Superfund Research Program
The University of Arizona

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Understanding the Gold King Mine Spill

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Figure 1: The mining tunnel from which the spill occurred (US EPA via Flickr, 2015).

On Wednesday August 5, 2015, during a United States Environmental Protection Agency (US EPA) mine site investigation of the abandoned Gold King Mine near Silverton, Colorado, heavy equipment disturbed loose material around a soil "plug" at the mine entrance. Acid mine drainage had built up behind the plug, which unexpectedly gave way due to water pressure in the tunnel, and a torrent of water gushed out (Figure 1). This accident resulted in the release of approximately 3 million gallons of acid mine drainage into Cement Creek, a tributary of the Animas River, which in turn flows into the San Juan River and ultimately into the Colorado River. The water contained a number of heavy metals such as lead and arsenic.

> To date, surface water and sediment concentrations along the affected waterways have returned to pre-spill levels. The risk of short-term effects is expected to be minimal, but long-term impacts to the surrounding environment are not yet known. (US EPAa, 2015; CDPHEa, 2015)

The Gold King Mine spill occurred in the Colorado River Basin (Figure 2 shows the San Juan River portion closest to the spill). This watershed includes six US states (Colorado, Utah, New Mexico, Arizona, Nevada, and California), and 12 Native American tribes live along the tributaries. The Southern Ute Indian Tribe, the Navajo Nation, the Ute Mountain Ute Indian Tribe, and the Jicarilla Apache Tribe are tribes nearest to the spill. Community meetings have been held to provide updates and minimize acute exposure, but many people still have questions.

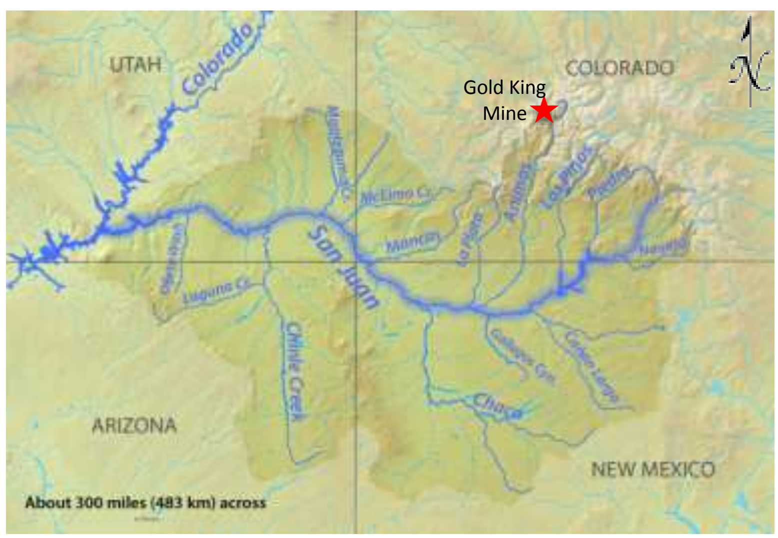

Figure 2: The San Juan River portion of the Colorado River Basin. The red star indicates the site of Gold King Mine spill. (Adapted from "Sanjuanrivermap" by Shannon via **Wikimedia Commons**.)

For an interactive map of water and sediment sampling locations from the mine site down to Lake Powell, including results for arsenic, cadmium, lead and mercury, visit the Arizona Geological Survey Gold King Mine Spill Water and Sediment Sample Locations Map at: http://maps.azgs.az.gov/gold-king-mine-spill/index.html.

Why did the water turn yellow?

Many abandoned mines have deep tunnels below the water table that were created to mine ore. During mining, water is pumped out of the tunnels, but after the mine is closed, the water table can rise back up, filling the empty tunnels with water. When the ore in the tunnels is exposed to water and air, acid is generated and metals from the rock seep into the water. This creates a thick, metal-filled mixture called “acid mine drainage.” Acid mine drainage is usually a rusty red to orange color due to the presence of iron. When a spill occurs into a waterway, and the acid mine drainage is mixed with fresh water, it becomes less acidic, which changes the way iron and other metals interact with the water and with solids in the water. The iron from the red-orange acid mine drainage settles into the water, turning it yellow. Old-time miners referred to this as “yellow boy.” As more water is mixed in, iron and other metals become even more dilute and/or get stuck to solids, causing them to drop out of the water and settle into river bottom sediments, and the water color returns to normal.

Within days following the Gold King spill, the yellow color at the leading edge of the plume was no longer visible, due to the movement and dilution of the river. Within a week, the Animas River began returning to its usual color. (US EPAd, 2015)

The color, smell, or taste of water is not enough to know whether it is safe or not. The only way to be sure of the water quality is to sample and test it. Follow state and federal notices concerning water use for drinking, agriculture, and recreation.

How big was the spill and what went into the water?

The acid mine drainage released in the spill contained a number of metals and salts totaling about 190 tons of solids, including several forms of toxic metals such as lead, arsenic, mercury and cadmium (Table 1). These solids were mixed in 3,043,067 gallons of water. This volume of water is approximately 9.3 acre-feet, or 9 football fields spread out at one foot deep.

Table 1. Weight of metals (in pounds) released in 3,043,067 gallons of acid mine drainage from Gold King Mine; estimated by the University of Arizona from US EPA measurements at the Cement Creek 14th St. Bridge on Aug. 5, 2015 16:00 (US EPAb, Preliminary Analytical Data, 2015).

Metal	Pounds	Metal	Pounds	Metal	Pounds
Iron	248,582	**Copper**	919	**Cobalt**	10
Aluminum	23,657	**Sodium**	586	**Antimony**	8
Calcium	11,365	**Barium**	244	**Nickel**	7
Magnesium	6,984	**Arsenic**	206	**Mercury**	6
Potassium	5,307	**Vanadium**	137	**Cadmium**	4
Lead	4,481	**Molybdenum**	50	**Beryllium**	3
Manganese	1,953	**Silver**	28	**Selenium**	n.d.*
Zinc	1,101	**Chromium**	18	**Thallium**	n.d.*

*** n.d. = not detected at or above the method detection limit.**

What was done to control the Gold King Mine spill?

Immediately after the Gold King Mine spill occurred, US EPA and relevant federal, state, and tribal agencies began working to control additional acid mine drainage and began making water quality measurements to evaluate impacts of the spill.

Because the Animas River is a fast flowing river with no dams, stopping the contamination or pumping the spill when it first occurred was not possible. The only alternative at the time of the spill was to allow the acid mine drainage to become naturally diluted as it flowed downstream. As the initial pulse of the spill moved down the river, it began mixing with and becoming diluted in the local waterways. As this mixing occurred, the spill water became less acidic and metals became diluted or were bound to solids, causing them to drop out of the water and settle into river bottom sediments.

Within two days after the spill occurred, the US EPA built settling ponds to divert additional acid mine drainage flow away from Cement Creek, and treated the water to neutralize the acid and remove solids and metals from the water (Figure 3; US EPAe, 2015). These ponds remain in use as of October 2015. The US EPA has announced it will install a portable treatment system to handle the ongoing discharge (approximately 550 gallons per minute) from Gold King throughout the winter of 2015-2016, as freezing temperatures will make it unsafe to continue to treat it using settling ponds. The treatment system will lower the acidity and remove solids and metals from the acid mine drainage before it reaches Cement Creek (US EPAd, 2015). To date, US EPA has not made a decision about whether to build a wastewater treatment plant at the site (US EPAa, 2015).

Figure 3: Settling ponds built near Gold King mine allow acid mine drainage to pool, where contaminants can settle to the bottom and acidity can be treated. (US EPA via Flickr, 2015).

> Acid mine drainage is a chronic issue in this region and continues to enter waterways in the Upper Animas Watershed at hundreds of gallons per minute from Gold King and other mines in the area, as it did before the August 2015 spill occurred.

Where does the water flow, and how much was the spill diluted?

The Gold King Mine spill occurred in the Colorado River Basin (see Figure 2, above). The approximately 9.3 acre-feet of acid mine drainage released in the spill became diluted very quickly in the flow of the affected waterways. Estimated dilutions of the spill at different locations can be calculated using data from the United States Geological Survey (USGS) National Water Information System (USGS, 2015). The following sections trace the flow of the water in more detail and describe the estimated dilution of the acid mine drainage.

For an interactive map of water and sediment sampling locations from the mine site down to Lake Powell, including results for arsenic, cadmium, lead and mercury, visit the Arizona Geological Survey Gold King Mine Spill Water & Sediment Sample Locations Map at http://maps.azgs.az.gov/gold-king-mine-spill/index.html.

Cement Creek and the Animas River

The Gold King mine spill occurred in Cement Creek, which flows south into the Animas River through Durango, Colorado, where residents rely on the Animas River for recreation, agriculture, and drinking water. Measured data showed that levels of metals had already decreased by half by the time the plume had moved 10 miles downstream (ADEQ, 2015). Sixty miles downstream, the Animas River at Durango was flowing at 1,414 acre-feet per day on the day of the spill. This means that within the day, the 9.3 acre-feet of acid mine drainage would have been further diluted by 1:150, or one part acid mine drainage to 150 parts of river water. The Animas River flows south from Durango and joins the San Juan River at Farmington, New Mexico.

San Juan River

The San Juan River flows west through the Four Corners, and continues flowing west through southern Utah until it flows into the Colorado River and Lake Powell. It is used for recreation, agriculture, and drinking water. The San Juan River supports the largest concentrated area of local Navajo farming and the Ute Mountain Ute also have local farms along the San Juan. When water from the spill reached the San Juan River at Four Corners, it would have been further diluted by 1:550, or one part acid mine drainage to 550 parts of river water.

Colorado River

From the San Juan confluence, the Colorado River flows south into northern Arizona, and encounters Lake Powell, formed by the Glen Canyon Dam. The water is used for recreation, agriculture, and drinking water.

The leading edge of the plume (no longer visible) likely entered Lake Powell on August 12, 2015 (US EPAa, 2015). Lake Powell contained more than 12 million acre-feet of water in August 2015 (Lake Powell Water Database, 2015). This would have further diluted the 9.3 acre feet of acid mine drainage released in the Gold King Mine spill by 1:1,200,000, or 1 part acid mine drainage to more than a million parts of lake water. Because of the retention time in Lake Powell, biologists estimate the plume may take 18 months to two years to reach Glen Canyon Dam (AzEIN, 2015). The sediments (i.e., solid matter and metals moving in the water) released in the spill totaled approximately 190 tons. Roughly 44.4 million tons of sediment produced by river erosion arrives at Glen Canyon Dam each year (Andrews, 1990; Weisheit, 2003). Thus, if all the sediment from the Gold King Mine spill were to reach Glen Canyon Dam, it would be diluted more than 600 times in one day by the 121 thousand tons of erosion sediment that enter the lake each day.

After the Glen Canyon Dam in Arizona, the Colorado River passes Lee's Ferry, Arizona, the official dividing point of the upper and lower Colorado River. Here, the average river flow is 14 million acre-feet per year (Graf, 1997), or 38,000 acre-feet per day; any water from the spill that passed through Lake Powell and into the lower Colorado River would then be diluted by an additional 1:4000, or one part already-diluted acid mine drainage to 4,000 parts of river water.

The Colorado River then flows south towards Nevada at Lake Mead and the Hoover Dam, and continues south through Arizona until it reaches Mexico. However, no measurable impacts beyond Lake Powell are expected.

Who regulates abandoned mines?

Prior to the 1970's, mining operations were not well-regulated and as a result, there is a legacy of abandoned mines in the United States. Today, these mining sites are subject to environmental regulations in order to protect human and environmental health. The US EPA is the agency charged with overseeing abandoned mines, and works to clean up and close such sites. However, this is a large problem; there are thousands of inactive or abandoned mines on federal, state, tribal, and private lands, especially throughout the western US. These mines are often abandoned by prospectors and mining companies who typically are not held liable to cleaning up these mines. There are approximately 5,105 abandoned mines in Colorado; 3,989 in New Mexico; 10,697 in Utah; and 24,183 in Arizona (Bureau of Land Management, 2015). Some abandoned mines pose little risk while others pose larger risks. Reclamation of abandoned mines to a pre-mining state of land is difficult, if not impossible, and when done, it is often a long, challenging, and expensive process. For example, the US EPA Office of Inspector General identified 156 “mega” hard rock mining sites nationwide that could cost $24 billion to clean up and maintain, a cost more than 12 times the annual US EPA budget for remediation of large hazardous waste (i.e., Superfund) sites (Lovingood et al., 2004).

What is the history of mining in the Upper Animas watershed?

The Gold King Mine was discovered in 1887 and operated until 1922 (Figure 4). It is only one of many abandoned gold and silver mines located near Silverton, Colorado within the Upper Animas watershed, reflecting more than 120 years of gold, silver, lead, zinc, and copper mining, spanning from 1871 to 1991. During these years an estimated 8.6 million tons of mill tailings were discharged into the waterways (Church et al., 2007). Studies have shown that both natural weathering and continuous acid mine drainage generated from the abandoned mines have impacted water quality in the area, where the water is often acidic and contaminated with heavy metals (Church et al., 2007; US EPAc, 2015).

Figure 4: Gold King Mine circa 1899 (Church et al., 2007).

The US EPA conducted a Superfund site assessment of the Upper Animas River Basin near Silverton in the 1990s, and focused again on the Upper Cement Creek area in the late 2000s-early 2010s, to determine whether it should be included on the US EPA National Priorities List (ARSG, 2015; US EPAc, 2015). This label would give US EPA the authority to clean up the area and identify potentially responsible parties (e.g. mine owners) to pay for it. Although the poor water quality and impacts to aquatic life made the Upper Animas and/or Cement Creek areas eligible for Superfund status, in response to community concerns over the stigma attached to it (e.g. potential impacts to real estate and tourism), the sites were not listed. Mine reclamation and remediation projects have been undertaken by local groups such as the Animas River Stakeholders Group (ARSG, 2015; US EPAc, 2015). US EPA continues to monitor and investigate the area.

How are the impacts of the spill being assessed?

To track the impacts of the spill, sampling of drinking water, surface water, sediment, and fish tissue is being performed from the Gold King Mine site, along the Animas, San Juan, and Colorado Rivers down to Lake Powell and the Glen Canyon Dam by local, tribal, and state agencies, as well as the US EPA. Arizona and Nevada state officials expect minimal impacts to the lower Colorado River, but will continue to monitor relevant waterways. Testing is being done to determine the concentration of metals typically found in acid mine drainage, as well as to determine water quality factors such as hardness and acidity. Results are being compared to pre-spill levels or to historical water quality data. Based on sampling results, relevant local, state, tribal, and federal agencies are making recommendations for using water for activities such as drinking, recreation, aquatic life, and agriculture.

For an interactive map of water and sediment sampling locations from the mine site down to Lake Powell, including results for arsenic, cadmium, lead and mercury, visit the Arizona Geological Survey Gold King Mine Spill Water & Sediment Sample Locations Map at http://maps.azgs.az.gov/gold-king-mine-spill/index.html.

> In general, surface water and sediment metal concentrations along the affected waterways have returned to historic/pre-spill levels, and are below relevant health-protective screening levels. The waterways have been opened for recreation, agriculture, and drinking water (with appropriate treatment). The risk of short-term effects is expected to be minimal, but long-term impacts to the surrounding environment are not yet known. (US EPAa, 2015; CDPHEa, 2015)

What are short-term impacts of the spill and recommendations for water use?

Although short-term exposure to very high doses of metals such as those released in the Gold King Mine spill can cause serious health effects, such exposures are unlikely to have occurred. According to the Agency for Toxic Substances and Disease Registry, the US EPA, the Colorado Department of Public Health and the Environment, and the San Juan Basin Health Department, adverse health effects are not expected from skin contact or incidental (unintentional) ingestion of the water during typical recreational use (US EPAa, 2015; CDPHEb, 2015). The risk of health effects in livestock that may have been exposed is also low.

Cement Creek

Water quality was dramatically affected in Cement Creek following the Gold King Mine spill. Although the levels of metals declined throughout August 2015, as of mid-September 2015, the levels of most metals remained above historic/pre-spill levels in Cement Creek (CDPHEa, 2015). Cement Creek is typically used for recreation and agriculture; as of September 15, 2015, Cement Creek was still not meeting regulatory standards for agriculture due to elevated copper and zinc. However, metals and acidity of water and sediments downstream in the Animas, San Juan, and Colorado Rivers, as well as Lake Powell, have returned to pre-spill levels and can be used for recreation, agriculture, and drinking water (US EPAd, 2015; CDPHEb, 2015; NPS, 2015).

Recreation

The Animas River was closed for recreation following the Gold King Mine spill, but reopened for recreation within a week. The San Juan and Colorado Rivers remain open for recreation.

Agriculture

Intakes for irrigation water were turned off along the Animas and San Juan Rivers following the spill, but have since been flushed and reopened. Water quality along the affected waterways has returned to pre-spill levels and can be used for irrigation (CDPHEb, 2015). According to the Agency for Toxic Substances and Disease Registry, the US EPA, the Colorado Department of Public Health and the Environment, and the San Juan Basin Health Department, crops grown during the spill are safe for consumption, given that irrigation ditches were shut down very quickly after the spill occurred (CDPHEb, 2015). Many local Navajo farmers rely exclusively on the San Juan River to irrigate their fields and water their livestock. Many tribal irrigation intakes in the area close to the spill were shut off for a long time, following water-use restrictions issued by the Navajo Nation. The Fruitland Canal System, which provides irrigation water to the communities of San Juan, Upper Fruitland, and Nenahnezad, was not reopened until late August. Due to closure of irrigation intakes, the crop yields of many Navajo farmers were dramatically impacted.

Livestock

As of mid-August 2015, the Colorado Department of Agriculture State Veterinarian's Office declared that water from the Animas River could be used to water livestock (CDPHEa, CDPHEb, 2015). However, excess sulfate in the irrigation water could have decreased the availability of copper in hay and pastures, therefore cattle ranchers and farmers should check with their veterinarians on whether they need to supplement cattle feed with copper (CDPHEb, 2015). For help interpreting water quality test results for irrigation or livestock water, see the Colorado State Water Quality Interpretation Tool, https://erams.com/wqtool/.

Gardening

The Colorado Department of Public Health and Environment advises gardeners who use water from the Animas River and grow leafy vegetables and root crops to call the Colorado State University Extension office at 970-382-6463 for specific advice, as answers to questions are site- and crop-specific (CDPHEa, 2015).

Aquatic Life (Fish, Birds, Mammals)

As of September 2, 2015, the Colorado Department of Public Health and Environment declared that trout from the Animas River are safe to eat (CDPHEa, 2015). Due to continual slow releases of acid mine drainage into the Animas River, there were already a limited number of fish in waterways in the area where the spill occurred; following passage of the spill water, no fish kills were observed (CDPHEb, 2015, EPA, 2015). To find out if the spill could affect developing/young wild fish, 108 fingerling rainbow trout were placed in cages in the Animas River near Durango before the spill reached the area, and kept in the river for five days until the plume passed. One fish died, unrelated to water quality, and the other 107 remained healthy, with no signs of stress, throughout the exposure. The fish were sent to the Colorado Department of Public Health and Environment to test their tissues and organs for metals. Metals in the fish were either not detectable or within a range found in fish before the spill; all samples were below short-term risk thresholds. The relevant departments in the state of Colorado will continue to monitor levels of metals in fish in the Animas River. To date, no effects have been seen on ducks or land mammals along the Animas River (CDPHEb, 2015).

Drinking Water

States are working with public drinking water systems to ensure safe drinking water. Sampling performed by the Colorado Department of Public Health and Environment demonstrated that public drinking water systems drawing from groundwater wells near the Animas River, or even directly from the river itself (with appropriate treatment), are providing safe drinking water (CDPHEa, 2015). Contact your water provider if you have questions about the water quality at your tap.

The US EPA as well as relevant state and local agencies are testing private drinking water wells throughout the areas affected by the spill (CDPHEa, 2015; US EPAd, 2015). As of late August 2015, only 7 out of 105 tested wells along the Animas River in Colorado exceeded any drinking water standards; it is unknown whether the water quality issues were related to the spill. Residents with wells located within a mile of the Animas River are advised to have their well water tested by a professional; contact the San Juan Basin Health Department or state health department for questions on testing and understanding test results. For general information on drinking water well contaminants and home water treatment options, see Uhlman et al. (2009) and Artiola et al. (2009). For help interpreting water quality test results for drinking water, see the Colorado State Water Quality Interpretation Tool, https://erams.com/wqtool/.

What are possible long-term effects of the Gold King Mine spill?

Although there appear to be no short-term effects to health or the environment following the Gold King Mine spill, we will not understand the long-term impacts of this highly concentrated release of metals into our environment for quite some time. This longer-term question will depend on the behavior of metals deposited in sediments. There is a potential for such sediments to be stirred up and metals released during high water events or recreational use. The metals could become concentrated in fish that live in the river and feed on things that grow in the sediments. Metals in the sediments could seep into the groundwater, resulting in impacts to drinking and irrigation water. If the metal-rich sediments deposit on river shores, they could potentially dry out and be blown as dust by the wind, where they could contaminate surrounding soil, and could also be inhaled.

It will take time to know what the long-term sediment effects and possible exposure levels will be in the Upper Colorado River Basin, or if these exposures will be different from exposure levels before the spill. It will also take time to determine if these potential levels of environmental exposure will be high enough to result in human health risks or affect flora and fauna over the long term. The chances of significant exposure to metals from the spill in the Lower Colorado River Basin are negligible.

The US EPA will be working with local agencies, the states of Colorado and New Mexico, and the Navajo Nation to continue to monitor the environmental impacts along the Animas and San Juan Rivers (CDPHEb, 2015). The Arizona Department of Environmental Quality and Game and Fish Department will continue to sample and test water quality and fish from Lake Powell to monitor potential long-term impacts (AzEIN, 2015). The Glen Canyon National Recreation Area will continue to be monitored by the National Park Service, US EPA, United States Geological Survey, Bureau of Reclamation, and the states of Utah and Arizona (NPS, 2015). Lake Mead in Nevada is not expected to be impacted by the spill, but the Southern Nevada Water Authority will sample and test water in the lake and water treatment plants (SNWA, 2015). Future measurements can be compared to background levels that were measured in previous years, to better understand the long-term impact of the Gold King Mine spill.

What can I do to limit my exposure?

- It is important to know where your drinking water comes from (e.g., do you get it from a water company, own a well, or haul your water?) and to have it tested if it is not regulated for drinking water standards.

- Water companies are required to test your water and produce an annual report. If you own your own well or haul water from an unregulated source, you are responsible for testing and treatment.
- For help interpreting water quality test results for drinking water, irrigation, or livestock, see the Colorado State Water Quality Interpretation Tool, https://erams.com/wqtool/.

- The Colorado Department of Public Health and Environment recommends that people do not drink untreated water directly from the river **at all**, as it is not potable (regardless of the spill) and should be treated.
  - Water used for animals, large and small, should be allowed to stand at least 24 hours to allow any sediment particles to settle out as much as possible.
- As of September 16, 2015, the Colorado Department of Public Health and Environment declared the risk of adverse health effects from typical recreational activities or incidental contact with river sediment to be low (CDPHEa, 2015). However, they do advise:
  - Avoid contact with orange/yellow-colored river water, or orange/yellow-colored sediments around creeks and riverbeds, whether for recreation or ceremonial purposes.
  - Limit disturbances to river sediments during recreation.
  - Wash hands and clothes thoroughly with soap and water after contact with sediments.
  - Young children (<6 years of age) should be supervised by adults when visiting areas along the river, to ensure they do not consume river sediment.

Resources for more information

- US EPA Hotline (toll-free): 844-607-9700
- US EPA, Emergency Response to August 2015 Release from Gold King Mine: http://www2.epa.gov/goldkingmine
- Navajo Nation Operation Yellow Water http://operationyellowwater.com
- Arizona Geological Survey, Gold King Mine Spill Water & Sediment Sample Locations: http://maps.azgs.az.gov/gold-king-mine-spill/index.html
- Colorado Department of Public Health and Environment, Animas River spill: https://www.colorado.gov/pacific/cdphe/animas-river-spill
- Colorado State University Water Quality Interpretation Tool: https://erams.com/wqtool/
- New Mexico Environment Department, Gold King Mine Wastewater spill: https://www.env.nm.gov/riverwatersafety/
- San Juan Basin Public Health Department, Gold King Mine Incident Updates: http://sjbhd.org/public-health-news/gold-king-mine-incident/
- Utah Department of Environmental Quality, Gold King Mine Release: http://www.deq.utah.gov/Topics/Water/goldkingmine/
- Additional local, state, and tribal resources: http://www2.epa.gov/goldkingmine/gold-king-mine-resources-information
- Agency for Toxic Substances and Disease Registry website, for health information about exposure to metals: http://www.atsdr.cdc.gov/toxfaqs/index.asp

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