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December 16, 2009

Arsenic Fact Sheet

We are all exposed to arsenic because of its natural presence in water, food, soil, and air. Whether arsenic is harmful, however, depends on the nature and extent of exposure. This fact sheet presents some general information about arsenic and potential exposures related to arsenic in coal ash released to the environment, with specific reference to the Kingston Fossil Plant ash spill. The following sections describe the chemical properties, occurrence, and movement of arsenic in the environment; the different ways that one might be exposed to arsenic in coal ash in the environment; the toxic effects of arsenic depending on exposure; and how the potential for health effects is assessed.

Arsenic in the Environment and in Coal Ash

Arsenic occurs naturally in the earth's crust within various minerals. Arsenic is present in coal ash because of its presence in plants, minerals, and thus, in coal, a natural byproduct of these materials. Once released to the environment, the chemical form of arsenic can change depending on pH (how acidic or basic), the presence or absence of oxygen, and the concentration of other elements or organic matter. The form of arsenic can greatly affect its toxicity and ability to move in the environment. Arsenic in combination with elements such as oxygen, sulfur, chlorine, or other metals like iron is called "inorganic" arsenic, whereas arsenic in combination with carbon and hydrogen is called "organic" arsenic. Arsenic forms in soil and water are generally inorganic arsenic, whereas arsenic taken up in the food chain is largely organic arsenic.

Inorganic arsenic may be bound within minerals, attached to organic matter or other elements in soil or sediments, or dissolved in water. Inorganic arsenic in soil and coal ash generally does not dissolve well in water and therefore has a low potential to leach from these materials into water. Under conditions of low oxygen (such as when buried deeply), however, arsenic may become more soluble in water and thereby more mobile. In several parts of the world, bedrock with naturally high levels of arsenic has elevated arsenic levels in groundwater.

Background concentrations of arsenic reported in Tennessee soils range from 0.1 to 120 milligrams per kilogram (mg/kg) or parts per million (ppm), with an estimated naturally occurring background level around 10 ppm. Concentrations of arsenic in Kingston impoundment ash samples ranged from 2.8 to 166 ppm with very few samples exceeding 120 ppm. Soil arsenic concentrations can be much higher in areas of the U.S. that are enriched with naturally occurring arsenic-bearing minerals.

When exposed to inorganic arsenic, most organisms transform a large portion of the arsenic into organic arsenic forms. Soluble forms of inorganic arsenic dissolved in water can be taken up by algae, aquatic plants, and fish, and then converted into organic forms. Microscopic organisms in water or sediments also transform inorganic arsenic to organic forms. The predominant organic forms are rapidly excreted by animals and are generally considered non-toxic. Inorganic arsenic is also less toxic to animals than to humans. Therefore, exposures for fish and other animals to arsenic in the environment and food chain are generally less of a concern than for human exposures to inorganic arsenic forms.

How Can One Be Exposed to Arsenic in Coal Ash?

Exposure to substances in coal ash released to land or water may potentially occur in several ways (Figure 1). People may contact coal ash on river banks or in near-shore sediments. Recreational activities may result in people contacting and swallowing river water containing arsenic leached from ash or consuming fish caught from the river. Arsenic in buried sediments may leach to groundwater that is used for drinking water. If coal is mixed with yard soil, people may be exposed through soil contact or home grown vegetable consumption. People may also inhale windblown dust from the deposited coal ash. However, whether exposure actually occurs in any of these ways depends on several factors.

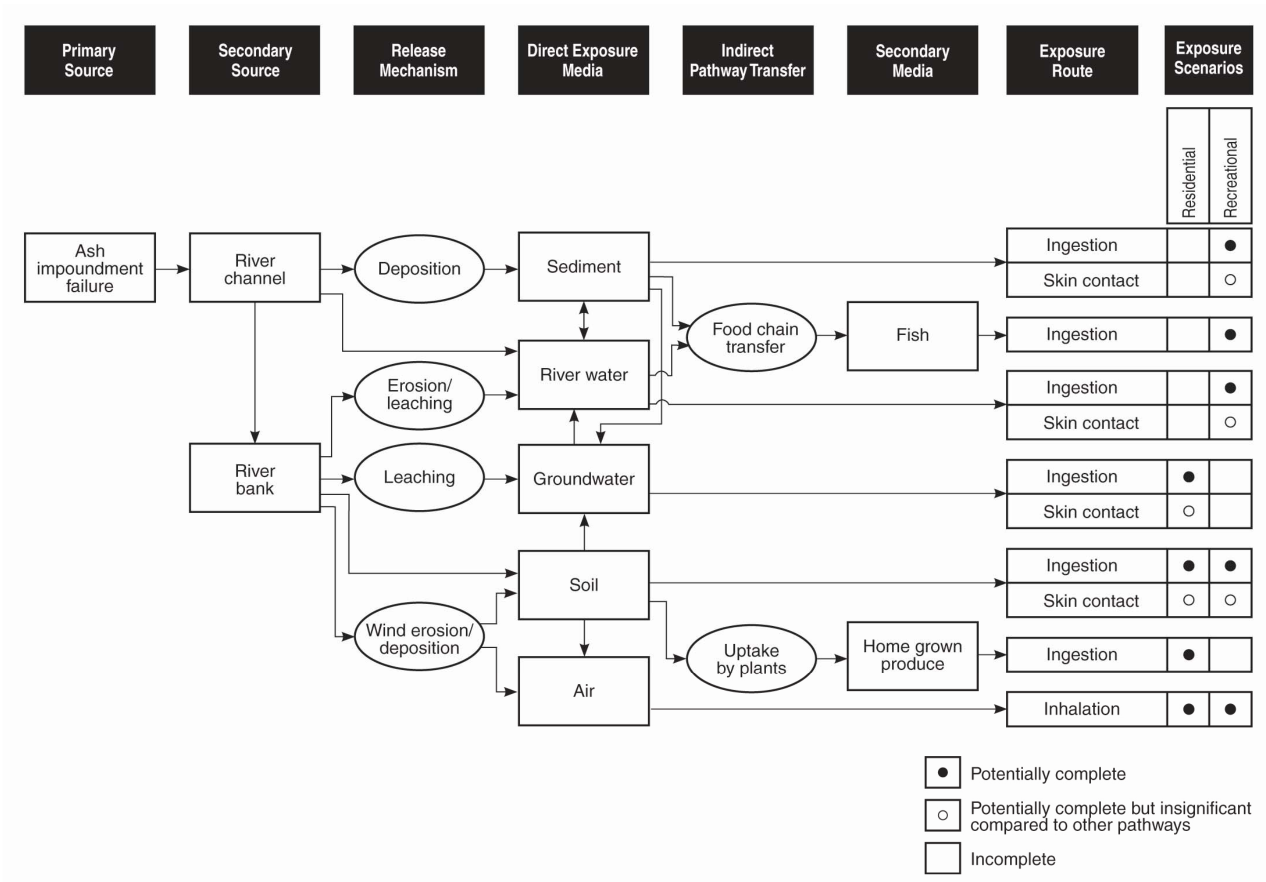

Figure 1. Possible pathways of exposure to arsenic from coal ash in the environment

Soil/Ash Ingestion. For coal ash that is deposited in areas frequently contacted by people, the primary means of exposure is by ingestion of coal ash in soil or sediments from inadvertent hand-to-mouth contact. However, unlike arsenic in drinking water, arsenic in solid materials is not as well absorbed by the body. Once soil or sediment is swallowed, absorption of arsenic from the digestive tract into the blood stream is reduced by the binding of arsenic to soil minerals. As a result, the "bioavailability" of arsenic in soil must be considered when assessing exposure.

Skin Absorption. Arsenic is not absorbed very well through the skin. Even using arsenic-contaminated water for bathing and washing does not appear to elevate arsenic levels in the body as long as one does not drink the water. Arsenic in soil would be even less well absorbed through the skin than arsenic in water.

Home-Grown Vegetables. If coal ash is incorporated into garden soil, vegetables may take up some arsenic from the soil, although the amount of uptake of arsenic from soil into vegetables is relatively low. Eating vegetables grown in soil with elevated arsenic levels has not been shown to increase people's arsenic exposure in residential areas affected by smelting, mining, or pesticides.

Inhalation of Dust. For people who have no contact with coal ash in soils, inhalation of windblown dust from coal ash may be the only means of exposure. Consequently, TVA has implemented dust suppression measures and TVA and the Tennessee Department of Environment and Conservation (TDEC) have been monitoring the air around the Kingston site. Results of the monitoring are routinely reported by both agencies.[1] Air levels of arsenic have been undetectable in many samples. Overall, the levels measured have been consistent with background arsenic air levels in remote areas of the U.S., which average <0.001 to 0.003 micrograms per cubic meter of air ($\mu g/m^3$).[2] By comparison, background levels in U.S. urban areas are 0.02 to 0.03 $\mu g/m^3$.

Fish. As noted above, exposure to inorganic arsenic in fish is reduced by transformation of much of the arsenic to relatively non-toxic organic arsenic. Given the arsenic levels in coal ash at the Kingston site and these transformation processes, adverse effects from human exposures to arsenic in fish from coal ash are not anticipated.

River Water. Surface water arsenic concentrations in the Emory River have generally been below the arsenic drinking water standard (10 micrograms per liter, $\mu g/L$, or parts per billion, ppb) and undetectable in most samples.[3] Thus, swallowing water while swimming or wading should not pose a health concern. Drinking water exposures would depend on the extent of leaching to groundwater and whether any affected groundwater is being used for drinking water.

Groundwater Wells. The direction of groundwater flow for drinking water wells located near the Kingston site is from the wells toward the ash disposal area and not from the ash disposal area toward the residential drinking water wells. Consequently, drinking water wells near the

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[1] http://www.tva.gov/kingston/air/index.htm; http://www.state.tn.us/environment/kingston/air/

[2] ATSDR (2007)

[3] 0.93 ppb method detection limit; http://state.tn.us/environment/kingston/surface_water.shtml

site are "upstream" in the groundwater flow and are not expected to be affected by the coal ash. Testing of more than 100 private wells by TDEC has not shown sample results for arsenic (and many other metals) above primary drinking water standards.[4]

In summary, the current information does not indicate that increased exposure to arsenic from coal ash is occurring at the Kingston site.

What are the Health Effects of Arsenic?

Popular perception of the toxicity of arsenic stems from its infamy as a poison since ancient times, as portrayed in movies such as Arsenic and Old Lace.[5] Arsenic poisoning has been well documented from studies of people who received high doses of soluble or more toxic forms of arsenic. Such exposures have resulted from historical use of arsenic in medical treatment, consumer products and pesticides; naturally contaminated well water; and historical industrial exposures to arsenic fumes and dust before modern pollution control devices and worker protection. We know from these cases that the likelihood and severity of health effects depends on the amount of exposure.

In addition to the form and amount of arsenic, the risk and type of health effects depends on how long one has been exposed and the route of exposure (inhalation or oral). A one time or short-term exposure to arsenic may have no effect. However, when the same daily dose of arsenic is repeated over a long time period, chronic health effects may result. Health risks of concern for environmental exposures to arsenic are those that may result from long-term chronic exposure, rather than the effects reported after a brief, very high exposure level.

Health Effects from Inhaling Arsenic

Studies of historical smelter workers have reported that breathing high concentrations of airborne arsenic for many years can increase the risk of lung cancer. Air concentrations of arsenic averaged over time for these smelter workers were 213 to 1,487 $\mu g/m^3$ for low to high exposure groups.[6] By comparison, average air concentrations of arsenic for maintenance workers in four coal-fired power plants were much lower ($<6\ \mu g/m^3$).[7] Some peak arsenic air measurements were as high as 380 $\mu g/m^3$ for workers exposed to high levels of coal fly ash dust. However, no reports have been made of elevated risk of cancer or other diseases related to arsenic for workers handling coal fly ash within power plants. Possible reasons may be because of overall lower air levels of arsenic over time and a less toxic form of arsenic in coal fly ash than in smelter dust.

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4 http://www.state.tn.us/environment/kingston/pdf/comm_guid/factsheet100109.pdf

5 Actually, arsenic was probably not the chemical added to the poisoned wine that dispatched the old gentlemen so efficiently. The old ladies added twice as much arsenic as strychnine, but strychnine is more than twice as acutely toxic as arsenic and the effects of strychnine would have more swiftly and neatly killed the gentlemen. "Strychnine and Old Lace", however, doesn't have the same appeal.

6 http://www.epa.gov/ncea/iris/subst/0278.htm, ATSDR (2007)

7 Hicks (2003)

People living near historical smelters have also been studied because of their elevated arsenic exposure (although much lower than for workers). Even in more recent times (around 1980), arsenic air levels in the community near the Tacoma, Washington smelter were 0.8 $\mu g/m^3$ on average with occasional measurements up to 10 $\mu g/m^3$. Despite these elevated exposures, increased rates of cancers or disease related to arsenic have not been found for this community. These levels are considerably higher than levels measured in Kingston which are similar to background levels reported for remote areas of the U.S. (<0.001 to 0.003 $\mu g/m^3$).

Health Effects for Ingesting Arsenic

Health effects of long-term oral intake of arsenic have been studied in populations drinking arsenic in well water in various countries including Southwest Taiwan, Bangladesh, West Bengal, India, Inner Mongolia, Argentina, and Chile. Exposure over much of a lifetime in these populations led to skin and internal cancers (e.g., lung and bladder). Other commonly noted effects include skin lesions (e.g., wart-like structures, pigmentation changes), as well as cardiovascular and neurological effects (primarily in the hands and feet). Poor nutrition in some of these populations may have also increased their susceptibility to the toxic effects of arsenic. Levels of arsenic in drinking water for these populations were generally several hundred ppb and ranged up to more than 1,000 ppb. The U.S. Environmental Protection Agency (EPA) defined an arsenic drinking water concentration of 170 ppb as a lowest effect level for skin lesions in the Southwest Taiwanese population (equivalent to a daily dose of 14 μg per kg body weight per day).[8] By comparison, the U.S. drinking water standard is 10 ppb (daily dose of 0.29 μg/kg-day).

Populations exposed to arsenic concentrations in water largely below 100 ppb have not shown such increases in risk of long-term disease (e.g., bladder cancer) from arsenic exposure. Populations included in these studies were from the U.S., South America, Finland, Denmark, and Taiwan. Risks may be slightly increased for smokers but the data were insufficient to determine if this was caused by arsenic or because of other factors that were not evaluated.

People (non-workers) living near historical smelters also received oral exposure to arsenic deposited in yard soil and house dust. Studies of these populations overall have not found increases in diseases caused by residential arsenic exposure. Consequently, our knowledge of chronic health risks from oral ingestion of arsenic is based on soluble arsenic in drinking water, not in soil.

How Are Health Risks of Arsenic Assessed?

Regulatory decisions to protect public health are based on a process called “risk assessment”. According to EPA, a sensitive effect of arsenic (i.e., an effect occurring at the lowest dose) is an increase in cancer risk. EPA assessments of arsenic cancer risk at lower doses are based on studies at high exposures in air for smelter workers and in water for a population in Southwest Taiwan. EPA assumes that the relationship between dose and cancer risk at high doses also holds true at lower doses and that there is no lower threshold dose at which the cancer risk is zero. To protect health, EPA assumes that risk may be present even though studies at lower

8 http://www.epa.gov/ncea/iris/subst/0278.htm

exposure levels have not shown such risks. EPA evaluates if the risk calculated for a certain exposure is acceptable by comparing the risk level with a target range for "acceptable" risk (risk of 1 in a million to 1 in 10,000 of contracting cancer in a lifetime). By comparison, the general lifetime risk of developing cancer in the U.S. is 1 in 2 for men and 1 in 3 for women, according to the American Cancer Society.[9]

Some evidence indicates that EPA's assumptions overestimate risks from arsenic at low exposures. In addition to the lack of increased risk observed at low water or air exposure levels, toxicity studies indicate that the mechanism by which arsenic causes toxic effects and cancer at high doses would not operate at low doses. Thus, EPA's risk assessment methods are very health protective and likely overstate risks at low doses such as those that may occur from exposure to coal ash in the environment at the Kingston site.

One way to place the potential risk from different arsenic exposures in context is by comparison to general background exposure to inorganic arsenic in the U.S. Drinking water and food are the primary sources of inorganic arsenic exposure for the general population, rather than soil or air. As shown in Figure 2, arsenic in water at the U.S. drinking water standard (10 ppb) results in far greater exposure over a lifetime than from residential exposure to soil with arsenic levels of 10 or 100 ppm (Figure 2).[10] Exposure to background levels of arsenic in soil (e.g., 10 ppm) is less than the average intake of inorganic arsenic from diet and water (Figure 2). Even exposure to an elevated arsenic soil concentration of 100 ppm is within the normal variation in inorganic arsenic intake from diet and water for the U.S. population.

The estimates shown in Figure 2 are consistent with the results of biomonitoring studies of populations living on arsenic-contaminated soils. These studies show no increase in arsenic exposure from soil, except when arsenic soil concentrations are relatively high (e.g., 300 ppm). Because arsenic levels in coal ash are generally below 100 ppm, coal ash mixed with residential soil would result in arsenic exposures to residents within the normal ranges in inorganic arsenic exposure from daily diet and water consumption.

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[9] Based on data from 2004-2006; http://www.cancer.org/docroot/CRI/content/CRI_2_6x_Lifetime_Probability_of_Developing_or_Dying_From_Cancer.asp

[10] Calculations are based on EPA reasonable maximum exposure and assume daily ingestion of soil at a higher than average rate and a high amount of arsenic absorption from soil (80 percent) compared to scientific studies (generally < 50 percent) (Tsuji et al. 2007)

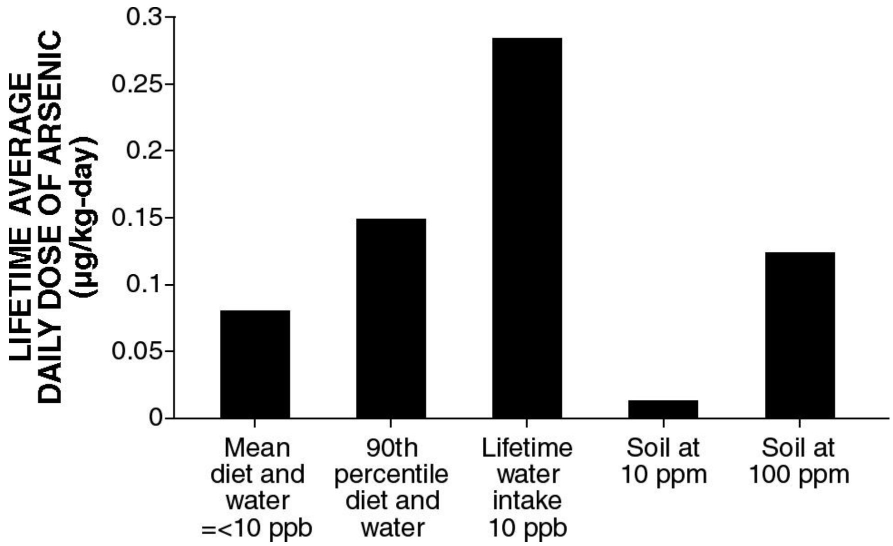

Figure 2. Comparison of arsenic dose averaged over a lifetime for background diet and water, drinking water containing arsenic at the drinking water standard (10 ppb), and residential soil with 10 ppm or 100 ppm arsenic concentration.

Additional Information

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