The Role of Arsenic in the Mining Industry

The purpose of this briefing is to provide a general overview about the occurrences of arsenic, its economic uses, and its environmental and health impacts. SME through this discussion presents information to inform and engage in meaningful dialogue about safety and best practices, including recycling, utilized by the mining industry in extracting sulfur-based minerals that may include arsenic, which is a critical mineral and has numerous industrial uses. Technical references regarding the health and environmental impacts of arsenic are included at the end of this briefing.

Issue

Arsenic is a naturally occurring element commonly found in rocks, soils, water, air, and biological materials, and as an impurity in metallic ores and locally other mineral deposits. Arsenic is classified as a critical mineral and is produced commercially for use in solar panels, space research, telecommunications, pesticides, wood preservatives, and metal alloys[1,2]. However, arsenic can be toxic in large doses, and the mining industry monitors and prevents its release into the environment at modern mining operations[3,4]. Other sources of arsenic in the environment are industrial emissions, forest fires, and volcanic eruptions. The challenge for the mining industry is to obtain enough production of arsenic to meet economic demands and provide a safe environment with zero arsenic emissions.

Background

Arsenic is the 20th most abundant component of the Earth's crust, and is widely distributed in rocks and soils, in natural waters, some mineral deposits, and in small amounts in most living things[5]. It is a metalloid, which means that it can behave as a metal or as a nonmetal[6]. Arsenic does not melt, but sublimes directly into gas at high temperatures and it is a poor conductor. At sufficient dosages, arsenic is toxic. Arsenic is rarely found as a pure metal, but is typically found as a component of sulfur-containing minerals, the most common of which are arsenopyrite and pyrite. Commercially, arsenic is produced as arsenic trioxide or as a pure metal[2,7]. However, these have not been produced in the United States since 1985[2]. Arsenic also can be obtained from copper, gold, and lead smelter flue dust as well as from roasting arsenopyrite, the most abundant arsenic mineral. However, arsenic is generally not recovered from these sources, which are instead disposed of in an environmentally safe manner. Arsenic has been commercially recovered from realgar and orpiment (arsenic sulfide minerals) in China, Peru, and the Philippines, from cobalt-arsenide ores in Morocco, and from copper-gold ores in Chile[2]. Arsenic also can be recovered from enargite, a copper mineral.

Currently, the only recycling of limited quantities of arsenic metal has been from recycling gallium-arsenide semiconductor scrap[2]. Arsenic-containing process water was internally recycled at local wood treatment plants where chromated copper arsenate (CCA) was used[2]. SME supports increased recycling efforts for arsenic.

Arsenic as a critical mineral

Critical minerals in the United States are defined as nonfuel mineral commodities that are essential to the economic or national security of the United States and are from a supply chain that is vulnerable to global and national supply disruptions. The reported world production of arsenic was 61,000 metric tons in 2022[2]. The U.S. imports all of the arsenic used in manufacturing, mostly from China and Morocco[2]. Globally, an estimated 45% of arsenic produced continues to be used to make arsenic-based insecticides and herbicides, and another 29% is used to make CCA wood preservatives widely used in marine applications and timber poles. Canada and the U.S. entered into a voluntary agreement in 2003 to ban the use of CCA in residential applications[3,8]. Electronics and technology account for an estimated 8% of global arsenic consumption. Arsenic is critical in defense applications in telecommunications and light emitting diodes (LEDs). The electronics industry uses arsenic to make gallium-arsenic semiconductors for use in cell phones, solar panels, and aerospace research. Arsenic is used in glassmaking, and to harden metal alloys in car batteries (including those in electric cars), ammunition, solders, and bearings. Arsenic trioxide is obtained as a byproduct from dusts and residues produced during the treatment of other metal ores such as gold and copper. The arsenic trioxide can be purified on site or sold to a refinery. Increases in demand in these industries are expected, requiring additional supplies of arsenic in the future, but the total world resources of arsenic are unknown[2].

Arsenic toxicity

Inorganic arsenic is classified as a known human carcinogen by the International Agency for Research on Cancer. The primary source of arsenic toxicity to the general population is by contaminated water, soil, and food products[9]. Consuming a large amount of arsenic over a lifetime can increase the risk of cancer in internal organs such as the bladder, lungs, and liver[10]. In areas with naturally high levels of arsenic in the groundwater, arsenic poisoning from drinking water is a serious concern[11,12]. Countries with elevated arsenic levels in their groundwater include Bangladesh, Taiwan, Mexico, Chile, China, India, and many others, including certain regions of the United States[11,12,21]. High concentrations of arsenic in lakes and streams also can be lethal to freshwater fish, invertebrates, and plant life[12].

Natural sources of arsenic

Arsenic is released into the environment naturally through the weathering, oxidation and erosion of sulfide and arsenide minerals[5]. These sulfide minerals can form soils with very high concentrations of arsenic, and the arsenic can dissolve in water. An estimated 25% of arsenic emissions into the atmosphere come from natural sources, mostly volcanoes[13]. Arsenic also is released to the atmosphere by petroleum refining, pharmaceutical, glass, and cement manufacturing, pulp and paper production, burning fossil fuels and other industrial activities. The majority of the arsenic released by all sources ends up in the soil

and the ocean[13].

Since valuable metals such as copper and gold also can be found in sulfide mineral deposits, mineral exploration companies will often look for soil and water with a naturally high arsenic content as a means of locating an ore body[14]. It is, therefore, very important to establish baseline or existing arsenic concentrations in the surrounding environment in order to distinguish between mining, mineral processing, and the metallurgical industries; other human contamination (pesticides, fungicides); and natural background levels[15]. The measurement of baseline concentrations of metals in soils and water is usually part of the environmental impact assessment processes practiced in more than 100 countries[16].
The U.S. Public Health Service adopted a 50 ppb standard in 1942. With the passage of the Safe Drinking Water Act in 1975, the Environmental Protection Agency (EPA) adopted the 50 ppb level as an interim regulation. In 2001, the EPA lowered the arsenic levels in drinking water standard to 10 ppb.

Realgar (arsenic sulfide) with pararealgar (yellow), Palomo Mine, Castrovirreyna Province, Huancavelica, Peru (Sample 17631, New Mexico Bureau of Geology and Mineral Resources Mineral Museum).

Human activities that intensify the release of arsenic

A number of human activities have the potential to increase arsenic concentrations in the air, water, and soil on a local scale[4,5]. The rate of arsenic release from sulfide minerals can be accelerated by mining activities, which expose the minerals to weathering processes during excavation[4]. Arsenic oxide dust is produced during copper and gold smelting, and coal combustion. The direct application of arsenic in the form of pesticides, fungicides or wood preservatives has historically been a major source of arsenic in soils, as arsenic is strongly attracted to soil particles and sediments. Freshwaters and associated ecosystems can be impacted by arsenic dissolution in runoff from contaminated sites. In contrast, it is the natural release of arsenic from geologic materials which has threatened drinking water supplies around the world [11].

Arsenic in the mining industry

Atmospheric arsenic emissions from copper smelting represent the largest contribution of arsenic from the mining and metals industry and have been the focus of pollution control technologies and increasingly stringent regulations[4,13]. Arsenic also can be leached out of some metal ores by cyanide or acid rock drainage, but can be captured and removed from wastewater before it is released into the environment[4,17,18].

Locally, arsenic also can be present in coal used to generate electricity[19]. When coal is burned, ash is produced which contains most of the naturally occurring arsenic. More than 99% of the ash is collected and is either sent to specially designed ash ponds or disposal sites, or recycled into commercial products. In the United States, health effects due to exposure to arsenic from coal is rare, but arsenic exposure due to domestic coal use is far more common in countries such as China, India, and South Africa[19].

Like other industries, mining is strictly regulated and monitored by multiple government departments, agencies, and bureaus at the local, state and federal levels[20, 21]. Regulations, including EPA's Resource Conservation and Recovery Act and Land Disposal Restrictions, have both narrative and numerical criteria and standards for protection of human health, aquatic life, air quality, endangered and threatened species, disposal of solid wastes, and the environment in general.

How the mining industry prevents arsenic pollution?

A number of technologies are being used to capture and remove arsenic from smelting stacks and mine tailings[4]. Air pollution can be controlled effectively using scrubbers, electrostatic precipitators, and baghouses in smelters, which are capable of removing over 99% of the dust and fumes produced during roasting and smelting[22]. Mine tailings and wastewater can be treated for arsenic removal using current technologies, e.g., the use of ferric reagents to precipitate and absorb dissolved arsenic species into disposable and relatively inert iron compounds[18]. Aqueous arsenic species also can be filtered from waste and tailings with a variety of adsorbents, including iron oxides, clay liners, and activated

charcoal filters, which can be disposed of safely[18]. The use of plants, wetlands, and iron nanoparticles to remove arsenic from already contaminated areas is also presently being investigated[18, 23]. Recent advances in the bioremediation of arsenic-contaminated groundwaters have proved successful[24,25]. Nanomembrane and membrane technologies have also improved in the recovery of arsenic[26,27]. State-of-the-art advanced technologies and protocols for monitoring, analyzing, treating and disposing of liquids and solid wastes containing arsenic are available and applied in the mining industry to ensure the appropriate level of protection for humans and the environment.

SME Statement of Technical Position

- Arsenic is a naturally occurring element commonly found as an impurity in metal-bearing mineral ores and some other mineral deposits.
- Arsenic is widely distributed in rocks and soil, in natural waters, and in small amounts in most living things.
- Arsenic is a critical mineral and used in numerous industrial products including gallium-arsenic semiconductors for use in cell phones, solar panels, telecommunications, aerospace research and light emitting diodes (LEDs).
- Products at the end of life need to be recycled instead of disposed of, so that less arsenic ends up in landfills and other disposal sites.
- The direct application of arsenic in the form of pesticides, fungicides or wood preservatives has historically been a major anthropogenic source of arsenic in soils, as arsenic is strongly attracted to soil particles and sediments.
- The natural release of arsenic from geologic materials threatens drinking water supplies around the world.
- The rate of arsenic release from sulfide minerals can be accelerated by mining activities, which expose the minerals to weathering processes during excavation. Also, arsenic can be mobilized by weathering of stored waste byproducts produced during the subsequent metal recovery process.
- It is, therefore, very important to establish a baseline of arsenic concentrations in the surrounding environment in order to distinguish between arsenic from mining, mineral and metallurgical processing; human activities; and natural background levels.
- The modern mining industry has a number of technologies designed to capture arsenic and prevent it from being released to the environment.
- The mining, mineral processing and metallurgical industries support and strictly follow state and federal regulations to ensure protection of the environment and the health of industry workers.

References

[1]Fortier, S.M., Nassar, N.T., Lederer, G.W., Brainard, J., Gambogi, J., and McCullough, E.A., 2018, Draft Critical Mineral List - Summary of Methodology and Background Information - U.S. Geological Survey Technical Input Document in Response to Secretarial Order No. 3359: U.S. Geological Survey Open-File Report 2018-1021, 15 p., https://pubs.usgs.gov/of/2018/1021/ofr20181021.pdf (accessed January 24, 2024).

[2]U.S. Geological Survey. Mineral Commodity Summaries, 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf (accessed January 24, 2024).

[3]IARC Monograph on the Evaluation of Carcinogen Risks to Humans: Arsenic, Metals, Fibres and Dusts, Volume 100C, A Review of Human Carcinogens, 2012.

[4]Bowell, R.J. and Craw, D., 2014, The management of arsenic in the mining industry: Reviews in Mineralogy and Geochemistry, v. 79, p. 507-532, https://pubs.geoscienceworld.org/msa/rimg/article/79/1/507/141106/The-Management-of-Arsenic-in-the-Mining-Industry?searchresult=1 (accessed January 24, 2024).

[5]Wang, S. and C.N. Mulligan, Occurrence of Arsenic Contamination in Canada: Sources, Behavior and Distribution. Science of the Total Environment, 2006. 366(2–3): p. 701-721.

[6]Arsenic - Element information, properties and uses | Periodic Table (rsc.org) (accessed January 24, 2024).

[7]GreenFacts. Scientific Facts on Arsenic. Publications 2012 [cited 2012 May 18]; Available from: http://www.greenfacts.org/en/arsenic/index.htm (accessed January 24, 2024).

8Carex Canada. Arsenic. Profiles and Estimates, 2012 [cited 2012 May 24]; Available from: http://www.carexcanada.ca/en/arsenic/ (accessed January 24, 2024).

[9] https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=22&tid=3 (accessed January 24, 2024).

[10]Canada, Health Canada. Guidelines for Canadian drinking water quality: Guideline technical document -- Arsenic, 2006; Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/arsenic/index-eng.php (accessed January 24, 2024).

[11]International Groundwater Resources Assessment Centre. Arsenic in Groundwater: A World Problem, 2009; Available from: https://www.un-igrac.org/resource/arsenic-groundwater-world-problem (accessed January 24, 2024).

[12]Canadian Council of Ministers of the Environment, Canadian Water Quality Guidelines for the Protections of Aquatic Life: Arsenic, 2001, Canadian Council of Ministers of the Environment: Winnipeg.

[13]Matschullat, J. Arsenic in the Geosphere -- A Review. The Science of the Total Environment, 2000. https://doi.org/10.1016/S0048-9697(99)00524-0 (accessed January 24, 2024).

[14]Health Canada. Appendix A: Screening Contaminants of Potential Concern for Local or Regional Background (Natural) Soil, Groundwater and Surface Water Concentrations. Federal Contaminated Site Risk Assessment in Canada Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA), 2007

[15] ARSENIC AND ARSENIC COMPOUNDS - Arsenic, Metals, Fibres and Dusts - NCBI Bookshelf (nih.gov) (accessed January 24, 2024).

[16]Noble, B.F., Introduction to Environmental Impact Assessment: A Guide to Principles and Practice, 2006, Don Mills, Ontario: Oxford U. Press.

[17]Williams, M., Arsenic in Mine Waters: An International Study. Environmental Geology, 2001. 40(3): p. 12.

[18]Straskraba, V. and R.E. Moran, Environmental Occurrence and Impacts of Arsenic at Gold Mining Sites in the Western United States. International Journal of Mine Water, 1990. 9(1-4): p. 11.

[19]Arsenic in coal: U.S. Geological Survey Fact Sheet, 4 p., https://pubs.usgs.gov/fs/2005/3152/fs2005-3152.pdf (accessed January 24, 2024).

[20]The arsenic rule: Environmental Protection Agency, The Arsenic Rule: Background and Rule Provisions. (epa.gov) and Drinking Water Arsenic Rule History | US EPA (accessed January 24, 2024).

[21]Agency for Toxic Substances and Disease Registry: Arsenic Toxicity. Case Studies in Environmental Medicine. https://www.atsdr.cdc.gov/csem/arsenic/standards.html (accessed January 24, 2024).

[22]Vallero, D.A., Fundamentals of Air Pollution, 2007, Amsterdam: Elsevier.

[23]Rice University Press Release. First 'nanorust' field test slated in Mexico, 2009 [cited 2012 May 31]; Available from: http://www.understandingnano.com/nanoparticle-water-pollution-iron-oxide-arsenic.html (accessed January 24, 2024).

[24]Zouboulis, A.I. and Katsoyiannis, I.A., 2005, Recent advances in the bioremediation of arsenic-contaminated groundwaters: Environment International 31, p. 213–219.

[25]Irshad, S. Zuoming Xie, Z., Sajid Mehmood3 & Asad Nawaz4 & Allah Ditta5,6 & Qaisar Mahmood, Q., 2021, Insights into conventional and recent technologies for arsenic bioremediation: A systematic review: Environmental Science and Pollution Research, v. 28, p. 18870–18892, https://doi.org/10.1007/s11356-021-12487-8 (accessed January 24, 2024).

[26]Woroua, C.N., Chena, Z. and Bacharou, T., 2021, Arsenic removal from water by nanofiltration membrane: potentials and limitations: Water Practice & Technology, v. 16, no. 2, http://iwaponline.com/wpt/article-pdf/16/2/291/874323/wpt0160291.pdf (accessed January 24, 2024).

[27]Trina Duttaa , Chiranjib Bhattacherjeeb , Sangita Bhattacherjee, 2012, Removal Of Arsenic Using Membrane Technology – A Review: International Journal of Engineering Research and

Technology, (IJERT), vol. 1 Issue 9, https://www.ijert.org/removal-of-arsenic-using-membrane-technology-a-review (accessed January 24, 2024).