GOLD AND SILVER

A. Commodity Summary

Gold and silver are discussed together in this report since most of the processes used to recover one will also recover the other. In addition, both metals are often found together in nature. A particular mine is generally classified as a gold or silver mine based on which metal recovered yields the greatest economic value to the operator. Exhibit 1 presents the names and locations of known gold and silver smelters and refineries. Exhibit 2 presents the names and locations of the twenty-five leading gold producing mines in the United States.

EXHIBIT 1

SUMMARY OF KNOWN GOLD AND SILVER SMELTERS AND REFINERIES

Facility Name	Facility Location
ASARCO, Inc.	Amarillo, TX Omaha, NE
AURIC-CHLOR, Inc.	Rapid City, SD
David Fell & Company, Inc.	City of Commerce, CA
Drew Resources Corp.	Berkeley, CA
Eastern Smelting & Refining Corp.	Lynn, MA
Englehard Industries West, Inc.	Anaheim, CA
GD Resources, Inc.	Sparks, NV
Handy & Harman	Attleboro, MA South Windsor, CT
Johnson Matthey	Salt Lake City, UT
Metalor USA Refining Corp.	North Attleboro, MA
Multimetco, Inc.	Anniston, AL
Nevada Gold Refining Corp.	Reno, NV
Sunshine Mining Co.	Kellogg, ID
Williams Advanced Materials	Buffalo, NY

Source: Randol Mining Directory, 1994, pp. 741-743.

EXHIBIT 2

TWENTY-FIVE LEADING GOLD-PRODUCING MINES IN THE UNITED STATES (IN ORDER OF OUTPUT)

Mine	Location	Source of Gold
Nevada Mines Operations, Newmont Gold Company	Elko and Eureka, NV	Gold ore
Gold Strike, Barrick Mercur Gold Mines, Inc.	Eureka, NV	Gold ore
Bingham Canyon, Kennecott-Utah Copper Corp.	Salt Lake, UT	Copper ore
Jerritt Canyon (Enfield Bell), Freeport-McMoran Gold Company	Elko, NV	Gold ore
Smoky Valley Common Operation, Round Mountain Gold Corp.	Nye, NV	Gold ore
Homestake, Homestake Mining Company	Lawrence, SD	Gold ore
McCoy and Cove, Echo Bay Mining Company	Lander, NV	Gold ore
McLaughlin, Homestake Mining Company	Napa, CA	Gold ore
Chimney Creek, Gold Fields Mining Company	Humboldt, NV	Gold ore
Fortitude and Surprise, Battle Mountain Gold Company	Lander, NV	Gold ore
Bulldog, Bond Gold, Bullfrog, Inc.	Nye, NV	Gold ore
Mesquite, Goldfields Mining Company	Imperial, CA	Gold ore
Getchell, FMG, Inc.	Humboldt, NV	Gold ore
Sleeper, Amax Gold, Inc.	Humboldt, NV	Gold ore
Cannon, Asamera Minerals (U.S.), Inc.	Chelan, WA	Gold ore
Ridgeway, Ridgeway Mining Company	Fairfield, SC	Gold ore
Jamestown, Sonora Mining Corp.	Tuolumne, CA	Gold ore
Paradise Peak, FMC Gold Company	Nye, NV	Gold ore
Rabbit Creek, Rabbit Creek Mining, Inc.	Humboldt, NV	Gold ore
Barney's Canyon, Kennecott Corp.	Salt Lake City, UT	Copper ore
Continental, Montana Resources	Silver Bow, MT	Gold ore
Zortman-Landusky, Pegasus Gold, Inc.	Phillips, MT	Gold ore
Golden Sunlight, Golden Sunlight Mines, Inc.	Jefferson, MT	Gold ore
Wind Mountain, Amax Gold, Inc.	Washoe, NV	Gold ore
Foley Ridge & Amie Creek, Wharf Resources	Lawrence, SD	Gold ore

Source: Mining Industry Profile Gold, 1993, pp. 5.

The United States is the second largest gold producing nation in the world. Gold lode and placer mines are located mostly in western states and Alaska while production in Nevada and California accounts for 70% of domestic production. The 1994 mine production value was over $4.1 billion. Uses of gold include jewelry and arts, 71%; industrial (electronic), 22%; and dental, 7% [1] The 1994 silver production was valued at $240 million. Nearly three-fourths of the 1994 silver mine production was in Nevada, Idaho, Arizona, and Montana. Approximately 50% of the refined silver consumed domestically during 1993 was used in the manufacture of photographic products; 20% in electrical and electronic products; 10% in electroplated ware, sterlingware, and jewelry; and 20% in other uses.[2]

Silver occurs as native metal, but is usually found combined with sulfur. About two-thirds of the world silver reserves and resources are contained in copper, lead, and zinc deposits. Ores in which silver or gold is the main component account for the remaining one-third of total world reserves and resources. The chief silver minerals found in domestic reserves are native silver, argentite, ceragyrite, polybasite, proustite, pyrargyrite, and tetrahedrite. Other ore minerals of silver are the tellurides, stromeyerite, and pearceite. Gold occurs mainly as native metal, alloyed with silver and/or other metals, and as tellurides. A naturally occurring alloy of gold and silver is known as electrum. Other gold minerals are rare. Gold is commonly associated with the sulfides of antimony, arsenic, copper, iron, and silver.[3]

B. Generalized Process Description

Precious metals may be recovered from the ore or from refining processes of base metals such as copper and lead. Because these are distinct and separate recovery methods, they are discussed separately in this report. Section 1 describes precious metal recovery from the ore while Section 2 describes precious metal recovery from refinery slimes. Section 3 is a discussion of precious metal refining operations.

SECTION 1: PRECIOUS METAL RECOVERY FROM ORES

1. Discussion of Typical Production Processes

Most domestic gold comes from surface lode mines. Silver is mined using open pit and underground methods. Several processes may be used to recover gold and silver from their ores. These include gravity separation, amalgamation, froth flotation, and cyanidation. Several processes may be combined at any given plant. These processes are discussed in more detail below.

2. Generalized Process Flow Diagram

Gravity Separation

Gravity separation relies on density differences to separate desired materials from host rock. Devices used include gold pans, sluices, shaking tables, and jigs. Gravity separation is used at most placer mines and at some lode or vein deposits.[4]

Amalgamation

Fine gold in placer deposits is often not separable from the ore minerals by density alone. The fine concentrate stream from a gravity separator, called "black sand" because of its color, often contains several dense minerals as well as

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[1] John Lucas, "Gold," from Mineral Commodity Summaries, U.S. Bureau of Mines, January 1994, pp. 72-73.

[2] Robert Reese, "Silver," from Mineral Commodity Summaries, U.S. Bureau of Mines, January 1995, pp. 154-155.

[3] John M. Lucas, "Gold," from Minerals Yearbook Volume 1 Metals and Minerals, U.S. Bureau of Mines, 1992, pp. 535-561.

[4] U.S. Environmental Protection Agency, "Gold and Silver," from, 1988 Final Draft Summary Report of Mineral Industry Processing Wastes, Office of Solid Waste, 1988, pp. 3-100- 3-115.

fine gold. This fine gold may be recovered by amalgamation which involves the dissolution of gold or silver in mercury. The resulting alloy, amalgam, is relatively soft and will adhere readily to other pieces of amalgam or to mercury.[5]

Historically, amalgamation was widely used in the United States for recovery of gold and silver from their ores. Although this method is still practiced in other parts of the world, amalgamation most likely occurs domestically on a very limited scale.

Ore Preparation

The extracted ore must be milled to prepare it for further recovery activities. Uniformly sized particles may be obtained by crushing, grinding, and wet or dry classification. The degree of milling performed on the ore depends on the gold concentration of the ore, mineralogy and hardness of the ore, the mill's capacity, and the next planned step for recovery. Milled ore is pumped to the next operation unit in the form of a slurry. Fugitive dust generated during crushing and grinding activities is usually collected by air pollution control devices and recirculated into the beneficiation circuit. Most mills use water sprays to control dust from milling activities.[6]

After milling, sulfide ores may be subjected to oxidation by chlorination, bio-oxidation, roasting, or autoclaving. Chlorination is not commonly used to oxidize sulfide ores because of high equipment maintenance costs caused by the corrosive nature of the oxidizing agent. Bio-oxidation of sulfide ores employs bacteria to oxidize the sulfur-bearing minerals. This technique is currently used on an experimental basis at the Homestake Tonkin Springs property in Nevada. Roasting of sulfide ores involves heating the ores in air to convert them to oxide ores and break up their physical structure, allowing leaching solutions to penetrate and dissolve the gold. In effect, roasting oxidizes the sulfur in the ore, generating sulfur dioxide that can be captured and converted to sulfuric acid. Roasting temperatures are dependent on the mineralogy of the ore, but range as high as several hundred degrees Celsius. Roasting of carbonaceous ores oxidizes the carbon to prevent interference with leaching and reduced gold recovery efficiency. Autoclaving (pressure oxidation) is a relatively new technique that operates at lower temperatures than roasting. Autoclaving uses pressurized steam to start the reaction and oxygen to oxidize sulfur-bearing minerals. Heat released from the oxidation of sulfur sustains the reaction. The Getchell and Barrick Goldstrike Mines in Nevada, the McLaughlin Mine in California, and the Barrick Mercur Mine in Utah are currently using pressure oxidation (autoclave) technology, totally or in part, to beneficiate sulfide or carbonaceous gold ores.[7]

Agglomeration

Because ores with a high proportion of small particles may retard the percolation of the lixiviate, agglomeration is used to increase particle size. This operation includes mixing the crushed ore with portland cement and/or lime, wetting the ore evenly with cyanide solution to start leaching before the heap is built, and mechanically tumbling the ore mixture so fine particles adhere to larger particles.

Cyanidation - Leaching

Cyanidation leaching is the primary means of recovery of fine gold and silver. In this process, solutions of sodium or potassium cyanide are brought into contact with an ore which may or may not have required extensive preparation prior to leaching. Gold and silver are dissolved by cyanide in solutions of high pH in the presence of oxygen. There are three general methods of contacting ores with leach solutions: (1) heap leaching, (2) vat leaching, and (3) agitation leaching. Cyanidation heap leaching and vat leaching account for most gold and silver recovery.[8] These leaching methods are discussed in detail below.

(1) Cyanidation - Heap Leaching

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[5] Ibid.

[6] U.S. Environmental Protection Agency, Technical Resource Document, Extraction and Beneficiation of Ores and Minerals, Vol. II, July 1994.

[7] Ibid.

[8] Personal communication between ICF Incorporated and Robert G. Reese, U.S. Bureau of Mines, September 23, 1994.

Heap leaching, shown in Exhibit 3, is the least expensive process and therefore, low value ores are most often treated by heap leaching. In 1993, heap leaching accounted for 39 percent of gold production.[9] In many cases, heaps are constructed on lined pads with ore sent directly from the mine with little or no preparation. However, at about half of the heap leaching operations, ore is crushed and agglomerated prior to placement on the heap to increase permeability of the heap and maintain the high pH (optimally 10.5) needed for leaching to occur.

Two common types of pads used in gold heap leaching include permanent heap construction on a pad from which the leached ore is not removed and on-off pads, which allow the spent ore to be removed following the leach cycle and fresh ore to be placed on the pad. Permanent heaps are typically built in lifts. Each lift is composed of a 5 to 30 foot layer of ore. On-off pads are not commonly used in the industry and are constructed to allow spent ore to be removed after the leaching cycle and re-use of the pad.

After the ore is piled on a leaching pad, the leaching solution is applied to the top of the pile by sprinklers. The solution generally has a concentration of 0.5 to 1 pound of sodium cyanide per ton of solution.[10] The precious metals are dissolved as the solution trickles through the pile and the metal bearing solution is collected on the impervious pad and pumped to the recovery circuit. Following rejuvenation, the solution returns for reuse once the metals are removed. The leaching process will continue until no more precious metal is extracted. Typical operations will involve leaching for several

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[9] Personal communication between ICF Incorporated and John M. Lucas, U.S. Bureau of Mines, September 15, 1994.

[10] U.S. Environmental Protection Agency, Technical Resource Document, Treatment of Cyanide Heap Leaches and Tailings, Office of Solid Waste Special Waste Branch, 1994, pp. 2-4.

EXHIBIT 3

Gold-Silver Leaching

Graphic Not Available.

Source: 1988 Final Draft Summary Report of Mineral Industry Processing Wastes, 1988, 3-100 - 3-115.

months on each heap. The process is relatively inexpensive and can be operated for less than two dollars per ton of ore. However, as much as half of the gold and silver may not be extracted either because the leach liquor never contacts the precious metal or because the metal bearing solution is trapped in blind channels. Waste streams from this process include spent ore and leaching solutions as well as residual leach liquor in the pile.[11]

(2) Cyanidation - Vat Leaching

Vat leaching, shown in Exhibit 3, is used when greater solution control than that afforded by heap leaching is necessary. In 1993, vat leaching accounted for 53 percent of gold recovery.[12] In this system, prepared ore is placed in a vat or tank and flooded with leach liquor. The solution is continuously cycled through, draining from the bottom of the vat, proceeding to gold recovery, rejuvenation, and returning to the top of the vat. The process is more expensive than heap leaching because the material must be removed from the vat at the end of the leaching process. While the primary advantage of vat leaching is better solution contact, channelization and stagnant pockets of solution still occur (almost as severely as in heap leaching) when solution is drained from the vat. However, some of the trapped solution is recovered when the solids are removed from the vat. Wastes from this process include spent ore and leaching solutions.[13]

(3) Cyanidation - Agitation Leaching

High value ores are treated by agitation leaching, shown in Exhibit 4, to maximize the recovery of metal values. The ore is crushed and ground in water to form a slurry. Cyanide is usually added at the grinding mill to begin the leaching process and more cyanide may be added to the leaching tanks. Ores may be leached anywhere from 24 to 72 or more hours. Silver ores tend to require longer leaching times. The method of recovering the precious metal from solution determines how the solution is separated from the solids. If the Merrill-Crowe or carbon-in-column metal recovery process is used, the leach liquor will be washed out of the solids, usually by a combination of counter-current decantation and filtration washing with water. This produces a concentrated wash solution and recovers the maximum pregnant liquor from the solids. The resultant slurry will contain very little cyanide or gold and would not be expected to any exhibit hazardous characteristics. If carbon-in-leach or carbon-in-pulp metal recovery is practiced, the slurry may be discarded without washing. The carbon should remove all of the precious metals, and the solution is recovered from the tailings treatment and recycled to the process.[14]

Cyanidation - Metal Recovery

In leaching operations, after dissolving the metal, the leach solution is separated from the ore, and the gold and silver are removed from solution in one of several ways: (1) the Merrill-Crowe process, (2) activated carbon loading, and (3) activated carbon stripping. The primary difference between recovery methods is whether the metal is removed by precipitation with zinc or by absorption on activated carbon. Zinc cyanide is more soluble than gold or silver cyanide and if pregnant liquor is contacted with metallic zinc the zinc will go into solution and the gold and silver will precipitate.[15] The different recovery methods are described below.

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[11] U.S. Environmental Protection Agency, 1988, Op. Cit., pp. 3-100 - 30-115.

[12] Personal communication, September 15, 1994.

[13] U.S. Environmental Protection Agency, 1988, Op. Cit., 3-100 - 3-115.

[14] Ibid.

[15] U.S. Environmental Protection Agency, 1988, Op. Cit., pp. 3-100 - 3-115.

EXHIBIT 4

AGITATION LEACHING WITH MERRILL-CROWE RECOVERY

Graphic Not Available.

Source: <u>1988 Final Draft Summary Report of Mineral Industry Processing Wastes</u>, 1988, 3-100 - 3-115.

(1) Cyanidation - Metal Recovery - Merrill-Crowe

In the Merrill-Crowe process, the pregnant leaching solution is filtered for clarity, then vacuum deaerated to remove oxygen and decrease precious metal solubility. The deaerated solution is then mixed with fine zinc powder to precipitate the precious metals. The solids, including the precious metals, are removed from the solution by filtration and the solution is sent back to the leaching circuit. The solids are melted and cast into bars. If silver and gold are present, the bars are called doré. In most cases, the metal is then sent to an off-site refinery. Most operations using zinc precipitation in the United States use some variation of the Merrill-Crowe process.[16]

(2) Cyanidation - Metal Recovery - Activated Carbon Loading

Precious metal leach solutions can be brought into contact with activated carbon by carbon-in-column, carbon-in-pulp, and carbon-in-leach processes.

Carbon-in-column systems are used at heap and vat leach operations and in other situations where the leaching solution is separated from the solids being leached prior to precious metal recovery. The leaching solution is passed through a series of columns containing beds of activated carbon. The gold and silver are adsorbed as cyanide complexes on the surfaces of the carbon. After passing through the columns, the solution is returned to the leaching circuit. When the carbon in a column is loaded with precious metals, the column is switched to a stripping circuit.[17]

In many agitation plants, the gold is recovered from the leached material before the solution is separated from the solids. In the *carbon-in-pulp* system, the leached pulp passes from the last stage of the leaching circuit into another series of agitation tanks. Each tank contains activated carbon granules. The slurry flows from tank to tank in series while the carbon is retained by screens. When the carbon in the first tank is fully loaded with precious metals, it is removed and sent to the stripping and reactivation circuit, the carbon in the other tanks is moved ahead one stage and new carbon is added to the last stage. The carbon moves counter-current to the leached slurry and the leached slurry is finally sent to the tailings area for dewatering.[18] A process flow diagram of carbon-in-pulp metal recovery is shown in Exhibit 5.

Carbon-in-leach is similar to carbon-in-pulp except that the carbon is in the leaching tanks instead of in a separate recovery circuit. One advantage of carbon-in-leach over carbon-in-pulp is that some cyanide is released when gold adsorbs on carbon, making it available for more leaching. Another advantage is that fewer agitation tanks are necessary since the separate recovery circuit is eliminated. However, the agitation is more aggressive in the leach circuit causing more attrition of the carbon than in the carbon-in-pulp, thus, the finely abraded carbon and its load of precious metals may be lost, reducing recovery and increasing costs due to increased carbon replacement.[19] A process flow diagram of carbon-in-leach metal recovery is presented in Exhibit 5.

(3) Cyanidation - Metal Recovery - Activated Carbon Stripping

Gold stripping from loaded activated carbon is usually done with a hot, concentrated alkaline cyanide solution, sometimes including alcohol. These conditions favor the desorbtion of the precious

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[16] Ibid.

[17] Ibid.

[18] Ibid.

[19] Ibid.

EXHIBIT 5

Carbon-In-Pulp And Carbon-In-Leach Metal Recovery

Graphic Not Available.

Source: 1988 Final Draft Summary Report of Mineral Industry Processing Wastes, 1988, 3-100 - 3-115.

metals into the stripping solution. The solution then goes into an electrowinning cell where the precious metals are plated out, generally onto a steel wool cathode. The solution is recycled to the stripping stage and the cathode is sent on to refining. Some operations refine the steel wool on site to make doré while others ship it directly to commercial refineries. The primary waste from carbon stripping is the spent stripping solution.[20]

Carbon Regeneration

After stripping, the carbon is reactivated on or off site and recirculated to the adsorption circuit. Carbon used in adsorption/desorbtion can be reactivated numerous times. The regeneration technique varies with mining operations, but generally involves an acid wash before or after extraction of the gold-cyanide complex, followed by reactivation in a kiln. The activated carbon is washed with dilute acid solution (pH of 1 or 2) to dissolve carbonate impurities and metal-cyanide complexes that adhere to the carbon along with the gold. This technique may be employed either immediately before or after the gold-cyanide complex is removed. Acid washing before the gold is removed enhances gold recovery. The Barrick Mercur Mine in Utah, the Barrick Goldstrike Mine in Nevada, and the Ridgeway Gold Mine in South Carolina are examples of facilities using acid prewash techniques. The Golden Sunlight Mine in Montana and the Battle Mountain Mine in Nevada use acid postwash techniques.[21]

The acid used for carbon washing depends on what impurities need to be removed. Usually, a hydrochloric acid solution is circulated through 3.6 metric tons of carbon for approximately 16 to 20 hours. Nitric acid is also used in these types of operations, but is thought to be less efficient than hydrochloric acid in removing impurities. The resulting spent acid wash solutions may be neutralized with a high pH tailings slurry, dilute sodium hydroxide solution, or water rinse. When the wash solution reaches a stable pH of 10, it is sent to a tailing impoundment. Metallic elements may also be precipitated with sodium sulfide.[22]

The carbon is screened to remove fines and thermally reactivated in a rotary kiln at about 730°C for 20 minutes. The reactivate carbon is subsequently rescreened and reintroduced into the recovery system. Generally, about 10 percent of the carbon is lost during the process because of particle abrasion. Recirculating the carbon material gradually decreases performance in subsequent absorption and reactivation series. Carbon adsorption efficiency is closely monitored and fresh carbon is added to maintain efficiency at design levels.[23]

3. Identification/Discussion of Novel (or otherwise distinct) Process(es)

None identified.

4. Beneficiation/Processing Boundaries

EPA established the criteria for determining which wastes arising from the various mineral production sectors come from mineral processing operations and which are from beneficiation activities in the September 1989 final rule (see 54 Fed. Reg. 36592, 36616 codified at 261.4(b)(7)). In essence, beneficiation operations typically serve to separate and concentrate the mineral values from waste material, remove impurities, or prepare the ore for further refinement. Beneficiation activities generally do not change the mineral values themselves other than by reducing (e.g., crushing or grinding), or enlarging (e.g., pelletizing or briquetting) particle size to facilitate processing. A chemical change in the mineral value does not typically occur in beneficiation.

Mineral processing operations, in contrast, generally follow beneficiation and serve to change the concentrated mineral value into a more useful chemical form. This is often done by using heat (e.g., smelting) or chemical reactions (e.g., acid digestion, chlorination) to change the chemical composition of the mineral. In contrast to beneficiation operations, processing activities often destroy the physical and chemical structure of the incoming ore or mineral feedstock such that the materials leaving the operation do not closely resemble those that entered the operation. Typically, beneficiation wastes are earthen in character, whereas mineral processing wastes are derived from melting or chemical changes.

EPA approached the problem of determining which operations are beneficiation and which (if any) are processing in a step-wise fashion, beginning with relatively straightforward questions and proceeding into more detailed

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[20] Ibid.

[21] U.S. Environmental Protection Agency, July 1994, Op. Cit., pp. 1-12.

[22] Ibid.

[23] Ibid.

examination of unit operations, as necessary. To locate the beneficiation/processing "line" at a given facility within this mineral commodity sector, EPA reviewed the detailed process flow diagram(s), as well as information on ore type(s), the functional importance of each step in the production sequence, and waste generation points and quantities presented above in Section B.

EPA determined that for this specific mineral commodity, the beneficiation/processing line occurs between cyanidation metal recovery and refining because this is where significant physical/chemical changes occur. Therefore, because EPA has determined that all operations following the initial "processing" step in the production sequence are also considered processing operations, irrespective of whether they involve only techniques otherwise defined as beneficiation, all solid wastes arising from any such operation(s) after the initial mineral processing operation are considered mineral processing wastes, rather than beneficiation wastes. EPA presents below the mineral processing waste streams generated after the beneficiation/processing line, along with associated information on waste generation rates, characteristics, and management practices for each of these waste streams.

SECTION 2: PRECIOUS METAL RECOVERY FROM REFINERY SLIMES

1. Discussion of Typical Production Processes

Gold and silver are also recovered from the refining processes for base metals, primarily lead and copper. Smelting operations remove iron, sulfur, and other impurities from the ore and produce copper anodes for electrolytic refining. In refining operations the anodes produced from smelting are purified electrolytically to produce copper cathodes. The refinery slimes from these operations are processed for precious metals recovery. The recovery of precious metals in lead refineries is a normal part of the operation called "desilverizing."

2. Generalized Process Flow Diagram

A major source of precious metals from the copper industry is electrolytic cell slimes. The slimes are periodically removed from the cells in the refinery for treatment. The first stage of treatment removes the copper in the slimes by acid leaching, either as is or after roasting. The decopperized slimes are then placed in a furnace and melted with a soda-silica flux. The siliceous slag formed in this melting is removed and air is blown through the molten material. Lime is added and a high lead content slag is formed which is combined with the siliceous slag and returned to the copper anode casting furnace. Next, fused soda ash is added to the furnace and air is again blown through the melt, forming a soda slag which is removed and treated to recover selenium and tellurium. The remaining doré in the furnace is removed and sent to refining to recover the precious metals.[24] See the selenium and tellurium chapters for a more detailed discussion of product recovery.

The desilverizing process takes advantage of the solubility of precious metals in molten zinc which is greater than their solubility in molten lead. Lead from previous stages of refining is brought in contact with a zinc bath, either in a continuous operation or in batches. The zinc absorbs the precious metals from the lead and the lead is then passed onto a dezincing operation. The zinc bath is used until it contains 5,000 to 6,000 troy ounces of precious metal per ton of zinc. The zinc bath is then retorted to recover zinc by distillation. The zinc is returned to the desilverizing process and the "retort metal" is treated by cupellation to produce doré bullion. In the cupellation step, the base metals in the retort metal are oxidized with air and removed from the precious metals. The oxides are all treated for the recovery of their various precious metals. The doré is then sent to refining.[25]

3. Identification/Discussion of Novel (or otherwise distinct) Process(es)

None identified.

4. Beneficiation/Processing Boundaries

Since gold is recovered as a by-product of other metals, all of the wastes generated during gold recovery are mineral processing wastes. For a description of where the beneficiation/processing boundary occurs for this mineral commodity, see the reports for lead and copper presented elsewhere in this document.

SECTION 3: PRECIOUS METAL REFINING

1. Discussion of Typical Production Processes

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[24] U.S. Environmental Protection Agency, 1988, Op. Cit., pp. 3-100 - 3-115.

[25] Ibid.

The refining process used for gold and silver depends on the composition of the material in the feed. The most basic operation is "parting" which is the separation of gold and silver. Parting can be done electrolytically or by acid leaching. In either case, the silver is removed from the gold. Further treatments may be necessary to remove other contaminants. These treatments have the potential to produce wastes with hazardous characteristics, primarily corrosivity, since strong acids are used.[26]

2. Generalized Process Flow Diagram

Like several other gold refineries, at the Newmont facility in Nevada the gold cyanide solution is electrowon onto steel wool cathodes after carbon stripping. The barren cyanide solution is returned to the leach circuit for gold recovery. Sludge from the bottom of the electrowinning cell is filtered and sent to the retort for mercury recovery. The gold/steel wool cathode is placed in a vat containing a sulfuric acid solution. The solution dissolves the steel wool from the gold and silver, leaving a solid gold residue. The waste sulfuric acid and steel wool solution is discharged to the tailings slurry. The gold solids are filtered under vacuum through diatomaceous earth. The gold filter cake is then sent to the retort furnace where it is subjected to 1,200 F for 14 hours. After retorting, a flux of silica and borax is added and the gold is smelted in an induction furnace. It is from this induction furnace that gold doré bars are poured. The slag generated from this smelting is sent to a ball mill for crushing, grinding, and gold recovery. Some of the slag is immediately recycled back to the smelting process to recover its gold content. The gold slag may have between 3 and 4 ounces per ton of recoverable gold.[27]

Silver Chloride Reduction

Silver metal is produced from silver chloride by a dissolution and cementation process. The silver chloride is dissolved in a dilute solution of ammonium hydroxide and recovered by cementation. The silver is replaced in solution, causing the silver ions to be reduced and precipitated from solution as silver metal.

Mercury Recovery

Many gold-bearing ores from the Western United States contain small quantities of mercury. The presence of mercury decreases the gold-loading capacity of the activated carbon. During cyanidation of mercury-bearing gold-silver ores, significant amounts of mercury are extracted. Addition of calcium sulfide to the cyanide leach slurry precipitates the solubilized mercury and also some silver.[28] Primary mercury is also produced from gold-bearing ores by roasting or calcining. These processes are described in more detail in the chapter on mercury.

Exhibit 6 presents an overall process flow sheet for gold production.

3. Identification/Discussion of Novel (or otherwise distinct) Process(es)

None identified.

4. Beneficiation/Processing Boundaries

As discussed above, EPA approached the problem of determining which operations are beneficiation and which (if any) are processing in a step-wise fashion, beginning with relatively straightforward questions and proceeding into more detailed examination of unit operations, as necessary. To locate the beneficiation/processing "line" at a given facility within this mineral commodity sector, EPA reviewed the detailed process flow diagram(s), as well as information on ore type(s), the functional importance of each step in the production sequence, and waste generation points and quantities presented above in Section B.

EPA determined that for recovering gold and silver from precious metal refining, the beneficiation/processing line occurs between retorting and smelting because this is where a significant chemical change ocurrs. Therefore, because EPA has determined that all operations following the initial "processing" step in the production sequence are also considered processing operations, irrespective of whether they involve only techniques otherwise defined as beneficiation, all solid wastes arising from any such operation(s) after the initial mineral processing operation are

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[26] Ibid.

[27] U.S. Environmental Protection Agency, Trip report for Newmont Gold Corporation, South Operations Facilities, Carlin Nevada, May 17, 1995.

[28] Simpson, W.W., W.L. Staker, and R.G. Sandberg, Calcium Sulfide Precipitation of Mercury From Gold-Silver Cyanide-Leach Slurries, U.S. Department of Interior, 1986.

considered mineral processing wastes, rather than beneficiation wastes. EPA presents below the mineral processing waste streams generated after the beneficiation/processing line, along with associated information on waste generation rates, characteristics, and management practices for each of these waste streams.

C. Process Waste Streams

1. Extraction/Beneficiation Wastes

Mining

Mine water is a waste stream generated from gold and silver production. This waste consists of all water that collects in mine workings, both surface and underground, as a result of inflow from rain or surface water, and ground water seepage. If necessary, the water is pumped to allow access to the ore body or to keep the mine dry. This water may be pumped from sumps within the mine pit or from interceptor wells. Mine water may be used and recycled to the beneficiation circuit, pumped to tailings ponds, or discharged to surface water. Quantity and chemical composition of mine water varies from site to site.[29]

Waste Rock. Overburden and mine development is referred to by the industry as waste rock. This waste is generally disposed of in waste rock piles or dumps. An estimated 25 million metric tons of overburden and mine development rock was generated in 1980 and 39 million metric tons in 1982. At surface mines, 71 percent of all material handled is discarded as waste. At underground mines, 20 percent is discarded as waste. The quantity and composition of the waste rock varies by site. Depending on the composition of the ore body, this waste may contain sulfides or oxides.

Amalgamation

Waste rock, clay, and sand may be disposed of in a tailings pond.

Black sand may contain residual mercury and be disposed of in a tailings pond.

Mercury bearing solution may be sent to mercury recovery or a tailings pond.

Ore Preparation

Sulfur dioxide may be routed to an acid plant and converted to sulfuric acid. This may be sold to other mines or used on-site for carbon washing and regeneration. At least two facilities generate sulfuric acid, the Goldstrike Mine operated by American Barrick and Newmont's facility in Nevada.

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[29] U.S. Environmental Protection Agency, Mining Industry Profile, Gold, Office of Solid Waste, Special Waste Branch, 1993, pp. 41-45.

EXHIBIT 6

OVERVIEW OF GOLD PRODUCTION

Graphic Not Available.

Source: Technical Resource Document, Extraction and Beneficiation of Ores and Minerals, July 1994, pp. 1-12.

Cyanidation

Spent carbon.

Spent ore. The ore from leaching may contain residual cyanide. The ore in continuous or valley fill heaps is stacked in lifts and left in place for subsequent leaching, detoxification, and closure. Ore placed on on-off heap pads is periodically removed for ultimate disposal at an alternative site, such as waste rock or spent ore disposal sites. Typically, detoxification of the spent ore involves rinsing with water until the cyanide concentration in the effluent is below a specific standard set by the State regulatory agency. The heap may then be reclaimed with wastes in place. Spent ore from vat leaching exists in the form of a slurry composed of gangue and process water bearing cyanide and cyanide-metal complexes. The spent ore may be treated to neutralize cyanide prior to disposal. The slurry is typically disposed of in a tailings impoundment with some of the liquid component being recirculated to the tank leach as make-up water.[30]

Spent leaching solution. During the leaching operations, most of the barren cyanide solution is recycled to leaching activities; however, the build-up of metal impurities may interfere with the dissolution and precipitation of gold and, therefore, require a portion of the solution volume to be bled off and disposed. These solutions may contain free cyanide and metallo-cyanide complexes of copper, iron, nickel, and zinc, as well as other impurities, such as arsenic and antimony, mobilized during the leaching. Management practices for these solutions are unclear; however, they have been discharged to tailings impoundments or land-applied after treatment to detoxify cyanide.[31]

Merrill-Crowe

Filter cake resulting from zinc precipitation consists primarily of fine gangue material and may contain gold-cyanide complex, zinc, free cyanide, and lime. The filter may be washed with water, which is disposed of as part of the waste. The waste is typically sent to tailings impoundments or piles.

Spent leaching solution from zinc precipitation is often returned to leaching process.

Activated Carbon Stripping

Spent stripping solution.

Tailings in slurry form, composed of gangue (including sulfide materials and dissolved base metals) and process water bearing cyanide and cyanide-metal complexes, are generated from carbon-in-pulp and carbon-in-leach processes. The characteristics of this waste vary depending on the ore, cyanide concentration, and water source (fresh or recycled). The characteristics of the gangue are dependent on the ore source. The slurry is typically disposed of in a tailings impoundment with some of the liquid component being recirculated to the tank leach or other water consumptive system.[32]

Waste sulfuric acid may be corrosive.

Waste steel wool solution may be corrosive.

Carbon Regeneration

Carbon fines and acid wash solution are wastes from the reactivation circuit. The carbon may contain small amounts of residual base metals and cyanide. The acid wash residues may contain metals, cyanide, and the acid (typically hydrochloric or nitric). The acid is usually neutralized in a totally enclosed system prior to release to a tailings impoundment. Most operations capture less-than-optimum-size carbon particles and, prior to disposal, extract additional gold values. This may involve either incinerating the carbon/gold that could not be desorbed chemically during the normal course of operations or subjecting the material to an extended period of concentrated cyanide leaching. Any liquids used to wash or transport carbon material are recirculated.[33] These wastes are non-uniquely associated with mineral processing operations.

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[30] U.S. Environmental Protection Agency, 1994, Op. Cit., pp. 1-12.

[31] Ibid.

[32] Ibid.

[33] Ibid.

2. Mineral Processing Wastes

Smelting and Refining

Slag. This waste may be recycled to leaching and smelting operations. Although no published information regarding waste generation rate or characteristics was found, we used the methodology outlined in Appendix A of this report to estimate a low, medium, and high annual waste generation rate of 100 metric tons/yr, 360,000 metric tons/yr, and 720,000 metric tons/yr, respectively. We used best engineering judgement to determine that this waste may exhibit the characteristic of toxicity for silver. This waste is classified as a byproduct.

WWTP sludge. This waste may be recycled. Although no published information regarding waste generation rate or characteristics was found, we used the methodology outlined in Appendix A of this report to estimate a low, medium, and high annual waste generation rate of 100 metric tons/yr, 360,000 metric tons/yr, and 720,000 metric tons/yr, respectively. We used best engineering judgement to determine that this waste may exhibit the characteristic of toxicity for silver. This waste is classified as a sludge.

Spent furnace dust. Although no published information regarding waste generation rate or characteristics was found, we used the methodology outlined in Appendix A of this report to estimate a low, medium, and high annual waste generation rate of 100 metric tons/yr, 360,000 metric tons/yr, and 720,000 metric tons/yr, respectively. We used best engineering judgement to determine that this waste may exhibit the characteristic of toxicity for silver. This waste is recycled and is classified as a byproduct.

Wastewater is generated from numerous sources, including the smelter APC, silver chloride reduction, electrolytic cell wet APC, and electrolyte preparation wet APC. Wastewater from electrolyte preparation wet APC, electrolytic cell wet APC, and smelter wet APC may contain toxic metals, suspended solids, oil, and grease. This waste may be recycled.[34] Although no published information regarding waste generation rate or characteristics was found, we used the methodology outlined in Appendix A of this report to estimate a low, medium, and high annual waste generation rate of 440,000 metric tons/yr, 870,000 metric tons/yr, and 1,700,000 metric tons/yr, respectively. We used best engineering judgement to determine that this waste may exhibit the characteristic of toxicity for arsenic, silver, cadmium, chromium, and lead. This waste is classified as a sludge.

Refining wastes. The most basic refining operation for the separation of gold and silver is "parting" which can be done electrolytically or by acid leaching. Further treatments are sometimes necessary to remove additional contaminants. Although no published information regarding waste generation rate or characteristics was found, we used the methodology outlined in Appendix A of this report to estimate a low, medium, and high annual waste generation rate of 100 metric tons/yr, 360,000 metric tons/yr, and 720,000 metric tons/yr, respectively. We used best engineering judgement to determine that this waste may exhibit the characteristic of toxicity for silver and corrosivity. This waste is recycled to extraction/beneficiation units.

D. Ancillary Hazardous Wastes

Ancillary hazardous wastes may be generated at on-site laboratories, and may include used chemicals and liquid samples. Other hazardous wastes may include spent solvents (e.g., petroleum naptha), acidic tank cleaning wastes, and polychlorinated biphenyls from electrical transformers and capacitors. Non-hazardous wastes may include tires from trucks and large machinery, sanitary sewage, waste oil (which may or may not be hazardous), and other lubricants.

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[34] U.S. Environmental Protection Agency, Development Document for Effluent Limitations Guidelines and Standards for the Nonferrous Metals Manufacturing Point Source Category, Vol. V, 1989, pp. 2185-2186.

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