit (MRL) for lead (Alert issued by Thomas J Maloney, Supervisory Hydrologist, Denver, CO).

Acceptable containers (after proper cleaning per EPA protocols) for Antimony, Arsenic, Cadmium, Copper, Lead, Nickel, Selenium, Silver, Thallium, and Zinc: 500-mL or 1-L fluoropolymer, conventional or linear polyethylene, polycarbonate, or polypropylene containers with lid [1003].

Notes on total vs. acid soluble vs. dissolved metals:

> Although most of the lab tests done to develop water quality criteria and other benchmarks were originally based on "total" values rather than "dissolved" values, the lab settings were typically fairly clean and the numbers generated by the lab tests are therefore often even more comparable to field "dissolved" values than to field "total" values (Glen Suter, Oak Ridge National Lab, Personal Communication, 1995).
>
> In 1985, EPA gave 11 reasons why Acid Soluble Lead (the lead that passes through a 0.45 um membrane filter after the sample is acidified to pH 1.5 to 2 with nitric acid) is probably the best measure to compare with water quality criteria (1985 update of Ambient Water Quality Criteria Document for Lead) [30 (1985 update)]. After acid treatment and filtration, the analysis can be done with either ICP or with Atomic Absorption [30 (1985 update)]. However, previous criteria of 1980 [30] and later criteria of 1986 [302] gave criteria in total lead. The gold book pointed out there was no approved method for acid soluble lead [302]. Many water analyses since 1986 have continued to be made for total lead, and most criteria, unless otherwise stated, have presumably been for total (recoverable) lead. However, to further clarify (confuse?) matters, as of January 1995, the U.S. EPA was recommending that states use dissolved measurements in water quality standards for metals, in concert with recommendations EPA previously made for the Great Lakes [672]. The conversion factors recommended by EPA for converting total recoverable metals criteria to dissolved metal criteria were given as follows [672]:
>
> > Lead conversion for acute criteria: 0.875; Lead conversion for chronic criteria: 0.792 (for

example, total recoverable chronic lead criteria x 0.792 = dissolved chronic lead criteria).

The conversion factors recommended by EPA for converting total recoverable lead to dissolved concentrations in the January 1997 draft EPA Guidelines for 5 year 305(B) assessments were:

Lead conversion at a hardness of 50 mg/L: 0.892.

Lead conversion at a hardness of 100 mg/L: 0.791.

Lead conversion at a hardness of 200 mg/L: 0.690.

> Note: None of these generic conversion factors may uniformly work for all areas. Both total and dissolved concentrations should be checked at new locations before relying on generic conversion factors (Pat Davies, Colorado Division of Wildlife, personal communication, 1997).

Filtration and Acidification of Water Samples:

For ICP water samples for metals, EPA recommends the following (40 CFR Part 136, Appendix C, pertaining to ICP analyses using method 200.7, 1994 edition of CFR Part 40):

1) For samples of "total or total recoverable elements," samples should be acidified to a pH of two or less at the time of collection or as soon as possible thereafter.

> Note: In more recent (1996) guidance related to the more rigorous method 1669, EPA clarified (some would say confused or added data variability) the issue of when to acidify by stating:
>
> > "Preservation recommendations for Antimony, Arsenic, Cadmium, Copper, Lead, Nickel, Selenium, Silver, Thallium, and Zinc: Add 5 mL of 10% HN03 to 1-L sample; preserve on-site or immediately upon laboratory receipt" [1003].
> >
> > > Note: the nitric acid (triple distilled or not?) and dilution water (contaminated or not?) and containers (proper type, cleaned correctly or not?) used are all potential sources of contamination (see more detailed note below

related to data variation factors).

2) For determination of dissolved elements, the samples must be filtered through a 0.45 micron membrane filter as soon as soon as practical after collection, using the first 50-100 ml to rinse the filter flask. Acidify the filtrate with nitric acid to a pH of 2 or less. Normally 3 mL of (1+1) of nitric acid per liter should be sufficient to preserve the sample.

3) For determination of suspended elements, the samples must be filtered through a 0.45 micron membrane filter as soon as soon as practical after collection. The filter is then transferred to a suitable container for storage and shipment, with no preservation required.

Contaminants data from different labs, different states, and different agencies, collected by different people, are often not very comparable (see additional discussion in the disclaimer section at the top of this entry). As of 1997, the problem of lack of data comparability (not only for water methods but also for soil, sediment, and tissue methods) between different "standard methods" recommended by different agencies seemed to be getting worse, if anything, rather than better.

The trend in quality assurance seemed to be for various agencies, including the EPA and others, to insist on quality assurance plans for each project. In addition to quality control steps (blanks, duplicates, spikes, etc.), these quality assurance plans call for a step of insuring data comparability [1015,1017]. However, the data comparability step is often not given sufficient consideration. The tendency of agency guidance (such as EPA SW-846 methods and some other new EPA methods for bio-concentratable substances) to allow more and more flexibility to select options at various points along the way, makes it harder in insure data comparability or method validity. Even volunteer monitoring programs are now strongly encouraged to develop and use quality assurance project plans [1015,1017].

At minimum, before using contaminants data from diverse sources, one should determine that field collection methods, detection limits, and lab quality control techniques were acceptable and comparable. The goal is that the analysis in the concentration range of the comparison benchmark concentration should be very precise and accurate.

It should be kept in mind that quality control field and lab blanks and duplicates will not help in the data quality assurance goal as well as intended if one is using a method prone to false negatives. Methods may be prone to quality assurance problems due to the use of detection limits that are too high, the loss or addition of contaminants through inappropriate handling, or the use of inappropriate methods.

Additional discussion of sources of potential variation in contaminants data:

> Variation in concentrations of contaminants may sometimes be due to differences in how individual investigators treat samples in the field and lab rather than true differences in environmental concentrations. It was recognition that collectors and labs often contaminate samples that led EPA to develop the 1600 series of water protocols for low detection limit applications [1001,1002,1003,1004]. In comparing contaminants data from different labs, different states, and different agencies, one should keep in mind that they are often not very comparable. They may be as different as apples and oranges since:
>
> > 1) Different Agencies (EPA, USGS, NOAA, and various State Agencies) publish different lab and field protocols. Each of these protocols is different and has typically changed over time.
> >
> > > Note: Even "Standard EPA Methods" which are supposedly widely used by consultants, industry, and academia, have been variable over time and between application category (Drinking Water vs. NPDES, vs. RCRA, vs. CERCLA, vs. Water-Quality Based permits, etc.).
> > >
> > > Preservation and other details of various EPA lab and field protocols have changed over the years, just as they have at USGS and various States and other agencies. USGS data from 30 years ago may be different than USGS data today due to differences (drift) in lab and field protocols rather than differences in environmental concentrations.
> >
> > 2) Independent labs and field investigators are not always using "the latest and greatest methods," and it is difficult for them to keep up with all the changes from various agencies in the midst of their "real world" busy lives. Updates are not always convenient to obtain. For example, EPA changes are scattered through various proposed Federal Register Notices, various updates of CFRs, and numerous publications originating in many different parts of EPA and their contractors. The wording is sometimes imprecise and is often inconsistent between EPA methods for different applications.
> >
> > 3) The details of the way one person collects, filters, and acidifies water samples in the field may be different than the way another does it.

Sources of potential variation include the following:

A) The protocol phrases "As soon as practical or as soon as possible." Different situations can change the elapsed time considered by the field collector to be "as soon as practical." It may take different amounts of time to get to a safe or otherwise optimum place to filter and/or acidify and cool the samples. In one case precipitation and other changes could be going on in the collection bottle while the bottle is on the way to filtration and acidification. In other cases, the field collector filters and acidifies the samples within minutes. Weather, safety concerns, and many other factors could play a role.

B) Differences in numerous other details of the method used can drastically change the results. Some cold, wet, hurried, or fire ant-bitten collectors might decide that it is not "practical" to filter and acidify quite so immediately in the field, and may decide the shore, a vehicle, a motel room, or even a remote lab are more "practical" locations. Filtering and acidifying in the field immediately has been thought of as a better option for consistency (see copper and silver entries for examples of what can happen if there is a delay). However, in recent methodology designed to prevent some the contamination and variability listed above, EPA has recently suggested that waiting until the sample arrives at the lab before acidifying is OK [1003].

C) What kind of .45 micron filter was used? The flat plate filters that were used for years tended to filter .45 micron sizes at first and then smaller and smaller sizes as the filtering proceeded and the filter loaded up with particulate matter. As the filter clogged, the openings grew smaller and colloids and smaller diameter matter began to be trapped on the filter. For this reason, both the USGS and EPA 1600 series protocols have gone to tortuous-path capsule filters that tend to filter .45 micron sizes more reliably over time. Example of specifications from EPA method 1669:

> Filter—0.45-um, 15-mm diameter or larger, tortuous-path capsule filters, Gelman

Supor 12175, or equivalent [1003].

D) "Normally 3 mL of (1+1) of nitric acid per liter should be sufficient to preserve the (water) sample" (40 CFR Part 136, Appendix C, pertaining to ICP analyses using method 200.7, 1994 edition of CFR Part 40). Sometimes it is not, depending on alkalinity and other factors. What field collectors sometimes (often?) do is just use pop tabs of 3 mL of nitric acid and hope for the best rather than checking to see that the acidity has been lowered to below a pH of two. EPA CFR guidelines just call for a pH of below two, whereas samples meant to be "acid soluble" metals call for a pH of 1.5 to 2.0 [25]. See also, various USEPA 1984 to 1985 Ambient Water Quality Criteria Documents for individual metals.

Note: Some shippers will not accept samples with a pH of less than 1 for standard shipping (John Benham, National Parks Service Personal Communication, 1997).

E) One person might use triple distilled concentrated nitric acid rather than reagent grades of acid to avoid possible contamination in the acid, while another may not. When using very low detection limits, some types of acid may introduce contamination and influence the results. Using a 10% dilution of nitric acid as called for by EPA [1003] is another potential source of contamination, since the dilution water and/or containers may be contaminated. Sometimes people may be incorrectly determining that background concentrations are high due to contamination sources such as these (Pat Davies, Colorado Division of Wildlife, personal communication, 1997).

Note: Just using triple distilled nitric acid may not be the total answer to potential contamination. The key issue to be sure that the acid used is free of the metals being analyzed. In guidance for EPA method 1669, the use of "ultrapure nitric acid; or Nitric acid, dilute, trace-metal grade" is specified [1003]. In guidance for EPA method 1638, the use of "Nitric acid—concentrated (sp gr 1.41), Seastar or equivalent" is

> specified [1003].
>
> In EPA method 1638, the guidance is given "Do not dip pH paper or a pH meter into the sample; remove a small aliquot with a clean pipet and test the aliquot [1003]. When the nature of the sample is either unknown or known to be hazardous, acidification should be done in a fume hood" [1003].

F) Holding times can strongly influence the results and there can be quite a bit of variation even within EPA recommended 6 month limits (see Silver entry for details). Holding times recommended for EPA for water samples of metals other than mercury or chromium VI have usually been listed as 6 months (Federal Register, Volume 49, No. 209, Friday, October 28, 1984, page 43260). In the 1994 version of the CFR, NPDES holding times for mercury and Chromium VI are the same ones listed in 1984, but no EPA holding times are given for other metals (40 CFR, Part 136.3, Table 2, page 397, 1994). EPA sources stated this was a typo, that no one else brought it to their attention in the last 3 years, that 6 months is still an operable holding time for "other metals" including this one, and that 6 months is actually an artifact from the days when 6 month composite samples were used for NPDES permits rather than having been originally scientifically derived.

> Counterpoint: Although some information suggests that 6 months is probably too long for some contaminants in some scenarios (see silver and copper entries), not all of the information in the literature casts the 6 month metals holding time in such questionable light. In one study, two EPA research chemists found that preservation under certain conditions of drinking water (EPA Method 200.8) metals samples to a pH of less than 2 effectively stabilized the metal concentrations for 6 months. They found that trace metal standards in the 10 to 50 ug/L concentration could be held in 1% nitric acid if a 5% change of concentration was acceptable [1009]. Some metal concentrations changed more than 5% (Zinc up to 24%, Selenium up to 23%) [1009]. Vanadium, Manganese and

Arsenic changed up to 5-7% [1009]. In some of the trials, metals were higher after 6 months due to leaching from containers, while in some they were lower [1009]. The changes were nevertheless considered not of great consequence related to drinking water MCLs and EPA method 200.8 [1009]. However, it is not clear that the careful measures utilized (like rechecking to make sure the pH was less than 2, the use of particular kinds of water samples, the use of particular acids, etc.) in this one study replicates what goes on in day to day ("real world") contaminants lab work around the country.

Some EPA sources state that 6 months should be OK if the sample bottle is vigorously shaken and re-acidified in the lab prior to lab analyses, a practice not universally or even particularly commonly done in labs today. The degree to which a water sample is re-acidified, re-checked for pH, shaken before analysis, and the length of time it sits before and after these steps, seems to vary a lot between laboratories, and EPA guidance for various methods is not consistent. Some labs recheck pH, some don't. Some shake, some don't, etc. For drinking water, preservation is considered complete after the sample is held in pH of less than 2 for at least 16 hours [1007]. New EPA Method 1638 specifies:

> "Store the preserved sample for a minimum of 48 h at 0–4°C to allow the acid to completely dissolve the metal(s) adsorbed on the container walls. The sample pH should be verified as <2 immediately before withdrawing an aliquot for processing or direct analysis. If, for some reason such as high alkalinity, the sample pH is verified to be >2, more acid must be added and the sample held for sixteen hours until verified to be pH <2" [1003].

For many other methods, the minimum holding time in acid is not stated or is different (see various EPA and other Agency methods).

G) If present, air in head space can cause changes in water sample concentrations (Roy Irwin, National Park Service, Personal Communication, based on several discussions with EPA employees and various lab managers in February 1997).

> Note: air from the atmosphere or in headspace can cause oxidation of anaerobic groundwater or anaerobic sediment samples. This oxidation can cause changes in chemical oxidation states of contaminants in the sample, so that the results are not typical of the anaerobic conditions which were present in the environment prior to sampling (John Benham, National Park Service, Personal Communication, 1997).

H) When is the sample shaken in the lab or the field? If the filter is acidified in the field, it will be shaken on the way back to the lab. If lab acidified, how much and when is the sample shaken and then allowed to sit again for various times periods before analyses? Many methods treat this differently, and what many field collectors and labs actually do before analyzing samples is different as well. For EPA method 1638, the word shake appears in the "Alternate total recoverable digestion procedure":

> "..Tightly recap the container and shake thoroughly" [1003].

I) If one field filters and acidifies, one often changes metal concentrations and colloidal content compared to samples not treated in this manner. Acidifying effects microbial changes. If one holds the samples a while before filtering and acidifying, the situation changes. In collection bottles, there are potential aging effects: temperature changes, changes in basic water chemistry as oxygen and other dissolved gasses move from the water into the headspace of air at the top, potential aggregation of colloidal materials, precipitation of greater sizes over time, development of bigger and more colloids, and more sorption (Roy Irwin, National Park Service, personal communication, 1997).

4) The guidance of exactly where to take water samples varies between various state and federal

protocols. Taking water samples at the surface microlayer tends to increase concentrations of various contaminants including metals. Other areas of the water column tend to produce different concentrations. Large quantities of anthropogenic substances frequently occur in the surface microlayer at concentrations ranging from 100 to 10,000 times greater than those in the water column [593]. These anthropogenic substances can include plastics, tar lumps, PAHs, chlorinated hydrocarbons, as well as lead, copper, zinc, and nickel [593]. Sometimes a perceived trend can be more the result of the details of the sample micro-location rather than real changes in environmental concentrations (Roy Irwin, National Park Service, personal communication, 1997). The new EPA method 1669 mentions the microlayer, and states that one can use a fluoropolymer closing mechanism, threaded onto the bottle, to open and close a certain type of bottle under water, thereby avoiding surface microlayer contamination [1003]. However, even this relatively new EPA method 1669 also gives recommendations for ways to sample directly at the surface, and does not discourage the use of surface samples.

5) Although the above examples are mostly related to water samples, variability in field and lab methods can also greatly impact contaminant concentrations in tissues, soil, and sediments. Sediment samples from different microhabitats in a river (backwater eddy pools vs. attached bars, vs. detached bars, vs. high gradient riffles vs. low gradient riffles, vs. glides, etc.) tend to have drastically different concentrations of metals as well as very different data variances (Andrew Marcus, Montana State University, personal communication, 1995). Thus, data is only optimally comparable if both data collectors were studying the same mix of microhabitats, a stratified sampling approach which would be unusual when comparing random data from different investigators.

6) Just as there are numerous ways to contaminate, store, ship, and handle water samples, so are there different agency protocols and many different ways to handle samples from other media. One investigator may use dry ice in the field, another may bury the samples in a large amount of regular ice immediately after collection in the field, while a third might place samples on top of a small amount of ice in a large ice chest. The speed with which samples are chilled can result in different

results not only for concentrations of organics, but also for the different chemical species (forms) of metals (Roy Irwin, National Park Service, personal communication, 1997).

7) In comparing contaminants metals data, soil and sediment contaminant concentrations should usually be (but seldom has been) normalized for grain size, total organic carbon, and/or acid volatile sulfides before biologically-meaningful or trend-meaningful comparisons are possible (Roy Irwin, National Park Service, Personal Communication, 1997).

8) There has been tremendous variability in the precautions various investigators have utilized to avoid sample contamination. Contamination from collecting gear, clothes, collecting vehicles, skin, hair, collector's breath, improper or inadequately cleaned sample containers, and countless other sources must carefully be avoided when using methods with very low detection limits [1003].

Highlights from EPA Lab Method 1640: Determination of trace elements in ambient waters by on-line chelation preconcentration and inductively coupled plasma-mass spectrometry:

This method is for the determination of dissolved elements in ambient waters at EPA water quality criteria (WQC) levels using on-line chelation preconcentration and inductively coupled plasma-mass spectrometry (ICP-MS) [1003]. It may also be used for determination of total recoverable element concentrations in these waters [1003]. This method was developed by integrating the analytical procedures contained in EPA Method 200.10 with the quality control (QC) and sample handling procedures necessary to avoid contamination and ensure the validity of analytical results during sampling and analysis for metals at EPA WQC levels [1003]. This method contains QC procedures that will assure that contamination will be detected when blanks accompanying samples are analyzed [1003]. This method is accompanied by Method 1669: Sampling Ambient Water for Determination of Trace Metals at EPA Water Quality Criteria Levels (the "Sampling Method") [1003]. The Sampling Method is necessary to ensure that contamination will not compromise trace metals determinations during the sampling process [1003].

This method is applicable to the following elements:

Cadmium (Cd), Copper (Cu), Lead (Pb), and Nickel (Ni) [1003].

Many of the requirements for this method are similar to those for other EPA 1600 series methods [1003].

As of March 1997, the EPA 1600 series methods had not yet been officially approved in 40 CFR for use in NPDES permits, but the improvements in these methods were suggested by EPA staff to be wise practice when attempting low detection limit analyses for metals [1003].

For dissolved metal determinations, samples must be filtered through a 0.45-um capsule filter at the field site [1003]. The Sampling Method describes the filtering procedures [1003]. The filtered samples may be preserved in the field or transported to the laboratory for preservation [1003]. Procedures for field preservation are detailed in the Sampling Method; provides procedures for laboratory preservation are provided in this method [1003].

Acid solubilization is required before the determination of total recoverable elements to aid breakdown of complexes or colloids that might influence trace element recoveries [1003].

This method should be used by analysts experienced in the use of inductively coupled plasma mass spectrometry (ICP-MS), including the interpretation of spectral and matrix interferences and procedures for their correction; and should be used only by personnel thoroughly trained in the handling and analysis of samples for determination of metals at EPA WQC levels [1003]. A minimum of six months' experience with commercial instrumentation is recommended [1003].

Sample preservation—Preservation of samples and field blanks for both dissolved and total recoverable elements may be performed in the field when the samples are collected or in the laboratory [1003]. However, to avoid the hazards of strong acids in the field and transport restrictions, to minimize the potential for sample contamination, and to expedite field operations, the sampling team may prefer to ship the samples to the laboratory within 2 weeks of collection [1003]. Samples and field blanks should be preserved at the laboratory immediately when they are received [1003]. For all metals, preservation involves the addition of 10% HNO3 to bring the sample to pH <2 [1003]. For samples received at neutral pH, approx 5 mL of 10% HNO3 per liter will be required [1003].

Store the preserved sample for a minimum of 48 h at 0–4°C to allow the acid to completely dissolve the metal(s) adsorbed on the container walls [1003]. The sample pH should be verified as <2 immediately before an aliquot is withdrawn for processing or direct analysis [1003]. If, for some reason such as high alkalinity, the sample pH is verified to be >2, more acid must be added and the sample held for 16 h until verified to be pH <2 [1003].

Highlights from EPA Method 1669 for Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels [1003]:

As of March 1997, the 1600 series methods had not yet been officially approved in 40 CFR for use in NPDES permits, but the improvements in these methods were suggested by EPA staff to be wise practice when attempting low detection limit analyses for metals [1003].

This "field method details" protocol is for the collection and filtration of ambient water samples for subsequent determination of total and dissolved Antimony, Arsenic, Cadmium, Copper, Chromium III, Chromium VI, Lead, Mercury, Nickel, Selenium, Silver, Thallium, and Zinc, at low (Water Quality Criteria Range) concentrations [1003]. It is designed to support the implementation of water quality monitoring and permitting programs administered under the Clean Water Act [1003].

This method is not intended for determination of metals at concentrations normally found in treated and untreated discharges from industrial facilities [1003]. Existing regulations (40 CFR Parts 400–500) typically limit concentrations in industrial discharges to the mid to high part-per-billion (ppb) range, whereas ambient metals concentrations are normally in the low part-per-trillion (ppt) to low ppb range [1003]. This guidance is therefore directed at the collection of samples to be measured at or near the water quality criteria levels [1003]. Often these methods will be necessary in a water quality criteria-based approach to EPA permitting [1001]. Actual concentration ranges to which this guidance is applicable will be dependent on the sample matrix, dilution levels, and other laboratory operating conditions [1003].

The ease of contaminating ambient water samples with the metal(s) of interest and interfering substances cannot be overemphasized [1003]. This method includes sampling techniques that should maximize the ability of the sampling team to collect samples reliably and eliminate sample contamination [1003].

Clean and ultraclean—The terms "clean" and "ultraclean" have been used in other Agency guidance [1004] to describe the techniques needed to reduce or eliminate contamination in trace metals determinations [1003].

These terms are not used in this sampling method due to a lack of exact definitions [1003]. However, the information provided in this method is consistent with summary guidance on clean and ultraclean techniques [1004].

Preventing ambient water samples from becoming contaminated during the sampling and analytical process is the greatest challenge faced in trace metals determinations [1003]. In recent years, it has been shown that much of the historical trace metals data collected in ambient water are erroneously high because the concentrations reflect contamination from sampling and analysis rather than ambient levels [1003]. Therefore, it is imperative that extreme care be taken to avoid contamination when collecting and analyzing ambient water samples for trace metals [1003].

There are numerous routes by which samples may become contaminated [1003]. Potential sources of trace metals contamination during sampling include metallic or metal-containing sampling equipment, containers, labware (e.g. talc gloves that contain high levels of zinc), reagents, and deionized water; improperly cleaned and stored equipment, labware, and reagents; and atmospheric inputs such as dirt and dust from automobile exhaust, cigarette smoke, nearby roads, bridges, wires, and poles [1003]. Even human contact can be a source of trace metals contamination [1003]. For example, it has been demonstrated that dental work (e.g., mercury amalgam fillings) in the mouths of laboratory personnel can contaminate samples that are directly exposed to exhalation [1003].

For dissolved metal determinations, samples must be filtered through a 0.45-um capsule filter at the field site [1003]. The filtering procedures are described in this method [1003]. The filtered samples may be preserved in the field or transported to the laboratory for preservation [1003].

This document is intended as guidance only [1003]. Use of the terms "must," "may," and "should" are included to mean that EPA believes that these procedures must, may, or should be followed in order to produce the desired results when using this guidance [1003]. In addition, the guidance is intended to be performance-based, in that the use of less stringent procedures may be used so long as neither samples nor blanks are contaminated when following those modified procedures [1003]. Because the only way to measure the performance of the modified procedures is through the collection and analysis of uncontaminated blank samples in accordance with this guidance and the referenced methods, it is highly recommended that any modifications be thoroughly evaluated and demonstrated to be effective before field samples are collected [1003].

The method includes a great many details regarding prevention of field contamination of samples, including clothing needed, clean hands vs. dirty hands operations, and numerous other details [1003].

Surface sampling devices—Surface samples are collected using a grab sampling technique [1003]. Samples may be collected manually by direct submersion of the bottle into the water or by using a grab sampling device [1003]. Grab samplers may be used at sites where depth profiling is neither practical nor necessary [1003].

An alternate grab sampler design is available [1003]. This grab sampler is used for discrete water samples and is constructed so that a capped clean bottle can be submerged, the cap removed, sample collected, and bottle recapped at a selected depth [1003]. This device eliminates sample contact with conventional samplers (e.g., Niskin bottles), thereby reducing the risk of extraneous contamination [1003]. Because a fresh bottle is used for each sample, carryover from previous samples is eliminated [1003].

Subsurface sampling devices—Subsurface sample collection may be appropriate in lakes and sluggish deep river environments or where depth profiling is determined to be necessary [1003]. Subsurface samples are collected by pumping the sample into a sample bottle [1003]. Examples of subsurface collection systems include the jar system device or the continuous-flow apparatus [1003].

Advantages of the jar sampler for depth sampling are (1) all wetted surfaces are fluoropolymer and can be rigorously cleaned; (2) the sample is collected into a sample jar from which the sample is readily recovered, and the jar can be easily recleaned; (3) the suction device (a peristaltic or rotary vacuum pump, is located in the boat, isolated from the sampling jar; (4) the sampling jar can be continuously flushed with sample, at sampling depth, to equilibrate the system; and (5) the sample does not travel through long lengths of tubing that are more difficult to clean and keep clean [1003]. In addition, the device is designed to eliminate atmospheric contact with the sample during collection [1003].

Selection of a representative site for surface water sampling is based on many factors including: study objectives, water use, point source discharges, non-point source discharges, tributaries, changes in stream characteristics, types of stream bed, stream depth, turbulence, and the presence of structures (bridges, dams, etc.) [1003]. When collecting samples to determine ambient levels of trace metals, the presence of potential sources of metal contamination are of extreme importance in site selection [1003].

Ideally, the selected sampling site will exhibit a high degree of cross-sectional homogeneity [1003]. It may be possible to use previously collected data to identify locations for samples that are well mixed or are vertically or horizontally stratified [1003]. Since mixing is principally governed by turbulence and water velocity, the selection of a site immediately downstream of a riffle area will ensure good vertical mixing [1003]. Horizontal mixing occurs in constrictions in the channel [1003]. In the absence of turbulent areas, the selection of a site that is clear of immediate point sources, such as industrial effluents, is preferred for the collection of ambient water samples) [1003].

To minimize contamination from trace metals in the atmosphere, ambient water samples should be collected from sites that are as far as possible (e.g., at least several hundred feet) from any metal supports, bridges, wires or poles [1003]. Similarly, samples should be collected as far as possible from regularly or heavily traveled roads [1003]. If it is not possible to avoid collection near roadways, it is advisable to study traffic patterns and plan sampling events during lowest traffic flow [1003].

The sampling activity should be planned to collect samples known or suspected to contain the lowest concentrations of trace metals first, finishing with the samples known or suspected to contain the highest concentrations [1003]. For example, if samples are collected from a flowing river or stream near an industrial or municipal discharge, the upstream sample should be collected first, the downstream sample collected second, and the sample nearest the discharge collected last [1003]. If the concentrations of pollutants is not known and cannot be estimated, it is necessary to use precleaned sampling equipment at each sampling location [1003].

One grab sampler consists of a heavy fluoropolymer collar fastened to the end of a 2-m-long polyethylene pole, which serves to remove the sampling personnel from the immediate vicinity of the sampling point [1003]. The collar holds the sample bottle [1003]. A fluoropolymer closing mechanism, threaded onto the bottle, enables the sampler to open and close the bottle under water, thereby avoiding surface microlayer contamination [1003]. Polyethylene, polycarbonate, and polypropylene are also acceptable construction materials unless mercury is a target analyte [1003]. Assembly of the cleaned sampling device is as follows:

Sample collection procedure—Before collecting ambient water samples, consideration should be given to the type of sample to be collected, the amount of sample needed, and the devices to be used (grab, surface, or subsurface samplers) [1003]. Sufficient sample volume should be collected to allow for necessary quality control analyses, such as matrix spike/ matrix spike duplicate analyses [1003].

Highlights from EPA Method 1637: Determination of Trace Elements in Ambient Waters by Off-Line Chelation Preconcentration and Stabilized Temperature Graphite Furnace Atomic Absorption [1003]:

This method, proposed by EPA in 1996, provides procedures for the determination of dissolved elements in ambient waters at EPA water quality criteria (WQC) levels using off-line chelation preconcentration and stabilized temperature graphite furnace atomic absorption (GFAA) [1003]. It may also be used for determination of total recoverable element concentrations in these waters [1003]. This method was developed by integrating the analytical procedures in EPA Method 200.13 with the stringent quality control (QC) and sample handling procedures necessary to avoid contamination and ensure the validity of analytical results during sampling and analysis for metals at EPA WQC levels [1003]. This method contains QC procedures that will ensure that contamination will be detected when blanks accompanying samples are analyzed [1003]. This method is accompanied by Method 1669: Sampling Ambient Water for Determination of Trace Metals at EPA Water Quality Criteria Levels (the "Sampling Method") [1003]. The Sampling Method is necessary to ensure that contamination will not compromise trace metals determinations during the sampling process [1003].

As of March 1997, the EPA 1600 series methods had not yet been officially approved in 40 CFR for use in NPDES permits, but the improvements in these methods were suggested by EPA staff to be wise practice when attempting low detection limit analyses for metals.

For Lead, EPA method 1637 allows a water MDL detection limit of 0.036 ug/L [1003]. EPA method 1640 allows a water MDL detection limit of 0.0081 [1003]. Lowest EPA water quality criterion is 0.14 ug/L [1003].

Highlights from EPA Method 1638: Determination of Trace Elements in Ambient Waters by Inductively Coupled Plasma – Mass Spectrometry:

This 1996 proposed EPA method is for the determination of dissolved elements in ambient waters at EPA water quality criteria (WQC) levels using inductively coupled plasma-mass spectrometry (ICP-MS) [1003]. It may also be used for determination of total recoverable element concentrations in these waters [1003]. This method was developed by integrating the analytical procedures in EPA Method 200.8 with the quality control (QC) and sample handling procedures necessary to avoid contamination and ensure the validity of analytical results during sampling and analysis for metals at EPA WQC levels [1003]. This method contains QC procedures that will assure that contamination will be detected when blanks accompanying samples are analyzed [1003]. This method is accompanied by Method 1669: Sampling Ambient Water for Determination of Trace Metals at EPA Water Quality Criteria Levels ("Sampling Method") [1003]. The Sampling Method is necessary to assure that trace metals determinations will not be compromised by contamination during the sampling process [1003].

This method may be used with the following metals:

Antimony (Sb), CAS 7440-36-0
Cadmium (Cd), CAS 7440-43-9
Copper (Cu), CAS 7440-50-8
Lead (Pb), CAS 7439-92-1
Nickel (Ni), CAS 7440-02-0
Selenium (Se), CAS 7782-49-2
Silver (Ag), CAS 7440-22-4
Thallium (Tl), CAS 7440-28-0
Zinc (Zn), CAS 7440-66-6

As of March 1997, the EPA 1600 series methods had not yet been officially approved in 40 CFR for use in NPDES permits, but the improvements in these methods were suggested by EPA staff to be wise practice when attempting low detection limit analyses for metals [1003].

This method is not intended for determination of metals at concentrations normally found in treated and untreated discharges from industrial facilities [1003]. Existing regulations (40 CFR Parts 400–500) typically limit concentrations in industrial discharges to the mid to high part-per-billion (ppb) range, whereas ambient metals concentrations are normally in the low part-per-trillion (ppt) to low ppb range [1003].

The ease of contaminating ambient water samples with the metal(s) of interest and interfering substances cannot be overemphasized [1003]. This method includes suggestions for improvements in facilities and analytical techniques that should maximize the ability of the laboratory to make reliable trace metals determinations and minimize contamination [1003]. These suggestions are ...based on findings of researchers performing trace metals analyses [1003]. Additional suggestions for improvement of existing facilities may be found in EPA's Guidance for Establishing Trace Metals Clean Rooms in Existing Facilities, which is available from the National Center for Environmental Publications and Information (NCEPI) at the address listed in the introduction to this document [1003].

Clean and ultraclean—The terms "clean" and "ultraclean" have been applied to the techniques needed to reduce or eliminate contamination in trace metals determinations [1003]. These terms are not used in this method because of their lack of an exact definition [1003]. However, the information provided in this method is consistent with the summary guidance on clean and ultraclean techniques [1003].

The procedure given in this method for digestion of total recoverable metals is suitable for the determination of silver in aqueous samples containing concentrations up to 0.1 mg/L [1003]. For the analysis of samples containing higher concentrations of silver, succeedingly smaller volume, well-mixed sample aliquots must be prepared until the analysis solution contains <0.1 mg/L silver [1003].

Sample preservation—Preservation of samples and field blanks for both dissolved and total recoverable elements may be performed in the field at time of collection or in the laboratory [1003]. However, to avoid the hazards of strong acids in the field and transport restrictions, to minimize the potential for sample contamination, and to expedite field operations, the sampling team may prefer to ship the samples to the laboratory within two weeks of collection [1003]. Samples and field blanks should be preserved at the laboratory immediately upon receipt [1003]. For all metals, preservation involves the addition of 10% HNO3 to bring the sample to pH <2 [1003]. For samples received at neutral pH, approx 5 mL of 10% HNO3 per liter will be required [1003].

Do not dip pH paper or a pH meter into the sample; remove a small aliquot with a clean pipet and test the aliquot [1003]. When the nature of the sample is either unknown or known to be hazardous, acidification should be done in a fume hood [1003].

Store the preserved sample for a minimum of 48 h at 0–4°C to allow the acid to completely dissolve the metal(s) adsorbed on the container walls [1003]. The sample pH should be verified as <2 immediately before withdrawing an aliquot for processing or direct analysis [1003]. If, for some reason such as high alkalinity, the sample pH is verified to be >2, more acid must be added and the sample held for sixteen hours until verified to be pH <2 [1003].

In some situations (as when background concentrations are low), water detection limits as low as 0.029 ug/L may be necessary for silver, using EPA method 1638, since EPA Water Quality Criteria are as low as 0.31 ug/L [1001].

In some situations (as when background concentrations are low), water detection limits as low as 0.0097 ug/L may be necessary for antimony, using EPA method 1638, since EPA Water Quality Criteria are as low as 14 ug/L [1001] [1003].

In some situations (as when background concentrations are low), water detection limits as low as 0.0079 ug/L may be necessary for thallium, using EPA method 1638, since EPA Water Quality Criteria are as low as 1.7 ug/L [1001] [1003].

In some situations (as when background concentrations are low), water detection limits as low as 0.14 ug/L may be necessary for zinc, using EPA methods 1638 or 1639, since EPA Water Quality Criteria are as low as 28 ug/L [1001] [1003].

Previous EPA Drinking Water Monitoring Requirements [893]:

Tap water monitoring for lead and copper to determine whether a system is subject to the treatment technique requirements. Water quality parameter sampling to determine the effectiveness of optional corrosion control treatment. Source water monitoring for lead and copper to determine source water's contribution to total tap water lead and copper levels, and the need for treatment. Monitoring schedules vary by system size and type of monitoring [893].

Lead in Blood:

Lead effects the synthesis and life span of red blood cells [366]. Many analyses are available for lead in blood [945]. A common blood test for exposure to lead is the ALA-D (ALAD) test [488]. ALA is an abbreviation for aminolevulinic acid [488]. Fish and mammal ALA-D levels are sensitive (inversely correlated) to lead levels in the blood. Lead inactivates essential ALA-D sulfhydryl groups, resulting in reduced hemoglobin formation and anemia in lead-exposed individuals [488]. Since many other metals (Cu, Cd, Zn, and Hg) do not inhibit ALA-D levels in fish, the ALA-D test is considered a valuable diagnostic indicator of recent lead poisoning in fish.

Zinc protoporphyrin concn was used as an index of blood lead concn. Analysis of zinc protoporphyrin consists of diluting whole blood (1:500), adding dimethyldodecylaminoxide and measuring the fluorescence at 594 nm (excitation at 424 nm). A correlation coefficient of 0.87 for zinc protoporphyrin and blood lead concn (by AAS) /was found/. Iron deficiency anemia will also reduce zinc protoporphyrin concn. /Inorganic lead/ (Lamola AA et al; Clin Chem 21,1: 93-7, 1975, as cited in NIOSH; Criteria Document: Inorganic Lead p.XI-29, 1978, DHEW Pub. NIOSH 78-158) [940].