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A Small Dose of Arsenic
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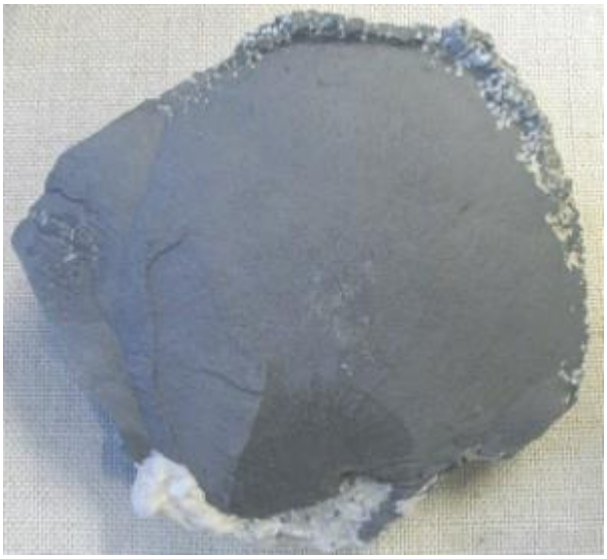
Overview



People long ago recognized that depending on the dose, arsenic could either treat an illness or be used as a poison to cause death. Its medicinal use to treat syphilis and amebic dysentery ended with the introduction of penicillin and other antibiotics in the twentieth century. Arsenic-based compounds are currently used to treat some forms of cancer. As a poison, arsenic trioxide (As_2O_3) has several desirable qualities: it looks like sugar and is tasteless, and it only takes about a tenth of gram to kill someone. While its use as a human poison has greatly declined, arsenic is still used as an herbicide, particularly in growing cotton, and as a wood preservative. Arsenic poisoning from well water remains a serious worldwide human health concern. (Image: Native arsenic with quartz and calcite, from Ste. Marie-aux-mines, Alsace, France)

Arsenic, Introduction and History

Arsenic is a versatile metal, forming various compounds, either inorganic or organic. Inorganic arsenic is widely distributed in nature, usually in the trivalent form (As^{3+}) but also as pentavalent arsenic (As^{5+}). Most rocks contain 1-5ppm of arsenic. The trivalent forms include arsenic trioxide, sodium arsenite, and arsenic trichloride. Organic arsenic, much less toxic than inorganic arsenic, is produced in a biomethylation process by many organisms including humans and shellfish. Though arsenic occurs naturally in rocks and soil, the majority of arsenic released into the environment is from industrial smelting.

Uses

Arsenic use and production has declined with recognition of its toxicity and the development of suitable replacements. It is not mined but produced as byproduct of smelting for copper, lead, and zinc. The last U.S. smelter producing arsenic closed in 1985 in Tacoma, Washington. (See Tacoma Smelter.) Smelters

typically released the trivalent arsenic trioxide and lead into the atmosphere, which contaminated the local environment and left an unwelcome legacy for local residents.
Arsenic is used in the manufacture of silicon-based computer chip technology and in glass manufacture to control color. Inorganic arsenic is no longer used as a pesticide in cotton fields and orchards, but some forms of organic arsenic continue to be applied to cotton fields. The wood preservative CCA, chromated copper arsenate, has been phased out for use residentially and in children's play areas by the US EPA. (See the next page, Case Studies, for more information on CCA.) Inorganic arsenic is also released from coal-fired electric generation facilities, and cigarette smokers inhale some arsenic fromtobacco. Organic arsenic compounds are also used as a feed additive to enhance growth of poultry and swine. The import of arsenic into the US has declined from 20,000 metric tons in 2002 and 2003 to less that 8,000 metric tons in 2007.

Exposure

We are exposed to constant but low levels of arsenic, unless receiving greater exposure in an occupational setting or from arsenic-contaminated drinking water. Normally, the background air contains less than 0.1 µg/m3 and drinking water less than 5 µg/L, but water levels can be significantly higher. Food usually supplies less than 10 µg/day of arsenic but can be higher with the consumption of fish and particularly shellfish, which can have arsenic levels up to 30 µg/g.
The majority of arsenic in food is organic, a form that is generally less toxic than inorganic arsenic. The total average daily exposure to arsenic is about 20 µg/day from food and water (assuming 2000 mL/day average water consumption at 5 µg/L arsenic). Children have higher levels of exposure, particularly if drinking water concentrations of arsenic are elevated, because of their smaller size and greater consumption of water relative to their size. Several state health departments and public interest groups have expressed concern about children repeatedly exposed to arsenic form playing on arsenic-treated desk or play structures. Some exposure and associated risk calculations exceed EPA's acceptable risk levels. Arsenic exposure can also occur if arsenic-treated wood is burned or if sawdust from treated wood is inhaled.
Arsenic poisoning from well water remains a serious worldwide human health concern. In West Bengal and Bangladesh, more than 75 million people are exposed to arsenic-laden water that threatens their health. (See Arsenic Poisoning in Bangladesh.) People of Argentina, Chile, and Taiwan also have elevated arsenic in their drinking water. In the United States, federal agencies fiercely debate arsenic drinking water standards, which would limit the amount of arsenic in municipal wells. This is particularly relevant to areas of the western United States that have elevated levels of arsenic in drinking water.

Arsenic Case Studies

Arsenic in Drinking Water

Arsenic in drinking water is a worldwide problem affecting the lives of millions of people. High levels of arsenic in local soil or rock contaminate the local water supply. In the United States, the federal government has struggled for many years to establish standards of arsenic in the drinking water. The U.S. Environmental Protection Agency has recently lowered the standard from 50 ppm (50 µg/L) to 10 ppm. This standard will require additional treatment of a number of municipal water supplies, particularly in the western United States. The standard is being lowered because chronic exposure to

low levels of arsenic can cause skin cancer and other illnesses. Even at the new standard of 10 ppm, there is a risk of cancer.
In other areas of the world, such as Bangladesh, elevated arsenic levels in drinking water is more acutely life threatening. People were encouraged to establish local wells to reduce exposure to bacteria-contaminated drinking water, but it was subsequently discovered that many of these wells have high levels of arsenic in the water. It is estimated that 75 million people in Bangladesh are exposed to arsenic-contaminated water, resulting in 200,000 to 270,000 deaths from cancer each year. In addition, people suffer from skin changes on the palms of hands and soles of feet. (See Arsenic Poisoning in Bangladesh.)

Pressure-treated Wood

By far the largest use of arsenic is in treating wood to prevent decay or insect damage. Several compounds are used, but the vast majority of wood is treated with a pesticide called chromated copper arsenate (CCA), first used in the 1940s. CCA is a water-based mixture of inorganic salts of chromium, copper, and arsenic that is forced into the wood under pressure. Wood treated with CCA is still found in decks, playground equipment, outdoor furniture, fences, construction lumber, utility poles, piers, and pilings. The amount of arsenic in treated wood can be quite large. A standard eight-foot length of treated 2" x 4" lumber contains as much as 15 grams of arsenic. To put this in perspective the lethal dose of arsenic in humans is 70 to 200 mg or about 1 mg/kg. Since December 31, 2003, CCA was no longer used in wood for most residential settings, including decks and play sets. There are a number of arsenic-free wood preservatives on the market that are registered for use in treated wood for residential use.
The health risks of exposure to arsenic-treated lumber have been debated for years, although it is well known that inhaling sawdust from construction with treated lumber can be quite dangerous. Ideally the arsenic-based wood preservative is "fixed" to the wood, but research has shown that arsenic leaches from the wood with rainfall and that arsenic can be rubbed off from the surface by hand contact. Arsenic contamination of soil under decks often exceeds hazardous waste cleanup standards. Children who play on decks or other treated surfaces pick up arsenic on their hands and later ingest some of the arsenic when they put their hands in their mouth or pick up food. Health professionals, the wood preserving industry, and public interest groups have hotly debated the hazards of these exposures. In 2002, producers of arsenic-treated wood reached an agreement with EPA to phase out the residential uses of arsenic treated lumber, including decks, play equipment, fences, etc. CCA will still be available for commercial uses such as utility poles. The alternative wood treatment most used to replace CCA is a copper-based preservative called ammoniacal copper quaternary, or ACQ. ACQ has a much lower toxicity to humans than CCA.

Biological Properties and Health Effects of Arsenic

Biological Properties

Soluble inorganic arsenic compounds, such as arsenic trioxide, are readily absorbed from the intestine (80-90%). Organic arsenic compounds found in seafood are not well absorbed. Arsenic can also be absorbed through the lungs and skin. Most of the arsenic in the blood is bound to red blood cells. Once ingested, inorganic arsenic is biotransformed by the liver to a methylated form of arsenic and excreted in the urine with a half-life of 3 to 5 days. Arsenic is also excreted in the outer layer of skin cells and in

sweat. Arsenic binds to sulfhydryl-containing proteins and concentrates in the hair and fingernails. At higher levels of exposure, white bands, called Mees' lines, are visible in the nails.

Health Effects

The acute effects of inorganic arsenic poisoning are well known from the incidence of suicidal, homicidal, and accidental poisonings. Ingestion of 70 to 180 mg of arsenic trioxide can be fatal, but initial effects may be delayed for several hours. Symptoms following oral ingestion include constriction of the throat with difficulty in swallowing, severe intestinal pain, vomiting, diarrhea, muscle cramps, severe thirst, coma, and death. If the patient survives the acute symptoms there is often peripheral nervous system damage.

The symptoms of chronic arsenic exposure are most often associated with contaminated drinking water. Early signs of arsenic exposure are garlic odor on the breath, excessive perspiration, muscle tenderness and weakness, and changes in skin pigmentation. More advanced symptoms include anemia, reduced sensation in the hand and feet from damage to the peripheral sensory system (stocking and glove syndrome), peripheral vascular disease, skin changes on palms and soles, and liver and kidney involvement. Changes in circulation can lead to gangrene of extremities, especially of the feet, which has been referred to as blackfoot disease. Hyperpigmentation and hyperkeratosis of palms and soles occurs in 6 to 3 months with repeated ingestion of 0.4 mg/kg per day. Many of the symptoms are dose and time dependent. In other words, repeated low levels of exposure over an extend period of time can produce effects similar to a one-time, high level of exposure.

Arsenic causes both skin and lung cancer. Skin cancer was observed over 100 years ago in patients treated with arsenical compounds, and lung cancer was seen in smelter workers who chronically inhaled arsenic dust. Although arsenic is an established human carcinogen, it has been difficult to confirm and study in animal models. Arsenic readily crosses the placenta, but there appears to be increased methylation of arsenic to its organic form, which reduces its toxicity to the fetus.

Reducing Exposure to Arsenic

The toxicity of chronic exposure to arsenic is well established and the best recommendation is to avoid arsenic exposure entirely. The most common home exposure is from contaminated drinking water and arsenic-treated lumber. Certain areas of the country have higher levels of arsenic in water. The EPA has lowered the arsenic drinking water standard to 10 ppb and required water providers to meet the new standard by January 2006.

Avoid inhalation of sawdust from arsenic-treated lumber, and never burn any treated lumber or sawdust. Families with decks, play equipment, furniture, or other structures made with arsenic-treated lumber should take steps to reduce exposure, especially to children. Home uses of arsenic-treated lumber have been phased out in the United States, but it is estimated that approximately 60 billion board feet of arsenic-treated lumber are still in use in the United States as of 2002. This is about enough to cover half the state of California with a deck two inches thick. Several state agencies have recommended that treated lumber on which children may play be coated periodically with paint or other sealer to reduce hand contact and subsequent ingestion of arsenic. Those who choose to remove arsenic-treated decks or other structures may want to test the soil underneath to see if levels exceed state standards. And always wash your hands after coming in contact with any arsenic-treated product.

Regulatory Standards for Arsenic

EPA - Drinking water 10 µg/L (10 ppb)
EPA - RfD - 0.3 µg/kg/day (inorganic chronic exposure)
OSHA - Workplace air - 0.5 mg/m3
ATSDR - MRL - 0.3 µg/kg/day (chronic exposure)

Arsenic - Recommendation and Conclusion

Arsenic is an ancient and well-known hazard and, along with lead and mercury, is a significant environmental contaminant. The inorganic form is far more toxic than organic arsenic, which is commonly found in seafood. Arsenic-contaminated drinking water is a worldwide problem that affects millions of people. Human exposure also occurs from arsenic-treated lumber.

The best recommendation is to avoid or reduce exposure to inorganic arsenic

Arsenic - Additional Resources

European, Asian, and International Agencies

- World Health Organization (WHO). Online: <http://www.who.int/mediacentre/factsheets/fs210/en/index.html> (accessed: 9 April 2009).
  WHO arsenic in drinking water fact sheet.
- World Health Organization (WHO). Arsenic in Drinking Water and Resulting Arsenic Toxicity in India & Bangladesh. Online: < http://www.searo.who.int/EN/Section314_4291.htm> (accessed: 9 April 2009).
  WHO report on arsenic in drinking water.

North American Agencies

- Health Canada - Arsenic in the Drinking Water Online. Health Canada provides information on the health effects of Arsenic in drinking water. U.S. Food and Drug Administration (FDA). Online. (accessed: 9 April 2003).
- FDA Guidance Document for Arsenic in Shellfish.
- U.S. Environmental Protection Agency (EPA). Online. (accessed: 19 June 2004).
  Draft Preliminary Probabilistic Risk Assessment for Children Who Contact Chromated Copper Arsenate (CCA) Treated Playsets and Decks
- U.S. Environmental Protection Agency (EPA). Online. (accessed: 9 April 2003).
  Site has general information and research on arsenic.
- U.S. Environmental Protection Agency (EPA) - Integrated Risk Information System. Online. (accessed: 9 April 2003).
  Site contains EPA's risk assessment evaluation of arsenic.

- U.S. Environmental Protection Agency (EPA) - Toxics Release Inventory (TRI) Program. Online. Available (accessed: 9 April 2003).
  Site has information on arsenic release in the United States.
- U.S. ATSDR - Agency for Toxic Substance Disease Registry
  - Toxicology Profile Series Arsenic. Online. (accessed: 9 April 2003).
- U.S. National Research Council (NRC) - Arsenic in Drinking Water: 2001 Update. Online. (accessed: 9 April 2003).
  The NRC report on arsenic can be access from their web site.
- U.S. Geological Services (USGS) Online. (accessed: 9 April 2003).
  Site contains a map of United States showing arsenic in water.
- U.S. Geological Services (USGS) Online. (accessed: 24 October 2010).
  Arsenic in Coal fact sheet.

Non-Government Organizations

- Arsenic Crisis Information Center - Arsenic in West Bengal & Bangladesh. Online. (accessed: 9 April 2003).
  Site has information and pictures related to arsenic poisoning in West Bengal and Bangladesh.
- Harvard University. Online. (accessed: 9 April 2003).
  Site has information on health effects of chronic arsenic poisoning.
- Arsenic: A Murderous History. Dartmouth toxic metals research program. (Accessed: June 30, 2003). A great historical look at the use of arsenic a poison.
- Medline Plus on Arsenic
- eMedicine

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