1. INTRODUCTION

Some gold and silver deposits are enriched in mercury. Mining and processing of these deposits to recover the precious metals also liberates the mercury from the ore. Modern mines employ environmental protection technologies and emission control devices to capture much of the mercury contained in the ore. The domestic gold mining industry is thus a primary source of new, metallic mercury in the U.S. The mercury produced by U.S. gold mines is sold into commerce.

This paper describes the occurrence of mercury in precious metals ores, how mercury is managed during mining and mineral recovery activities, the environmental protection technologies used at U.S. gold mines to limit air releases of mercury to the environment, and the health and safety programs employed to minimize worker exposure to mercury. This paper concludes with a discussion of the industry’s ongoing commitment to work with state and federal regulators to gain an increased understanding of mercury and the environment and to achieve further reduction of mercury emissions.

This paper is compiled to be educational in nature and does not take an environmental advocacy stance, however it should be put in the proper context with the other papers presented at this workshop that refer to mercury and mining in Nevada (Gustin, 2000b, Johnson, 2000, Sladek, 2000, Wickens, 2000 and Zehner, 2000). It provides an overview of the presence of mercury in gold ore and the environmental control technology and
monitoring applicable to mercury. It also provides information on the air quality controls for the collection of elemental mercury in various parts of the process.

This paper presents this information under the following topics:

- Exploration;
- Mining;
- Beneficiation;
- Mercury metal production and sales into commerce;
- Mercury and employees; and,
- Future activities.

2. EXPLORATION

Mercury occurs naturally in many rock formations and is particularly concentrated in areas associated with recent volcanic activity, high crustal heat flow and tectonic boundaries. Mercury is common in many of the geologic formations, and specifically gold deposits, in Nevada (Zehner, 2000). Because of its occurrence with gold deposits, mercury can be used as a geochemical tracer in exploration.

Exploration drilling is done to identify new ore deposits and also to delineate ore bodies in more detail prior to mining. Samples of drill core or cuttings are analyzed for total metal content on a regular basis. These analyses provide information on ore grade and may also provide information on other metals, including mercury, present in the rock.

Extensive research has been done on the presence and formation of mercury deposits (e.g. McCormack, 1986, Bateman, 1988). Mercury sulfide, or cinnabar, is the most common form of mercury mineralization both in mercury mines and also in precious metal deposits in Nevada and throughout the west. Cinnabar is amongst the least soluble of the metallic sulfides as shown experimentally in acids and by its calculated solubility product (Barnes, 1997).

Figure 1 shows typical values of mercury vs. depth in samples taken from exploration drill holes. The mercury values range from almost zero to about 100 mg/kg. This is indicative of the variations observed in ore bodies.

Precious metal ore bodies are complex, both structurally and mineralogically. While it has been found that cinnabar is the most prevalent form of mercury in precious metal deposits, there are indications that other mercury minerals may be present in some ores. The information on mercury minerals and occurrence can be taken into account when future mining of the ore body is planned. It is therefore possible to make estimates of potential mercury production at a mine.
Figure 1 - Mercury Concentrations from Typical Drill Holes
3. SURFACE AND UNDERGROUND MINING

Rock removed in surface and underground mining operations consist of ore, waste rock, and/or overburden. The former has a high enough metal content to make it economic under present market conditions while the latter may contain low metal grades or none at all. As a result of the disseminated nature of most ore bodies, the waste rock can contain the same minerals and metals as the ore.

Explosives are used to break the rock so that it can be removed for processing. Samples of all the rock are taken on a regular basis for assaying to obtain information about the precious metal content. Samples are also taken for other testing including whole rock analysis, acid base accounting, meteoric water mobility tests, etc. Results from these tests can be used to estimate the amount of mercury present in the ore and waste rock as well as the relative solubility to meteoric water.

4. BENEFICIATION

The term beneficiation is used to describe a number of processes for the extraction of precious metals from the ore. The ore can be finely crushed and processed (milling) prior to leaching or it can be directly heap leached with little or no preparation. Both milling and heap leaching contain a number of operations that are complex in their own right. These processes have been extensively discussed and researched. There are many publications on these processes e.g. Marsden and House (1992) and Van Zyl, Hutchison and Kiel (1988). This section provides a brief summary of each process; it is focused on the presence, monitoring and management of mercury and not the technical details of the unit operations.

4.1 Milling

The principle steps in the milling process are:

- Crushing of ore;
- Grinding of the ore;
- Pretreatment of the ore (if required):
  - Autoclaving to oxidize the sulfides, and/or
  - Roasting to oxidize the carbonates;
- Cyanide leaching and recovery of the gold, silver, or mercury from the ore;
- Management of tailings (containing the finely ground material and liquid);
- Carbon stripping and regeneration;
- Refining
  - Electrowinning or zinc precipitation;
  - Mercury Retorting; and
  - Refining.
**Crushing and Grinding**

In general, mercury can be released from the ore in the beneficiation steps where heat is applied (such as pretreatment) and cyanide is used for leaching. During the first two steps of beneficiation, namely crushing and grinding, the mercury remains with the ore.

**Pretreatment**

The first point of significant liberation of mercury is the pretreatment step. Autoclaves are used to oxidize sulfides in the ore and roasters are used to oxidize carbonates and some sulfides; this allows the recovery of gold through cyanide leaching. The ore is heated in both autoclaving and roasting. The typical operating temperature for autoclaving is less than 1000 degrees Fahrenheit and roasting is generally greater than 1,000 degrees Fahrenheit. Both of these processes are well controlled and typically contain various mercury capturing devices. Both processes are widely used at the larger gold mines in Nevada. However, it should be noted that many Nevada mines do not use a pretreatment step.

The mercury capturing devices used on autoclaves and roasters include:

- Wet scrubbers;
- Gas cooling and cleaning plant;
- Mercury removal plant;
- Sulfuric acid plant; and,
- Carbon filter.

These devices are efficient and satisfy the Nevada regulatory requirements. At some of the Nevada operations the mercury in roaster emissions is measured periodically, using EPA testing methodology (EPA Method 29 or modified Method 101A). Using these methods a distinction can be made between particulate-bound mercury (that captured on the sample filter) and total mercury (that captured on the sample filter and that recovered in the potassium permanganate impinger solution). It has been found that typically very little of the mercury is in the particulate form.

**Cyanide Leaching**

Cyanide leaching is used to remove the gold and silver from the ore and results in the dissolution of some mercury as a cyanide-mercury complex. Mercury forms a relatively weak complex with cyanide and it is easily retained on activated carbon (Smith and Mudder, 1991). The mercury is therefore adsorbed onto the activated carbon used for adsorbing the gold and silver cyanide complexes.
Tailings

After recovery of the gold and silver onto the activated carbon, the remaining liquid and solids, called tailings, are deposited in impoundments for storage of the solids and recycling of the liquid. Mercury concentrations vary in tailings solids and liquids. Tailings solids and liquids can be sampled and analyzed for metals. The metals may include mercury sulfides or other complexes. The tailings liquid can be analyzed for total and dissolved mercury. Typically low concentrations of dissolved mercury are found in the tailings liquid. Most of the tailings disposal facilities in Nevada are lined and therefore contains both the tailings solids and liquids.

Carbon Stripping and Regeneration

The silver, gold and other metallo-cyanide complexes (including mercury) are stripped from the loaded carbon to produce a solution containing high concentrations of these metals. The solution is pumped to the refinery while the carbon is regenerated at high temperature before re-use in the carbon leach circuit. The regeneration kilns maybe fitted with mercury control devices such as wet scrubbers.

Refining

In the refinery the metals are recovered from the solution using electrowinning where the metals are deposited on metal cathodes (typically stainless steel or steel wool) through electrical processes. The metals can also be precipitated on zinc dust. These are all closed circuit processes generally with air pollution control devices.

For high mercury ores the zinc precipitate or metal-bearing sludge from the cathodes are taken from either the filter presses or electrowinning cells and dried in a mercury retort. A typical procedure is to heat the precipitate first to evaporate all the water. Then some of the mercury is evaporated at about 600 degrees Fahrenheit for about 4 hours. This is followed by superheating the precipitate at a temperature of up to 1400° Fahrenheit for 5 to 8 hours to vaporize and remove all available mercury from the gold and silver. The mercury vapor is condensed and collected in a water-cooled mercury separator/condenser.

The precipitate is next refined at high temperature to produce dore (a mixture of gold, silver and some impurities), the final product from a gold mine.

4.2 Heap Leaching

Heap leaching of crushed or run-of--mine ore is done at a number of mines. Cyanide is used as a process reagent to dissolve the gold and silver. Mercury contained in the ore will form a mercury-cyanide complex in the leaching solution which will be subsequently adsorbed on activated carbon. This mercury also
follows the concentrated solutions to the refining stage, which is the same as discussed above for milling. Following carbon adsorption and refining, the remaining “barren solution” is then recycled for reuse in the leaching cycle.

There are indications that not all the mercury is adsorbed onto the activated carbon from the pregnant gold/silver bearing solution. Some of it may remain in the circulating load (as recycled barren solution) that accumulates over time. Treatment of the process solution with specially patented liquid reagents forming organic sulfide precipitates that are deposited in the heap is used by some Nevada mines. This reduces the availability of weak cyanide-mercury complexes in the process stream and therefore the mercury production (Wickens, 2000).

4.2 Mercury Releases to the Air

Air pollution control devices at Nevada mines include:

- Condensers/water chillers;
- Mercury recovery/suppression processes;
- Wet electrostatic precipitators;
- Wet scrubbers;
- Baghouses; and,
- Carbon filters.

These devices limit the amount of mercury and other constituents released to the atmosphere. The data from the 1998 Toxic Release Inventories (TRI) for air emissions of mercury compounds are as follows:

- Metal mining SIC Code 10 (new) – 4,610 pounds mercury compounds
- Total all sources (original and new) – 29,656 pounds mercury and mercury compounds

5. MERCURY METAL PRODUCTION AND SALES INTO COMMERCE

Mercury is produced at various unit operations in the beneficiation of gold and silver ores in Nevada. As previously indicated mercury is liberated from the ore when the ore is heated or leached by cyanide, and recovered using the control devices described above. Mercury produced in this manner from Nevada mines is estimated at:

- 1999 – 30,000 pounds
- 2000 – 40,000 pounds (projected)

1 1998 EPA TRI Public Data Release, Revision September 2000, Table 3 – 15, p. 3-33
2 1998 EPA TRI Public Data Release, Revision September 2000, Appendix A, Table A - 1A
3 1998 EPA TRI Public Data Release, Revision September 2000, Appendix B, Table B - 1
6. MERCURY AND EMPLOYEES

The Nevada Mining Industry has placed significant emphasis on the safety and health of their employees in the handling of mercury containing solutions and processes for a long time. In August 1987 the Mine Safety and Health Administration (U.S. Department of Labor), State of Nevada Division of Mine Inspection and the Nevada Mining Association sponsored a conference on Mercury in Mining in Elko, Nevada. Most of the papers in the Proceedings of the conference dealt with mercury health and safety issues.

Exposure to mercury is minimized through training and hazard identification. Typical information and training elements in handling mercury precipitate may include:

- Mercury vapor is hazardous and must not be inhaled;
- Wear protective masks and clothing when precipitate;
- Avoid spillage of precipitate and clean up spills promptly; and,
- Always have ventilation fans running when working in the press and retort area.

Containment and contingency plans are in-place for accidental mercury releases and workers are routinely monitored for mercury exposure.

7. FUTURE ACTIVITIES

Future activities for the gold mining industry in Nevada with respect to mercury issues include the following:

- Increased understanding of the sources of mercury;
- Increased understanding of the mercury balance through the mining and beneficiation processes;
- Increased understanding of the recovery efficiencies and air-pollution controls;
- Increased understanding of offsite transport of mercury; and
- Increased information and technology transfer on this very important topic.

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8. REFERENCES


