

California Air Resources Board

Proposed Identification of
Inorganic Arsenic
as a Toxic Air Contaminant

STAFF REPORT

State of California
Air Resources Board
Stationary Source Division

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PROPOSED IDENTIFICATION OF INORGANIC ARSENIC
AS A TOXIC AIR CONTAMINANT

Prepared by the Staffs of
the Air Resources Board and
the Department of Health Services

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What is a Toxic Air Contaminant?

Health and Safety Code section 39655 defines a toxic air contaminant as an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health."

Does Airborne Inorganic Arsenic Qualify as a Toxic Air Contaminant?

The staffs of the Air Resources Board (ARB) and the Department of Health Services (DHS) have reviewed the available scientific evidence on the presence of inorganic arsenic in the atmosphere of California and its potential adverse effect on public health. Based on findings of carcinogenicity and the results of risk assessment, the DHS staff finds that inorganic arsenic meets the definition of a toxic air contaminant.

Does the ARB Staff Recommend Inorganic Arsenic Be Identified as a Toxic Air Contaminant?

Yes. The staff of the Air Resources Board recommends that the Board identify inorganic arsenic as a toxic air contaminant. Furthermore, the staff of the DHS found that there is not sufficient available scientific evidence at this time to support the identification of an exposure level below which no significant adverse health impacts are anticipated; the DHS staff therefore recommends that inorganic arsenic be treated as having no identified threshold.

Why Does the ARB Staff Recommend Inorganic Arsenic Be Identified as a Toxic Air Contaminant:

The DHS staff found “the evidence for human carcinogenicity due to inhaled arsenic to be strong.” The DHS staff reports that several studies of smelter industry and insecticide manufacturing workers have demonstrated that there is a "strong association between respiratory cancer mortality and arsenic exposure." The DHS staff found this association to be consistent, replicable, of substantial magnitude, and having a clear dose-response relationship with high statistical significance.

Substances that have been identified by the Administrator of the United States Environmental Protection Agency (U.S. EPA) as hazardous air pollutants must be identified by the state board as toxic air contaminants (Health and Safety Code section 39665; Title 42 United States Code Sec. 7412). The USEPA Administrator listed inorganic arsenic as a hazardous air pollutant on June 5, 1980 (45 Federal Register, page 37886 ff.). Thus, the state board must identify inorganic arsenic as a toxic air contaminant.

Inorganic arsenic is emitted from a variety of sources and can be detected in the ambient air throughout California. Inorganic arsenic is highly mobile in the environment, and is not naturally removed or detoxified at a rate that would significantly reduce public exposure.

What Are the Findings of the Scientific Review Panel?

In accordance with the provisions of Health and Safety Code section 39661, the Scientific Review Panel (SRP) has reviewed the reports of the staffs of the ARB and DHS on the public exposure and biologic and health effects of inorganic arsenic, and the public comments on these reports. Based on this review, the SRP finds that the reports are without serious deficiencies and agrees with the staff of the ARB and DHS that:

1. The evidence for carcinogenicity in humans due to inhaled arsenic is strong.
2. Inorganic arsenic is emitted into the outdoor air by a variety of stationary sources in California.
3. Hot spot exposures can present a significant source of inorganic arsenic, e.g., smelters, windblown dust (such as from the dry beds of Owens and Mono Lakes), pesticide application, agricultural burning, and tobacco smoke. Exposure by various routes to these sources should be considered as more data becomes available, and further research in this area should be conducted.
4. Based on the average particle size, inorganic arsenic has an estimated atmospheric lifetime of nine days.
5. Approximately 20.3 million people in California are estimated to be exposed to a population-weighted mean inorganic arsenic outdoor air concentration of 1.9 nanograms per cubic meter.
6. Based on available data, indoor exposures to inorganic arsenic may be significantly greater than most outdoor exposures when tobacco smoke is present in indoor environments.
7. Adverse health effects other than cancer are not known to occur at predicted concentrations of inorganic arsenic in ambient outdoor air.
8. Based on available scientific information, an inorganic arsenic exposure level below which carcinogenic effects are not expected to occur cannot be identified.

9. Based on an interpretation of available scientific evidence, DHS staff estimated lifetime excess cancer risk from exposure to airborne arsenic. Risks were evaluated separately by sex and for four smoking categories: never, former, light (less than 1 pack per day), and heavy smokers. Based on the upper 95 percent confidence limit of potency, the estimated range of lifetime excess lung cancer mortality risk from exposure to 1 microgram per cubic meter of atmospheric inorganic arsenic is from 6.3×10^{-4} (female never smokers) to 1.3×10^{-2} (male heavy smokers). Based on available data, 3.3×10^{-3} per microgram per cubic meter is the most plausible estimate of the upper bound of the overall unit risk. These upper bound excess risks are health protective estimates; the actual risks may be below these values.
10. Using the population-weighted annual inorganic arsenic exposure concentration of 1.9 nanograms per cubic meter (California's population-weighted average ambient concentration), the DHS staff estimates the number of excess cancer deaths among non-smokers due to airborne inorganic arsenic exposure to be 0.8 to 2 per million persons exposed throughout their lives. For former smokers, the risk ranges from 3 to 10 per million; for light smokers, from 5 to 14 per million; for heavy smokers, the risk ranges from 10 to 25 per million people at the current average ambient levels of airborne inorganic arsenic. The overall population-weighted average, based on current smoking levels in California, is estimated to range from 4 to 6 deaths per million. The upper bound of excess cancer mortality risk from a lifetime of exposure to 1.9 nanograms per cubic meter of inorganic arsenic ranges from 1 to 25 cases per million persons exposed. This is to be compared with the background lifetime lung cancer rates estimated to range from 0.6 to 14.5 percent (for female never smokers to male heavy smokers).
11. Lifetime exposure to the mean ambient outdoor air concentration (weighted by population) of 1.9 nanograms of arsenic per cubic meter for a population of

20.3 million Californians could result in up to 130 excess cancers, based on the most plausible upper bound estimate of unit risk. Residential indoor exposure associated with environmental tobacco smoke could add an unknown additional number of lung cancers based on this unit risk estimate.

12. Existing data suggests there is a potential for reproductive effects in humans. Although there appears to be a sufficient margin of safety between the ambient exposure and the observed effect levels. This issue should be revisited as hot spot exposure data become available.
13. Identification of inorganic arsenic as a toxic air contaminant is required by Health and Safety Code section 39655, since it has been identified as a hazardous air pollutant under Section 112 of the U.S. Clean Air Act.

For these reasons, we agree with the ARB staff recommendation to its Board that inorganic arsenic be listed by the ARB as a toxic air contaminant.

What Are the Sources of Airborne Inorganic Arsenic Emissions?

Combustion and high-temperature processes are the largest sources of inorganic arsenic emissions to the atmosphere. Major sources of inorganic arsenic emissions in California include:

- o Wood and fossil-fuel combustion sources such as fireplaces, woodstoves, external combustion boilers, internal combustion engines;
- o Geothermal steam development, transmission, usage and release; and
- o Arsenical pesticide/herbicide use.

Other sources of inorganic arsenic emissions may include mining and quarry operations, windblown dust from the dry lakebeds and playas of eastern California, cement manufacturing, glass manufacturing, agricultural burning, waste incineration, secondary lead smelting, resource recovery operations, and the smoking of tobacco.

How Much Inorganic Arsenic Is Released into California's Air?

Total airborne inorganic arsenic emissions in California are estimated to have a minimum range of from 7.4 to 24 tons per year. Fuel combustion (e.g., wood, distillate oil, residual oil and waste oil combustion) is responsible for the majority of the total statewide emissions of inorganic arsenic.

Does Arsenic Exist in More Than One Form?

Yes. Arsenic exists in both organic and inorganic compounds, and in both the gas and particulate matter phases. The majority of atmospheric arsenic is highly respirable inorganic arsenic particulate matter smaller than 2.5 micrometers. Two valences (III or +3, and V or +5) predominate, with arsenic (III) being the most common inorganic arsenic form found in emissions from high temperature sources such as combustion and smelting. Studies at a California site of relatively high inorganic arsenic concentrations yielded an average arsenic (III)-to-arsenic (V) ratio of 1.2 to 1, with an average particle size of 1.5 microns which is highly respirable. Conditions in the ambient atmosphere favor oxidation, so inorganic arsenic (V) compounds are generally expected to predominate in unimpacted ambient air. Inorganic arsenic (III) compounds such as arsenic trioxide are generally more toxic than inorganic arsenic (V) compounds, while inorganic arsenic (V) compounds have been teratogenic in animal studies more frequently than inorganic arsenic (III) compounds. Insufficient data are available to evaluate or quantify the relative carcinogenicity of the two valences, as no carcinogenic mechanism has been defined.

Is the ARB's Inorganic Arsenic Sampling and Analysis Method Scientifically Valid and Effective?

Yes. Particulate matter inorganic arsenic is the predominant arsenic form in the atmosphere. The ARB sampling and analysis method used to detect inorganic arsenic in the atmosphere is a particle collection and analysis technique that does not collect arsenic in the gas phase. Additionally, a maximum 20 percent of all gas and particle phase arsenic may be organic arsenic. Because the ARB's arsenic method does not collect gas phase inorganic arsenic but does collect the particulate matter portion of the organic arsenic, the ARB staff consider the atmospheric concentration data generated from the sampling and analysis to be reasonably representative of inorganic arsenic concentrations.

Now Long Does Inorganic Arsenic Remain in the Atmosphere?

The atmospheric residence time of inorganic arsenic is estimated to be nine days. Inorganic arsenic particulate matter can settle out of the atmosphere as dry deposition or be washed out with precipitation. Some inorganic arsenic may be emitted in the gas phase, but can later adsorb to particulate matter in the atmosphere.

What Are the Ambient Concentrations of Inorganic Arsenic in the State?

The statewide population-weighted exposure to inorganic arsenic for 1986 (based on an exposed population of 20,339,250) was estimated to be 1.9 nanograms per cubic meter with a lower bound of 1.5 nanograms per cubic meter and an upper bound of 2.6 nanograms per cubic meter. The highest concentrations of ambient arsenic were found in the South Coast Air Basin where the population-weighted exposure for 1986 was estimated to be 2.8 nanograms per cubic meter with a lower bound of 2.1 nanograms per cubic meter and an upper bound of 3.8 nanograms per cubic meter.

Are There “Hot Spots” Emissions of Inorganic Arsenic in the State?

Yes. A special ARB study of a secondary lead smelter in the South Coast Air Basin has demonstrated that over 1,000 Californians have been exposed to inorganic arsenic concentrations of up to 392 nanograms per cubic meter. In another case, x-ray fluorescence analysis of filters from a short-term monitoring study of an agricultural burn in Northern Sonoma County demonstrated a maximum unspiciated arsenic concentration of 12,639 nanograms per cubic meter. The extremely high arsenic concentrations had resulted from burning vine support posts (pressure-treated with copper arsenate to control rotting) with the vine cuttings; the use of arsenical pesticides on the vines prior to combustion would not result in concentrations of this magnitude.

In addition to smelting operations and agricultural burning, potential “hot spot” sources of airborne inorganic arsenic emissions may include resource recovery operations, arsenical pesticide applications, windblown dusts from dry lakebeds and playas in eastern California, waste incinerators, and the smoking of tobacco.

“Hot spot” exposures to inorganic arsenic represent a much more significant public health risk than does exposure to ambient inorganic arsenic concentrations.

What About Indoor Exposure to Inorganic Arsenic?

Except for unusual cases of high inorganic arsenic exposures in buildings constructed on top of arsenic waste sites and in homes burning wood that had been treated with arsenical wood preservatives, there are no significant sources of inorganic arsenic in offices and homes of nonsmokers. In one study comparing the indoor concentrations of arsenic in the homes of both non-smokers and smokers to outdoor concentrations, results indicated that arsenic concentrations in both types of homes were generally about the same as outdoor concentrations.

Are There Other Routes of Exposure to Inorganic Arsenic?

In addition to exposure to airborne inorganic arsenic, exposure can also occur from consumption of drinking water, food, and tobacco smoke. In some areas of California (e.g., parts of the San Joaquin Valley), the drinking of water will result in a greater intake of inorganic arsenic than does inhalation of ambient air. Waterborne arsenic is usually in arsenic (V) form, although arsenic (III) can be found in surface water impacted by sources of airborne inorganic arsenic.

Growing plants take up arsenic from the soil; in areas with high arsenic concentrations in groundwater and soils, food crops may take up additional arsenic. Arsenic in foods occurs primarily as complex organoarsenicals, although inorganic forms of arsenic can be present in some foods.

Inorganic arsenic is present in the mainstream smoke inhaled directly into the smoker's lungs, and is presumed to be present in the sidestream smoke that is emitted in the interval between puffs. Inorganic arsenic inhalation for a smoker is estimated to be about 0.8 to 2.4 micrograms per pack of cigarettes. Approximately 40 percent of this would be deposited in the respiratory tract.

What Are the Health Effects of Inorganic Arsenic Exposure?

The health effects of inorganic arsenic exposure have been reviewed and evaluated to determine whether inorganic arsenic meets the definition of a toxic air contaminant. The following text summarizes the DHS findings regarding the health effects of inorganic arsenic exposure:

Carcinogenic and Potentially Carcinogenic Effects

Evidence for carcinogenicity in humans due to inhaled arsenic is strong. Studies of smelter workers exposed to arsenic and workers in the pesticide manufacturing industry have found strong, consistent, statistically significant associations between respiratory cancer mortality and arsenic exposure.

The International Agency for Research on Cancer (IARC) evaluated arsenic in 1980 and classified “arsenic and arsenic compounds” into its Group 1, which includes the chemicals and groups of chemicals which are "causally associated with cancer in humans.”

The staff of the DHS concluded that confounding exposures (e.g., smoking or exposure to other carcinogens) does not explain the strong association observed between arsenic and respiratory cancer. The interaction of smoking with arsenic exposure on respiratory cancer rates appears to be greater than additive, however; at low (ambient environmental) levels of arsenic exposure, the interaction may be as high as multiplicative.

Arsenic is genotoxic: it induces chromosomal aberrations and sister chromatic exchange, and it may inhibit DNA repair.

Non-Carcinogenic Health Effects

The DHS staff has concluded that “it is unlikely that noncarcinogenic adverse health effects would be caused by the levels of arsenic compounds currently found in the ambient air.”

What Is the Risk Assessment for Exposure to Inorganic Arsenic?

Using the population-weighted annual inorganic arsenic exposure concentration of 1.9 nanograms per cubic meter (California's population weighted average ambient concentration), the DHS staff estimates the number of excess cancer deaths among non-smokers due to airborne inorganic arsenic exposure to be 0.8 to 2 per million persons exposed throughout their lives. For former smokers, the risk ranges from 3 to 10 per million; for light smokers, from 5 to 14 per million; for heavy smokers, the risk ranges from 10 to 25 per million people at the current average ambient levels of airborne inorganic arsenic. The overall population-weighted average, based on current smoking levels in California, is estimated to range from 4 to 6 deaths per million. The upper bound of excess cancer mortality risk from a lifetime of exposure to 1.9 nanograms inorganic arsenic per cubic meter ranges from 1 to 25 cases per million persons exposed.

The excess cancer risk per million is based on the unit risk (the number of excess lung cancer deaths due to lifetime exposure to 1 microgram per cubic meter) for inorganic arsenic exposure. Because the sex-specific patterns of lung cancer and all-cause mortality in California differ from those in the United States as a whole, the unit risk for California ranges from 400 to 13,000 excess cancer deaths per million people exposed to 1 microgram inorganic arsenic per cubic meter, while the unit risk for the U.S. ranges from 420 to 11,000 excess cancer deaths per million people exposed. The staff of the DHS recommends that the overall unit risk of 3.3×10^{-3} per microgram per cubic meter be considered the best estimate of the upper bound of risk.

“Hot Spot” exposure to airborne inorganic arsenic may increase the risk of respiratory cancer. For example, a one-month monitoring study downwind from a secondary lead smelter in the South Coast Air Basin's City of Industry demonstrated an average inorganic arsenic concentration of 61 nanograms per cubic meter. These concentrations were subsequently reduced

as a result of the study. If these concentrations had continued unabated for a lifetime (75 years), as many as 6 to 9 excess cancer deaths might have occurred among the 725,000 persons residing nearby.

Based on the finding of inorganic arsenic-induced carcinogenicity and the results of the risk assessment, the DHS staff finds that inorganic arsenic is an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health.

What Are the Alternatives to Identifying Inorganic Arsenic as a Toxic Air Contaminant?

Government Code Section 11346.14 requires agencies to describe alternatives to the regulation considered by the agency and the agency's reasons for rejecting those alternatives. The only alternative to identifying inorganic arsenic as a toxic air contaminant is to not identify it as such. The ARB staff is not recommending this alternative because inorganic arsenic meets the statutory definition of a toxic air contaminant.

What Would Be the Environmental Impact of the Identification of Inorganic Arsenic as a Toxic Air Contaminant?

The identification of inorganic arsenic as a toxic air contaminant is not in itself expected to result in any environmental effects. The identification of inorganic arsenic as a toxic air contaminant by the Board may result in the Board and air pollution control districts adopting control measures in accordance with the provisions of state law (Health and Safety Code sections 39665 and 39666). Any such toxic control measures would result in reduced emissions of inorganic arsenic to the atmosphere, resulting in reduced ambient concentrations, thereby reducing the health risk due to inorganic arsenic exposure. Therefore, the identification of inorganic arsenic as a toxic air contaminant may ultimately result in environmental benefits. Environmental impacts identified with respect to specific control measures will be included in the consideration of such control measures pursuant to Health and Safety Code sections 39665 and 39666.