Health Consultation

Exposure Investigation

Biological Testing for Exposure to Lead and Arsenic near

ASARCO HAYDEN SMELTER SITE
HAYDEN AND WINKELMAN, ARIZONA

MARCH 27, 2017

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

You May Contact ATSDR Toll Free at
1-800-CDC-INFO
or
Visit our Home Page at: http://www.atsdr.cdc.gov

HEALTH CONSULTATION

Exposure Investigation

Biological Testing for Exposure to Lead and Arsenic near

ASARCO HAYDEN SMELTER SITE
HAYDEN AND WINKELMAN, ARIZONA

Prepared By:

U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry (ATSDR)
Division of Community Health Investigations

Table of Contents

Executive Summary 1

Introduction 5

Site Location, History, and Status 5

Environmental Contamination in Hayden and Winkelman 6

Current Lead and Arsenic Exposure Pathways for Hayden and Winkelman Residents 8

Past Lead and Arsenic Biological Testing 9

Exposure Investigation Process and Methods 9

Results 15

Discussion 20

Uncertainties and Limitations 25

Conclusions 27

Recommendations 28

Public Health Action Plan 29

References 48

List of Figures

Figure 1: Asarco Hayden Smelter Site Map and Community Demographics 31
Figure 2. Asarco Hayden Exposure Investigation participant blood lead levels by participant age 32
Figure 3. Asarco Hayden Exposure Investigation participant blood lead levels by household 33
Figure 4: Participant blood lead levels compared to U.S. population 2011–12 median and 95th percentile levels and the exposure investigation follow-up level 34
Figure 5: Participant urinary total arsenic (creatinine corrected) results by household 35
Figure 6: Participant urinary total arsenic levels (creatinine corrected) by age group compared to 2011–12 U.S. population median and 95th percentile levels and the exposure investigation follow-up level 36
Figure 7: Percentage of detected results and limits of detection for each arsenic species among exposure investigation participants and the U.S. population 37
Figure 8: Correlation of participant blood lead and urine arsenic (creatinine corrected) levels 38
Figure 9: Relative contribution of smelter and background sources to 2013–15 air contamination levels at Hayden and Winkelman monitoring stations when the smelter was operating and shut down 39

List of Tables

Table 1: Federal and state agency roles for the Asarco Hayden Exposure Investigation 40
Table 2. Number of participants by age group, gender, and contaminant tested 40
Table 3. Exposure investigation participant and U.S. population (NHANES) blood lead median and 95th percentile levels and confidence intervals 41
Table 4: Exposure investigation participant and U.S. population (NHANES) total urinary arsenic (creatinine corrected) median and 95th percentile levels and confidence intervals 41

Table 5: Arsenic levels (creatinine corrected and uncorrected) for Asarco Hayden Exposure Investigation participants with urinary creatinine above 300 mg/dL (n = 4) compared with the investigation follow-up level and U.S. population (NHANES) age specific 90th percentile 42
Table 6: Exposure investigation participant and U.S. population (NHANES) urinary inorganic-related arsenic species 50th percentile (median) and 95th percentile levels and confidence intervals (creatinine corrected) 42
Table 7: Average lead and arsenic ambient air concentrations across all Hayden and Winkelman monitoring stations in 2015 and during smelter shutdown 43
Table 8: Average lead and arsenic ambient air concentrations at each Hayden and Winkelman monitoring station in 2015 and during smelter shutdown 44
Table 9: Exposure investigation participant and U.S. population urinary inorganic-related arsenic species 50th percentile (median) and 95th percentile levels and confidence intervals 45

List of Appendices

Appendix A: Map of ambient air monitoring stations in Hayden and Winkelman, Arizona 54
Appendix B: Positive Matrix Factorization Model Results 55
Appendix C: Exposure Investigation Participant and U.S. Population Urinary Creatinine Levels 57
Appendix D: Asarco Hayden Exposure Investigation Report Summary 59

Abbreviations and Acronyms

As	Arsenic
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ATSDR	Agency for Toxic Substances and Disease Registry
BLL	Blood lead level
CDC	Centers for Disease Control and Prevention
DMA	Dimethylarsinic acid
DLS	Division of Laboratory Sciences
EI	Exposure investigation
EPA	Environmental Protection Agency
IQ	Intelligence quotient
LOD	Limit of detection
mg/dL	Milligrams per deciliter
µg/dL	Micrograms per deciliter
µg/g	Micrograms per gram
µg/L	Micrograms per liter
$\mu g/m^3$	Micrograms per meter cubed
ml	Milliliter
MMA	Monomethylarsonic acid
NAAQS	National Ambient Air Quality Standard
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
NPL	National Priorities List
OMB	Office of Management and Budget
Pb	Lead
PM_{10}	Particulate matter 10 micrometers or less in diameter
PMF	Postive Matrix Factorization
ppb	Parts per billion
ppm	Parts per million
WHO	World Health Organization

Executive Summary

Purpose	In April 2015, the Agency for Toxic Substances and Disease Registry (ATSDR) provided lead and arsenic testing for Hayden and Winkelman, Arizona residents most at risk for lead and arsenic exposure or health effects. ATSDR offered the testing to determine whether residents have elevated levels of these metals in their bodies. This report summarizes the results.
Background	The Asarco Hayden Smelter Plant Site is in rural Arizona, about 90 miles southeast of Phoenix (Figure 1). The site includes the small towns of Hayden and Winkelman. Historic and ongoing copper smelting and processing caused environmental contamination in these towns. Lead and arsenic are present in the air, mine waste piles, and soil in some non-residential locations. In addition to smelter-related contamination, lead may be present in old paint and some other sources in homes (e.g., pottery), while arsenic may be in certain foods (e.g., seafood and rice). The United States Environmental Protection Agency (EPA) has completed residential soil clean up at 266 Hayden and Winkelman yards and publicly accessible areas. Though residential soil has been cleaned up, residents may be exposed to lead and arsenic from current copper production related emissions and other potential sources of contamination. The populations most at risk for exposure or negative health effects of exposure include young children, pregnant women, and women who may become pregnant. Community members asked they be tested for lead and arsenic exposure. ATSDR worked with EPA, the Arizona Department of Health Services (ADHS), and the Arizona Department of Environmental Quality (ADEQ) (Table 1) to offer free, voluntary blood and urine testing for residents most at risk for lead and arsenic exposure or health effects. Children ages 9 months to 5 years were eligible for blood lead testing. Children and adolescents 6 to 17 years, pregnant women of any age, and women of childbearing age (up to age 44) were eligible for blood lead and urinary arsenic testing. Testing participants included 83 residents (ages 1 to 40 years) of Hayden and Winkelman from 29 different households. All participants received blood lead testing and 58 participants received urine arsenic testing (Table 2). ATSDR mailed results letters to participants in June 2015.

Conclusion 1	Some children in Hayden and Winkelman have been exposed to lead at levels that could harm their health.
Basis for Conclusion 1	Two children exceeded the exposure investigation blood lead follow-up level [5 micrograms per deciliter (µg/dL)] (one in the 1–5 year age group and one in the 6–11 year age group) (Figures 2, 3, and 4). In addition, two children in the 1–5 year age group had blood lead levels (BLLs) between 4 and 5 µg/dL. ATSDR's exposure investigation blood lead follow-up level is based on the Centers for Disease Control and Prevention's (CDC's) current reference level.
Conclusion 2	Overall, children and adolescent participants had more lead in their bodies than children and adolescents from across the United States.
Basis for Conclusion 2	The median blood lead levels for children and adolescent participant age groups (1–5, 6–11, and 12–19 years) were about two times higher than U.S. population medians for those age groups (Table 3). No safe blood lead level in children has been identified.
Conclusion 3	ATSDR needs more information to determine how much arsenic participants have in their bodies when air pollution levels are typical for the community. Asarco shut down the smelter for maintenance during the time of ATSDR's testing, which lowered lead and arsenic levels in the air.
Basis for Conclusion 3	Asarco shut down the smelter for maintenance in the days before ATSDR collected blood and urine samples. As a result, participants were exposed to about eight times less arsenic and seven times less lead in the air than other times in 2015 (Table 7, Figure 9, and Appendix B). Since arsenic is typically excreted from the body within several days of exposure, the lower level of arsenic in air in the days before testing could have led to a lower amount of arsenic in participants' urine. Since lead stays in blood longer than arsenic stays in urine, ATSDR does not expect that the shutdown had a significant effect on participants' blood lead results. No participant had a total urinary arsenic result (creatinine corrected) that exceeded the exposure investigation follow-up level (Figures 5 and 6). Median total and inorganic arsenic levels (creatinine corrected) were similar to U.S. population age group-specific medians (Table 4).

Recommendations	ATSDR recommends that EPA, ADEQ, Asarco, and the Gila County Health Department take the following steps to protect the health of the community.
	• Reduce lead and arsenic air emissions at the Asarco Hayden Smelter Plant.
	• Continue environmental sampling and clean-up efforts in Hayden and Winkelman.
	    o Consider resampling residential soil at a limited number of homes in areas with higher levels of air contamination to address community concerns that soil may have been recontaminated since they were cleaned up.
	    o Sample soil for lead at a specific Winkelman home that was not previously sampled to ensure that residential soil exposures did not contribute to a participant's elevated blood lead level.
	• Incorporate ATSDR's exposure investigation results in human health risk assessments, as appropriate.
	• Implement a home lead paint testing and abatement project, as outlined in the 2015 EPA/Asarco settlement.
	
	ATSDR recommends that exposure investigation participants take part in a second round of arsenic testing. ATSDR intends to offer this testing when the smelter is operating normally.
	
	ATSDR recommends that Hayden and Winkelman residents
	• Take the steps listed in the summary factsheet (Appendix D) to reduce their exposure to lead and arsenic.
	• Participate in the home lead paint testing project that Asarco will develop and fund as part of the 2015 EPA/Asarco settlement.
	
	ATSDR recommends that parents/guardians of the two child participants whose blood lead results were above the follow-up level discuss the child's result with their primary health care provider.
	
	ATSDR recommends that health care providers follow the Advisory Committee for Childhood Lead Poisoning Prevention's recommendations for management of children with blood lead levels above the CDC reference level.

Limitations and Uncertainties	The results of this exposure investigation are subject to several limitations and uncertainities. They are summarized here and discussed in detail later in the report. • Exposure investigation results are applicable only to the individuals tested and cannot be generalized to other individuals or areas. • Test results cannot be used to determine the sources of lead or arsenic exposures. • Single blood lead and urinary arsenic tests are snap shots of exposure and may not accurately represent a person's past or long term lead and arsenic exposures. Arsenic is excreted within several days of exposure, while the half life of lead in blood is about a month. • The Asarco smelter was shut down for maintenance during the ATSDR testing event, reducing the levels of lead and arsenic in the air and potentially reducing participants' urine arsenic levels. • ATSDR used creatinine corrected urine arsenic results to adjust for variation in urine dilution and compare arsenic results between participants. However, participants in this exposure investigation had higher creatinine levels than the U.S. population. The difference in creatinine levels creates some uncertainty when comparing participant creatinine corrected arsenic results with U.S. population results. • Children less than 6 years of age were not eligible for urinary arsenic testing because there are no national values for comparison. • Comparisons between adult participants (women 20–40 years old) and U.S. population adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.
For More Information	If you have questions about this report call ATSDR toll-free at 1-800-CDC-INFO and ask for information on the Asarco Hayden Smelter Plant site.

Introduction

In Hayden and Winkelman, Arizona, lead and arsenic are present in the air, mine waste piles, and soil in some non-residential locations. In addition, lead may be present in old paint in homes. Community members requested they be tested for lead and arsenic. In 2015, ATSDR partnered with EPA, the Arizona Department of Health Services (ADHS), and the Arizona Department of Environmental Quality (ADEQ) to offer blood and urine testing for people in the community (ATSDR 2015b). ATSDR collected blood and urine samples in April 2015 and mailed results to participants in June 2015. This report summarizes the results from all participants.

Site Location, History, and Status

The Asarco Hayden Smelter Plant Site is in rural Arizona, about 90 miles southeast of Phoenix and 70 miles northeast of Tucson (Figure 1). The site includes the small towns of Hayden and Winkelman, Arizona (populations 662 and 353, respectively) (Census 2010a). The area is dry, windy, and sparsely vegetated. Historic and ongoing copper smelting and processing has caused environmental contamination in these towns (EPA 2015a). Companies have processed copper ore at several smelting operations and other facilities at this site for over 100 years (EPA 2014a). Asarco continues to operate a copper concentrator and smelter, producing copper from copper sulfide ore (Asarco 2015a). Ore and concentrate are transported by railroad from the nearby Ray mine and concentrator to the Hayden concentrator and smelter (Asarco 2015a). Residential and public areas in Hayden and Winkelman are near various current and past copper production related facilities, conveyances, and waste areas. Residents of Hayden live within ¼ mile of the site, while residents of Winkelman live within 1 mile of the site (Figure 1).

EPA, ADEQ, and Asarco Grupo Mexico LLC (Asarco) are cleaning up lead, arsenic, and copper contamination at the site through a Superfund alternative process (EPA 2015a).[1] Historic smelter emissions and other copper production-related activities deposited these contaminants across the area. In addition, active copper production in Hayden contributes to elevated levels of lead, arsenic, and copper in the air throughout the area (EPA 2015a).

Separate from the Superfund alternative process, in 2015, EPA announced a Consent Decree (i.e., legal settlement) with Asarco to resolve Clean Air Act violations at Asarco's Hayden facility (EPA 2015d). The settlement requires the company to install new equipment and pollution control technology at the Hayden smelter, fund local environmental health projects (including a lead-based paint testing and abatement program for homes, schools, and other public buildings in Hayden and Winkelman), replace a diesel locomotive with a cleaner model, and pay a civil penalty (EPA 2015d).

[1] Through the Superfund alternative approach, Asarco has agreed to complete the same investigation and cleanup process that is used for National Priorities List (NPL) sites, without EPA listing the site on the NPL (EPA 2017).

Environmental Contamination in Hayden and Winkelman

EPA and ADEQ have been investigating environmental contamination at the site since 2002. Environmental data indicated elevated levels of lead and arsenic in Hayden and Winkelman air and some non-residential and residential soils. EPA's Phase I Remedial Investigation focused on residential soil and air contamination (EPA 2008) and led to clean up of 266 residential yards with elevated levels of lead and/or arsenic (EPA 2015b). In the ongoing Phase II Remedial Investigation, EPA will assess air, non-residential soils, groundwater, surface water, and sediment contamination.

Copper production-related environmental contamination

Due to past and current copper production activities in the community, lead and arsenic are present above EPA and ATSDR screening levels in air, some non-residential soils, and in mine waste areas. Contaminated non-residential areas include Asarco-owned industrial areas (e.g., two large tailing piles), arroyos (i.e., dry creek beds), and railroad track areas, including those located near residences. Levels of contamination in non-residential soils (largely collected as surface soil samples) range from 3.5 to 1,230 parts per million (ppm) of lead and from 0.4 to 1,720 ppm of arsenic (EPA 2008; Table 4-3). EPA screening levels for lead in commercial and residential soil are 800 ppm and 400 ppm, respectively. For arsenic in residential soils, ATSDR uses 15 ppm as a screening value for determining whether to conduct a more detailed exposure evaluation.

EPA completed soil clean up at 266 Hayden and Winkelman residential yards between 2008 and 2014 (EPA 2015b). EPA also completed soil remediation in dirt alleys and public parks. Residential soil was cleaned up to below 400 ppm for lead and 23.4 ppm for arsenic (EPA 2015b).

Air quality monitoring indicates that smelter emissions contribute to elevated levels of metals in the air in both the Hayden and Winkelman communities. Lead levels in local air sometimes exceed EPA's National Ambient Air Quality Standard (NAAQS) for lead [0.15 micrograms per meter cubed ($\mu g/m^3$)]. From 2012-2014, three month rolling average lead levels at individual local air monitoring stations in Hayden and Winkelman ranged from 0.02 $\mu g/m^3$ to 1.18 $\mu g/m^3$ (EPA 2014a). EPA redesignated the Hayden area a nonattainment area for the lead NAAQS in August 2014 (EPA 2014b) and it remains a nonattainment area as of September 2016 (EPA 2016a).[2]

ATSDR analyzed EPA-collected air quality data from 2015 at 10 monitoring stations located throughout Hayden and Winkelman to learn more about air quality at the time of the April 2015 testing. Appendix A includes a map of the air monitoring stations; many are in or adjacent to residential areas.

[2] EPA defines nonattainment areas as "any area that does not meet (or that contributes to ambient air quality in a nearby area that does not meet) the national primary or secondary ambient air quality standard for the pollutant." (EPA 2015c).

The Asarco smelter was shut down for maintence between April 6 and May 21, 2015. The average level of lead across all stations for 2015, excluding the April 6–May 21 smelter shutdown, was 0.11 µg/m^3. Average lead levels for 2015 (excluding the shutdown timeframe) at individual monitoring stations ranged from 0.016 µg/m^3 (ST-2, Winkelman High School) to 0.49 µg/m^3 (ST-14, smelter parking lot).

Arsenic levels across all monitoring stations averaged 0.06 µg/m^3 in 2015, excluding the smelter shutdown timeframe. Individual monitoring station averages ranged from 0.006 µg/m^3 (ST-2, Winkelman High School) to 0.27 µg/m^3 (ST-14, smelter parking lot). EPA's regional screening level for arsenic in air is 0.0065 µg/m^3. California's acute, 8 hour, and chronic Reference Exposure Levels[3] for arsenic in air are 0.2, 0.015, and 0.015 µg/m^{3,} respectively (OEHHA 2016).

In the 2008 remedial investigation, EPA used data from the the Organ Pipe National Monument area southwest of Tucson, which is unaffected by mining or other human activity, for a background ambient air point of comparison (EPA 2008). This area had average arsenic concentrations of 0.0004 µg/m^3 or less and average lead concentration of 0.001 µg/m^3 (EPA 2008 and 2015a). During 2015, the average levels of arsenic and lead in Hayden and Winkelman air (excluding the shutdown timeframe) were about 150 and 110 times that of the area unaffected by smelting, respectively. Urban areas generally have mean arsenic levels in air ranging from 0.02 to 0.03 µg/m^3 (ATSDR 2007c).

Other local environmental sources of lead and arsenic

In addition to contamination from copper production, there are other sources of lead and arsenic in the community. About 44% of the housing units were constructed before 1950 (Census 2010b), when lead was widely used in paint.

Hayden and Winkelman residents receive drinking water from two public drinking water systems, which draw from local groundwater sources. Arsenic is often found in groundwater in some parts of the United States, including the Southwest. EPA collected drinking water samples in 2006 and found arsenic levels ranged from 3.6–5 µg/L across all sample locations in Hayden and Winkelman (EPA 2008, Table 4-22). Although both systems contain low levels of arsenic, they are below EPA's Maximum Contaminant Level for arsenic (10 micrograms per liter µg/L). Lead was not detected in the 2006 drinking water samples from either town. These 2006 levels are similar to those described in the Hayden and Winkelman drinking water systems' 2014 and 2015 water quality reports (Asarco 2014 and 2015b; Arizona Water Company 2014 and 2015). Those reports note both systems detected arsenic concentrations up to 5 µg/L (based on 2012 and 2013 samples for Winkelman and 2013 samples for Hayden). In 2013, the highest lead level detected by the Hayden water system was below 4 ppb lead, while the Winkelman system's highest detection was 1 ppb. EPA's action level for lead in drinking water is 15 ppb (EPA 2016b). While lead has not been detected above this level in the Hayden and Winkelman drinking water

---

[3] Reference Expsoure Levels are airborne concentrations of a chemical that are not anticipated to result in adverse non–cancer health effects for specified exposure durations in the general population, including sensitive subpopulations (OEHHA 2014).

systems, the plumbing and fixtures in older buildings may contain lead, potentially increasing lead levels in the water of some buildings.

Current Lead and Arsenic Exposure Pathways for Hayden and Winkelman Residents

The environmental data summarized above indicate that community members are at risk for exposure to lead and arsenic. Hayden and Winkelman residents may be exposed to lead and arsenic from copper production operations by breathing air and accidentally ingesting non-residential soils in the community.

Hayden and Winkelman community demographics indicate several risk factors for higher blood lead levels, including living in older housing (44% of housing units were built before 1950), and in poverty (38% of people across both towns have a poverty income ratio[4] < 1.24) (Census 2010a; Census 2010b; CDC 2013; Bernard et al. 2003; Jones et al. 2009). If deteriorating lead-based paint is present in Hayden and Winkelman homes, children in those homes are at greater risk for higher blood lead levels. In addition, 57% of participants self-identified as Mexican-Amercian, which may increase their risk of exposure to lead in products imported from Mexico (e.g. candies, pottery and folk remedies) (Dixon et al. 2009). Drinking water is not a significant lead exposure pathway for Hayden and Winkelman community members.

Community members may be exposed to arsenic in local air and soils. They may also be exposed to low levels of arsenic in dietary sources, such as seafood and rice, and drinking water. There are several types of arsenic that fall into two categories, organic and inorganic (see Box 1). While exposure to organic arsenic is likely not associated with health concerns, exposure to inorganic arsenic can harm people's health (ATSDR 2007a).

Box 1: Arsenic: Sources and Types

Arsenic is an element that is widely distributed in the earth's surface. Arsenic is released into the environment from both human activities (e.g., mining, commercial use) and natural processes (e.g., weathering of arsenic-containing minerals in soil and groundwater).

There are two basic types of arsenic:

Organic arsenic exposure doesn't usually cause health problems. It is often found in fish and seafood, so eating fish or seafood before arsenic testing may increase a person's organic and total arsenic level.

Inorganic arsenic exposure may cause health problems. It is found in many places in the environment, like in soil and water, and in some foods, such as some types of rice.

[4] A family's income divided by their poverty threshold is their poverty income ratio. See https://www.census.gov/hhes/www/poverty/about/overview/measure.html.

Past Lead and Arsenic Biological Testing

Previous lead and arsenic testing in Hayden and Winkelman has been limited. From 2003-2012 laboratories and physicians reported to ADHS 46 blood lead test results in Hayden and 86 results from Winkelman for children 0 to 16 years of age.[5] Two children in Hayden had a blood lead level (BLL) over 10 micrograms per deciliter (µg/dL) and six children in Winkelman had blood lead levels between 5–10 µg/dL.

In 1999, with funding from Asarco, the University of Arizona and ADHS conducted blood lead testing for young children (with an emphasis on children less than 3 years old) and spot urine[6] arsenic testing for adults and children of any age[7] in Hayden and Winkelman (Burgess et al. 2000; ADHS 2002). All fourteen children[8] tested had blood lead levels below 10 µg/dL (the level of concern at that time) and their average level was 3.6 µg/dL.[9] About 77% of the 224 participants tested for arsenic were over 20 years old (Hysong et al. 2003). The average urinary total arsenic concentration of individuals tested was 13.7 µg/L, less than the study reference level of 30 µg/L. For the 18 participants with total arsenic concentrations exceeding 30 µg/L, speciated analysis was used to measure inorganic arsenic. Five of those individuals had inorganic urinary arsenic concentrations exceeding 30 µg/L, up to a maximum of 47 µg/L. Urinary arsenic concentrations were not adjusted for creatinine and could have been influenced by dietary sources (e.g., seafood). Results from this lead and arsenic exposure survey are further discussed in the Discussion section of this report.

Exposure Investigation Process and Methods

In 2013, EPA requested that ATSDR conduct an exposure investigation to measure Hayden and Winkelman residents' lead and arsenic exposure levels. EPA had received requests from residents for additional biological testing.[10] ATSDR conducted the exposure investigation to provide both individual residents and federal, state, and local agencies with more information about lead and arsenic exposures in Hayden and Winkelman.

Agency roles

ATSDR, the lead agency for the investigation, collaborated with EPA, ADHS, ADEQ, and the Centers for Disease Control and Prevention (CDC). The roles of each agency are described in Table 1.

---

[5] Arizona law requires physicians to report to ADHS blood lead levels ≥ 10 µg/dL, while laboratories are required to report all blood lead test results, regardless of blood lead level (ADHS 2016).

[6] Generally first morning urine samples.

[7] Participants had to be able to collect urine in a cup.

[8] Blood lead tests were provided to two children less than 6 months, seven children 6 months to 36 months, and five children older than 36 months (Burgess et al. 2000).

[9] The limit of detection for these blood lead tests was 1 µg/dL (Burgess et al. 2000).

[10] Community members expressed interest in lead, arsenic, and copper biological testing to EPA. At the time of this exposure investigation, ATSDR did not have established methods to conduct a biological test and interpret results for copper,

Recruitment and participant eligibility
In March 2015, ATSDR and partner organizations visited Hayden and Winkelman to share information, answer questions, and sign-up eligible participants for testing appointments. Representatives worked toward these goals by holding public meetings, open house events, and door to door conversations in Hayden and Winkelman. To raise awareness about the testing opportunity, ATSDR developed a website on the project (http://www.atsdr.cdc.gov/sites/HWAZ/; ATSDR 2015b), twice sent postcards to all Hayden and Winkelman households, posted information in prominent locations in the towns, and left fact sheets (in English and Spanish) at local businesses and institutions (ATSDR 2015a). Community partners also distributed information. For instance, the Hayden-Winkelman Unified School District sent fact sheets home with eligible students and posted information on their Facebook page.

ATSDR sought to enroll people living in Hayden or Winkelman who may be at higher risk for health effects from exposure to lead and arsenic (e.g., young children and pregnant women) (Box 2). Initially, the following groups of Hayden or Winkelman residents were eligible to participate in the exposure investigation.

- Children between the ages 9 months to 11 years were eligible for lead testing.
- Children between the ages of 6 years to 11 years were eligible for arsenic testing.[11]
- Pregnant women of any age were eligible to participate in both lead and arsenic testing.

Later in the recruitment period, ATSDR expanded the eligibility criteria to allow the following groups to participate in both lead and arsenic testing (Box 2). [12]

- Adolescents aged 12–17 years
- Women of childbearing age (up to age 44)

[11] ATSDR did not offer arsenic testing to children ages 9 months to 5 years because (1) it is difficult to collect urine samples from young children, especially those wearing diapers, and (2) ATSDR cannot interpret the testing results because national comparison values do not exist.

[12] During the course of recruitment ATSDR learned that parents also wanted testing for adolescents ages 12–17 living in Hayden and Winkelman. Adolescents ages 12–17 are not as likely to be exposed to lead and arsenic from soil because they play differently than younger children do. However, because they are still growing and developing, adolescents have more susceptibility to health effects of lead and arsenic than adults. Because of parental interest and because resources were available to offer testing slots, ATSDR expanded the eligibility to include adolescents ages 12–17 before the testing appointments began. During the recruitment period ATSDR also expanded eligibility to include women of childbearing age (up to age 44) who live in Hayden and Winkelman. ATSDR expanded to this group because ATSDR had resources available to offer testing slots and a developing baby is sensitive to lead and arsenic in the mother’s body.

Box 2: Eligibility Criteria
People living in Hayden and Winkelman who met the following criteria were eligible to participate.

Lead testing only
- Children ages 9 month to 5 years

Lead and arsenic testing
- Children and adolescents ages 6 years to 17 years
- Pregnant women of any age
- Women of childbearing age (up to age 44)

The exposure investigation team faced several challenges while recruiting participants. Some people who worked for Asarco expressed concern that their family's participation could put their employment at risk. Others were concerned that the findings might be used as a rationale for shutting down the smelter, negatively affecting the local economy. Finally, some parents noted that their child's health care provider tested them regularly for lead and/or arsenic.

Particpants and testing appointments
In April 2015, ATSDR offered free, voluntary blood lead and urine arsenic testing to Hayden and Winkelman residents. ATSDR and ADHS representatives completed testing April 17–19, 2015 for 83 residents from 29 different Hayden and Winkelman households. All participants received lead testing and 58 participants also received arsenic testing (see Results section for additional information on participants).

Biologic sample collection and analysis
Participant consent and questionnaire
ATSDR administered consent, assent, and parental permission forms prior to collecting the blood and urine samples. Blood and spot urine (generally first morning) samples were collected April 17–19, 2015. ATSDR team members collected pertinent information from the head of each household using an Office of Management and Budget (OMB) approved questionnaire (OMB # 0923-0048). The household questionnaire included questions on demographics, characteristics and age of residence, and activities that might result in exposure to lead and arsenic. ATSDR collected information on participant race and ethnicity as part of the questionnaire. This information helped ATSDR understand differences between the participant population and the U.S. population. It also allowed ATSDR to compare individual and aggregate participant results to appropriate U.S. subpopulations, when necessary.

Confidentiality
Federal rules require that ATSDR maintain confidentiality of the information gathered through interviews as well as the results of laboratory tests unless the data is aggregate and without identifiable information. Arizona law (A.A.C. R9-4-301) requires laboratories to report all blood lead tests to the Arizona Department of Health Services (ADHS 2016). In compliance with this

statute, ATSDR provided all blood lead testing results to ADHS. In addition, all participants gave ATSDR permission to share their test results with other environmental and health government agencies.

Blood lead sampling and laboratory analysis

Blood lead sampling is the most reliable method for measuring lead exposure from all sources (Barbosa et al. 2005). ATSDR obtained whole blood samples by venous puncture. A phlebotomist (medical professional who draws blood from a vein) collected three milliliters (ml) of blood from each participant. CDC provided the collection tubes and supplies. To maintain privacy, the samples were labeled with a unique identification number. After collection, blood samples were maintained near four degrees Celsius throughout the collection period and during overnight shipment. These samples were delivered for analysis to the CDC laboratory in Atlanta, Georgia. The CDC environmental health laboratory performed blood lead analysis using Division of Laboratory Science (DLS) method 3016.8 for blood metals (CDC 2014a).

Urine arsenic sampling and laboratory analysis

Determining urinary arsenic levels is the most reliable method to measure recent exposures to arsenic (i.e., exposures experienced within the past few days) (Orloff et al. 2009). A 24-hour urine collection is optimal due to fluctuations in excretion rates. However, most studies use a first morning or random spot urine sample because it is convenient and increases compliance. Both methods correlate well with 24-hour collection results (Orloff et al. 2009), though first morning samples more so than random spot (Wang et al. 2016). ATSDR collected 58 spot, generally first morning, urine samples. The collection cups were supplied by the CDC laboratory. Most participants collected their urine sample at home on the day of their blood sample appointment, froze the sample, and then brought it to the collection location at the time of their blood sampling appointment. Some participants collected their urine sample at the blood sampling location. To maintain privacy, the samples were labeled with a unique identification number. Urine samples were kept frozen on dry ice and shipped to the CDC laboratory.

The CDC environmental health laboratory performed urinary arsenic analyses (total and speciated arsenic for all participants) using the following methods: DLS 3018A.4 for urine total arsenic and DLS 3000.14 for arsenic speciation (CDC 2014b and 2014c). The lab also measured creatinine levels in urine samples to allow ATSDR to calculate creatinine corrected arsenic levels.

Inorganic-related arsenic species

ATSDR calculated the sum of inorganic-related arsenic species for each participant because "inorganic-related arsenic may be a more toxicologically and health relevant measure than total urinary arsenic, which includes non-toxic organic arsenic species" (CDC 2015). Following the methods CDC outlined in the February 2015 updated National Exposure Report tables (CDC 2015), ATSDR summed arsenic (V) acid, arsenous (III) acid, dimethylarsinic acid (DMA), and monomethylarsonic acid (MMA) for each participant. When the value of a species was less than the laboratory's limit of detection (LOD), as was the case for some participants' arsenic (V) acid level, an imputed (i.e., substitute) value was used. The imputed value was calculated as the LOD divided by the square root of two (Hornung and Reed 1990).

Creatinine correction for urinary arsenic

ATSDR used participants' urine creatinine concentration to adjust arsenic results for urine dilution (Barr et al. 2005). Creatinine corrected arsenic results are reported as microgram of arsenic per gram creatinine (µg of arsenic per g creatinine). Creatinine correction allowed ATSDR to compare arsenic results across participants who were more or less hydrated and thus have different urine concentrations. However, creatinine concentrations also vary by age, sex, race/ethnicity, and certain health conditions (Barr et al. 2005). To account for variation in creatinine levels by age, ATSDR compared age group specific participant and U.S. population (NHANES) creatinine corrected arsenic levels.[13,14] ATSDR also compared participant and U.S. population (NHANES) age group specific creatinine levels.

In addition, ATSDR used participant creatinine levels to gauge the validity of a urine sample (Barr et al. 2005). In a state of under or over hydration, the kidney's excretion rate of contaminants changes, which can yield results that are not an accurate reflection of the participant's exposure. World Health Organization (WHO) urinary creatinine concentrations guidelines are often used to determine valid spot urine samples for occupational monitoring. The guidelines suggest resampling if a urine sample is too dilute (creatinine concentration < 30 mg/dL) or too concentrated (creatinine concentration > 300 mg/dL) to provide a valid measure (Barr et al. 2005).[15] While the WHO guidelines were developed for adults rather than children, the focus of this investigation, ATSDR used them to help identify participants whose creatinine corrected arsenic results might be biased.

Exposure investigation follow-up levels

ATSDR compared blood lead and urine arsenic test results from individual participants and specific age groups to the U.S. population [National Health and Nutrition Examination Survey (NHANES) results] (CDC 2015). For individual participant blood lead results, ATSDR used the CDC's blood lead 5 µg/dL reference value as the exposure investigation follow-up level. CDC uses a reference level of 5 µg/dL to identify children with blood lead levels that are higher than most children's levels (CDC 2012a and 2012b). This level is based on the U.S. population of children ages 1–5 years who are in the highest 2.5% of children when tested for lead in their blood (i.e., the 97.5th percentile of the NHANES's blood lead distribution in children). The National Institute for Occupational Safety and Health (NIOSH) also uses 5 µg/dL as the blood lead reference level for adults (NIOSH 2015). ATSDR compared individual total urinary arsenic

[13] Comparisons between the adult participant age group (women 20–40 years old) and U.S. population adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.

[14] To further investigate participant's inorganic-related arsenic species levels, ATSDR used both creatinine corrected and uncorrected results.

[15] Creatinine correction for a target chemical (e.g., arsenic) measured in a highly concentrated urine sample (i.e., elevated creatinine) tends to underestimate the concentration of the target chemical. Conversely, creatinine correction for a target chemical measured in a very dilute urine sample (i.e., low creatinine) tends to overestimate the concentration of the chemical.

results (creatinine corrected) to the exposure investigation follow-up level of 28.4 µg/g creatinine. The arsenic exposure investigation follow-up level was the lowest 95th percentile level for any age group in the 2009–10 NHANES (the 12–19 year age group). ATSDR chose this level as a conservative screening value to identify participants with a potentially elevated urinary arsenic level.

Individual result letters and follow-up

In June 2015, ATSDR sent results letters to individual participants along with a fact sheet on ways to reduce exposure to lead and arsenic (ATSDR 2015c). ATSDR and ADHS also contacted participants with elevated results to discuss their results and recommend steps to take to protect the participant's health.

Air monitoring data

Between 2013 and 2015, Asarco, with EPA oversight, collected air monitoring data on lead, arsenic, and other contaminants at 10 monitoring stations located throughout Hayden and Winkelman (Appendix A). ATSDR used this data to assess levels of lead and arsenic in the area. Specifically, ATSDR used measurements of lead and arsenic in particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10}) from 23+ hour samples collected every six days at each monitoring station. Asarco used Thermo Scientific Partisol Plus 2025 sequential air samplers configured with PM_{10} sharp cut cyclone inlets and AirMetrics™ MiniVol samplers with teflon, quartz, and capillary pore membrane polycarbonate (0.1 micron pore size) filters to collect the samples (EPA 2012).

Statistical analyses

ATSDR used R software (version 3.2.4) (R Core Team 2015) for statistical analyses of lead and arsenic testing data and analysis of air monitoring data.

<u>Statistical analysis of lead and arsenic results</u>

ATSDR calculated statistics to compare exposure investigation participants to U.S. population statistics. For lead and arsenic results, ATSDR estimated median (i.e., 50th percentile) and 95th percentile levels for participants (see Box 3). ATSDR also used percentile bootstrap methods (n = 2,000) to calculate 95% confidence intervals for lead and arsenic median and 95th percentile levels. These confidence intervals allowed ATSDR to gauge whether exposure investigation participant median and 95th percentile levels were statistically different (higher or lower) than U.S. population levels (Krzywinski and Naomi 2013).

<u>Statistical analysis of air monitoring data</u>

For lead and arsenic air monitoring data, ATSDR calculated mean (i.e., average, see Box 3) levels for various time periods and used the Wilcoxon rank sum test to determine whether differences were statistically significant. ATSDR also used the EPA Positive Matrix Factorization model to estimate the number and composition of air pollution sources and their relative contributions to contaminant levels (all contaminants, not just lead and arsenic) at each monitoring station (EPA 2015e).

Box 3: What are the median, mean, and 95th percentile?

The median and mean are different ways of measuring the center of a collection of numbers.

- The **median** is the middle value in a list of numbers. In a set of numbers it separates the higher half from the lower half.
- The **mean** (or average) is the sum of a set of numbers divided by the number of numbers in the set.

The **95th percentile** is the value below which 95 percent of the values in a data set are found.

Results

Participants in the exposure investigation

Eighty-three people (ages one year to 40 years) from 29 households participated in the exposure investigation. All 83 participants received blood lead testing, while 58 received urine arsenic testing as well (Table 2).[16] All participants were residents of the towns of Hayden or Winkelman, Arizona [59 from Hayden (71%) and 24 from Winkelman (29%)]. As noted earlier, ATSDR's focus was on enrolling young children, as they are often at higher risk for lead exposure. Thus, 65% of lead testing participants were children one year to 11 years, while 50% of arsenic testing participants were children 6–11 years. Adolescents age 12–19 made up 20% and 29% of lead and arsenic testing participants, respectively. All adults evaluated were women of childbearing age (defined as less than 45 years old), including one pregnant woman. Adult women (age 20–40) made up 14% of lead testing participants and 21% of arsenic testing participants. Table 2 provides additional information on participants by age and sex. Based on census estimates, approximately 37% of Hayden and Winkelman residents 9 months to 11 years old, ATSDR's primary target population, participated in the investigation.

Based on questionnaire responses, 90% (75 of 83) of the participants self-identified as Hispanic or Latino and 10% (8 of 83) self-identified as Non-Hispanic. Of the self-reported Hispanic or Latino participants, 57% (43 of 75) indicated they were of Mexican ethnicity, 8% (6 of 75) identified as being of Puerto Rican ethnicity and 35% (29 of 75) identified themselves as "other" Hispanic or Latino ethnicity. Five percent (4 of 75) identified themselves as having 2 or more Hispanic ethnicities. With regards to race, 83% (70 of 83) of participants (including Hispanics or Latinos) self-reported their race as white, one percent (1 of 83) self-reported their race as African American and one percent (1 of 83) self-identified as more than one race. Sixteen percent (13 of 83) of participants declined to answer with regard to race.

[16] ATSDR did not offer arsenic testing to children ages 9 months to 5 years because (1) it is difficult to collect urine samples from young children, especially those wearing diapers, and (2) ATSDR cannot interpret the testing results because national comparison values do not exist.

Blood lead results

As discussed in the methods section, CDC uses a reference level of 5 µg/dL to identify children (1–5 years) with blood lead levels that are higher than most children's levels (CDC 2012a and 2012b). NIOSH also uses 5 µg/dL as the blood lead reference level for adults (NIOSH 2015). For the Asarco Hayden exposure investigation, ATSDR used 5 µg/dL as the investigation level to identify participants for follow-up, including children older than 6 years, pregnant women, and women of child bearing age.

Two participants from different households exceeded the exposure investigation blood lead level (Figure 2 and Figure 3). A child in the 1–5 year old age group had the highest BLL, 5.9 µg/dL. A child in the 6–11 year old age group had a BLL of 5.3 µg/dL. In addition, two participants, both in the 1–5 year old age group, had BLLs between 4 and 5 µg/dL. One of these children and the 6–11 year old participant with the 5.3 µg/dL BLL were from the same household. A third participant from that household had a lower BLL (0.96 µg/dL) (Figure 3).

In addition to comparing individual participant results to the exposure investigation follow-up blood lead level, ATSDR compared individual participant results, and the median (50th percentile) and 95th percentile BLL estimates for each age group of participants to age group specific U.S. population (i.e., NHANES) median and 95th percentile BLLs. Twenty-four percent of participants 1–5 years, 38% of participants 6–11 years, and 35% of participants 12–19 years had BLLs above their age group specific NHANES 95th percentile level (Figure 4). Eight percent of adult participants had BLLs above the adult NHANES 95th percentile level.

Median BLLs for children (1–5 years: 1.9 µg/dL and 6–11 years: 1.3 µg/dL) and adolescents (12–19 years: 1.2 µg/dL) were about two times higher than U.S. population age specific comparison groups (Table 3), though only the 1–5 year old and 12–19 year old age groups were statistically different from the comparison age groups. The median BLL for adult participants (women age 20–40; 0.86 µg/dL) was slightly lower than the median for the adult U.S. population (1.05 µg/dL) (Table 3) and similar to the median for U.S. women of all ages (0.82 µg/dL). Age group-specific children and adolescent 95th percentile BLL estimates ranged from 1.5 to 2.4 times higher than U.S. population comparison age groups, though only the 12–19 year age group was statistically different. The estimated 95th percentile BLL for adult participants (women age 20–40; 2.61 µg/dL) was slightly lower than, but not statistically different from, the 95th percentile for the adult U.S. population (3.36 µg/dL) (Table 3) and similar to the 95th percentile for U.S. women of all ages (2.59 µg/dL).

Urinary arsenic results

ATSDR performed several evaluations of urinary arsenic results to understand how participant arsenic exposure levels compare to the U.S. population. ATSDR used urine samples to evaluate participant exposures to total arsenic, inorganic arsenic, and individual types (i.e., species) of arsenic.

Total arsenic

First, ATSDR compared each participant's total arsenic (creatinine corrected) results to the exposure investigation follow-up level [the lowest 95th percentile level for any age group in the 2009–10 NHANES (28.4 µg/g creatinine, 12-19 year age group)] (Figure 5). No participants exceeded that level. ATSDR used this comparison level in letters reporting total arsenic results to participants. The highest urinary total arsenic level measured was 28.3 µg/g creatinine in an 11-year-old male. This participant's inorganic-related arsenic species result was similar to the U.S. population in his age group. Review of the participant's organic arsenic species indicated that arsenobetaine accounted for the majority of the participant's total arsenic. The participant had eaten 1–2 portions of seafood in the week before the testing, which likely contributed to his elevated arsenobetaine level.

Second, ATSDR compared participant total arsenic results to age specific NHANES 2011-12 levels, which were released in February 2015. No participant's total urinary arsenic (creatinine corrected) exceeded the respective NHANES age group specific 95th percentile level (Figure 6).

Third, ATSDR estimated median and 95th percentile total arsenic exposure levels (creatinine corrected) for each participant age group and compared these levels to NHANES age group specific median and 95th percentile levels. Median total arsenic levels for each participant age group were similar to U.S. population age group-specific medians, while participant 95th percentile levels were lower than U.S. population 95th percentile levels (Table 4).

Total arsenic results for participants with creatinine concentrations outside the target range

As discussed in the methods section, ATSDR used participants' urine creatinine concentration to gauge the validity of a urine sample (Barr et al. 2005). WHO guidelines suggest resampling if a urine sample is too dilute (creatinine concentration < 30 mg/dL) or too concentrated (creatinine concentration > 300 mg/dL) to provide a valid measure (Barr et al. 2005).

Urine samples from two participants were below 30 mg/dL (29.03 and 29.97 mg/dL). Both participants were female. Neither of these samples resulted in a creatinine corrected arsenic result that was elevated and could potentially be confused for a falsely elevated result (7.3 and 9.0 ug/g of creatinine).

Urine samples from 4 of the 58 participants (6.8%) had a creatinine level above 300 mg/dL, ranging from 313.9 to 419.3 mg/dL. A creatinine level above 300 mg/dL could potentially result in an artificially low value for creatinine corrected urinary arsenic. Three of the four participants with elevated creatinine results were Hispanic males between the ages of 12–19. The fourth participant was a Hispanic female of child bearing age (20–40 years). Males generally have a higher creatinine level than females (Barr et al. 2005). Hispanics and Mexican-Americans generally report lower creatinine levels than the U.S. population (Barr et al. 2005). A prior study found that uncorrected and creatinine corrected concentrations of inorganic urinary arsenic were significantly correlated in a population with low-level environmental arsenic exposure as was the case in this investigation (Hinwood et al. 2002). The urine samples from all four participants had a creatinine corrected urinary arsenic level well below the 95th percentile and median of their 2011–12 NHANES age group as well as the exposure investigation follow-up level. In addition, the four participants' uncorrected total urinary arsenic results were all below the 90th percentile 2009–10 and 2011–12 NHANES levels for age, gender and race/ethnicity. While these participants' creatinine levels were outside of the target range, their total uncorrected urinary arsenic values suggest that they were below the exposure investigation follow-up level. Table 5 presents the creatinine corrected and uncorrected urinary arsenic results for these participants with the exposure investigation follow-up level and 90th percentile U.S. population levels.

<u>Inorganic-related arsenic species</u>
ATSDR estimated median and 95th percentile urinary inorganic-related arsenic species levels (creatinine corrected) for child (6–11 years) and adolescent (12–19 years) age groups (Table 6). For both participant age groups, inorganic-related arsenic species median levels (creatinine corrected) were similar to U.S. population medians. Age group specific 95th percentile inorganic-related arsenic species levels (creatinine corrected) were lower than the U.S. population 95th percentile levels. ATSDR did not include in this report inorganic-related arsenic species summary statistics for adult participants because 75% of adult participants had levels of arsenic (V) acid (one type of inorganic arsenic), below the lab's level of detection.

<u>Individual arsenic species</u>
ATSDR reviewed results on the individual species (or types) of arsenic measured in participants' urine samples. As an indicator of exposure, ATSDR compared how frequently each arsenic species was detected among participants as compared with the U.S. population in 2011–12. The CDC laboratory's levels of detection for each arsenic species changed between the time when NHANES 2011–12 samples were analyzed and this exposure investigation. Thus, ATSDR compared the percentage of detections using both the exposure investigation levels of detection and after adjusting participant results based on the NHANES 2011–12 levels of detection (i.e., counting as a non-detect any participant result that was below the NHANES 2011–12 level of detection, but above the exposure investigation level of detection).

Inorganic arsenic species [i.e., arsenic (V) acid, arsenous (III) acid, DMA, and MMA] were detected more frequently in exposure investigation participants than in the U.S. population (Figure 7). For instance, arsenous (III) acid was detected in all participants' urine samples, but only 32% to 39% of the U.S. population's urine samples, depending on the age group. Arsenic (V) acid was detected in 69% of participants 6–11 years old, but only 5% of the U.S. population in that age group. This trend was true for results based on the exposure investigation levels of detection and when results were adjusted based on NHANES 2011–12 levels of detection.

Correlation and spatial distribution of participant lead and arsenic results
ATSDR explored whether participants' lead and arsenic levels were correlated (e.g., whether participants with higher lead levels also have higher arsenic levels). ATSDR did not find a correlation between participants lead and arsenic results (Figure 8). In addition, ATSDR mapped participant lead and arsenic results, but did not see a clear trend in the spatial distribution of

lead or arsenic results. ATSDR does not include a map of participants' locations and results to protect their privacy.

Air monitoring results

After collecting participants' blood and urine samples (from April 17–19, 2015), ATSDR learned that the Asarco Hayden Smelter was shut down for maintenance 11 days before ATSDR started blood and urine sampling until 31 days after sampling ended (April 6–May 21, 2015) (personal communication with Tom Aldrich, ASARCO LLC, July 1, 2015). ATSDR used EPA air monitoring data from 10 monitoring stations located across Hayden and Winkelman to assess whether the shutdown changed the level of lead and arsenic in the air before and during our testing event. A map of the ambient air monitoring network is included in Appendix A.

Average concentrations of lead and arsenic were about 7 and 8 times lower respectively during the shutdown as compared with all of 2015 (excluding the shutdown timeframe) (Table 7). At individual monitoring stations, average lead levels for 2015 (excluding the shutdown timeframe) were between 3 (at ST-2 and ST-18) and 18 (at ST-16) times higher than during the shutdown timeframe (Table 8). Similarly, average arsenic levels at individual monitoring stations for 2015 (excluding the shutdown timeframe) were between 1.5 (at ST-2) and 18 (at ST-16) times higher than during the shutdown timeframe (Table 8).

To better understand how the shutdown affected local air quality, ATSDR used the EPA Positive Matrix Factorization (PMF) model to estimate the number and composition of air pollution sources and their relative contributions to contaminant levels (all contaminants, not just lead and arsenic) at each monitoring station. The model results indicate two primary sources of air contamination in Hayden and Winkelman: the smelter and a background source, which includes soil, dust, and other windblown sources.[17] Further, the results show a clear reduction in the relative contribution[18] of the smelter source to air contamination levels at all Hayden and Winkelman monitoring stations during the shutdown (Figure 9). While the background source contribution to air contamination levels was similar throughout the 2013–15 timeframe, including the shutdown period, the smelter source contribution was much lower during the 2015 shutdown than other periods (Appendix B; Figures B.1 and B.2).

---

[17] Initially, ATSDR attempted PMF modeling with two factors but chose to include a third factor because some air monitoring sites had a factor consisting of almost entirely chlorine. When ATSDR increased the number of factors to four, the arsenic and lead concentrations were assigned to separate factors. ATSDR determined that three factors gave the best fit with one factor including the majority of the lead and arsenic (smelter factor) and one factor containing the majority of crustal elements (background factor) while a third factor included chlorine or phosphorus but had some site dependence. This third factor is not used in this analysis.

[18] The average relative importance over the entire time period for each factor is defined to be 1.0.

Discussion

Smelter shutdown before and during testing

As noted earlier, ATSDR learned after collecting blood and urine samples that the smelter had been shut down in the days preceding and during the sample collection event. Due to differences in the way lead and arsenic behave in the human body, the smelter shutdown likely did not affect participant lead results, but could have affected arsenic results. Lead stays in the blood for several weeks, so it is likely that lead exposures experienced before the shutdown began would still be reflected in participants' blood 11–13 days later, when ATSDR collected samples. However, since arsenic is typically excreted from the body within several days of exposure, the lower level of arsenic in air in the days preceding testing, could have reduced the amount of arsenic ATSDR measured in participants' urine.

Lead and health effects

<u>Lead – background discussion</u>

Lead is a naturally occurring metal. Typically found at low levels in soil, lead is processed for many industrial and manufacturing applications, and it is found in many metallic alloys. Today, lead can be found in all parts of our environment because of past and current human activities including burning fossil fuels, mining, and manufacturing processes (ATSDR 2007b). Lead was previously found in many gasoline additives, but by the mid 1970's the U.S. began phasing out the use of lead in gasoline and the Clean Air Act banned the sale of leaded fuel for on-road vehicles in 1996 (EPA 1996). Lead was banned from paint in 1978.

Because lead is found throughout the environment, it is often found in the body at low levels. Lead exposure occurs primarily via the oral route, with some contribution from the inhalation route. The toxic effects of lead are the same regardless of the route of entry into the body.

Exposure to lead can have many health effects. Depending on the level of exposure, lead can harm the nervous system, kidney function, immune system, reproductive system, development, and cardiovascular system. Lead exposure also affects the oxygen carrying capacity of the blood. The health effects of lead most commonly encountered in current populations are neurological effects in children, and cardiovascular effects (e.g., high blood pressure and heart disease) in adults. Infants and young children are especially sensitive to low levels of lead, which may contribute to behavioral problems, learning deficits, and lowered IQ (ATSDR 2007b).

Lead in a pregnant woman's body can negatively affect the health of her unborn child. Lead exposure can also cause a miscarriage. It is not known for certain if lead causes cancer in humans. Rats and mice fed large amounts of lead in their food developed kidney tumors. DHHS classifies lead as "reasonably anticipated" to cause cancer and EPA considers lead a "probable" cancer causing substance (ATSDR 2007b).

No lower threshold can be identified for some of the adverse neurological effects of lead in children (ACCLPP 2012). Because of the absence of any clear threshold for some of lead's more sensitive health effects, ATSDR has not established guidelines for a low or no risk lead intake dose. Blood lead levels should be kept as low as possible since no safe blood lead level in children has been identified (ACCLPP 2012).

The half-life of lead in blood is approximately 28-36 days (ATSDR 2007b). Blood serves as the initial repository of lead that is absorbed into the body, but typically carries only a small portion of the total lead burden in the body. As lead moves through the body it harms various organ systems and can be stored in the bones and teeth. Lead that is not stored in bones and teeth is excreted from the body in urine and feces. About 99% of the amount of lead taken into the body of an adult will leave the body in urine or feces within four to five weeks, while only about 30% of the lead taken into the body of a child will leave the body in urine or feces (ATSDR 2007b). Lead can stay in bones for decades (ATSDR 2007b). Lead can leave bones and re-enter the blood and deposit in organs under certain circumstances; for example, during pregnancy and lactation, after a bone is broken, and during menopause in women (due to osteoporosis).

Some biological (e.g., age, sex) and social (e.g., race, socio economic status) factors make people either more vulnerable for lead exposure and/or susceptible to lead's health effects. Living in older housing (CDC 2013; Bernard et al. 2003), and poverty (CDC 2013; Jones et al. 2009), combined with being Mexican-American (Dixon et al. 2009; EPA 2013) and being non-Hispanic black (Bernard et al. 2003; CDC 2013; Jones et al. 2009) are risk factors for higher blood lead levels.

<u>Lead - participant blood lead results discussion</u>
Multiple environmental sources and risk factors likely contributed to the lead ATSDR measured in participants' blood. Some sources were community-wide (e.g., air), while others may have been household specific (e.g., lead paint). Other risk factors relate to individual behavior (e.g., a child putting their hands in their mouth or consuming certain Mexican candies). ATSDR collected information from participants about some risk factors, which ATSDR used to provide recommendations to participants with higher BLLs and to look for trends across participant results.

ATSDR asked participants (or their parent/guardian) about the age of their homes, since lead paint was used widely in homes built before 1950 and was phased out in 1978. ATSDR did not observe a difference in blood lead levels for participants who reported living in homes built before 1950 (n=26), between 1950 and 1979 (n=29), after 1979 (n=7), or did not answer (n=21).

ATSDR also collected information about the occupations of adult participants and the parents of child participants. Results did not suggest a relationship between participant blood lead levels and having a parent who worked at a mine, smelter, or other settings with potential lead exposure.

As noted in the results section, two participants had BLLs above the investigation follow-up level (5 µg/dL) and two other participants had BLLs close to the follow-up level, between 4–5 µg/dL. Two of the four participants with a BLL above 4 µg/dL resided in Winkelman and two resided in Hayden. The two from Hayden lived in the same household. In follow-up conversations with the participants' parents, ATSDR learned that at the time of testing the two participants from Winkelman did not reside in the same household but frequently spent time together.

ATSDR could not identify a clear exposure source that would account for these children's higher blood lead levels. None of these participants were reported to routinely eat dirt, but all four were reported to frequently put dirty hands or toys in their mouth, as is typical for toddlers and young children. The parents/guardians of 20 of 25 participants under 6 years old noted their child put dirty toys in their mouth. The four participants with higher BLLs are unlikely to be exposed to high levels of lead in their residential soils. During the residential soil clean up process, EPA sampled soil at the Hayden home and one of the two Winkelman homes. The soil at the Hayden household required clean up, which EPA completed in 2009. The soil at the Winkelman home that EPA sampled did not require clean up. The Winkelman home that EPA did not sample is located in the vicinity of several properties where levels of lead and arsenic in soil did not require clean up.

Exposure to lead-based paint may be a concern at the Hayden household, which was built in the 1950s. Lead-based paint may also be present in the Winkelman home where EPA collected soil samples, which the participant reported was built in the 1940s. The Winkelman home where soil was not sampled was constructed in the 1990s, after the phase out of lead-based paint.

The two participants with BLL above 4 µg/dL residing in Hayden lived in the same household and are siblings. ATSDR learned in a follow-up conversation with the family that they have spent time with family members in Mexico and that the children do routinely consume candy obtained from Mexico. ATSDR advised the parents that consumption of this candy is a potential source of lead exposure and that they should avoid continued consumption of candy that was obtained in Mexico.

Arsenic and health effects

<u>Arsenic – background discussion</u>

Arsenic is a naturally occurring element that is found in combination with either inorganic or organic substances to form many different compounds. Inorganic arsenic compounds are more toxic than organic arsenic compounds (ATSDR 2007a). Arsenic is also released into the environment from mining, ore smelting, and industrial use. In the past, inorganic arsenic was used as a pesticide and as a preservative for wood (commonly referred to as pressure-treated wood) (ATSDR 2007a). Inorganic arsenic compounds are found in groundwater, soils, sediments, and some foods (e.g., rice). Groundwater in several regions of the United States, including the southwest, have higher naturally occurring levels of inorganic arsenic than other areas. People can be exposed to inorganic arsenic by drinking arsenic-contaminated drinking water, ingesting arsenic after touching contaminated soil or wood preserved with arsenic, breathing arsenic-contaminated air, and eating foods contaminated with arsenic. Fish and shellfish commonly contain organic arsenic compounds, which can lead to organic arsenic exposure in people consuming seafood. Animal studies have found that organic arsenic appears to be less toxic than inorganic arsenic (ATSDR 2007a).

Inorganic arsenic has been linked to skin, liver, bladder, and lung cancer, and the Department of Health and Human Services (DHHS) has designated it as a known human carcinogen (ATSDR 2007a). Arsenic also induces a wide variety of non-cancer effects in humans (ATSDR 2007a and 2016). Unusually large doses of inorganic arsenic can cause symptoms ranging from nausea, vomiting, and diarrhea to dehydration and shock (ATSDR 2007a). Long-term exposure to high levels of inorganic arsenic in drinking water has been associated with skin disorders (e.g., hyperkeratosis and hyperpigmentation) and increased risks for diabetes and high blood pressure among other health risks (ATSDR 2007a and 2016). Long term exposure to arsenic in air at lower concentrations can lead to skin effects, and also to circulatory and nervous system problems (ATSDR 2007a).

<u>Arsenic - participant urine arsenic results discussion</u>
As noted in the methods section, ATSDR used creatinine correction to adjust arsenic results for urine dilution. Creatinine correction allowed ATSDR to compare arsenic results across participants who were more or less hydrated and thus have different urine concentrations. However, urine creatinine levels can vary depending on a person's age, sex, body mass, and certain health conditions (Barr et al. 2005). To account for variation by age, ATSDR used creatinine corrected age group specific U.S. population arsenic levels for comparison. ATSDR also compared participant and U.S. population (NHANES) creatinine levels.

Participant age group specific median creatinine levels were higher than comparable age group medians for the NHANES 2011-12 and NHANES III (1988-1994) U.S. population and Mexican American sub-population (Appendix C) (CDC 2015 and Barr et al. 2005). Several factors may contribute to differences between participant and U.S. population levels of urinary creatinine. First, following ATSDR direction, most participants collected first morning urine samples, whereas NHANES urine samples were collected at random times throughout the day. First morning urine samples are generally more concentrated (and thus have higher creatinine concentrations) than urine samples collected at other times (Barr et al. 2005). In addition, participants live in a warm, arid region which may affect their hydration status. ATSDR did not collect information on participant body mass and health conditions, but participants may have differed from the U.S. population on such factors. While participants included more women (59%) and persons who identified as hispanic or latino (90%) than the U.S. population, women, hispanics, and Mexican Americans generally report lower creatinine levels than the U.S. population (Appendix C).

To further investigate participant's inorganic arsenic exposure levels, ATSDR compared urinary inorganic-related arsenic species median and 95th percentile levels (without creatinine correction) for the younger age groups to the U.S. population (Table 9). For 6–11 year old participants, uncorrected inorganic arsenic median and 95th percentile levels were approximately double those of the U.S. population for that age. For the 12–19 year old age group, the median level was also double the U.S. population for that age, while the 95th

percentile level was similar to the U.S. population for that age. Given participants' higher creatinine levels, uncorrected inorganic-related arsenic species results may overestimate exposures relative to the U.S. population, while creatinine corrected results may underestimate exposures. However, a more detailed analysis would be required to determine whether creatinine correction introduced any bias.

ATSDR also found that each individual inorganic arsenic species was detected more frequently in participants' urine than in the U.S. population (though some more than others) (Figure 7). These results suggest higher levels, and perhaps different sources, of inorganic arsenic in the Hayden and Winkelman environment as compared with the United States generally.

<u>Arsenic – comparison of urinary levels to previous Hayden and Winkelman results and other smelter communities</u>
As noted earlier in this report, in 1999 the University of Arizona and ADHS conducted arsenic testing for 224 Hayden and Winkelman residents, 77 percent of which were over age 20 (Burgess et al. 2000 and Hysong et al. 2003). Due to differences in the age of the study population and analytical methods, many of the results of the 1999 exposure survey are not directly comparable to the ATSDR exposure investigation. That said, median total urinary arsenic levels provide one point of comparison. The median total urinary arsenic level for the 1999 exposure survey participants was 9.6 µg/L (Hysong et al. 2003). ATSDR exposure investigation participant median total urinary arsenic levels were: 12 µg/L, 11 µg/L, and 7.2 µg/L for the 6–11, 12–19, and 20–40 year age groups, respectively. This comparison suggests that Hayden and Winkelman residents were exposed to similar levels of arsenic in 1999 and 2015.

A University of Arizona exposure study of 70 children age 1 to 11 in Dewey-Humboldt, Arizona, a historic mining and smelting area (Loh et al. 2016), found arsenic exposure levels close to Hayden and Winkelman exposure investigation participants. Differences in the age of the Dewey-Humboldt study population make direct comparisons difficult. The median and 95th percentile levels of inorganic arsenic related species for Dewey-Humboldt study participants (age 1–11) were 10.4 and 28.5 µg/L respectively (Loh et al. 2016 and Personal communication with Miranda Loh, May 5, 2016). The median and 95th percentile levels of inorganic arsenic related species for the Hayden and Winkelman 6–11 year age group were 11.9 and 24.9 µg/L respectively. Though both towns share a mining and smelting history, the potential arsenic exposure sources are different. In Dewey-Humboldt, arsenic contamination of residential soils and drinking water (especially in private wells) are of greater concern (Loh et al. 2016). In Hayden and Winkelman, non-residential soils, ambient air (largely from active smelting operations), and drinking water are likely the primary sources of environmental arsenic exposure. House and wind-blown dust are likely sources of exposure in both communities. Despite these different exposure routes, children in these two Arizona communities have similar arsenic exposure levels.

Discussion of correlation and spatial distribution of lead and arsenic results
There are several potential reasons that ATSDR did not observe a correlation between individual participants' lead and arsenic levels nor a clear spatial pattern in the results. First,

environmental contamination in the community is not uniformly distributed. For instance, a child playing in a non-residential area with arsenic contaminated soil may not be exposed to lead in the soil concurrently. Second, there are several lead and arsenic exposure sources that could contribute to a participant's results independently. For instance, a participant may have been exposed to lead-based paint in their home, but little arsenic from dietary sources. Finally, because lead stays in the body longer than arsenic, the smelter shutdown during the days before ATSDR's testing may have affected arsenic results more than lead results.

Uncertainties and Limitations

All investigations have uncertainties and limitations. This exposure investigation has the following uncertainties and limitations:

- The results of this exposure investigation are applicable only to the individuals tested and cannot be generalized to other individuals or areas.
- The tests results cannot be used to
    - determine the sources of lead or arsenic exposures, or
    - predict the future occurrence of disease in individuals.
- The single blood lead and urinary arsenic tests are snap shots of exposure. They may not accurately represent a participant's past or long term lead and arsenic exposures.
    - Participant urinary arsenic results indicate very recent exposure to arsenic. Arsenic is rapidly metabolized and excreted from the body (e.g., half of the amount of ingested arsenic excreted in a 4 day period is excreted within the first 28 hours) (Orloff et al. 2009). In addition, urinary arsenic levels vary over time (Wang et al. 2016).
    - Participant blood lead results represent recent past exposure to lead. The half life of lead in an adult's blood is about 30 days (ATSDR 2007b).
- The Asarco Hayden Smelter was shut down 11 days before ATSDR began holding its three day blood and urine sample collection event, reducing the amount of lead and aresenic in local air. As a result, in the days before testing, participants were exposed to about seven times less lead and eight times less arsenic in local air as compared with all of 2015 (excluding the shutdown timeframe). Since arsenic is typically excreted from the body within several days of exposure, the lower level of arsenic in air in the days preceding testing, could have reduced the amount of arsenic ATSDR measured in participants' urine. Lead stays in blood for weeks and is stored in bones for years, so lead exposures experienced before the shutdown began were likely still reflected in participants' blood when ATSDR collected samples. As noted in conclusions 1 and 2, younger participants' blood lead levels (age groups 1–5, 6–11, and 12–19 years) were higher than U.S. population comparison age groups, while younger participants' urine arsenic levels (creatinine corrected) (6-11 and 12-19 years old) were not. While various sources likely contribute to participant lead exposures, these findings suggest that the shutdown may have affected urine arsenic levels more so than blood lead levels.

- ATSDR used creatinine corrected urine arsenic results to adjust for variation in urine dilution. Creatinine correction helped ATSDR compare arsenic results between participants. However, participants in this exposure investigation had higher creatinine levels than the comparison U.S. population. The difference in creatinine levels creates some uncertainty when comparing participant creatinine corrected arsenic results with the U.S. population. Participants' creatinine levels may have differed from the comparison NHANES participant population for several reasons.
    - Most exposure investigation participants provided first morning spot urine samples, whereas NHANES samples were random spot urine samples. First morning urine samples are generally more concentrated than other samples throughout the day.
    - Participants live in a hot, arid environment and thus may be less hydrated than the U.S. population.
    - Participants may differ from the U.S. population on certain physiological traits (e.g., body mass) and/or health conditions (e.g., diabetes) that affect creatinine levels.
    - The participant population included more women and Hispanics than the NHANES population. However, women and Mexican Americans typically have lower creatinine levels than than men and other racial/ethnic groups respectively (Barr et al. 2005).
- Comparisons between the adult participant age group and U.S. population adults should be interpreted with caution due to sex and age differences. Adult participants were exclusively women 20–40 years old, while the NHANES comparison age group included both men and women 20 years old and older.
- Children less than 6 years of age were not evaluated for arsenic in urine because there are no national values for comparison.
- ATSDR did not present separate summary exposure statistics for Hayden participants and Winkelman participants, as further subdividing each age group by town left some age groups with too few participants to draw conclusions.
- Due to the small number of participants in the 12–19 and 20–40 year old age groups (n = 17 and 12, respectively), the percentile bootstrap method ATSDR used may have produced narrow 95 percent confidence intervals for lead and arsenic median and 95th percentile levels for these age groups.

Conclusions

ATSDR has three main conclusions from this exposure investigation.

Conclusion 1
Some children in Hayden and Winkelman have been exposed to lead at levels that could harm their health.

Basis for Conclusion 1
Two children exceeded the exposure investigation blood lead follow-up level (5 µg/dL) (one in the 1–5 year age group and one in the 6–11 year age group) (Figures 2, 3, and 4). In addition, two children in the 1–5 year age group had BLLs between 4 and 5 µg/dL. ATSDR's exposure investigation blood lead follow-up level is based on the CDC's current reference level.

Conclusion 2
Overall, children and adolescent participants had more lead in their bodies than children and adolescents from across the United States.

Basis for conclusion 2
The median blood lead levels for children and adolescent participant age groups (1–5, 6–11, and 12–19 years) were about two times higher than U.S. population medians for those age groups (Table 3). No safe blood lead level in children has been identified.

Conclusion 3
ATSDR needs more information to determine how much arsenic participants' have in their bodies when air pollution levels are typical for the community. Asarco shut down the smelter for maintenance during the time of ATSDR's testing, reducing lead and arsenic levels in the air.

Basis for conclusion 3
In the days before ATSDR collected blood and urine samples, Asarco shut down the smelter for maintenance. As a result, participants were exposed to about eight times less arsenic and seven times less lead in the air than other times in 2015 (Table 7, Figure 9, and Appendix B). Since arsenic is typically excreted from the body within several days of exposure, the lower level of arsenic in air in the days before testing could have reduced the amount of arsenic ATSDR measured in participants' urine. Since lead stays in blood longer than arsenic stays in urine, the shutdown should not have had a significant effect on lead results.

No participant had a total urinary arsenic result (creatinine corrected) that exceeded the exposure investigation follow-up level (Figures 5 and 6). Median total and inorganic arsenic levels (creatinine corrected) were similar to U.S. population age group-specific medians (Table 4).

Recommendations

ATSDR recommends that EPA, ADEQ, Asarco, and the Gila County Health Department take the following steps to protect the health the community.

- Reduce lead and arsenic air emissions at the Asarco Hayden Smelter Plant.
- Continue environmental sampling and clean-up efforts in Hayden and Winkelman.
    - Consider resampling residential soil at a limited number of homes in areas with higher levels of air contamination to address community concerns that soil may have been recontaminated since they were cleaned up.
    - Sample soil for lead at a specific Winkelman home that was not previously sampled to ensure that residential soil exposures did not contribute to a participant's elevated blood lead level.
- Incorporate ATSDR's exposure investigation results in human health risk assessments, as appropriate.
- Develop and implement a lead-based paint testing and abatement project for homes, schools, and other public buildings, as outlined in the 2015 EPA/Asarco settlement (EPA 2015d).

ATSDR recommends that exposure investigation participants participate in a second round of arsenic testing. ATSDR intends to offer this testing when the smelter is operating normally.

ATSDR recommends that Hayden and Winkelman residents take the following steps to reduce their exposure to lead and arsenic.

- Participate in the home lead-based paint testing and abatement project Asarco will develop and fund as part of the 2015 EPA/Asarco settlement. Contact Amy Veek at Asarco (520-356-3296, aveek@asarco.com) for information about the status of this project.
- Take the steps listed in the summary factsheet (Appendix D) to reduce your exposure to lead and arsenic.

ATSDR recommends that parents/guardians of the two children whose blood lead results were above the follow-up level discuss the child's result with their primary health care provider. ATSDR further recommends that health care providers follow the Advisory Committee for Childhood Lead Poisoning Prevention's recommendations for management of children with blood lead levels above the CDC reference level (ACCLPP 2012).

Public Health Action Plan

The purpose of the Asarco Hayden exposure investigation was to to better understand residents' blood lead and urinary arsenic levels and provide a plan of action designed to prevent or mitigate adverse human health effects from exposures. The following public health action plan notes completed, proposed, and potential ATSDR and ADHS public health activities.

Completed actions

- Followed up with participants
    - In June 2015, ATSDR sent each participant a letter with their blood lead and urine arsenic results. ATSDR included a fact sheet on ways to reduce exposure to lead and arsenic with each letter.
    - In June 2015, ATSDR contacted the parents/guardians of participants with elevated lead results by phone to discuss their child's results and recommend steps to take to protect the child's health.
    - In 2015, ADHS sent additional materials with recommendations for preventing lead exposures to participants with elevated blood lead levels.
    - In 2016, ATSDR attempted to contact the parents/guardians of the four participants with results above or approaching the exposure investigation follow-up level again by phone. However, because ATSDR was not able to reach the participants by phone, an ATSDR representative visited the three homes of these participants in November 2016. Two of the homes are no longer occupied by participant families. The family of two of these participants had indicated in 2015 their intention to move away from the community. That home is now occupied by another family. Another participant home was vacant. At the third home, ATSDR learned that one child would soon receive a follow-up blood lead test. ATSDR also learned that the child from the now vacant home had received a follow-up test that was "okay," though ATSDR did not learn the test result.
- Supported the Gila County Health Department in initial preparations for a lead-based paint testing and abatement project in Hayden and Winkelman. Under the 2015 EPA/Asarco settlement Asarco agreed to develop a lead-based paint abatement project plan and provide funding to the Gila County Health Department to implement the project (EPA 2015d).
    - ATSDR shared participant lead results with the Gila County Health Department to help the county prioritize its outreach efforts (after entering into a data sharing agreement).
    - ATSDR advised the county on community outreach and recruitment strategies based on lessons learned during the exposure investigation.
    - ADHS provided the county with information on Hayden and Winkelman lead test results that have been reported to the state.

    - ADHS connected Gila County with an established residential lead testing and abatement program in another Arizona community, so Gila County could learn from their experience.

Future, proposed, and potential actions

- ATSDR will hold a public meeting in Hayden or Winkelman to present the results of the exposure investigation, explain steps community members can take to limit their exposure to lead and arsenic, and answer questions.
- ATSDR plans to offer a second round of arsenic testing for exposure investigation participants. ATSDR intends to conduct the testing at a time when the smelter is operating normally.
- ATSDR will continue to support the development and implementation of the Hayden and Winkelman lead-based paint testing and abatement project outlined in the 2015 EPA/Asarco settlement.
- Upon request, ATSDR is available to organize trainings for local health care providers on testing for lead and arsenic exposure, interpreting results, and reducing exposures.

Figure 1: Asarco Hayden Smelter Site Map and Community Demographics

Asarco Hayden Smelter Site

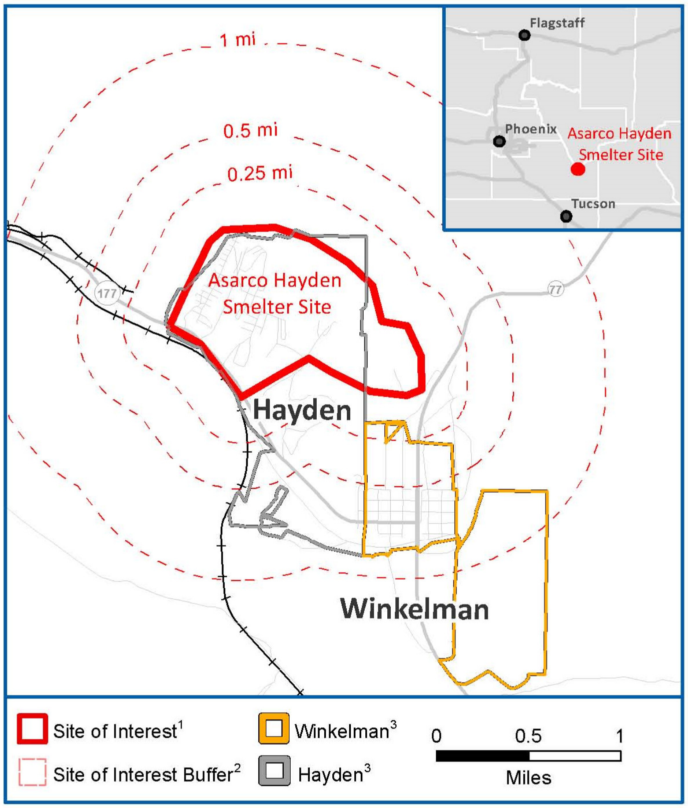
Hayden & Winkelman, Arizona

GENERAL SITE PROFILE

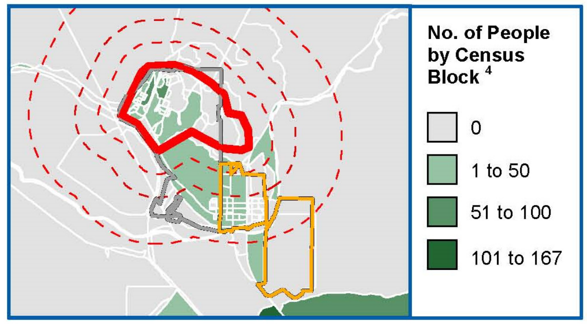
EPA FACILITY ID AZD008397127

INTRODUCTORY MAP SERIES

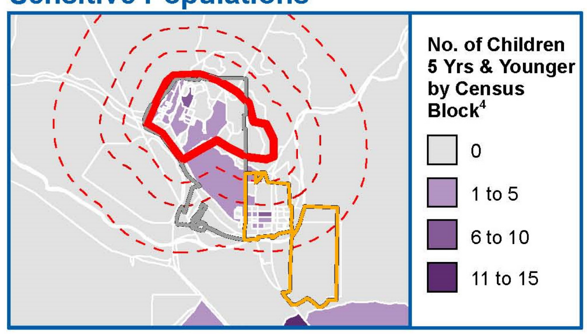
Site Vicinity Map

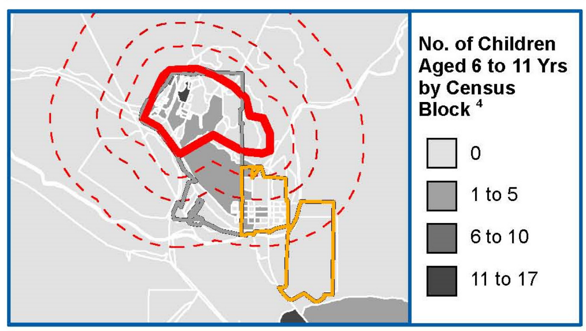


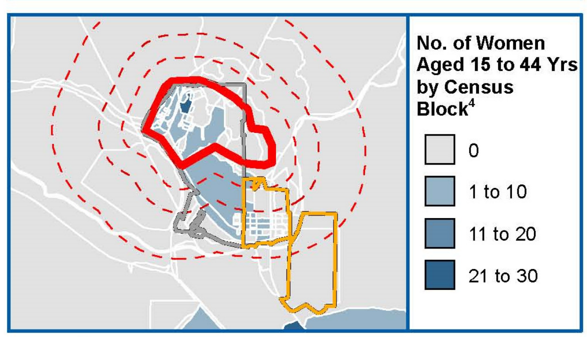
General Population



Sensitive Populations







Demographic Statistics[4,5]

Measure	Total Population	Children 0 to 5	Children 6 to 11	Women 15 to 44	Pregnant Women[6]	Total Hispanic
Hayden[4]	662	50	53	115	2	559
Winkelman[4]	353	24	20	58	1	291
Hayden and Winkelman[4]	1015	74	73	173	3	850
Within Site Boundary[5]	630	47	52	111	2	531
Within 0.25 mi. of Site[5]	664	50	55	116	2	556
Within 0.5 mi. of Site[5]	724	54	59	124	2	606
Within 1 mi. of Site[5]	1041	76	76	177	2	867

Data Sources: [1]ATSDR GRASP Hazardous Waste Site Boundary Database (2011). [2]ATSDR GRASP. [3]TomTom International BV (2012). [4]US Census 2010. **Notes:** [5]Calculated using area-proportion spatial analysis method. [6]Represents an estimation with potential errors due to rounding.

Projection: Projection for all map panels: NAD 1983 StatePlane Arizona East FIPS 0201 Feet.

PRJ 04451 YCK9 5/2/2014

GRASP

Agency for Toxic Substances and Disease Registry

Division of Toxicology and Human Health Sciences

ATSDR

Figure 2. Asarco Hayden Exposure Investigation participant blood lead levels by participant age

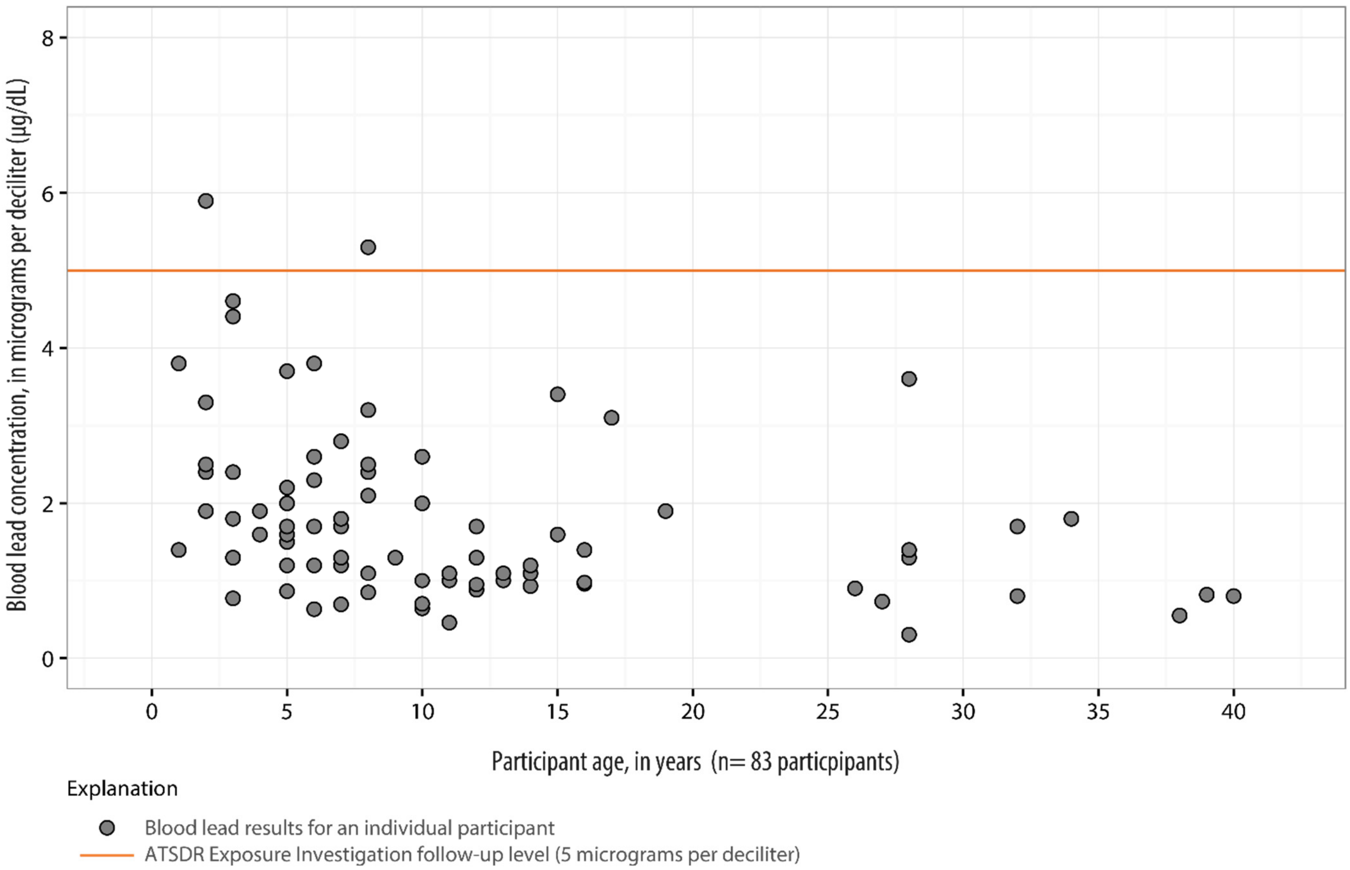


Figure 3. Asarco Hayden Exposure Investigation participant blood lead levels by household

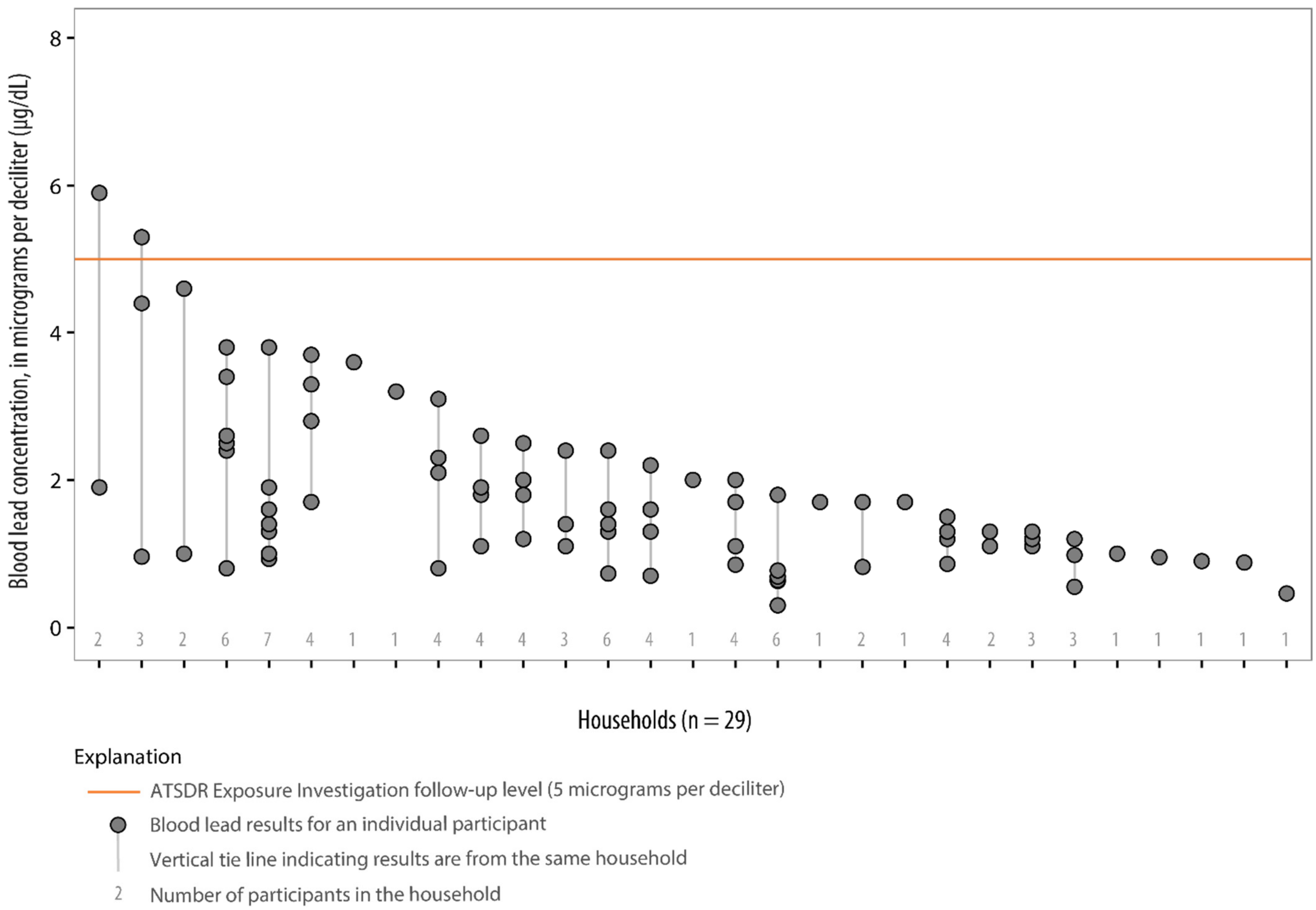
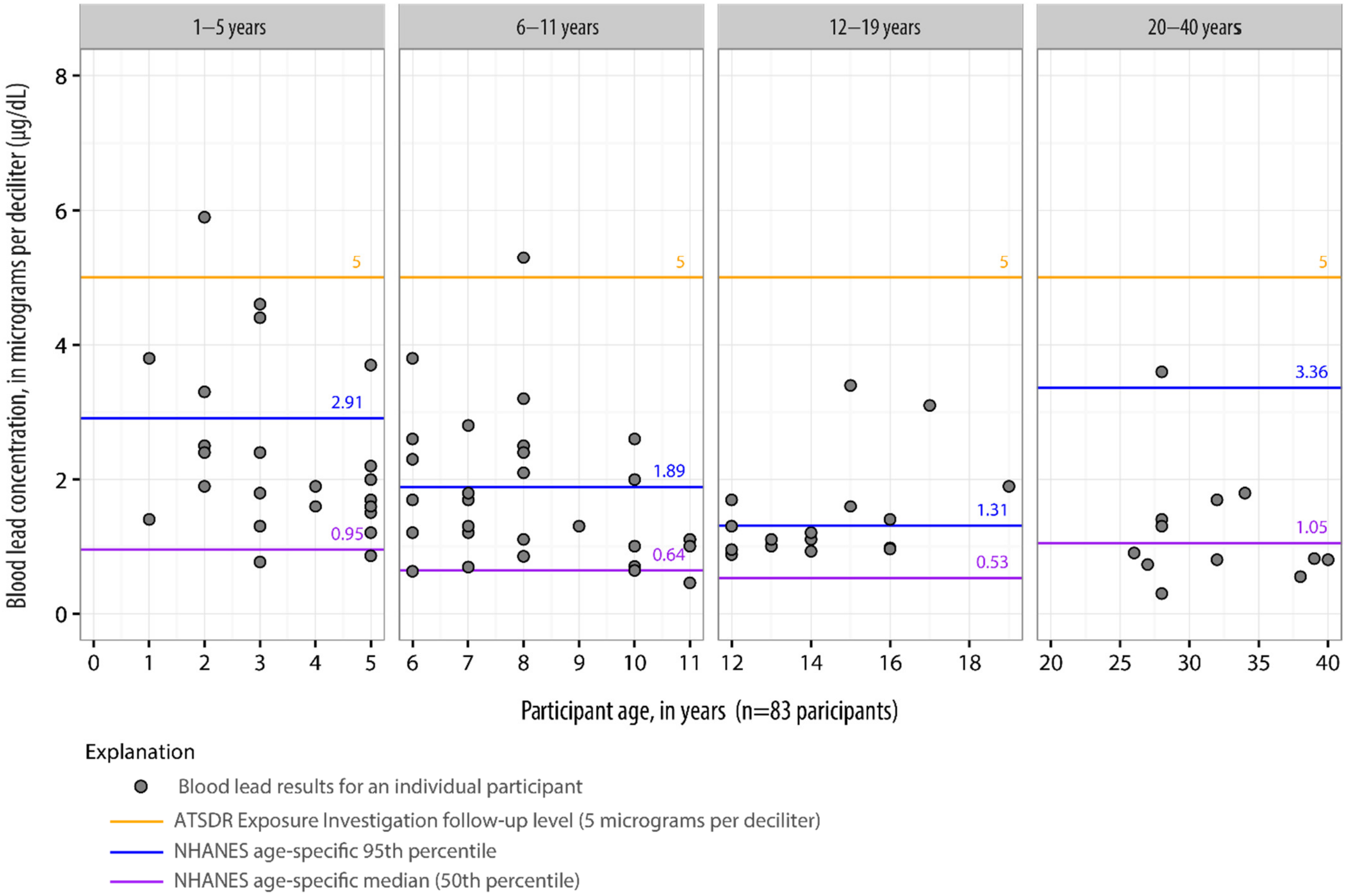


Figure 4: Participant blood lead levels compared to U.S. population 2011–12 median and 95th percentile levels and the exposure investigation follow-up level



The median and 95th percentile reference levels are from the National Health and Nutrition Examination Survey (NHANES) conducted during 2011–2012 and summarized in the Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables (CDC 2015).

Note: Comparisons between the adult participant age group (women 20 – 40 years old) and NHANES adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.

Figure 5: Participant urinary total arsenic (creatinine corrected) results by household

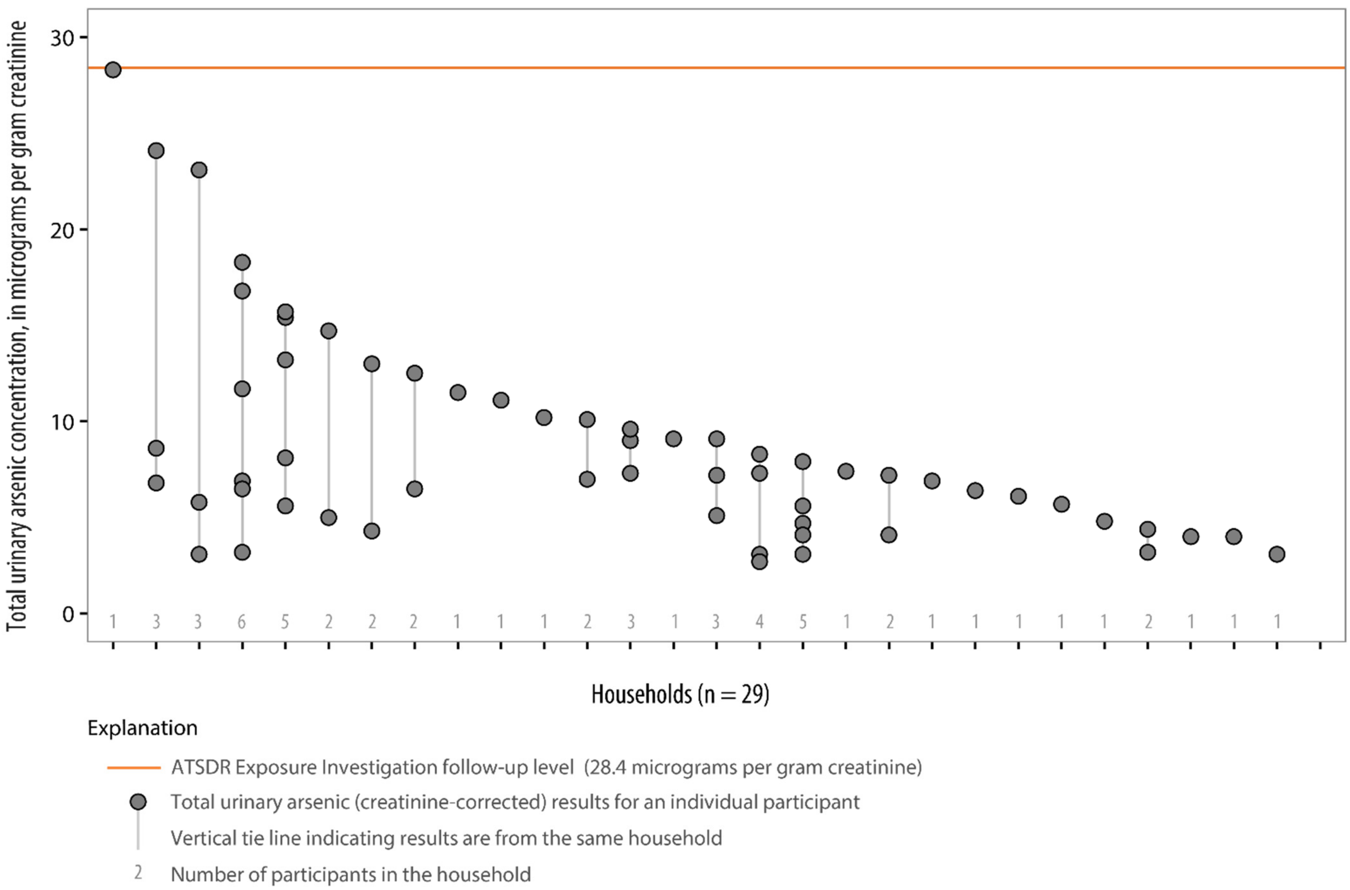
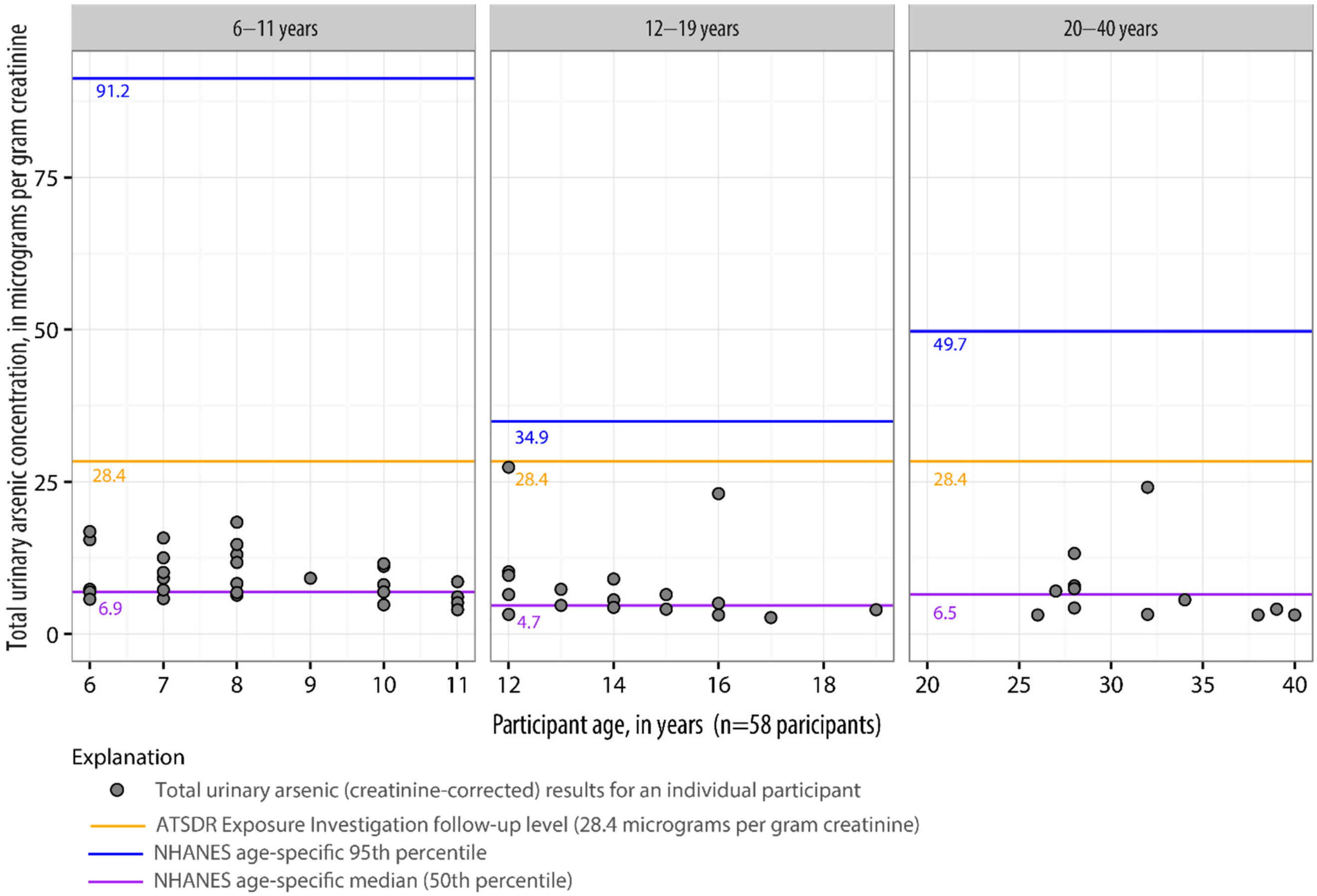


Figure 6: Participant urinary total arsenic levels (creatinine corrected) by age group compared to 2011–12 U.S. population median and 95th percentile levels and the exposure investigation follow-up level

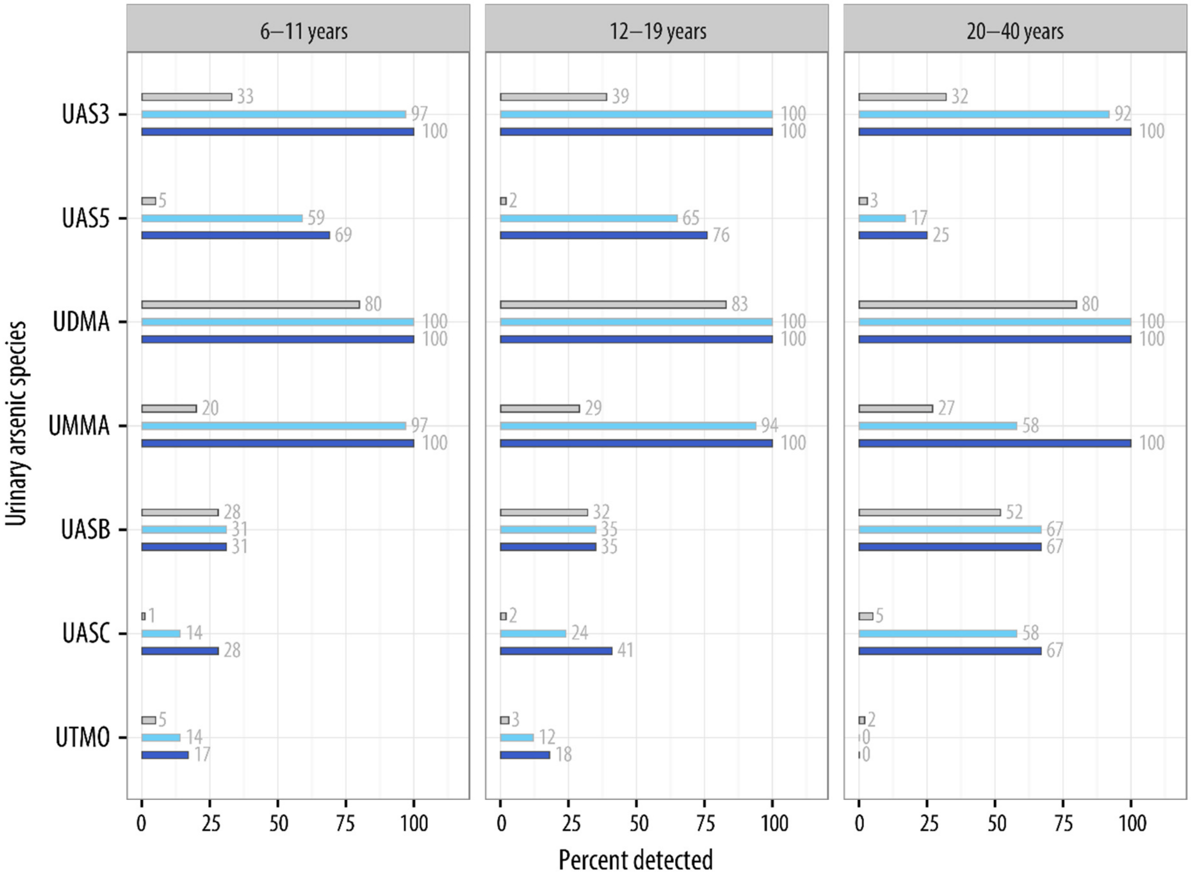


The median and 95th percentile reference levels are from the National Health and Nutrition Examination Survey (NHANES) conducted during 2011–2012 and summarized in the Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables (CDC 2015).

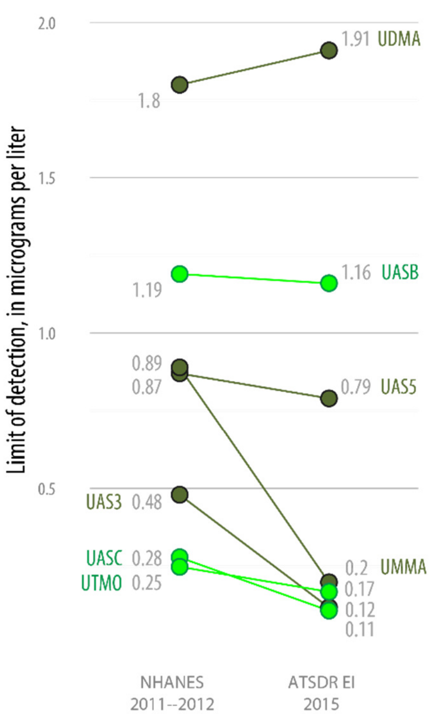
Note: Comparisons between the adult participant age group (women 20–40 years old) and NHANES adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.

Figure 7: Percentage of detected results and limits of detection for each arsenic species among exposure investigation participants and the U.S. population

A. Percentage of detected results



B. Limits of detection



Explanation

- National Health and Nutrition Examination Survey (NHANES) 2011–2012 (CDC 2015)
- ATSDR Exposure Investigation (EI) results adjusted using NHANES 2011–2012 detection limit values for each species. EI results below the NHANES 2011–2012 detection limit are considered nondetects.
- ATSDR Exposure Investigation results with current (2015) detection limits
- Inorganic species
- Organic species

Note: Comparisons between the adult participant age group (women 20 – 40 years old) and NHANES adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.

Abbreviations: UAS3, urinary arsenous (III) acid
UAS5, urinary arsenic (V) acid
UDMA, urinary dimethylarsinic acid
UMMA, urinary monomethylarsonic acid
UASB, urinary arsenobetaine
UASC, urinary arsenocholine
UTMO, urinary trimethylarsine oxide

Figure 8: Correlation of participant blood lead and urine arsenic (creatinine corrected) levels

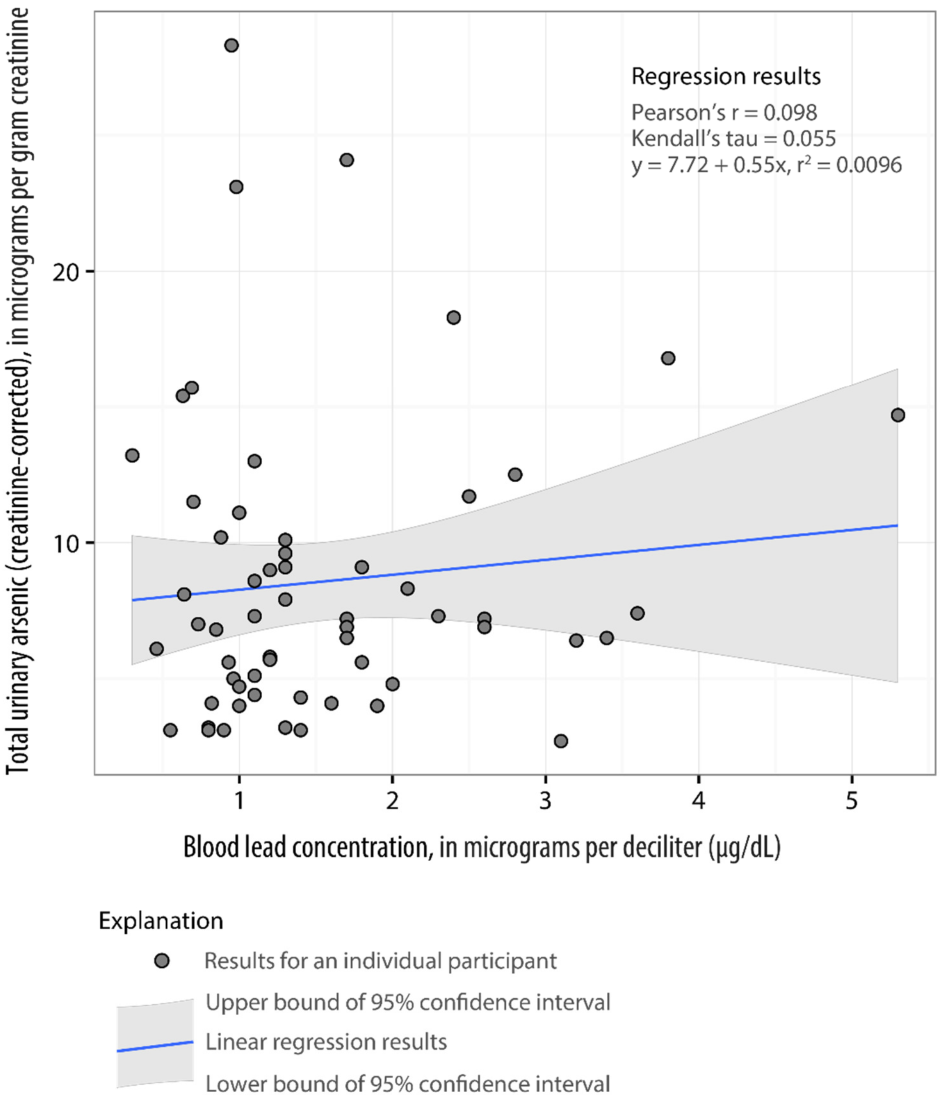
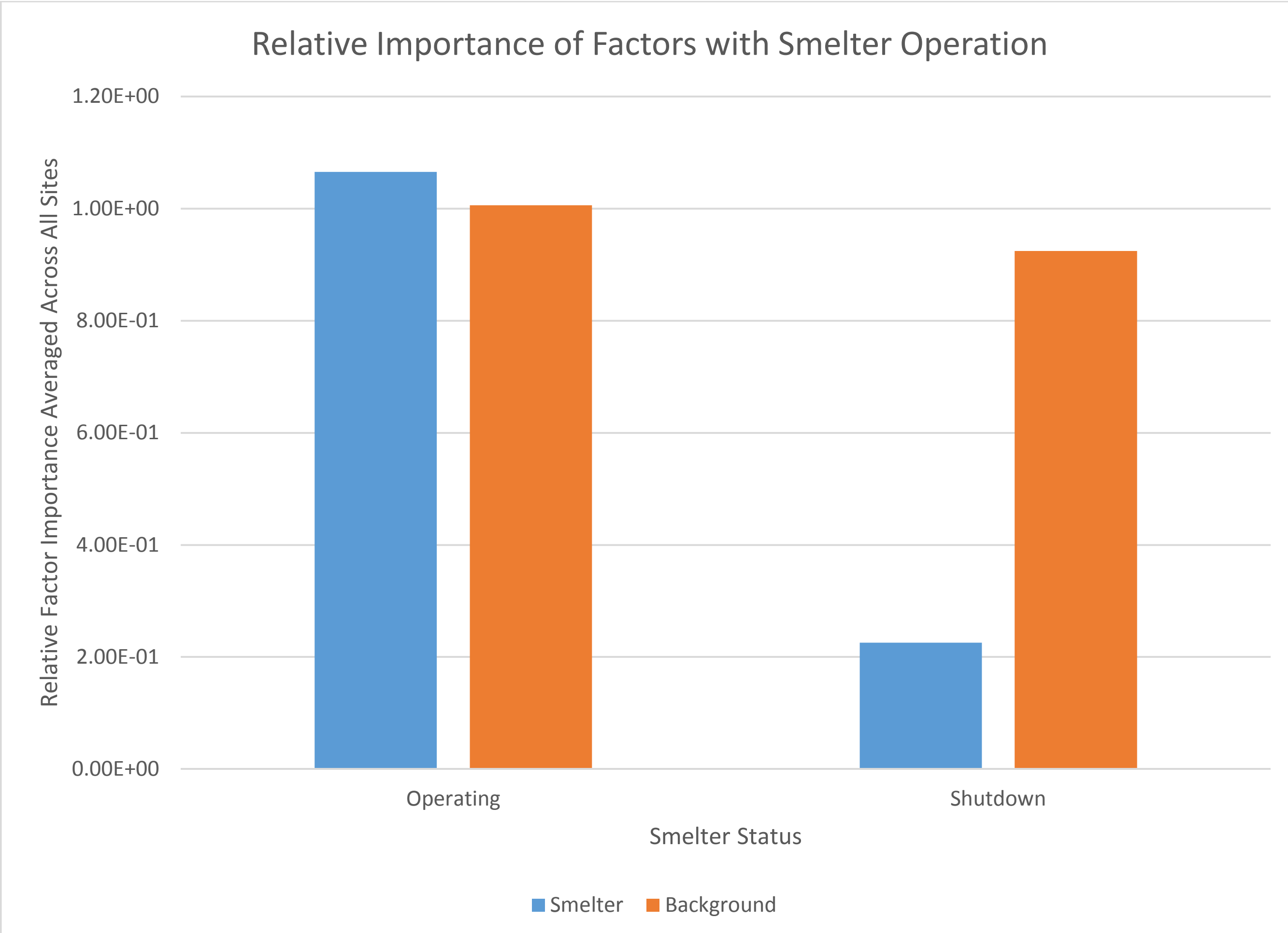


Figure 9: Relative contribution of smelter and background sources to 2013–15 air contamination levels at Hayden and Winkelman monitoring stations when the smelter was operating and shut down



Notes: Relative factors calculated using the EPA Positive Factorization Model (PMF) (EPA 2015e). The smelter was shut down April 6–May 21, 2015. Shutdown period estimates are based on data collected April 6–May 18, 2015. Air samples were not collected daily. Source: EPA air monitoring data (unpublished). Appendix B provides more detailed results from the PMF model.

Table 1: Federal and state agency roles for the Asarco Hayden Exposure Investigation

Activity	Agency*	Agency Roles
Developed exposure investigation protocol	ATSDR	Wrote the protocol, which included sampling and analysis plan, fact sheets, questionnaire, consent/ assent/permission forms, and results reporting plans
Communicated with community officials and organizations	ATSDR, ADHS, EPA, ADEQ	Conducted multiple conference calls, telephone calls, in-person meetings, and email briefings with local organizations about project
Recruited participants	ATSDR, ADHS, EPA, ADEQ	Worked as a team to conduct recruitment activities and schedule appointments
Collected biological samples	ATSDR, ADHS, EPA, ADEQ	Worked as a team to implement blood and urine sample collection from participants
Analyzed blood and urine samples	CDC	Used laboratory methods to analyze biological samples and provide results to ATSDR
Reported results back to participants	ATSDR	Prepared and mailed letters with results to individual participants Called participants with elevated results to discuss blood lead and urine arsenic results
Provided health information to participants with elevated lead results	ADHS	Mailed information about how to reduce lead exposures to participants with elevated lead results
Prepared the summary report	ATSDR	Analyzed data and wrote summary report

*Abbreviations: ATSDR, Agency for Toxic Substances and Disease Registry; ADHS, Arizona Department of Health Services; EPA, Environmental Protection Agency; ADEQ, Arizona Department of Environmental Quality; CDC, U.S. Centers for Disease Control and Prevention.

Table 2. Number of participants by age group, gender, and contaminant tested

Age group	Total		Female n=49 59% of total		Male n=34 41% of total		Number of participants tested for lead		Number of participants tested for arsenic	
Total	83		49		34		83		58	
1–5 yrs	25	*30%*	12	*24%*	13	*38%*	25	*30%*	0	*0%*
6–11 yrs	29	*35%*	19	*39%*	10	*29%*	29	*35%*	29	*50%*
12–19 yrs	17	*20%*	6	*12%*	11	*32%*	17	*20%*	17	*29%*
20–40 yrs	12	*14%*	12	*24%*	0	*0%*	12	*14%*	12	*21%*

* Italicized percentages in the body of the table are based on the totals in row 1 for each column category.

Table 3. Exposure investigation participant and U.S. population (NHANES) blood lead median and 95th percentile levels and confidence intervals

Age group	Number of participants		Blood lead level (BLL) and 95% confidence intervals, in micrograms per deciliter (µg/dL)			
			50th percentile (median)		95th percentile	
	ATSDR EI	NHANES	ATSDR EI	NHANES	ATSDR EI	NHANES
1–5 yrs	25	713	1.90* (1.45–2.28)	0.95 (0.87–1.04)	4.56 (3.06–5.95)	2.91 (2.41–3.83)
6–11 yrs	29	1,048	1.30 (0.51–1.74)	0.64 (0.60–0.70)	3.56 (1.9–5.09)	1.89 (1.36–2.94)
12–19 yrs	17	1,129	1.20* (0.92–1.47)	0.53 (0.49–0.57)	3.16* (2.31–4.83)	1.31 (1.16–1.65)
20–40 yrs†	12	5,030	0.86 (0.26–1.19)	1.05 (1.00–1.12)	2.61 (1.2–4.15)	3.36 (2.98–3.93)

* This value and the corresponding U.S. population (NHANES) value are statistically different.
† Comparisons between the adult participant age group (women 20–40 years old) and NHANES adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.
Confidence intervals calculated using percentile bootstrap methods, n=2,000.
Abbreviations: BLL, blood lead level; ATSDR, Agency for Toxic Substances and Disease Registry; EI, Exposure Investigation; NHANES, National Health and Nutrition Examination Survey (2011–12 data) (CDC 2015).

Table 4: Exposure investigation participant and U.S. population (NHANES) total urinary arsenic (creatinine corrected) median and 95th percentile levels and confidence intervals

Age group	Number of participants		Urinary total arsenic and 95% confidence intervals (µg/g creatinine)			
			50th percentile (median)		95th percentile	
	ATSDR EI	NHANES	ATSDR EI	NHANES	ATSDR EI	NHANES
6–11 yrs	29	401	8.3 (6.28–10.24)	6.87 (5.84–8.00)	16.36* (14.03–19.00)	91.2 (26.2–129.0)
12–19 yrs	17	392	5.6 (3.16–7.67)	4.69 (3.70–5.73)	24.14 (14.19–41.86)	34.9 (21.1–159.0)
20–40 yrs†	12	1,723	4.95 (1.75–7.4)	6.52 (5.88–7.69)	18.1* (8.63–30.85)	49.7 (38.2–70.1)

*This value and the corresponding U.S. population (NHANES) value are statistically different.
† Comparisons between the adult participant age group (women 20–40 years old) and NHANES adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.
Confidence intervals calculated using percentile bootstrap methods, n=2,000.
Abbreviations: ATSDR, Agency for Toxic Substances and Disease Registry; EI, Exposure Investigation; NHANES, National Health and Nutrition Examination Survey (2011–12 data) (CDC 2015).

Table 5: Arsenic levels (creatinine corrected and uncorrected) for Asarco Hayden Exposure Investigation participants with urinary creatinine above 300 mg/dL (n = 4) compared with the investigation follow-up level and U.S. population (NHANES) age specific 90th percentile

	Participant results			U.S. population based comparison levels		
Participant ethnicity, gender and age group	Creatinine (mg/dL)	Total arsenic, corrected (µg/g creat)	Total arsenic, uncorrected (µg/L)	Investigation follow-up level* total arsenic, corrected (µg/g creat)	2009-10 NHANES age specific, uncorrected total arsenic 90th percentile (µg/L)	2011-12 NHANES age specific, uncorrected total arsenic 90th percentile (µg/L)
Hispanic Female Age 20–40	313.9	4.1	13.0	28.4	52.1	33.2
Hispanic Male Age 12–19	390.0	3.1	12.0	28.4	25.9	25.9
Hispanic Male Age 12–19	413.0	2.7	11.0	28.4	25.9	25.9
Hispanic Male Age 12–19	419.3	4.1	17.0	28.4	25.9	25.9

* ATSDR compared individual total urinary arsenic results (creatinine corrected) to the exposure investigation follow-up level of 28.4 µg/g creatinine. The arsenic exposure investigation follow-up level was the lowest 95th percentile level for any age group in the 2009–10 NHANES (the 12–19 year age group). ATSDR chose this level as a conservative screening value to identify participants with a potentially elevated urinary arsenic level.

Table 6: Exposure investigation participant and U.S. population (NHANES) urinary inorganic-related arsenic species 50th percentile (median) and 95th percentile levels and confidence intervals (creatinine corrected)

Age Group*	Number of participants		Urinary inorganic-related arsenic species and 95% confidence intervals (µg/g creatinine)			
			50th percentile (median)		95th percentile	
	ATSDR EI	NHANES	ATSDR EI	NHANES	ATSDR EI	NHANES
6–11 yrs	29	401	8.9 (6.86–11.0)	7.33 (6.95–8.26)	15.52 (12.58–18.9)	20.2 (16.8–22.3)
12–19 yrs	17	392	5.5 (2.98–7.26)	4.76 (4.40–5.11)	10.86 (2.53–17.09)	16.8 (11.4–28.7)

* ATSDR does not report inorganic-related arsenic species summary statistics for adult participants because 75% of adult participants had levels of arsenic (V) acid (one type of inorganic arsenic), below the lab's level of detection.
Participant inorganic-related arsenic species levels calculated using methods outlined in the CDC
Confidence intervals calculated using percentile bootstrap methods, n=2,000.
Abbreviations: ATSDR, Agency for Toxic Substances and Disease Registry; EI, Exposure Investigation; NHANES, National Health and Nutrition Examination Survey (2011–12 data) (CDC 2015).
National Report on Human Exposure to Environmental Chemicals February 2015 Updated Tables (CDC 2015).

Table 7: Average lead and arsenic ambient air concentrations across all Hayden and Winkelman monitoring stations in 2015 and during smelter shutdown

Contaminant	Average ambient air concentrations (µg/m^3)		
	2015 (excluding shutdown)	April 6 – May 21, 2015 Smelter Shutdown*	P-value
Lead	0.114	0.016†	< 0.01
Arsenic	0.059	0.007†	< 0.01

* Shutdown period estimates are based on data collected April 6–May 18, 2015. Air samples were not collected daily.
† The difference between the shutdown timeframe average and 2015 average (excluding shutdown) is statistically significant (p-value < 0.05). P-values calculated using Wilcoxon rank sum test.
Note: EPA air monitoring data (unpublished).

Table 8: Average lead and arsenic ambient air concentrations at each Hayden and Winkelman monitoring station in 2015 and during smelter shutdown

Air Monitor Station	Average ambient air concentration of lead (µg/m³)			Average ambient air concentration of arsenic (µg/m³)		
	2015 (excluding shutdown) *(Number of samples)*	**April 6 – May 21, 2015 Smelter Shutdown*** *(Number of samples)*	**P-value**	**2015 (excluding shutdown)** *(Number of samples)*	**April 6 – May 21, 2015 Smelter Shutdown*** *(Number of samples)*	**P-value**
ST-01	0.066 *(14)*	0.010† *(6)*	< 0.01	0.035 *(14)*	0.006† *(6)*	0.01
ST-02	0.016 *(44)*	0.005† *(16)*	< 0.01	0.006 *(44)*	0.004 *(16)*	0.08
ST-05	0.082 *(44)*	0.020 *(16)*	0.08	0.034 *(44)*	0.007† *(16)*	0.01
ST-08	0.031 *(10)*	0.009† *(6)*	0.02	0.018 *(10)*	0.005† *(6)*	0.04
ST-09	0.056 *(42)*	0.007† *(16)*	< 0.01	0.026 *(42)*	0.006† *(16)*	< 0.01
ST-14	0.490 *(43)*	0.048† *(16)*	< 0.01	0.270 *(43)*	0.016† *(16)*	< 0.01
ST-16	0.092 *(45)*	0.005† *(16)*	< 0.01	0.049 *(45)*	0.003† *(16)*	< 0.01
ST-18	0.065 *(43)*	0.021† *(14)*	< 0.01	0.030 *(43)*	0.010† *(14)*	< 0.01
ST-23	0.086 *(43)*	0.016† *(15)*	< 0.01	0.044 *(43)*	0.006† *(15)*	< 0.01
ST-26	0.063 *(42)*	0.015† *(16)*	< 0.01	0.028 *(42)*	0.007† *(16)*	< 0.01

* Shutdown period estimates are based on data collected April 6–May 18, 2015. Air samples were not collected daily.
† The difference between the shutdown timeframe average and 2015 average (excluding shutdown) is statistically significant (p- value < 0.05). P- values calculated using Wilcoxon rank sum test.
Notes: EPA air monitoring data (unpublished). Appendix A includes a map of air monitoring locations.

Table 9: Exposure investigation participant and U.S. population urinary inorganic-related arsenic species 50th percentile (median) and 95th percentile levels and confidence intervals

Age Group†	Number of participants		Urinary inorganic-related arsenic species and 95% confidence intervals (µg/L)			
			50th percentile (median)		95th percentile	
	ATSDR EI	NHANES	ATSDR EI	NHANES	ATSDR EI	NHANES
6–11 yrs	29	401	11.9* (9.65–15.21)	5.36 (4.50–5.98)	24.88 (21.02–30.79)*	13.4 (11.6–16.2)
12–19 yrs	17	392	10.6* (8.49–12.71)	5.09 (4.24–6.00)	16.74 (15.00–19.61)	15.6 (10.8–23.9)

*This value and the corresponding U.S. population (NHANES) value are statistically different.
† ATSDR does not report inorganic-related arsenic species summary statistics for adult participants because 75% of adult participants had levels of arsenic (V) acid (one type of inorganic arsenic), below the lab's level of detection.
Confidence intervals calculated using bootstrap methods, n=2,000.
Abbreviations: ATSDR, Agency for Toxic Substances and Disease Registry; EI, Exposure Investigation; NHANES, National Health and Nutrition Examination Survey (2011–12 data) (CDC 2015).

Authors

Ben Gerhardstein, MPH
Environmental Health Scientist, Region 9
Division of Community Health Investigations

Bruce C. Tierney, MD
Captain, U.S. Public Health Service
Senior Medical Officer
Data Analysis and Exposure Investigation Team, Science Support Branch
Division of Community Health Investigations

Barbara Anderson, PE, MSEn E
Environmental Health Scientist
Data Analysis and Exposure Investigation Team, Science Support Branch
Division of Community Health Investigations

Jamie Rayman
Health Educator, Region 9
Division of Community Health Investigations

Contributors

James Durant, MSPH, CIH
Science Support Branch, Data Analysis and Exposure Investigation Team
Division of Community Health Investigations

Nina Dutton, MPH
ORISE Research Participant
Geospatial Research, Analysis and Ser ices Program
Division of Toxicology and Human Health Sciences

Bradley Goodwin, PhD
Lieutenant, U.S. Public Health Service
Science Support Branch, Data Analysis and Exposure Investigation Team
Division of Community Health Investigations

Aaron Grober
Lieutenant, U.S. Public Health Service
Health Service Officer
Science Support Branch, Data Analysis and Exposure Investigation Team
Division of Community Health Investigations

Michael Wellman, MS
Situation Awareness Team
Division of Emergency Operations
Office of Public Health Preparedness and Response (OPHPR)

Efomo Woghiren
Geospatial Research, Analysis and Services Program
Division of Toxicology and Human Health Sciences

Acknowledgements

This exposure investigation was a collaborative effort among federal, state, and local organizations. ATSDR appreciates the assistance and cooperation of the Arizona Department of Health Services, Arizona Department of Environmental Quality, U.S. Environmental Protection Agency, Hayden-Winkelman Unified School District, City of Hayden, City of Winkelman, Central Arizona Governments, Gila County Board of Supervisors, Gila County Health Department, Pinal County Health Department, Pinal County Supervisor Pete Rios, Hayden Senior Center, and St. Joseph's Catholic Church. Finally, ATSDR thanks the Hayden and Winkelman community members who participated in this exposure investigation.

References

[ACCLPP 2012] Advisory Committee on Childhood Lead Poisoning Prevention (ACCLPP) of the Centers for Disease Control and Prevention (2012). Low level lead exposure harms children: a renewed call for primary prevention. Available at http://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf. Last visited September 13, 2016.

[ADHS 2002] Arizona Department of Health Services (2002). Public Health Assessment, Asarco Hayden Smelter Site. Available at http://www.atsdr.cdc.gov/HAC/pha/PHA.asp?docid=905&pg=0. Last visited September 13, 2016.

[ADHS 2016] Arizona Department of Health Services (2016). Report Blood Lead Test Results. Available at http://azdhs.gov/preparedness/epidemiology-disease-control/childhood-lead/index.php#blood-lead-test-results. Last visited September 13, 2016.

Arizona Water Company (2014). Annual Water Quality Report for Winkelman, Arizona, PWSID #04-003. Available at http://azwater.com/files/water-quality/ccr-winkelman-2014.pdf. Last visited September 13, 2016.

Arizona Water Company (2015). Annual Water Quality Report for Winkelman, Arizona, PWSID #04-003. Available at http://azwater.com/files/water-quality/ccr-winkelman-2015.pdf. Last visited September 13, 2016.

[Asarco 2014] Asarco Groupo Mexico, Asarco LLC, Hayden Concentrator (2014). Annual Drinking Water Quality Report for PWS# 04-012. Available at http://www.asarco.com/wp-content/uploads/14rpt-Consumer-Confidence-Report.pdf. Last visited September 13, 2016.

[Asarco 2015a] Asarco Groupo Mexico (2015). Hayden Operations. Available at http://www.asarco.com/about-us/our-locations/hayden-operations/. Last visited September 13, 2016.

[Asarco 2015b] Asarco Groupo Mexico, Asarco LLC, Hayden Concentrator (2015). Annual Drinking Water Quality Report for PWS# 04-012. Available at: http://www.asarco.com/wp-content/uploads/2015-Annual-Drinking-Water-Quality-Report.pdf. Last visited September 13, 2016.

[ATSDR 2007a] Agency for Toxic Substances and Disease Registry (2007). Toxicological Profile for Arsenic. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp2.pdf. Last visited September 13, 2016.

[ATSDR 2007b] Agency for Toxic Substances and Disease Registry. (2007). Toxicological profile for lead (update). Available at http://www.atsdr.cdc.gov/toxprofiles/tp13.pdf. Last visited September 13, 2016.

[ATSDR 2007c] Agency for Toxic Substances and Disease Registry. (2007). Public Health Statement for Arsenic. Available at https://www.atsdr.cdc.gov/phs/phs.asp?id=18&tid=3. Last visited October 5, 2016.

[ATSDR 2015a] Agency for Toxic Substances and Disease Registry (2015). Lead and Arsenic Testing for Hayden and Winkelman Residents Spring 2015. Available at http://www.atsdr.cdc.gov/sites/HWAZ/docs/Hayden%20Testing%20Fact%20Sheet%20Final.pdf . Last visited September 13, 2016.

[ATSDR 2015b] Agency for Toxic Substances and Disease Registry (2015). Asarco Hayden Exposure Investigation. Available at http://www.atsdr.cdc.gov/sites/HWAZ/. Last visited September 13, 2016.

[ATSDR 2015c] Agency for Toxic Substances and Disease Registry (2015). Ways to Reduce Exposure to Lead and Arsenic and Protect Your Health in Hayden and Winkelman, Arizona Available at http://www.atsdr.cdc.gov/sites/HWAZ/docs/Hayden%20Ways%20To%20Reduce%20Exposure%20Final.pdf. Last visited September 13, 2016.

[ATSDR 2015d] Agency for Toxic Substances and Disease Registry (2015). Biological Testing for Exposure to Lead and Arsenic near Colorado Smelter, Pueblo, Colorado. Available at: http://www.atsdr.cdc.gov/HAC/pha/ColoradoSmelter/ColoradoSmelter_%20HC-EI%20(final)_%2009-10-2015_508.pdf. Last visited September 13, 2016.

[ATSDR 2016] Agency for Toxic Substances and Disease Registry (2016). Addendum to the Toxicological Profile for Arsenic. Available at: http://www.atsdr.cdc.gov/toxprofiles/Arsenic_addendum.pdf. Last visited September 13, 2016.

Barbosa F, Tanus-Santos JE, Gerlach RF, Parsons PJ (2005). A critical review of biomarkers used for monitoring human exposure to lead: Advantages, limitations and future needs. Environmental Health Perspective, 113:1669-1674.

Barr DB, Wilder LC, Caudill SP, Gonzalez AJ, Needham LL, Pirkle JL (2005). Urinary Creatinine Concentrations in the U.S. Population: Implications for Urinary Biologic Monitoring Measurements. Environmental Health Perspectives. 113(2): 192–200. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1277864/. Last visited September 13, 2016.

Bernard SM, McGeeing MA, Michael A (2003). Prevalence of Blood Lead Levels greater than 5µg/dL Among U.S. Children 1 to 5 Years of Age and Socioeconomic and Demographic Factors associated with Blood Lead Levels 5 to 10μg/dL, Third National Health and Nutrition Examination Survey, 1988–1994. Pediatrics. 112(6).

Burgess JL, Carter DE, O'Rouke MK (2000). Hayden-Winkelman Arsenic and Lead Survey. Available at: http://s3.documentcloud.org/documents/267080/hayden-winkelman-arsenic-and-lead-survey.pdf. Last visited September 13, 2016.

[Census 2010a] United States Census Bureau. (2010). 2010 Census.

[Census 2010b] United States Census Bureau. (2010). 2006–2010 American Community Survey.

[CDC 2012a] Centers for Disease Control and Prevention (2012). What Do Parents Need to Know to Protect Their Children? Update on Blood Lead Levels in Children. Available at http://www.cdc.gov/nceh/lead/acclpp/blood_lead_levels.htm. Last visited September 13, 2016.

[CDC 2012b] Centers for Disease Control and Prevention (2012). CDC Response to Advisory Committee on Childhood Lead Poisoning Prevention Recommendations in "Low Level Lead Exposure Harms Children: A Renewed Call of Primary Prevention." Available at https://www.cdc.gov/nceh/lead/acclpp/cdc_response_lead_exposure_recs.pdf. Last visited September 13, 2016.

[CDC 2013] Centers for Disease Control and Prevention (2013). Blood Lead Levels in Children Aged 1–5 Years — United States, 1999–2010. Morbidity and Mortality Weekly Report 62(13);245-248.

[CDC 2014a] Centers for Disease Control and Prevention (2014). Laboratory Procedure Manual. Blood Metals Panel. Method DLS 3016.8. Available at http://www.cdc.gov/nchs/data/nhanes/nhanes_13_14/PbCd_H_MET.pdf. Last visited September 13, 2016.

[CDC 2014b] Centers for Disease Control and Prevention (2014). Laboratory Procedure Manual. Urine Multi-Element. Method 3018A.4. Available at http://www.cdc.gov/Nchs/Data/Nhanes/Nhanes_13_14/UM_UMS_UTAS_UTASS_H_MET.pdf. Last visited September 13, 2016.

[CDC 2014c] Centers for Disease Control and Prevention (2014). Laboratory Procedure Manual. Urine Arsenic Speciation. Method DLS 3000.14. Available at http://www.cdc.gov/Nchs/Data/Nhanes/Nhanes_13_14/UAS_UASS_H_MET.pdf. Last visited September 13, 2016.

[CDC 2015] Centers for Disease Control and Prevention. Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables (February, 2015). Atlanta, GA: U.S. Department of

Health and Human Services, Centers for Disease Control and Prevention. http://www.cdc.gov/exposurereport/. Last visited September 13, 2016.

Dixon SL, Gaitens JM, Jacobs DE, Strauss W, Nagaraja J, Pivets T, Wilson JW, Ashley PJ (2009). Exposure of U.S. Children to Residential Dust Lead, 1999–2004: II. The contribution of lead contaminated dust to children's blood lead levels. Environmental Health Perspectives. 117(3):468-474.

[EPA 1996] Environmental Protection Agency (1996). EPA Takes Final Steps in Phase-out of Leaded Gasoline. Press Release. Available at https://archive.epa.gov/epa/aboutepa/epa-takes-final-step-phaseout-leaded-gasoline.html. Last visited September 13, 2016.

[EPA 2008] Environmental Protection Agency (2008). Asarco Hayden Plant. Phase 1 Remedial Investigation Report. Available at http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/3dc283e6c5d6056f88257426007417a2/4c3392df16ad6d4c882574b8006f1dbc!OpenDocument. Last visited September 13, 2016.

[EPA 2012] Environmental Protection Agency (2012). Final Phase II Remedial Investigation/Feasibility Study Work Plan Part 1 or 2 (Air), Appendix B – Sampling and Analysis Plan Ambient Air and Source Characterization, Part 2 – Field Sampling Plan.

[EPA 2013] Environmental Protection Agency (2013). Integrated Science Assessment for Lead. Office of Research and Development, National Center for Environmental Assessment. Research Triangle Park, NC. EPA/600/R-10/075F.

[EPA 2014a] Environmental Protection Agency (2014). Designation of Areas for Air Quality Planning Purposes; State of Arizona; Pinal County and Gila County; Pb. Federal Register Notice: Final Rule. Available at http://www.regulations.gov/document?D=EPA-R09-OAR-2014-0266-0041. Last visited September 13, 2016.

[EPA 2014b] Environmental Protection Agency (2014). Redesignation of the Hayden, Arizona Area to Nonattainment for the Lead (Pb) Standards, August 20, 2014. Available at http://www.epa.gov/region9/air/actions/pdf/az/hayden/epa-r09-oar-2014-0266-factsheet-hayden-nfr-2014-08-20.pdf. Last visited October 5, 2016.

[EPA 2015a] Environmental Protection Agency (2015). Asarco Hayden Plant. Available at http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/ViewByEPAID/AZD008397127. Last visited, September 13, 2016.

[EPA 2015b] Environmental Protection Agency (2015). Residential Soil Removal Action Report, Towns of Hayden and Winkelman, Arizona.

[EPA 2015c] Environmental Protection Agency (2015). Green Book Designations. Available at http://www.epa.gov/airquality/greenbook/define.html. Last visited September 13, 2016.

[EPA 2015d] Environmental Protection Agency (2015). ASARCO LLC Settlement. Available at http://www.epa.gov/enforcement/asarco-llc-settlement. Last updated on November 3, 2015.

[EPA 2015e] Environmental Protection Agency (2015). Positive Matrix Factorization Model for environmental data analyses. Available at https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses. Last updated on August 20, 2015.

[EPA 2016a] Environmental Protection Agency (2016). Lead (2008) Designated Area State/Area/County Report. Available at https://www3.epa.gov/airquality/greenbook/mbcs.html#AZ. Last visited October 5, 2016.

[EPA 2016b] Environmental Protection Agency (2016). Lead and Copper Rule. Available at https://www.epa.gov/dwreginfo/lead-and-copper-rule. Last visited October 5, 2016.

[EPA 2017] Environmental Protection Agency (2017). Superfund Alternative Approach. Available at https://www.epa.gov/enforcement/superfund-alternative-approach. Last updated January 27, 2017.

Haley & Aldrich, Inc. (2014). Ambient Air Quality Network Design Plan Phase II Remedial Investigation/Feasibility Study Asarco Hayden Plant Site Addendum No. 1.

Hinwood AL, Sim MR, de Klerk N, Drummer O, Gerostamoulos J, Bastone EB (2002). Are 24-hour urine samples and creatinine adjustment required for analysis of inorganic arsenic in urine in population studies? Environ Res Section A. 88, 219–224.

Hornung RW and Reed LD (1990). Estimation of average concentration in the presence of nondetectable values. Appl Occup Environ Hyg 5(1):46-51.

Hysong TA, Burgess JL, Garcia MEC, O'Rourke MK (2003). House dust and inorganic urinary arsenic in two Arizona mining towns. J. Expo. Anal. Environ. Epidemiol. 13,211–218.

Jones RL, Homa DM, Meyer PA, Brody DJ, Caldwell KL, Pirkle JL, Brown MJ (2009). Trends in Blood Lead Levels and Blood Lead Testing Among U.S. Children aged 1- 5 Years, 1988-2004. Pediatrics. 123(3).

Krzywinski M and Altman N. (2013) Error Bars. Nature Methods. Vol. 10 No. 10.

Loh MM, Sugeng A, Lothrop N, Klimecki W, Cox M, Wilkinson ST, Lu Z, Beamer PI (2016). Multimedia exposures to arsenic and lead for children near an inactive mine tailings and smelter site. Environ. Res. 146, 331–339

[NIOSH 2015] National Institute for Occupational Safety and Health. Adult Blood Lead Epidemiology and Surveillance (ABLES). (2015). Available at: http://www.cdc.gov/niosh/topics/ables/description.html. Last visited October 19, 2016.

[OEHHA 2014] Office of Environmental Health Hazard Assessment. California Environmental Protection Agency. 2014. Notice of Adoption of Revised Reference Exposure Levels for Benzene. Available at http://oehha.ca.gov/air/crnr/notice-adoption-revised-reference-exposure-levels-benzene. Last visited October 5, 2016.

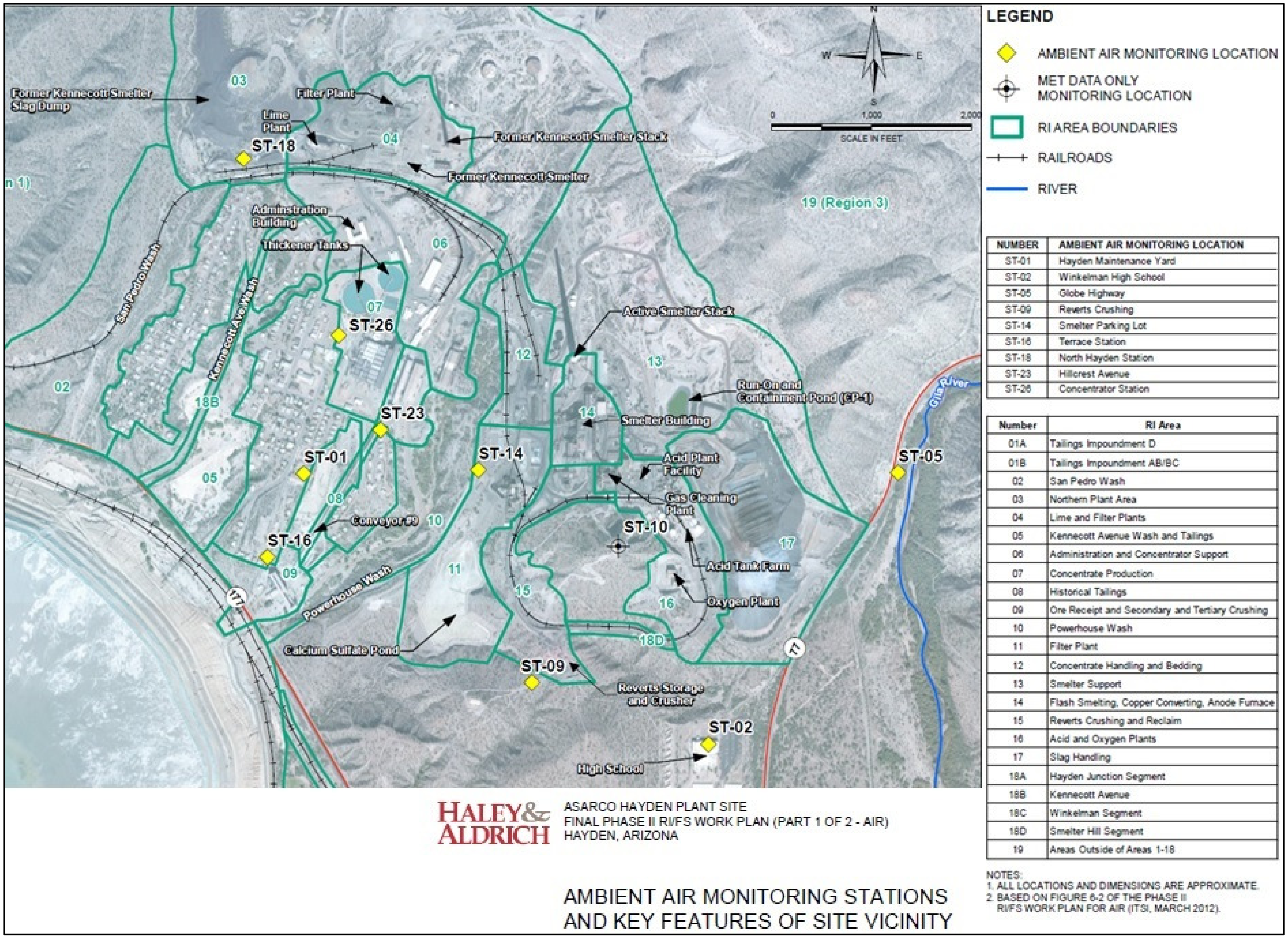
[OEHHA 2016] Office of Environmental Health Hazard Assessment. California Environmental Protection Agency. 2016. Arsenic (inorganic). Available at http://oehha.ca.gov/air/chemicals/arsenic-inorganic. Last visited October 5, 2016.

Orloff K, Mistry K, Metcalf S. (2009). Biomonitoring for Environmental Exposures to Arsenic. Journal of Toxicology and Environmental Health, Part B: Critical Reviews. 12:7, 509-524.

R Core Team. (2015). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. Available at https://www.R-project.org/. Last visited September 13, 2016.

Wang YX, Feng W, Zeng Q, Sun Y, Wang P, You L, Yang P, Huang Z, Yu SL, Lu WQ (2016). Variability of Metal Levels in Spot, First Morning, and 24-Hour Urine Samples over a 3-Month Period in Healthy Adult Chinese Men. Environmental Health Perspectives. 124(4). Available at http://ehp.niehs.nih.gov/1409551/. Last visited September 13, 2016.

Appendix A: Map of ambient air monitoring stations in Hayden and Winkelman, Arizona

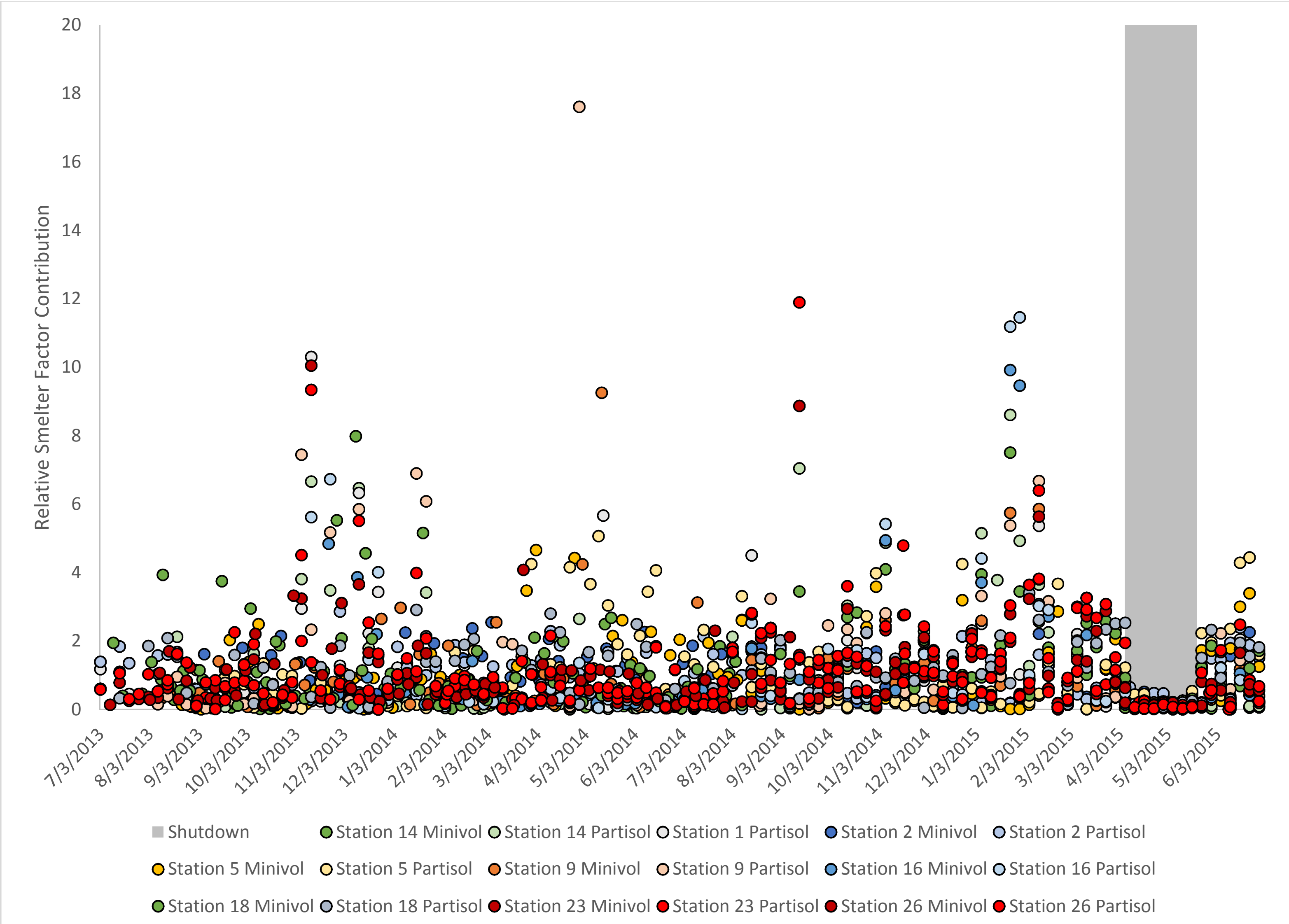


Adapted from Haley & Aldrich (2014).

Note: Air monitor station 8 is not shown on this map.

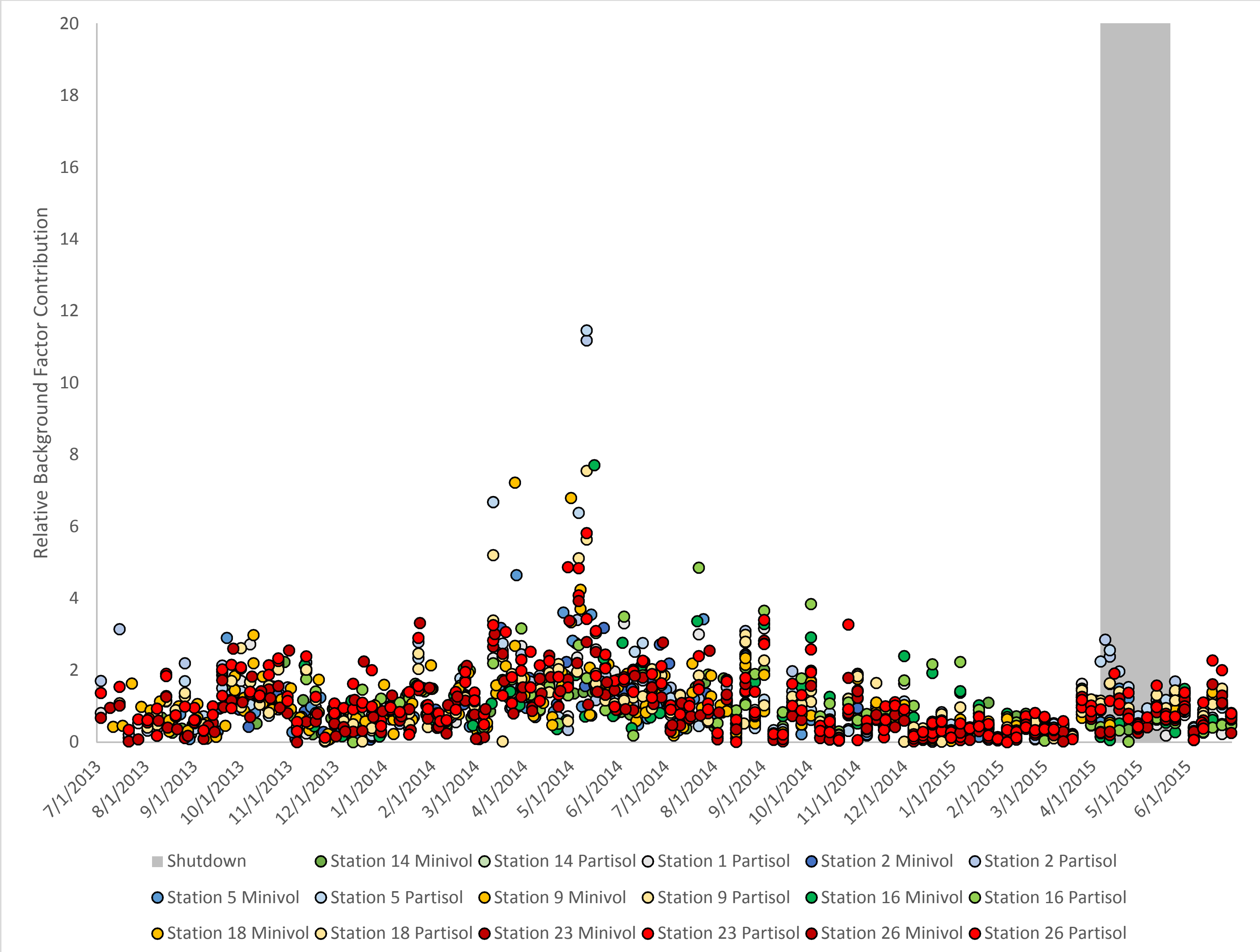
Appendix B: Positive Matrix Factorization Model Results

Figure B.1 Relative contribution of the smelter source to PM_{10} air contaminant levels at each Hayden and Winkelman air monitoring station July 2013–June 2015



Notes: Relative factors calculated using the EPA Positive Factorization Model (EPA 2015e). EPA air monitoring data (unpublished).

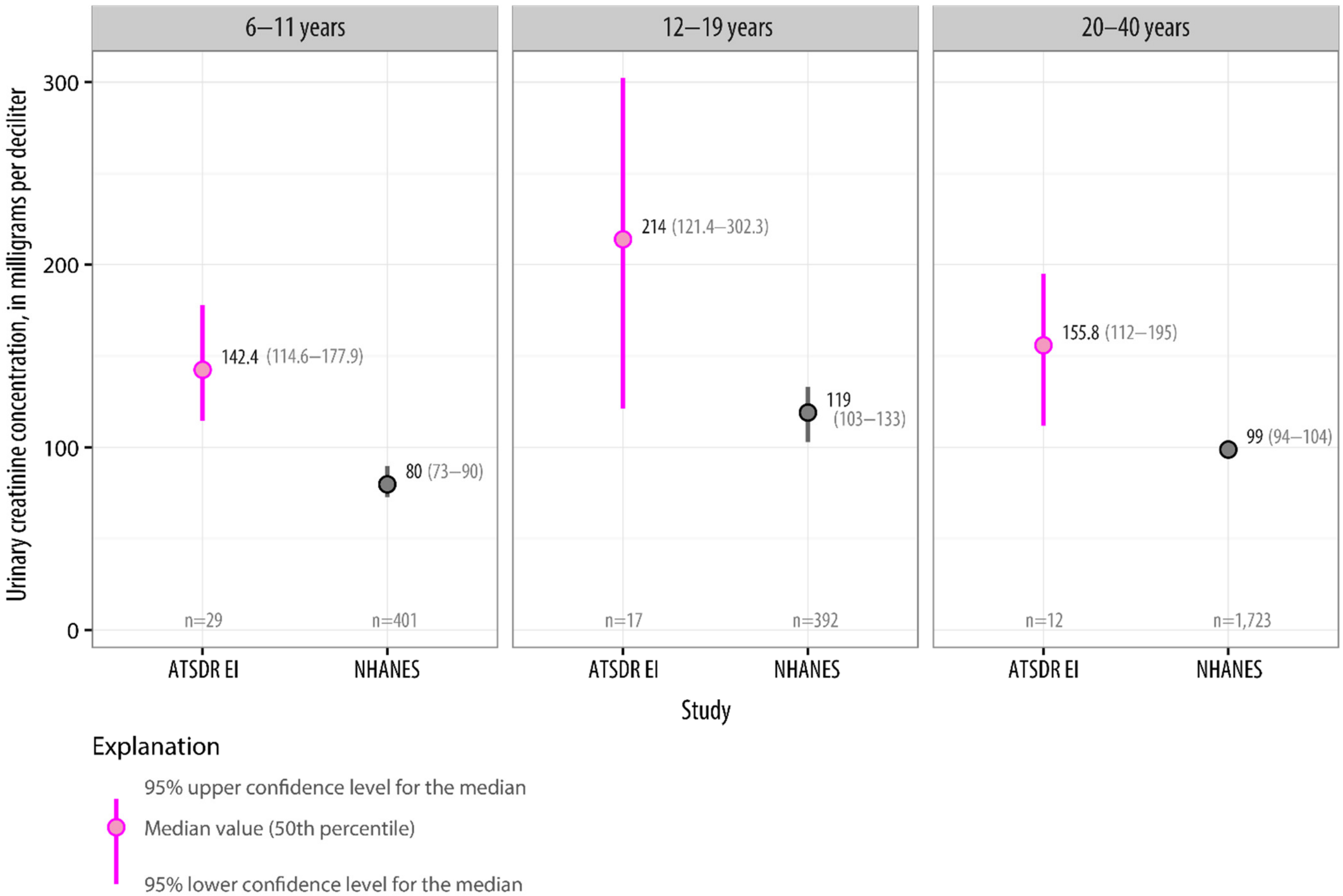
Figure B.2: Relative contribution of background sources to PM_{10} air contaminant levels at each Hayden and Winkelman air monitoring station July 2013–June 2015



Notes: Relative factors calculated using the EPA Positive Factorization Model (EPA 2015e). EPA air monitoring data (unpublished).

Appendix C: Exposure Investigation Participant and U.S. Population Urinary Creatinine Levels

Figure C.1: Comparison of exposure investigation participant and U.S. population (2011–12) median urinary creatinine levels by age group

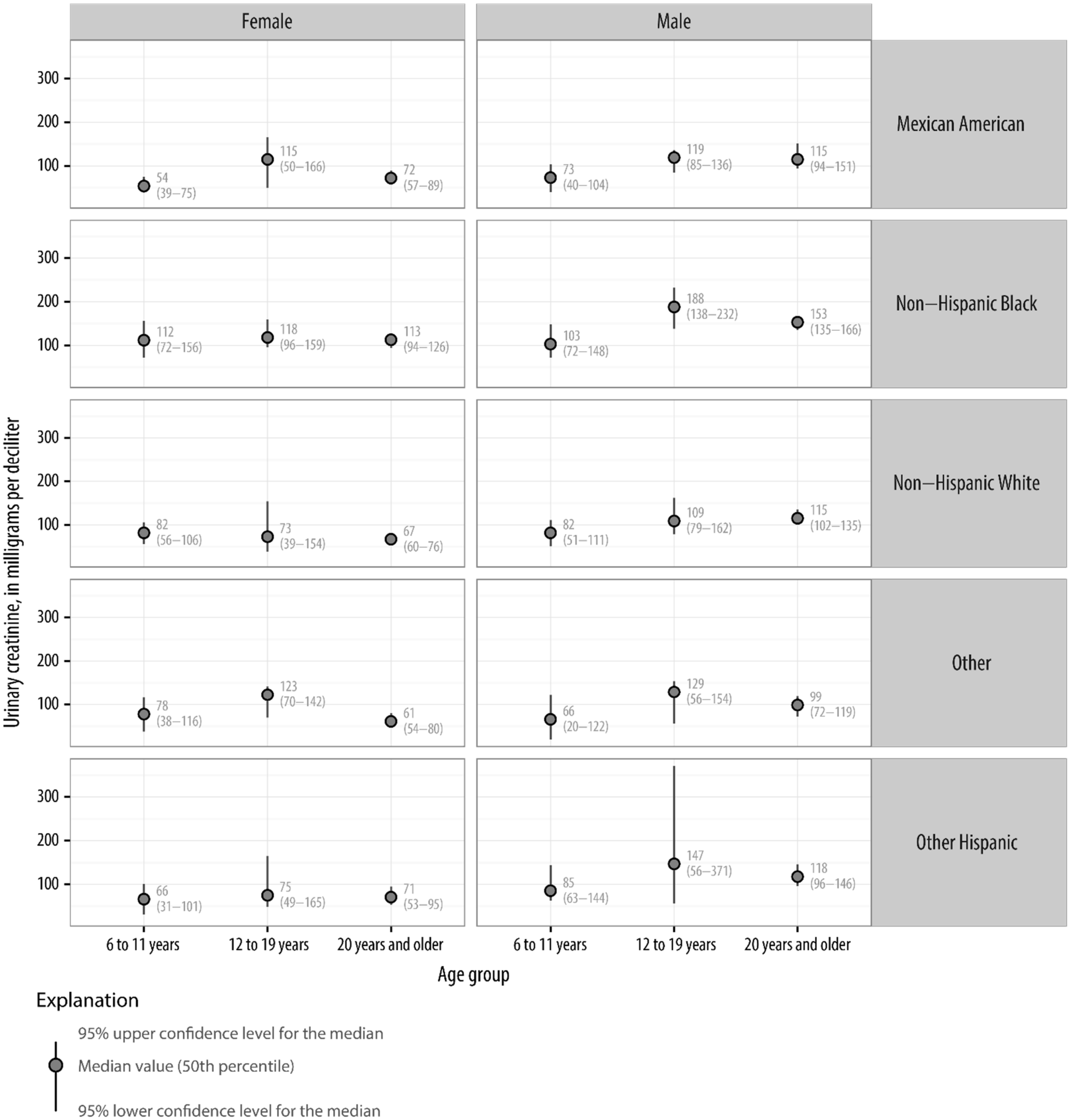


ATSDR EI, Agency for Toxic Substances and Disease Registry Exposure Investigation (2015)

NHANES, National Health and Nutrition Examination Survey (NHANES) 2011–2012 data (CDC 2015).

Note: Comparisons between the adult participant age group (women 20 – 40 years old) and NHANES adults (men and women 20 years and older) should be interpreted with caution due to sex and age differences.

Figure C.2 U.S. population (2011–12) median urinary creatinine levels by age, race, and gender



Data source: NHANES, National Health and Nutrition Examination Survey (NHANES) 2011–2012 data (CDC 2015).

Exposure investigation participant and historical (1988–94) U.S. population creatinine levels

Exposure investigation participant's creatinine levels were also higher than historical U.S. population levels. Median age group specific creatinine levels for the NHANES III (1988-94) U.S. population were 98.1, 150.2, 153.8, and 128.8 mg/dL for the 6–11, 12–19, 20–29, and 30–39 age groups respectively. Median age group specific creatinine levels for the NHANES III (1988-1994) Mexican American population were 88.0; 140.0, 148.9, and 132.4 mg/dL for the 6–11, 12–19, 20–29: and 30–39 age groups respectively (Barr et al. 2005).

Appendix D: Asarco Hayden Exposure Investigation Report Summary

Asarco Hayden Smelter Exposure Investigation

March 2017

A Summary of Findings

Hayden and Winkelman, Arizona

Overview

People in Hayden and Winkelman might be exposed to (come in contact with) unhealthy levels of lead and arsenic in the outdoor air, in mine waste piles, and in soil in some non-residential locations. Additionally, they may be exposed to lead from paint in older housing.

In April 2015, the Agency for Toxic Substances and Disease Registry (ATSDR) worked with federal and state agencies, and local leaders to test people in Hayden and Winkelman for levels of lead and arsenic in their bodies. Residents most at-risk for negative health effects from exposure (children, pregnant women, and women of childbearing age) were eligible for testing. ATSDR sent participants their individual results in June 2015.

This is a summary of the full ATSDR report.

Conclusions
Some children in Hayden and Winkelman have been exposed to lead at levels that could harm their health.
Overall, the children and adolescents ATSDR tested in Hayden and Winkelman had higher levels of lead in their bodies than children and adolescents from across the U.S.
ATSDR needs more information to determine how much arsenic participants have in their bodies when air pollution levels are typical for the community. Asarco shut down the smelter for maintenance during the time of ATSDR's testing, reducing lead and arsenic levels in the air.

A Note About the Tests

These tests tell us how much lead and arsenic were in a participant's blood and urine at the time of testing. They don't tell us where the lead and arsenic came from. The amount of lead and arsenic in a person's body can change over time.

Background

The Asarco Hayden Smelter Plant Site is in rural Arizona, about 90 miles southeast of Phoenix and 70 miles northeast of Tucson. The site includes the towns of Hayden and Winkelman (population 662 and 353, respectively). Past and current copper smelting and processing caused environmental contamination in these towns. Copper ore has been processed here for over 100 years. Asarco continues to operate a copper concentrator and smelter.

The U.S. Environmental Protection Agency (EPA), Arizona Department of Environmental Quality (ADEQ), and Asarco Grupo Mexico LLC (Asarco) are cleaning up contamination at the site through a Superfund alternative process. Between 2008 and 2014, EPA completed residential soil clean up at 266 Hayden and Winkelman yards and publicly accessible areas. Separate from this process, in 2015 EPA and Asarco announced a legal settlement to resolve Clean Air Act violations at the facility.

ATSDR Exposure Investigation Process

Based on requests from the community, EPA asked ATSDR to provide lead and arsenic testing to Hayden and Winkelman residents. In April 2015, ATSDR offered testing to at-risk residents with support from the Arizona Department of Health Services (ADHS), ADEQ, the Centers for Disease Control and Prevention (CDC), and EPA. ATSDR mailed individual results letters to participants in June 2015 and made follow up phone calls to participants whose blood lead results were higher than the investigation follow up level (see Box 1).

Box 1. Lead Follow Up Level

ATSDR followed up with participants with blood lead levels above 5. CDC uses 5 to identify children with blood lead levels that are higher than most children's levels. The units are micrograms per deciliter of blood, abbreviated µg/dL.

Exposure Investigation Report

What did ATSDR do?

ATSDR offered free, voluntary blood lead and urine arsenic testing to children, pregnant women, and women of childbearing age living in Hayden and Winkelman. These people are most at-risk from exposure because they are growing and developing or may become pregnant. ATSDR tested a total of 83 participants from 29 households. We tested:

- 25 children ages 1 – 5 years for lead;
- 29 children ages 6 – 11 years for lead and arsenic;
- 17 adolescents ages 12 – 19 years for lead and arsenic;
- 12 women ages 20 – 40 years for lead and arsenic.

ATSDR also looked at air monitoring data for Hayden and Winkelman from 2013 and 2015 to learn how a shutdown of the smelter affected air quality at the time of the testing. The air data were collected by Asarco with EPA oversight.

What did ATSDR find?

Lead

Two children had blood lead levels above 5.

- ATSDR found 2 children in Hayden and Winkelman with blood lead levels above the investigation follow up level [(5 micrograms of lead per deciliter of blood (µg/dL)].
- One child was in the age range 1 – 5 and one child was in the age range 6 – 11.
- Two other children had blood lead levels between 4 – 5 µg/dL, near the investigation follow up level.

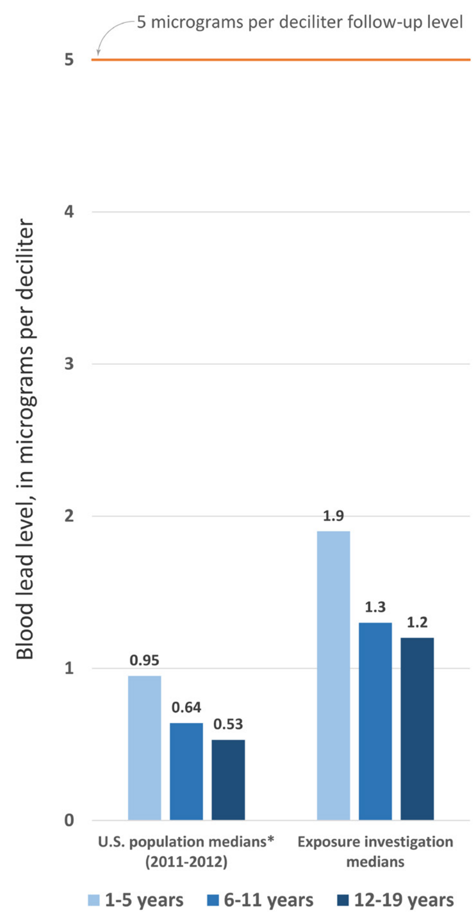
Children's (including adolescents') blood lead levels were above the U.S. median.

- The median blood lead levels by age group for children and adolescent participants were about two times higher than the U.S. population age groups. See Figure 1 and Box 3.

Adult blood lead levels were lower than the U.S. median.

- Median blood lead levels of adult participants (women age 20-40) in Hayden-Winkelman were slightly lower than adults 20 years and older from across the U.S.

Figure 1: Comparison of blood lead levels in children and adolescents in ATSDR's exposure investigation to those in the U.S. population



*Centers for Disease Control and Prevention. Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables, (February, 2015). Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. www.cdc.gov/exposurereport/

Box 2. Lead and Your Health

Lead exposure can cause learning and behavior problems in children and many other health effects. Some of the effects of exposure to lead may never go away. Lead can stay in your body for many years after exposure.

Box 3. What is the median?

The median is the middle value in a list of numbers. In a set of numbers it separates the higher half from the lower half.

Arsenic

ATSDR needs more information to determine participants' urinary arsenic levels when air pollution is typical for the area.

- The smelter was shut down before and during the urine testing, so participant arsenic levels may have been lower than they would be typically.

Urinary arsenic levels for all participants were similar to U.S. population results.

- No participants had urinary arsenic levels above the follow up level (28.4 micrograms of arsenic per gram of creatinine). You can read more about the follow up level ATSDR chose for arsenic in the methods section of the full report.

Box 4. Arsenic and Your Health

Exposure to low levels of arsenic for more than 1 year can cause dark patches of "warts" or "corns" on the skin. Arsenic exposure over many years also raises the risk of cancer of the skin, bladder, lung, and liver. Arsenic stays in your urine for about 3 days after exposure.

Air Quality

Due to the smelter shutdown, outdoor air pollutant levels were lower before and during the testing.

- In 2015, typical outdoor air pollutant levels in Hayden and Winkelman were
  - 7 times higher for lead and
  - 8 times higher for arsenic than during the smelter shutdown.
- The smelter was shut down for maintenance from April 6 – May 21, 2015.
- ATSDR collected participants' blood and urine samples April 17 – 19, 2015.

Box 5. The smelter shutdown and ATSDR's testing results

Since arsenic leaves the body within a few days, the lower level of arsenic in air before testing could have led to less than typical amounts of arsenic in participants' urine during testing. Since lead stays in blood longer, we expect the shutdown did not have much of an effect on lead results.

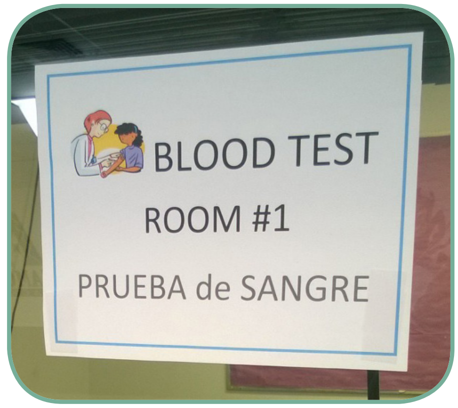
Other possible lead and arsenic sources

- **Housing:** About 44% of the housing units were built before 1950. Prior to 1955 there were no limits on lead in paint. Lead was widely used in house paint until the early 1980s. If paint in older housing is deteriorating, children in those homes are at greater risk for higher blood lead levels.
- **Hayden and Winkelman drinking water systems:**
  - **Arsenic:** Although both systems contain low levels of arsenic, they are below the EPA limits and at typical levels seen in other Arizona public water systems.
  - **Lead:** Both systems are well below EPA's action level for lead. Still, lead can get into drinking water from pipes and fixtures in your home. Homes built before 1986 are more likely to have plumbing with lead.
- **Mexican imports:** Some types of imported Mexican pottery and candies may contain lead.
- **Foods:** Some foods such as rice and seafood contain arsenic.

What can I do if my child has high blood lead levels?

ATSDR recommends that parents/guardians of the two children whose blood lead results were above the follow up level discuss the child's result with their primary health care provider. Follow the tips below to reduce your family's exposure to lead.

ATSDR further recommends that health care providers follow the Advisory Committee for Childhood Lead Poisoning Prevention's recommendations for management of children with blood lead levels above the CDC reference level.



How can my family reduce exposure to lead and arsenic?

Families and people in Hayden and Winkelman can take the following steps to protect their health.

Keep dirt and dust from getting into your body.

Outside

- Don't play in arroyos or on waste piles; stay away from railroad tracks in Hayden; do not trespass.

At Home

- Wipe shoes on a doormat and remove shoes before entering your house.
- Wet-mop or wet-wipe floors, windowsills, counters and hard-surface furniture every 2 – 3 weeks.
- Make sure your child does not chew on surfaces painted with lead-based paint.

Keep things clean

- Wash things children put into their mouths, such as pacifiers, bottles, and toys whenever they fall on the floor or ground.
- Wash your hands and your children's hands before eating and after being outside.
- Wash fruits, vegetables, and root crops (like potatoes) before preparing them to eat.

At work

- If you could be exposed to lead or arsenic in your workplace, change your clothes at work before returning home or immediately after arriving home.
- Wash your work clothes separately from the clothes of other family members.

Pets

- Wash pets that spend time outside and inside your home at least every 2-3 weeks.

Maintain healthy eating habits for your family.

- Give your family healthful meals rich in iron, calcium, zinc, and vitamin C. Children who eat healthy diets absorb less lead.

Participate in the home lead-based paint testing project Asarco will develop and fund as part of their 2015 legal settlement with EPA.

To learn about the status of this project, contact Amy Veek at Asarco (520-356-3296, aveek@asarco.com).

What will happen next?

To make sure the community is safe, ATSDR recommends that EPA, ADEQ, Gila County Health Department, and Asarco:

- Make changes to the smelter to reduce lead and arsenic in outdoor air.
- Continue environmental sampling and cleanup efforts in Hayden and Winkelman.
- Incorporate these exposure investigation results in future human health risk assessments, as appropriate.
- Implement a home lead testing and abatement project for local residents, as outlined in the legal settlement between EPA and Asarco.

ATSDR will also:

- Plan to offer another round of arsenic testing for existing participants at a time when the smelter is expected to be operating normally.
- Continue to support the development and implementation of the Hayden and Winkelman lead-based paint testing and abatement project outlined in the 2015 EPA/Asarco settlement.
- Give information about lead and arsenic testing to local doctors or nurses, upon request.

Where can I learn more?

- Visit the Asarco Hayden exposure investigation webpage. http://www.atsdr.cdc.gov/sites/HWAZ/
- Check out the full report. http://www.atsdr.cdc.gov/HAC/PHA/HCPHA.asp?State=AZ
- Learn more about lead. http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=93&tid=22
- Read about arsenic. http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=19&tid=3

Contacts

ATSDR

Dr. Bruce Tierney, Medical Officer,
btierney@cdc.gov & (770) 488-0771

Ben Gerhardstein, Environmental Health Scientist, bgerhardstein@cdc.gov & (415) 947-4316

Jamie Rayman, Health Educator,
jrayman@cdc.gov & (415) 947-4318

U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry