THE MASSACHUSETTS TOXICS USE REDUCTION INSTITUTE

Massachusetts Chemical Fact Sheet

Lead

This fact sheet is part of a series of chemical fact sheets developed by TURI to help Massachusetts companies, community organizations and residents understand the chemical's health and environmental effects, how it is used and the availability of safer alternatives. Since companies report usage under the Toxics Use Reduction Act, readers will learn what Massachusetts companies are using the chemical and where.

Lead is a natural, bluish-gray metal that possesses the general physical properties of other metals as a conductor of electricity and heat. Manufacturers use lead in many different products such as batteries, metal products, cables, ceramic glazes, pigments, and ammunition. Lead is a well-established human and environmental hazard.

In 2004, Massachusetts manufacturers used more than 3.5 million pounds of lead and lead compounds.

LEAD FACTS	
Chemical Formula	Pb
CAS Number	7439-92-1
Vapor Pressure	1.77 mm Hg at 1000 degrees C
Solubility	Pure lead is insoluble; lead compounds may vary from insoluble to soluble
Flammability	Not flammable
Description	Bluish, gray metal at room temperature

Health and Environmental Impacts

Human Health Effects

Chronic (long-term) exposure to lead in humans results in effects on the blood, central nervous system (CNS), blood pressure, kidneys, and Vitamin D metabolism. Children are particularly sensitive to the chronic effects of lead, with slowed cognitive development, reduced growth and other effects reported. Reproductive effects such as decreased sperm count and spontaneous abortions have also been associated with high lead exposure. The developing fetus is at particular risk from maternal lead exposure, with low birth weight and slowed postnatal neurobehavioral development noted. Human studies are inconclusive regarding a link between lead exposure and cancer.

Acute (Short-Term) Health Effects

Brain damage, kidney damage, and gastrointestinal distress (such as colic) are seen from acute exposure to high levels of lead in humans.

Death from lead poisoning is likely to occur in children who have blood lead levels greater than 125 micrograms per deciliter of blood (µg/dL). Effects on kidney function, neurodevelopment, and blood pressure are evident when blood lead levels are below 10 µg/dL.

The most sensitive targets for the toxic effects of lead are the kidneys and the hematological, cardiovascular, and nervous systems. Because of the multiple modes of action of lead in biological systems, lead could potentially affect any system or organ in the body.

Chronic (Long-Term) Health Effects

Human studies are inconclusive regarding lead exposure and the potential for increased cancer risk. Animal studies have reported kidney tumors in rats and mice exposed to lead via the oral route. EPA considers lead to be a Group B2, probable human carcinogen. International Agency for Research on Cancer (IARC) considers inorganic lead compounds to probably be carcinogenic to humans (Group 2A), and organic lead compounds to be not classifiable as to their carcinogenicity to humans (Group 3).

Studies on male workers using lead have reported severe depression of sperm count and decreased function of the prostate and/or seminal vesicles at blood lead levels of 40 to 50 µg/dL. Occupational exposure to high levels of lead has been associated with a high likelihood of spontaneous abortion in pregnant women. Exposure to lead during pregnancy produces toxic effects on the human fetus, including increased risk of preterm delivery, low birthweight, and impaired mental development.

Chronic exposure to lead in humans can affect the blood and the nervous system. Neurological symptoms have been reported in workers with blood lead levels of 40 to 60 µg/dL. Slowed conduction in peripheral nerves has been reported in adults with blood lead levels of 30 to 40 µg/dL. Children are particularly sensitive to the neurotoxic effects of lead.

Other effects from chronic lead exposure in humans include effects on blood pressure and kidney function, and interference with vitamin D metabolism. Animal studies have reported effects similar to those found in humans, with effects on the blood, kidneys, and nervous, immune, and cardiovascular systems noted.

Exposure Routes

Human exposure to lead occurs through a combination of inhalation and oral exposure, while dermal absorption of inorganic lead compounds is reported to be much less significant. Inhalation generally contributes a greater proportion of the dose for occupationally exposed groups, and the oral route generally contributes a greater proportion of the dose for the general population.

Worker Health

Potentially high levels of lead occur in the following industries: primary and secondary lead smelting and refining industries, steel welding or cutting operations, battery manufacturing plants, construction, rubber products and plastics industries, printing industries, firing ranges, radiator repair shops, and other industries requiring flame soldering of lead solder. In these work areas, the major routes of lead exposure are inhalation and ingestion of lead-bearing dusts. In the smelting and refining of lead, historical mean concentrations of lead in air have been measured at 4,470 $\mu g/m^3$; in the manufacture of storage batteries historical mean airborne concentrations of lead from 50 to 5,400 $\mu g/m^3$ have been recorded. While these values are based on older manufacturing processes (i.e., from the 1970s), they are significant when considering that the recommended upper exposure limit of lead in the air is 100 $\mu g/m^3$.

Public Health

The largest source of lead in the atmosphere has historically been from leaded gasoline combustion, but with the phase out of lead in automotive gasoline in the 1970s through 1980s, air lead levels have decreased considerably. On-going airborne sources include combustion of solid waste, coal, and oils, emissions from iron and steel production and lead smelters, emissions from general aviation aircraft and racing vehicles, combustion of marine fuels, and tobacco smoke.

Exposure of the general population to lead is most likely to occur through the ingestion of contaminated food and drinking water, and by the inhalation of lead particulates in ambient air. Fruits, vegetables, and grains may contain levels of lead in excess of background levels as a result of plant uptake of lead from soils and direct deposition of lead onto plant surfaces. A common source of lead exposure for children is from lead-based paint that has deteriorated into paint chips and lead dusts. Common sources of lead exposure for adults include occupational and non-occupational exposures from activities such as do-it-yourself paint scraping, renovations, and castings. For example, using heat guns or dry scraping of old lead containing paint during home reconstruction and remodeling can result in lead exposure.

Exposure to lead can also occur from food and soil. Children are also exposed by handling and mouthing lead-stabilized PVC plastics and lead alloy jewelry and toys. Lead exposure to the general public can also occur during the use of inadequately glazed or heavily worn earthenware vessels for food storage and cooking, as well as by engaging in certain hobbies such as using recreational shooting ranges, stained glass making, or using molten lead in casting ammunition, fishing weights, or toy figurines.

Environmental

Lead particles are removed from the atmosphere by precipitation and dry deposition. The average residence time of lead in the atmosphere is ten days, during which long distance transport reaching thousands of kilometers may take place. Elemental lead is by nature extremely persistent in both water and soil. The presence of lead and compounds in these media varies widely, however, depending on such factors as temperature, pH, and the presence of humic materials (i.e., dark colored organic material associated with the biological breakdown of living matter).

Biologists have studied the effects of lead sinkers and jigs on waterfowl, such as loons and swans, since the 1970s. A single fishing sinker swallowed with food or taken up as grit could be fatal to waterfowl. Lead adversely affects the function and structure of the kidney, central nervous system, bones, and production and development of blood cells in waterfowl. Exposure to lead, such as through ingestion of fishing sinkers, can cause lead poisoning in waterfowl, producing convulsions, coma, and death. A study of 522 loons found dead in New England was conducted between 1987 and 2000. The study revealed that for breeding adult loons, confirmed and suspected lead poisoning from ingested fishing weights accounted for almost half of the adult deaths.

(For section references, see endnote #1)

Use Nationally and in Massachusetts

The total global industrial consumption of lead in 2003 was estimated to be 15.1 billion pounds, and the U.S. consumption of lead in 2003 was estimated to be 3.06 billion pounds. The greatest use of lead is in lead-acid batteries, however lead-acid batteries are not manufactured in Massachusetts.

Lead has a low melting temperature (327° C) for a metal and is extremely malleable, which enables easy casting, shaping, and joining of lead products. Lead can be recycled as a secondary raw material from lead-acid batteries and other lead products.

The high density of lead is desirable for several product categories including weighting applications, and shielding against sound, vibration, and radiation.

Lead compounds have different physical properties than elemental lead, and are used for various products. The major lead compounds used in commerce are lead oxide (PbO), lead tetraoxide (Pb_3O_4), basic lead carbonate (white lead), tribasic lead sulfate, and dibasic lead phthalate.

Lead and its compounds have many desirable material properties and a variety of uses. Major products/uses of lead in the US include: batteries, ammunition, glass, heat stabilizer in plastics and resins, metal finishing, electronics (solder, board surface finish, components), sheet lead (sound barriers, roof flashing, radiation shielding), bulk metal (castings, weighting applications, ammunition), and pigments. For example, the reactions of lead oxide in dilute sulfuric acid are fundamental to the operation of a lead-acid battery.

Table 1: Consumption of Lead Nationally

By Use Category

Use	U.S. Consumption in 2005 (Million Pounds)	Percentage of Total U.S. Consumption
Storage batteries	2,580.0	88.4%
Ammunition	122.6	4.2%
Miscellaneous Uses	65.8	2.3%
Sheet lead	58.0	2.0%
Casting metals	39.0	1.3%
Oxides	28.2	1.0%
Solder	16.7	0.6%
Billets, ingots	4.2	0.1%
Extruded products	2.4	0.1%
Bearing metals	2.4	0.1%
TOTAL	2,919.3	100.0%
Source: USGS - Gabby (2007)		

In 2004, Massachusetts manufacturers used approximately 8.85 million pounds of lead and lead compounds.

The total U.S. consumption of lead in 2005 for various uses is shown in Table 1.

Table 2 summarizes the difference in reported use of lead in Massachusetts from 1990 to 2004. It is important to note that the reporting threshold for lead was lowered from 10,000 pounds to 100 pounds starting in 2001, so the number of facilities reporting in 2004 is significantly higher than in 1990.

Since the reporting threshold was lowered in 2001, many companies that were previously exempt entered the reporting process. For example, 59 electronics facilities, 31 metal products facilities, and 15 plastics/rubber companies entered the reporting process since 2001 due to this lower reporting threshold. In addition, concrete manufacturers and electricity generators facilities were not required to report in 1990.

Table 2. Massachusetts Lead Use by Industry Sector (1990 – 2004)

	1990		2004	
Use Category	Number of Facilities	Total Use (1,000 lb)	Number of Facilities	Total Use (1,000 lb)
Batteries	1	260.0	0	0
Ceramic Glazes	1	165.9	1	59
Colorants	2	293.8	5	467.7
Concrete - Ready Mixed and Concrete Products	0	0	38	11.5
Electricity Generation	0	0	15	2,803.5
Electronics	5	115.6	64	169.6
Glass-based Products	3	580.1	7	166.9
Inorganic chemicals	0	0	2	3.1
Metal Products	11	366.6	41	784.9
Paints and coatings	2	37.5	2	141.9
Paper, Paperboard and Coated Paper	2	54.6	4	2.3
Plastic or Rubber Products and Compounding	13	3,149.9	21	1,675.1
Silverware and Hollowware Tableware	2	110.9	2	2.1
Wire and Cable Insulation and Jacketing	9	2,018.5	18	2,544.5
Recycling of Mercury-Containing Products and Waste Oil	0	0	3	13.0
Miscellaneous	0	0	7	7.5
TOTAL	51	7,153.5	230	8,852.75

The information on chemical use is based on what has been reported to the Massachusetts Toxics Use Reduction Program for 1990 and 2004. The numbers presented do not reflect production changes in the companies over the time period. The primary industrial sectors reporting lead use in 2004 include electricity generation, wire and cable insulation and jacketing, plastics and rubber compounding, metal products and wire and cable colorants. Electricity generators represented the largest users of lead in 2004. This industry sector was not required to report in 1990.

The percent change in lead use between 1990 and 2004 is illustrated by industry sector in Figure 1. Note that sectors reporting zero use, or not required to report, in 1990 are not included on this chart.

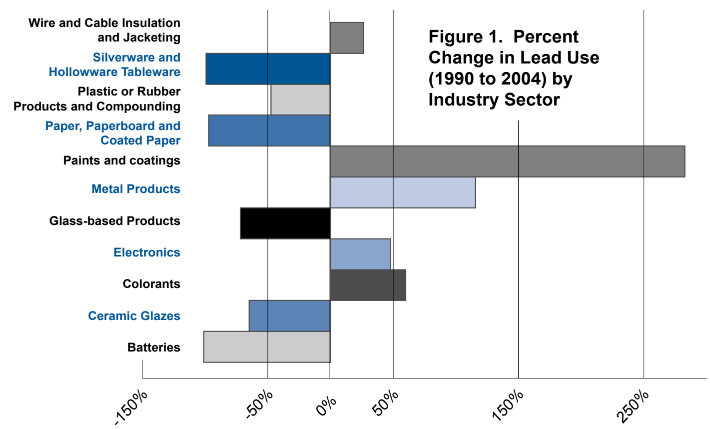


Figure 1. Percent Change in Lead Use (1990 to 2004) by Industry Sector

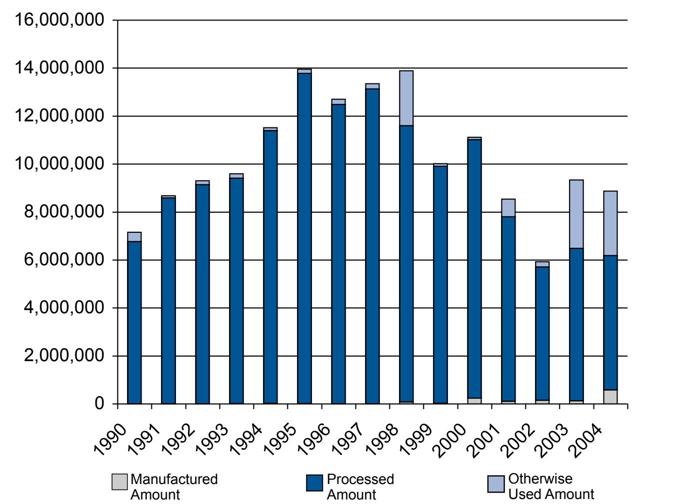
As shown in Figure 1, the highest percent increase (272%) in lead use in Massachusetts is associated with the paints and coatings industrial sector. However, as shown on Table 2, this industrial sector accounted for less than 2% of the total amount of lead reported in 2004. Ninety-eight percent of this industry sector's lead usage in 2004 was reported by one traffic paint manufacturer, Franklin Paint Co. Franklin Paint did not exceed reporting threshold amounts in 1990. Traffic paint is a demanding paint application that until recently required the use of lead pigments. This Massachusetts-based traffic paint manufacturer transitioned to lead-free pigments starting in 2006, which should be reflected in the 2006 and later reports.

The Metal Products sector, which represented less than 9% of the total amount of reportable lead in Massachusetts in 2004, experienced the second highest increase (97%) in lead use. This was mainly due to 31 new facilities reporting in this sector because of the impact of the lowered reporting threshold for lead in 2000.

Of the primary industry sectors reporting us of lead in Massachusetts in 2004, the metal products industries saw an increase in reportable amounts of lead of 114%, colorants (used primarily in the wire and cable coating industry) increased by 59%, and the wire and cable jacketing and insulation industry increased by 26%. Plastics and rubber products and compounds decreased its overall reportable use of lead by 47% from 1990 to 2004.

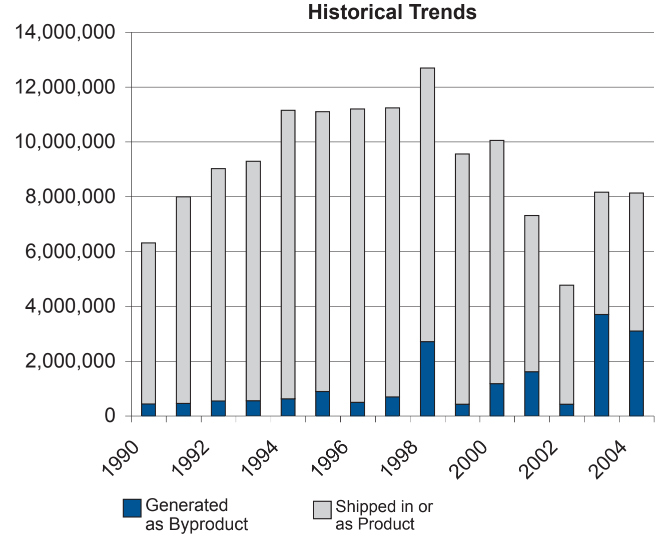
The annual reported quantities from 1990 to 2004 in absolute amount of inputs and outputs in Massachusetts are shown in Figures 2 and 3. The term "inputs' is the total use, consisting of amounts that are "manufactured" or "processed", as well as amounts that are "otherwise used" (i.e., ancillary uses that do not become incorporated into the final product).

Figure 2. Total Inputs of Lead in Massachusetts - Historical Trends



Outputs include lead and lead compounds that are "generated as byproduct" (i.e., all non-product material created by a process line prior to release, on-site treatment, or transfer) and the amount of lead and lead compounds that are "shipped in or as product". As shown in Figure 3, the majority of lead and lead compounds used are processed and subsequently shipped in product, though the trend, especially since 2000, has been towards a higher percentage of lead and lead compounds to be generated as byproduct.

Figure 3. Total Outputs of Lead in Massachusetts - Historical Trends



As shown in Figures 2 and 3, both inputs and outputs significantly increased during the time period from 1990 to the mid 1990's with peak values occurring in 1998. For the period 1998 to 2004, there has been a significant reduction in the Commonwealth for both inputs and outputs of lead and lead compounds. Specifically, from 1998 to 2004 the amount of lead and lead compounds "processed" was reduced by 51.3%, while the amount "shipped in or as product" over the same time period was reduced by 49.6%.

There was a major increase in lead "otherwise used" and "generated as byproduct" in 1998 because a new filer, Clean Harbors Environmental Services, was managing significant amounts of lead-bearing waste. Over the next few years, their use of lead decreased and was reclassified as "processed".

There was also a significant increase in lead reported as "otherwise used" and "generated as byproduct" in 2003 and 2004 because Municipal Solid Waste Combustors were required to report for the first time (as "waste to energy" facilities, their use is included in "electricity generation" in Table 2).

(For section references, see endnote #2)

Alternatives

Electronics

The European Union's directive called Restriction of the use of certain Hazardous Substances (RoHS) limits the use of lead in many consumer electronics applications. Many companies in the consumer electronics industry have already moved toward a standard alternative for lead solder. This alternative is an alloy consisting of tin, copper, and silver (SAC alloy). However, many companies that produce high reliability electronics products for industries such as aerospace, defense, and medical are currently exempt from this directive. The Institute has been involved with the electronics industry for the past seven years to research, test, and evaluate lead-free alloys for electronics assembly to assist companies that must comply with RoHS, as well as those that are currently exempt (go to www.turi.org and click on Industry to learn more).

Heat Stabilizers for Wire and Cable Applications

There are several commercially available alternatives for heat stabilizers for use in PVC applications, including: calcium-zinc, barium-zinc, magnesium-zinc, magnesium aluminum hydroxide carbonate hydrate, and magnesium zinc aluminum hydroxide carbonate. In general, the alternatives are more desirable from a human health and environmental standpoint. Alternatives are available that meet the wire and cable technical specifications, and research on new alternatives is ongoing. The cost differential between lead and non-lead heat stabilizers is estimated to be between cost neutral and a 10% premium for mixed metal heat stabilizers, which is anticipated to diminish as mixed metal heat stabilizers gain further market acceptance and as new materials reach commercialization. In addition, research into the use of synergistic materials, such as nanoclays, suggests that a combination of materials may lead to a better cost comparison while maintaining or improving the performance of non-leaded heat stabilizers.

A U.S. EPA Design for Environment project is underway to evaluate three specific wire/cable applications. The Institute and several Massachusetts manufacturers are participating in this project, which will provide life cycle assessment information for several heat stabilizer alternatives.

Metal Products

Fishing Sinkers

There are several commercially available alternatives for fishing sinkers including bismuth, ceramic, steel, tin, and tungsten. In general, these alternatives are more desirable from a human health and environmental standpoint, though there are some data gaps for the ceramic, bismuth, and tungsten alternatives which makes it difficult to make a full comparison. No one alternative meets the technical performance requirements for every sinker type or application but each alternative is successfully being used for one or more types of sinkers. While most alternatives are several times the price of equivalent lead sinkers, steel bullet weights and egg sinkers are competitive in price to the equivalent lead sinkers.

Wheel Weights

There are several commercially available alternatives for wheel weights including copper, steel, tin, and zinc. In general, these alternatives are more desirable from a human health and environmental standpoint, with the exception of aquatic toxicity for copper and zinc. The alternatives meet the performance requirements for use in automobile applications and steel and zinc weights are currently used by auto manufacturers. Steel and zinc weights are competitive in price with the coated lead weights used by auto manufacturers.

Paints and Coatings

Because of the demanding environmental conditions encountered by traffic paint, the use of lead chromate pigments has persisted for the application of yellow traffic lines. However lead-free alternatives are available. For example, Franklin Paint Co. uses Pigment Yellow 65 and Pigment Yellow 83 for their lead-free traffic paint. Other national and international paint manufacturers provide lead-free yellow traffic paint formulations for oil based, latex based, and rubber based painting applications.

Ammunition

There are several commercially available alternatives for ammunition used at shooting ranges including bismuth, copper, iron, tungsten, and zinc. In general, the alternatives are more desirable from a human health and environmental standpoint, with the exception of aquatic toxicity for copper and zinc. Alternatives are available that closely approximate the ballistic performance of lead ammunition and have the benefit of being frangible, which reduces the risk of injury from ricocheted bullets and reduces wear on targets. The current purchase price for alternatives is significantly higher than lead ammunition but studies suggest that operational costs of firing ranges can be reduced through the use of lead-free ammunition.

Batteries

Many available battery alternatives contain nickel, cadmium, or other toxic materials. Safer battery alternative technologies are still emerging, including many alternatives to lead-acid batteries, some of which utilize nanotechnology to improve overall performance for a variety of applications.

(For section references, see endnote #3)

Regulatory Context

Lead has been listed as a pollutant of concern to EPA's Great Waters Program due to its persistence in the environment, potential to bioaccumulate, and toxicity to humans and the environment. The National Ambient Air Quality Standard (NAAQS) are set by the U.S. EPA for pollutants that are considered to be harmful to public health and the environment. The NAAQS for lead is 1.5 μg/m^3.

The U.S. Environmental Protection Agency (EPA) created a maximum contaminant action level for lead in drinking water of 0.015 mg/l. EPA has not established an inhalation reference concentration (RfC) or an oral Reference Dose (RfD) for elemental lead or inorganic lead compounds. EPA has, however, established an RfD for tetraethyl lead of 1 x 10^{-7} mg/kg body weight per day.

The following occupational threshold limits have also been established:

- NIOSH Recommended Exposure Limit for an 8 to 10 hour time-weighted-average exposure = 0.10 mg/m^3.
- NIOSH Immediately Dangerous to Life or Health = 100 mg/m^3.
- OSHA Permissible Exposure Limit for an 8 hour work day = 0.5 mg/m^3.
- ACGIH Threshold Limit Value = 0.5 mg/m^3 over an 8 hour work shift.

Restrictions on Lead in Products

There are various restrictions on the use of lead in products that have been promulgated by some international, national and state agencies. These include:

The European Union's RoHS directive restricts the use of lead in many electronics applications if present in a homogenous material in amounts exceeding 0.1% by weight.

In the US, the Consumer Products Safety Commission (CPSC), under the Federal Hazardous Substance Act, has banned most "paint and surface coatings containing more than 0.06% lead, and furniture, toys and other articles intended for use by children that are coated with such paint."

In addition, any toy or article intended for use by children that is likely to expose the child to a sufficient amount of lead to present a hazard, according to CSPC's rules, is banned.

Several states in the Northeast have banned the use of certain lead sinkers for fishing. Massachusetts still allows the use of lead fishing sinkers except in the Quabbin and Wachusett Reservoirs.

In light of recent disclosures of lead in paint on children's toys, in children's jewelry, in vinyl products such as lunch boxes and bibs, and in lipsticks, there is growing concern about the need for more comprehensive regulations, testing and enforcement of lead restrictions in consumer products.

(For section references, see endnote #4)

Endnotes

1. Agency for Toxic Substances and Disease Registry (ATSDR) 2005, Draft Toxicological Profile for LeadU.S. Department of Public Health, Public Health Service, Atlanta, GA; International Agency for Research on Cancer (IARC) 2004, "Evaluation of Carcinogenic Risks to Humans, Inorganic and Organic Lead Compounds", vol. 87; Lohse, J., Sander, K. & Wirts, M. 2001, Heavy Metals in Vehicles II, Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of Europe Communities; Massachusetts Division of Occupational Safety 2004, Hazard Alert: Lead Exposure at Indoor Police Firing Ranges in Massachusetts; National Institute for Occupational Safety and Health (NIOSH), Carcinogen List. Available: http://www.cdc.gov/niosh/npotocca.html; National Research Council (NRC) 2004, Forensic Analysis: Weighing Bullet Lead Evidence, National Academies Press; New Jersey Department of Health and Senior Services 2001, Hazardous Substance Fact Sheet: Lead; Noll, M. & Clark, F. 1997, "Airborne Lead and Noise Exposures During Police Firearms Qualification", Applied Occupational and Environmental Hygiene, vol. 12, no. 10; Root, R.A. 2000, "Lead Loading of Urban Streets by Motor Vehicle Wheel Weights", Environmental Health Perspectives, vol. 108, no. 10, pp. 937-940; Scheuhammer, A.M. & Norris, S.L. 1995, A Review of Environmental Impacts of Lead Shotshell Ammunition and Lead Fishing Weights in Canada, Canadian Wildlife Service; Strigul, Nicolay et al. 2005, "Effects of Tungsten on Environmental Systems", Chemosphere, vol. 61, no. 2, pp. 248-258; Sidor, Inga F., Pokras, Mark A., Major, Andrew R., Poppenga, Kate M., Miconi, Taylor, Miconi, Rose M., Mortality of Common Loons in New England, 1987 to 2000, Journal of Wildlife Diseases: Vol 39, No 2. pp. 306 – 315, 2003; U.S. Environmental Protection Agency 1999, Integrated Risk Information System (IRIS) on Lead and Compounds (Inorganic), National Center for Environmental Assessment, Office of Research and Development, Washington, DC; United States Environmental Protection Agency (USEPA) 2005, Preliminary Exposure Assessment Support Document For the TSCA Section 21 Petition on Lead Wheel-Balancing Weights.United States Environmental Protection Agency (USEPA) 1994, Lead Fishing Sinkers: Response to Citizens' Petition and Proposed Ban; Proposed Rule; United States Environmental Protection Agency (USEPA) a, March 9, 2006-last update, Technology Transfer Network Air Toxics Website: Lead Compounds. Available: http://www.epa.gov/ttn/atw/hlthef/lead.html [2006, May, 2006].

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