



Scientific Facts on Arsenic

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GreenFacts

Level 2 - Details on Arsenic

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This Digest is a faithful summary of the leading scientific consensus report produced in 2001 by the International Programme on Chemical Safety (IPCS): *"Environmental Health Criteria for Arsenic and Arsenic Compounds (EHC 224)"*

The full Digest is available at: <https://www.greenfacts.org/en/arsenic/>



This PDF Document is the Level 2 of a GreenFacts Digest. GreenFacts Digests are published in several languages as questions and answers, in a copyrighted user-friendly Three-Level Structure of increasing detail:

- Each question is answered in Level 1 with a short summary.
- These answers are developed in more detail in Level 2.
- Level 3 consists of the Source document, the internationally recognised scientific consensus report which is faithfully summarised in Level 2 and further in Level 1.

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1. What is arsenic?

1.1 What are the properties of arsenic?

Arsenic is a metalloid - a natural element that is not actually a metal but which has some of the properties of a metal. It is a natural component of the Earth's crust, generally found in trace quantities in all rock, soil, water and air. However, concentrations may be higher in certain areas due to either natural conditions or human activities.

Arsenic can exist in many different chemical forms in combination with other elements. Some forms are inorganic, which do not contain carbon, and others are organic, which always contain carbon. Inorganic arsenic exists in four main chemical forms known as valency or oxidation states. Valency is a measure of the ability of a compound to combine with other elements, such as hydrogen. The dominant forms are arsenite, with a valency of 3, and arsenate, with a valency of 5.

The element arsenic itself is not soluble in water. Arsenic in combination with other elements (as salts) has a wide range of solubilities depending on the surrounding acidity and the presence of other chemicals.

1.2 How are arsenic levels measured?

There are various laboratory methods for the detection and measurement of arsenic. Some of these methods can distinguish between the different chemical forms (valency) of the arsenic. Sensitive measuring techniques exist for a limited range of arsenic compounds. A test kit based on a color reaction is currently used for groundwater testing in Bangladesh that is suitable for use under field conditions.

2. Where does environmental arsenic come from?

2.1 What are the natural sources of environmental arsenic?

The Earth's crust is an abundant natural source of arsenic. It is present in more than 200 different minerals, the most common of which is called arsenopyrite.

About one-third of the arsenic in the Earth's atmosphere is of natural origin. Volcanic action is the most important natural source. The next most important source is arsenic-containing vapor that is generated from solid or liquid forms of arsenic salts at low temperatures.

Inorganic arsenic of geological origin is found in groundwater used as drinking water in several parts of the world, for example Bangladesh, India and Taiwan.

Organic arsenic compounds, that is, those containing carbon, are mainly found in sea-living organisms, although some of these compounds have also been found in species living on land.

As seen in questions 5 [see <https://www.greenfacts.org/en/arsenic/1-2/arsenic-5.htm#0>] to 8 [see <https://www.greenfacts.org/en/arsenic/1-2/arsenic-8.htm#0>], inorganic arsenic poses more problems than organic arsenic.

2.2 What are the man-made sources of environmental arsenic?

Elemental arsenic is produced commercially from arsenic trioxide. Arsenic trioxide is a by-product of metal smelting operations. About 70% of the world production of arsenic is used in timber treatment, 22% in agricultural chemicals, and the remainder in glass, pharmaceuticals and metallic alloys.

Mining, metal smelting and burning of fossil fuels are the major industrial processes that contribute to arsenic contamination of air, water and soil. The use of arsenic-containing pesticides in the past has left large areas of agricultural land contaminated. The use of arsenic in the preservation of timber has also led to contamination of the environment.

2.3 How is arsenic transported and distributed in the environment?

The transport and distribution of arsenic in the environment is complex, due to the many chemical forms in which it may be present and because there is continuous cycling of different forms of arsenic through air, soil and water.

Much of the arsenic in the atmosphere comes from high-temperature processes such as coal-fired power plants, burning vegetation and volcanic activity. The arsenic is released into the atmosphere primarily as arsenic trioxide where it adheres readily onto the surface of particles. These particles are dispersed by the wind and eventually fall back to the earth due to their weight or during rain.

Natural, low-temperature biological reactions involving microbes also release arsenic into the atmosphere. Microbes acting on arsenic in soils and sediments generate arsine gas or other volatile arsenic compounds. Arsine reacts with oxygen in the air and is converted back to non-volatile forms of arsenic, which settle back to the ground.

Arsenic dissolved in water can be present in several different forms. In well-oxygenated water and sediments, nearly all arsenic is present in the stable form of arsenate. Some arsenite and arsenate forms are less stable and are interchangeable, depending on the chemical and biological conditions. Some chemical forms of arsenic adhere strongly to clay and organic matter and this can affect how they behave in the environment. There is potential for arsenic to be released from water and sediments, again depending on the chemical and biological conditions.

Lastly, weathered rock and soil containing arsenic may be transported by wind or water erosion. Since many arsenic compounds tend to adhere strongly to soils, water percolating down does not usually move arsenic through more than a short distance in soil.

3. What are the levels of exposure to arsenic?

3.1 How much arsenic is there in the environment?

Arsenic concentrations in air range from very low (0.02 to 4 ng/m³) in remote and rural areas, to low (3 to about 200 ng/m³) in urban areas. Much higher concentrations (more than 1000 ng/m³) can be found near some industrial sources such as smelters, although in some countries, very high levels are no longer found because of measures taken to reduce pollution.

Concentrations of arsenic in open ocean seawater are typically low (1–2 µg/litre). In rivers and lakes, concentrations are somewhat higher but generally below 10 µg/litre. Exceptions are near man-made sources such as pesticide manufacturing or mining, where individual samples in surface waters may be 1000 times higher (up to 5000 µg/litre). Arsenic levels in groundwater are typically as low as in open ocean water (about 1–2 µg/litre), except in areas with volcanic rock and sulphide mineral deposits where arsenic levels can range up to 3000 µg/litre.

In sediment, arsenic concentrations range from 5 to 3000 mg/kg. The higher levels are found in areas contaminated by mining and smelting. In soil, concentrations range from 1 to 40 mg/kg, usually averaging around 5 mg/kg. Naturally elevated levels of arsenic in soils may be associated with the presence of sulphide ores in the rock layers below the soil. Soils heavily contaminated by activities such as mining of gold and arsenic, metal smelting and agricultural chemical application can have concentrations of arsenic up to several thousand milligrams per kg (mg/kg) or more.

3.2 What levels of arsenic are found in living organisms?

Sea-living plants and animals normally contain organic arsenic residues. These are generated from inorganic forms of arsenic, either by microbes or by the plants and animals themselves. Amounts range from less than 1 to more than 100 mg/kg. Arsenic can build up (bioaccumulate) in the bodies of aquatic organisms, particularly those living in the sea. Arsenic concentrations in freshwater and land-living animals and plants are usually less than 1 mg/kg. Land-living plants may accumulate arsenic via uptake through the roots from the soil or by deposition of airborne arsenic on the leaves. Arsenic levels are higher in living organisms collected near man-made sources of arsenic or in areas with volcanic activity. Up to 3000 mg/kg has been found in some species at arsenical mine sites.

3.3 What levels of arsenic are humans exposed to?

Exposure of the general population to arsenic occurs mainly through food and water and in most areas, food is the main source. The daily intake of arsenic from food and beverages is generally between 20 and 300 µg/day. Arsenic in food is mainly in the form of organic arsenic, which is generally thought to pose less health problems than inorganic arsenic (see questions 5 to 8). About one-quarter of the arsenic present in the diet is inorganic arsenic, mainly from foods such as meat, poultry, dairy products and cereals. Fish and shellfish contain the highest concentrations of arsenic, but the proportion of inorganic arsenic in fish is very low, below 1%. In some areas, where levels of arsenic in groundwater are high, drinking water may be the main source of intake. In drinking water, arsenic is present in the more toxic, inorganic form.

Arsenic which is breathed in contributes around 1 µg/day in a non-smoker, 10 times as much in a smoker, and more in polluted areas. Contaminated soils such as mine tailings are also a potential source of arsenic exposure

The amount of arsenic absorbed into the body from all sources can be assessed on an individual basis by measuring the concentration of inorganic arsenic and its metabolites in urine. Generally, it ranges from 5 to 20 µg arsenic per litre of urine (µg/litre), but may even exceed 1000 µg/litre. (see 4.2)

In workplaces with up-to-date occupational hygiene practices, exposure concentrations generally do not exceed 10 micrograms per cubic meter of air (µg/m³). However, in some workplaces arsenic concentrations several hundred times higher have been reported.

4. What happens to arsenic in the body?

4.1 What happens to arsenic absorbed by the body?

The amount of arsenic absorbed into the body from inhaled airborne particles is highly dependent on two factors, the size of particles and their solubility. The size of the particles determines how far into the lungs they can penetrate – the further they penetrate the more likely arsenic is to be absorbed. The solubility of the particles in the fluid lining the lungs determines how easily arsenic will be absorbed into the blood stream. In the gut, soluble arsenic compounds from food and beverages are rapidly and extensively absorbed into the blood stream.

In humans and most common laboratory animals, inorganic arsenic is metabolized via two main types of reaction: (1) conversion of the pentavalent form of arsenic - arsenate - to the trivalent form - arsenite, and (2) methylation, i.e. addition of a methyl group comprising one atom of carbon and three of hydrogen (-CH₃) to the trivalent form. After methylation arsenic can be rapidly eliminated from the body with the urine. There can be large differences between individual humans in their capacity for methylation that is most likely due to differences in enzyme capacity in the body. It is not clear if children have a reduced capacity for methylation compared with adults. Studies suggest that the main pathway for getting rid of arsenic from the body, methylation, may be inhibited at high exposures.

The uptake and elimination of arsenic depends on its chemical form, particularly at high exposures. For example, ingested organic arsenic compounds are much less extensively metabolized and more rapidly eliminated in urine than inorganic arsenic in both laboratory animals and humans. In the case of inorganic arsenic, the trivalent forms pass more rapidly into the tissues compared with the pentavalent forms.

4.2 What are the indicators of arsenic exposure?

The amounts of arsenic or its metabolites in blood, hair, nails and urine are used as indicators - biomarkers - of arsenic exposure. Blood arsenic is only useful for indicating either acute poisoning or repeated high-level exposures occurring over a long period. This is because arsenic rapidly disappears from blood.

Arsenic persists longer in hair and nails, which can, therefore, be used as indicators of past exposure. The concentration of arsenic, along a hair may be used to estimate the timing of an exposure.

The best estimate of recent exposure to inorganic arsenic is to measure it and its specific chemical metabolites in urine. However, consumption of certain seafood high in organic arsenic, such as seaweed or mollusks, produces one of the same metabolites as inorganic arsenic and may therefore exaggerate estimates of inorganic arsenic exposure in some people at certain times. Such foods should be avoided for 2–3 days before urine sampling.

5. What are the effects of arsenic on laboratory animals?

Both inorganic and organic forms of arsenic may affect the health of laboratory animals. The effects range from rapid death to effects which only emerge later, such as cancer. The degree of toxicity depends whether the arsenic is inorganic or organic and on its chemical form (valency). Inorganic arsenic is generally more toxic than organic arsenic, and in the case of inorganic arsenic, trivalent forms are more toxic than pentavalent forms, at least at high doses. Many different parts of the body can be affected by arsenic, including the skin, lungs, heart, blood vessels, immune system, kidney, reproductive system, gut and nervous system.

According to IPCS, studies to investigate whether arsenic causes cancer in animals have been inconclusive. However, IARC now considers there is limited evidence for cancer in laboratory animals. For example, female mice of a particular type, given high levels of arsenic in drinking water for 2 years, developed tumors of the lung, liver, gut and skin. (Very recent studies show arsenic causes cancer in several organs and tissues of animals exposed before birth, via their mothers during pregnancy.) Other laboratory studies have investigated how cancer might be caused. Inorganic arsenic does not directly damage DNA, the inherited genetic material in cells. However, arsenic can damage whole chromosomes in cells grown in the laboratory, affect the repair of damaged DNA, cause cells to multiply, and promote the development of tumors induced by other chemicals. One study has indicated that one of the metabolites of arsenic found in the body may cause cancer of the bladder in male rats at high doses.

6. What are the effects of arsenic on the environment?

Water and land-living plants and animals show a wide range of sensitivities to different chemical forms of arsenic. Their sensitivity is modified both by biological factors and by their surrounding physical and chemical environment. In general, inorganic forms of arsenic are more toxic to the environment than organic forms and, among inorganic forms, arsenite is more toxic than arsenate. This is probably because the way in which the various forms are taken up into the body differs and once taken up, they act in different ways in the body. The reason why arsenite is toxic is thought to be because it binds to particular chemical groups - sulfhydryl groups - found on proteins. Arsenate, on the other hand, affects the key energy producing process that take place in all cells.

Arsenic compounds cause short-term and long-term effects in individual plants and animals and in populations and communities of organisms. These effects are evident, for example, in aquatic species at concentrations ranging from a few micrograms to milligrams per litre. The nature of the effects depends on the species and time of exposure. The effects include death, inhibition of growth, photosynthesis and reproduction, and behavioral effects. Environments contaminated with arsenic contain only a few species and fewer numbers within species. If levels of arsenate are high enough, only resistant organisms, such as certain microbes, may be present.

7. What are the effects of arsenic on human health?

7.1 Can arsenic cause cancer and skin changes?

Long-term exposure to arsenic in drinking water can cause cancer in the skin, lungs, bladder and kidney. It can also cause other skin changes such as thickening and pigmentation. The likelihood of effects is related to the level of exposure to arsenic and in areas where drinking water is heavily contaminated, these effects can be seen in many individuals in the population. Increased risks of lung and bladder cancer and skin changes have been reported in people ingesting arsenic in drinking water at concentrations of 50 µg/litre, or even lower.

Exposure to arsenic in the workplace by inhalation can also cause lung cancer. The likelihood of cancer is related to the level and duration of exposure. Increased risks of lung cancer have been observed at exposure levels that add up to more than 750 (µg/m³).year. This figure is obtained by multiplying the average concentration in the workplace by the number of years of exposure (for example, 15 years of exposure to a workroom air concentration of 50 µg/m³ correspond to 750 (µg/m³).year). Smoking and arsenic exposure combined increase the risk of lung cancer.

As regards the possible method by which arsenic causes cancer, the evidence in humans indicates that arsenic can cause damage to whole chromosomes (clastogenic effects) but does not appear to cause damage to individual genes.

7.2 What other health problems can arsenic cause?

Soluble inorganic arsenic can have immediate toxic effects. Ingestion of large amounts can lead to gastrointestinal symptoms such as severe vomiting, disturbances of the blood and circulation, damage to the nervous system, and eventually death. When not deadly, such large doses may reduce blood cell production, break up red blood cells in the circulation, enlarge the liver, color the skin, produce tingling and loss of sensation in the limbs, and cause brain damage.

Long-term exposure to inorganic arsenic in drinking water in Taiwan has caused blackfoot disease, in which the blood vessels in the lower limbs are severely damaged, resulting eventually in progressive gangrene. Its occurrence in Taiwan may be influenced by factors such as poor nutrition. However, arsenic exposure has caused other forms of blood vessel disease in the limbs in several other countries.

The relationship between arsenic exposure and other health effects is less clear. The evidence is strongest for high blood pressure, heart attacks and other circulatory disease. The evidence is weaker for diabetes and reproductive effects; it is weakest for strokes, long-term neurological effects, and cancer at sites other than lung, bladder, kidney and skin.

8. What has happened in areas where drinking water is heavily contaminated?

Arsenic levels in natural waters are usually low (a few $\mu\text{g}/\text{litre}$). However, there are several areas in the world where arsenic-bearing minerals are in contact with groundwater. In such areas, drinking water from underground wells can become heavily contaminated with natural inorganic arsenic, in excess of 1000 $\mu\text{g}/\text{litre}$ in some cases. This has been a serious health problem in countries like West Bengal in India, Taiwan, Chile and Mexico and is now a serious problem in Bangladesh.

In Bangladesh, the water in many districts is contaminated and large populations are regularly drinking water containing more than 50 $\mu\text{g}/\text{litre}$. Long-term exposure to inorganic arsenic in drinking water can cause adverse effects on health, such as skin changes and cancer, which have been reported in these regions over the last hundred years. In Taiwan, a resulting blood vessel disease, known as blackfoot disease, resulting eventually in progressive gangrene has been studied since the 1920s. (see question 7.2 [see <https://www.greenfacts.org/en/arsenic/1-2/arsenic-7.htm#2>]).

9. What have WHO and IARC established about arsenic?

International bodies have previously evaluated arsenic.

The World Health Organization (WHO) has set a provisional guideline value of 10 $\mu\text{g}/\text{litre}$ for arsenic in drinking-water as the practical quantification limit. That is, it is acknowledged that even this limit may not be entirely free of health risks but there are practical problems in many areas of the world in reducing levels in drinking water below this limit.

Arsenic and arsenic compounds were evaluated by the International Agency for Research on Cancer (IARC). There was sufficient evidence for carcinogenicity to humans and limited evidence for carcinogenicity to animals, and the overall evaluation was that "arsenic and arsenic compounds" are carcinogenic to humans (Group 1) . This evaluation applies to the group of chemicals (i.e. arsenic and arsenic compounds) as a whole and not necessarily to all individual chemicals within the group.