

Arsenic

Arsenic is a metalloid that is distributed widely in the earth's crust. Pure arsenic is rarely found in the environment. More commonly, it bonds with various elements such as oxygen, sulfur, and chlorine to form inorganic arsenic compounds and with carbon and hydrogen to form organic arsenic compounds. The water-soluble trivalent and pentavalent oxidation states of inorganic arsenic are the most toxic arsenic compounds. Atmospheric arsenic exists primarily in inorganic form and is absorbed by particulate matter, while soluble arsenate and arsenite salts are the most typical forms in water. Atmospheric arsenic deposits to the soil, and is then absorbed by plants, leached to groundwater and surface water, and taken up by plants and animals.

Airborne concentrations of arsenic range from a few nanograms per cubic meter (ng/m^3) to a few tenths of a microgram per cubic meter ($\mu\text{g}/\text{m}^3$), but concentrations may exceed $1 \mu\text{g}/\text{m}^3$ near stationary sources of emissions (Bencko 1987). A few micrograms per liter ($\mu\text{g}/\text{l}$) of arsenic are normally found in drinking water. In some locations, however, concentrations may exceed 1 milligram per liter (mg/l); see WHO (1981). Uncontaminated soil typically contains about 7 micrograms per gram ($\mu\text{g}/\text{g}$) arsenic, on average, but levels in the range of 100–2,500 $\mu\text{g}/\text{g}$ have been detected near stationary sources, and up to 700 $\mu\text{g}/\text{g}$ in agricultural soils treated with arsenic-containing pesticides (WHO 1987). High concentrations of arsenic, mainly fat-soluble or water-soluble organoarsenic compounds, have been observed in seafood (WHO 1981).

Sources and Uses

Arsenic occurs widely in the natural environment. The highest mineral concentrations can be found

as arsenides of copper, lead, silver, and gold, but high levels may also be found in some coal. The principal natural sources of arsenic in the atmosphere are volcanic activity and, to a lesser degree, low-temperature volatilization.

White arsenic (arsenic trioxide), a by-product of roasting sulfide ores, is the basis for manufacturing all arsenicals. The main uses of arsenicals, as components of pesticides and herbicides, have been banned in many countries. Arsenicals are also used in leather pigments. Chromated copper, sodium, and zinc arsenates are used in antifungal wood preservatives, and in some places, arsanilic acid is added to farm animal feed as a growth stimulant. Metallic arsenic is used in electronics and as a metal alloy, and sodium arsenite has been included in drugs for treating leukemia and other diseases. Arsenic is also used in lead crystal glass manufacturing, contributing to atmospheric emissions and the generation of highly toxic wastes.

The greatest part of anthropogenic arsenic emissions originates from stationary sources, including copper smelting (about 50%), combustion of coal, especially low-grade brown coal (about 20%), and other nonferrous metal industries (around 10%). The drying of concentrates in mining operations also contributes to atmospheric emissions of arsenic. The contribution of agriculture to anthropogenic arsenic releases, through the use of arsenicals as pesticides and herbicides and through the burning of vegetation and of wood treated with arsenic-containing preservatives, is estimated at around 20% (Chilvers and Peterson 1987). The largest contributors of arsenic in terrestrial waters are landfills, mines, pit heaps, wastewater from smelters, and arsenic-containing wood preservatives (Bencko 1987). Some iron and steel plants that

use iron pyrites from metal mines, as well as other industries, such as sulfuric acid plants, that use pyrite as a source of sulfur for production, could be substantial sources of arsenic pollution of both air and water.

Health Impacts of Exposure

Ingestion is the main route of exposure to arsenic for the general population. Arsenic can have both acute and chronic toxic effects on humans. It affects many organ systems including the respiratory, gastrointestinal, cardiovascular, nervous, and hematopoietic systems. When ingested in dissolved form, both inorganic and organic soluble arsenic compounds are readily absorbed from the gastrointestinal tract; less soluble forms have lower absorption rates.

Short-term acute poisoning cases involving the daily ingestion of 1.3–3.6 mg arsenic by children in Japan resulted in acute renal damage, disturbed heart function, and death (WHO 1981). Chronic exposure leads to accumulation of arsenic in the bone, muscle, and skin and, to a smaller degree, in the liver and the kidneys. Mild chronic poisoning causes fatigue and loss of energy. More severe symptoms include peripheral vascular disorders (“blackfoot disease”), gastrointestinal problems, kidney degeneration, liver dysfunction, bone marrow injury, and severe neuralgic pain. Such symptoms have been reported in populations consuming water with 500–1,000 µg/l arsenic content. Chronic exposure also results in dermatological disorders such as palm and sole hyperkeratosis, allergic contact dermatitis, and cancerous lesions (Bencko 1987). Long-term consumption of drinking water with arsenic concentrations exceeding 200 µg/l has been connected with the prevalence of skin cancer (Tseng et al.

1968). Further studies (cited by Wildavsky and Schleicher 1995) have failed to demonstrate a relationship at lower levels of exposure, which may indicate the existence of a lower threshold level for carcinogenic impacts of ingested arsenic.

Inhalation is a less significant pathway for arsenic exposure for the general population, although smokers are constantly exposed to some arsenic due to the natural arsenic content of tobacco leaf and the effect of arsenate insecticide treatment used by tobacco plantations.¹ There are some indications that smoking may exacerbate the effects of exposure to airborne arsenic. About 30% of inhaled arsenic is absorbed by the human body. Acute inhalation of inorganic arsenic compounds can result in local damage to the respiratory system, including perforation of the nasal septum. Increased mortality from cardiovascular diseases and lung cancer was associated with exposure of smelter workers to high levels of airborne arsenic. It is estimated that 1 µg/m³ arsenic in the air can be associated with a 0.003 lifetime risk of developing cancer (WHO 1987). The carcinogenic potential of inorganic arsenic is considered the key criterion in assessing the hazard from both environmental and occupational exposures.

Ingested organic arsenic compounds have no proven health effects even at relatively high concentrations.

Ambient Standards and Guidelines

Ambient standards and guidelines for arsenic are aimed at protecting the population, livestock, and other organisms from exposure to ambient arsenic. Table 1 presents EU, USEPA, and WHO reference standards and guidelines for ambient levels of arsenic in water. To protect health, stan-

Table 1. Reference Standards and Guidelines for Ambient Levels of Arsenic in Water
(micrograms per liter)

Use	EU limit values	EU guide values	USEPA standard	WHO guide values
Drinking water	50		50	10
Surface water intended for drinking				
Before normal treatment	50	10		
Before intensive treatment	100	50		

Sources: Drinking water: CEC 1980 (EU); United States, CFR, vol. 21, no. 52 (USEPA); WHO 1993. Surface water: CEC 1975 (EU).

dards for acceptable arsenic concentrations in ambient water focus on water intended for drinking. Since various treatment methods achieve different levels of purification, allowable concentrations before treatment may differ depending on the impact of treatment on drinking water. No reference ambient standards or guidelines have been set for atmospheric arsenic concentrations.

Conclusions

Considering differences in diets, habits, and the pathways through which arsenic may affect human health, as well as the complex biological cycle of arsenic, regulation through ambient standards may not be the best tool for protecting populations from the adverse health effects of exposure to environmental arsenic. Policymakers should adopt a complex approach to the abatement of arsenic exposure, emphasizing preventive measures and considering location-specific factors and the effects of the global cycle of arsenic across environmental media.

Recommendations

Stationary sources that contribute to the increase of arsenic in the environment should not exceed the arsenic emissions referred to in the relevant industry section of this *Handbook*. These emissions are normally achievable through good industrial practices.

In addition, the impacts of new sources on ambient concentrations of arsenic should be considered. When the use of certain fuels or industrial processes results in emissions that contribute to a significant increase in ambient arsenic concentrations, or in areas where the natural occurrence of arsenic is very high, the environmental assessment should ensure that arsenic emissions are properly abated, taking into consideration alternative fuels, technologies, and control measures. Intermittent monitoring of the surrounding water bodies, soil, and plants should ensure that arsenic concentrations do not impose an increased health threat to the population in the vicinity of the industrial plant.

Note

1. According to certain estimates (WHO 1987), about 6 μg of arsenic may be inhaled per pack of cigarettes smoked, of which about 2 μg would be retained in the lungs.

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