Final Report to

U.S. Environmental Protection Agency

Region IX

Mercury and Modern Gold Mining in Nevada

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October 24, 2005

A. Introduction

Mercury has long been associated with gold mining, and releases of mercury into the environment remain a concern due to its health effects on humans and other organisms. Much of the historic release of mercury has been associated with either primary mercury mining, or use of mercury for recovery of gold and silver via amalgamation from milled ore. For example, amalgamation processes were the primary source of mercury releases to the Carson River Superfund Site during the late 1800's, and occurred via tailings disposal, thermal processes, and other discharges to surface water, land and the atmosphere. In the United States, mercury amalgamation for gold recovery has effectively ceased, and introduction of new mercury from hard rock mining activities is primarily associated with inadvertent release of mercury during gold mining and processing. In recent years, all of the primary mercury mines in the U.S. have been closed, and the only significant source of new anthropogenic mercury into commerce is byproduct production, again, primarily from the gold mining industry.

In 2003, approximately 82% of gold produced in the U.S. came from Nevada mines (Nevada Bureau of Mines and Geology, 2003). Based on a review of the available information, the large majority of new byproduct mercury is also produced in Nevada. This report assesses how mercury is managed in gold mines in Nevada.

B. Objectives and Purpose of Report

Because of concerns about production and release of mercury into the environment, information is required to determine the sources of mercury from gold mining and how these are managed. We sought to answer the following questions:

(1) What is the total amount of by-product mercury produced annually in Nevada gold mining facilities? How is this mercury managed? Who purchases this mercury?
(2) How much mercury is released into the atmosphere from gold mines in Nevada? Are reductions in emissions observed, due to the current voluntary mercury emissions reduction program?
(3) What are other sources of mercury from gold mining? What is the significance of those sources?

C. Mercury Background

Mercury is a naturally occurring metal, and the only metallic element that is a liquid at ambient temperatures, having the appearance of a silver shiny metal. Mercury is 13.5 times heavier than water, although it is relatively volatile in the metallic state, with a vapor pressure of 1.2×10^{-3} torr at 20°C (CRC, 1969). Mercury is geologically concentrated in regions associated with volcanic activity, high heat flow, and plate tectonic boundaries, and is commonly found associated with gold deposits although the amount of mercury in gold ore can vary widely, from less than 0.1 mg/kg to over 100 mg/kg. The mercury released to the living environment has increased since the industrial age, and the increased loading presumably has come from human activity (USEPA, Mercury White Paper, 2003). The new non-anthropogenic mercury released into the living environment from natural sources (e.g. soils, and geothermal springs) is generally assumed to be relatively constant.

Mercury is known to cycle extensively in the atmosphere, and plant, soil and water systems involving complex processes that are not completely understood. Mercury undergoes extensive biological cycling in sediments to toxic and biologically available methylated forms and back to stable and less available sulfide complexes. Mercury can be photochemically released from soils as elemental mercury into the atmosphere, and, subsequently is transported in the atmosphere, where it is reoxidized in the atmosphere to an ionic form and is deposited on soils, plants or water (Gustin, et al., 2004). Certain natural sources of recycled mercury can be substantial (e.g. forest fires). Due to the difficulties in accurately measuring the loading of natural cyclical mercury, disagreement remains on the total mercury burden in the environment. Various discussions on mercury are available, and a recent extensive and widely considered overview is available from United Nations Environmental Program website (UNEP, 2003)

New anthropogenic mercury is defined as that mercury that is released into the living ecosystem from previously geologically isolated sources, and is most often derived from coal and metal mining activity, and, to a lesser extent from geothermal heat recovery. Air emissions and land releases of new mercury from anthropogenic sources include electric utility facilities, lime kilns, chemical manufacturers, mining operations and other thermal processes that utilize fossil fuels. The U.S. EPA suggests that 1/3 of the total U.S. emissions

of new mercury are deposited through wet and dry deposition in the continental 48 states. The remaining 2/3 is transported into the global reservoir outside the borders of the United States. One estimate has noted a total of 5,500 tons of atmospheric cyclical mercury is released into the global reservoir annually from natural, oceanic, and newly produced anthropogenic emission sources (USEPA White Paper, 2003).

Until 1998, the amount of mercury released into the atmosphere from gold mining activities had not been systematically measured and reported, and reliable estimates from this sector were not available. Since that time the amount of mercury released from mining to the atmosphere has been estimated, based on a series of emission factors as a result of EPA's Toxics Release Inventory (TRI) requirements. These estimates showed that a sizeable amount of mercury was being released from a small number of large mines, and subsequent efforts have been made to reduce those emissions.

Because gold mining is concentrated in Nevada, and mercury releases from these mines is considered a significant environmental issue, we focused on Nevada gold mines. Some efforts were made to examine gold producing facilities out of state, although very little data are available.

Governmental Regulations on Mercury

The U.S. EPA has developed an extensive array of regulatory requirements for atmospheric release of mercury. Summarized below is a short list of dates for regulation of mercury in the U.S. Shortly after the passage of the 1970 Clean Air Act, as well as the increasing awareness of the toxicity of mercury, domestic use began to decline, although a demand still exists and will likely continue.

Table C-1. Federal and State Regulations/Programs Affecting Mercury

Year	Federal Regulation	Comments
1970	Clean Air Act	Established EPA to set regulatory standards for hazardous air pollutants.
1971		In March of this year, mercury was designated a hazardous pollutant.
1972	Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)	Stopped the production of many pesticides which contained mercury.

1972	Federal Water Pollution Control Act	Gave EPA authority to enforce and regulate the discharge of mercury into waterways.
1973		In September of this year, mercury was designated a toxic pollutant.
1973		In October of this year, the dumping of mercury or mercury compounds in the ocean became prohibited.
1974	Safe Drinking Water Act	EPA was given the authority to establish and regulate safe standards for drinking water.
1978	Resource Conservation and Recovery Act	Regulations were established for the disposal of mercury-bearing waste.
1980	Comprehensive, Environmental Response, Compensation, and Liability Act	Established a $1.6 billion fund for clean up of toxic waste sites.
1986	Emergency Planning and Community Right-to-Know Act with Sec. 313 - TRI	Required specific industries to report releases of over 650 chemical and chemical categories. Establishing Sec. 313 as the Toxic Release Inventory
1997		U.S. EPA changed TRI toxic release requirements and required the metal mining industry to report, beginning in 1998.
2001	Voluntary Mercury Reduction Program	Four mining facilities in Nevada voluntarily agreed to VMRP goals on December 18 of this year.
2005	Clean Air Mercury Rule (Coal Fired Power Plants)	New regulations designed to reduce mercury emissions from coal power plants.

Sources:* Jasinski, 1994
State of Nevada, 2000
U.S. EPA, 28 October 2003

The laws and regulations above were originally a response to excessive mercury releases from four specific emission industries, accounting for roughly 83% of all 1995 anthropogenic emissions of mercury. These industries consist of medical waste incineration facilities (27% of total), municipal waste combustion facilities (23% of total), utility boilers

(21% of total) and commercial/industrial boilers (12% of total) (U.S. EPA, 1996). The mining industry emissions were not included in these totals.

Neither the U.S. EPA nor the Nevada Division of Environmental Protection (NDEP) currently regulates mercury emissions from Nevada mines, other than as water pollutants (Johnson, 2003), or as hazardous air pollutants when a single source exceeds 10 tons (20,000 lbs). Except for primary mining of mercury, which no longer exists in the U.S., mercury emissions from mining operations are not regulated under the National Ambient Air Quality Standards Act (NAAQS), the National Emission Standards for Hazardous Air Pollutants (NESHAP), or under Nevada's Hazardous Air Pollutants (NHAP) program. In spite of the fact that the larger gold mines emit more mercury per facility than the average coal fired power plants, the imposition of regulations was seen as costly to both the regulating agency and to the mining industry (USEPA, Nevada Mining Partnership Program 2003).

One regulatory option available to the EPA falls under the Clean Air Act , allowing the EPA to establish Maximum Achievable Control Technology (MACT) air emission limits for the mining industry in a voluntary program. In late 2001 the EPA (Region IX), the NDEP and four gold mining companies in Nevada implemented the Voluntary Mercury Reduction Program (VMRP). As part of this agreement, the four companies agreed to take steps to reduce mercury stack emissions by 50% in three years time. The Toxic Release Inventory for Nevada indicates that these four Nevada mining companies emitted roughly 90% of all reported mercury from Nevada in 2001 to the atmosphere. (U.S. EPA, October 2003). The participating Nevada facilities underwent investigations at each site to better understand mercury sources, to explore emission prevention solutions, and then to begin implementation of these source reductions. Under this program atmospheric mercury emissions from Nevada gold mines have demonstrated decreases for atmospheric mercury release.

D. Mercury from gold mining

Mercury is commonly observed in gold bearing areas of Nevada, and a major mercury belt exists in western Nevada, although concentrations vary substantially depending on each site. Reports of concentrations of mercury in gold ore can range from undetectable to over 0.01% by weight. (USGS, 2003; van Zyl and Eurick, 2001). Management of mercury in Nevada generally falls in three categories: 1) Byproduct production captured for sale, 2)

Atmospheric emissions, and 3) Wastes deposited on site, primarily as a minor component of waste rock. (van Zyl and Eurick, 2001)

By-Product Production Recoverable for Sale

Extraction of gold from ore most commonly utilizes basic solutions of cyanide as the lixiviant. Cyanide, in the presence of oxygen, converts elemental gold to a water soluble gold cyanide complex. These process fluids are then passed over activated charcoal, which captures the gold cyanide complex, and is thus removed from the aqueous solution. Mercury closely follows the chemistry and mechanism of capture of gold cyanide. In the presence of cyanide, mercury is converted to a highly water soluble di- or tetra-cyano mercury complex.

$$Hg^{++} + CN^{-} \rightarrow Hg(CN)_2 + Hg(CN)_4^{2-}$$

Mercury cyanide complexes are then captured with gold cyanide on activated charcoal and can ultimately be collected via retorts as liquid metallic mercury (van Zyl and Eurick, 2001). Recovered liquid byproduct mercury is placed into either 76 pound or one-ton flasks and stored on site until it can delivered to commercial facilities that are able to further refine the mercury for use in a variety of products.

Additional mercury can be collected from roasters or autoclaves using air pollution control processes, and this source now constitutes the largest amount of mercury recovered for sale. In Nevada the majority of mercury recovered for sale is from a mercury recovery process at the Barrick mines in northeastern Nevada. In this case, mercury is recovered from roasters in a process which sprays mercuric chloride droplets in a scrubber cell for the roaster. Mercuric chloride reacts with elemental mercury and forms mercurous chloride (calomel), which is not volatile.

$$HgCl_2 + Hg^{o} \rightarrow Hg_2Cl_2$$

The calomel is captured as a precipitate and transferred to a mercury recycler who presumably converts it to elemental mercury and sells it into commerce.

This report has examined only the Nevada byproduct mercury production. The byproduct production data were mostly obtained through voluntary reports from the various companies, because mercury by-product production is not reported in a publicly available

manner. We were unable to obtain information on byproduct production in other states and also found that international by-product mercury production is not reported in a manner that is accessible. However, based on discussions with the recycling companies that receive mercury from mines, byproduct mercury is produced primarily from gold production, and these data will provide the majority of byproduct mercury production in Nevada.

Previous information on mercury by-product production was found to generally be unreliable. There does not appear to be a systematic approach for recording mercury byproduct production in Nevada or the U.S., and when available, the data are incomplete. Because by-product mercury is not released into the atmosphere, land or water, it is not reported in the Toxic Release Inventory (TRI). During the development of this study, it was our understanding that mercury production was reported to the Nevada Tax Board as part of their annual reporting on Net Proceeds of Minerals. Due to the relatively diminutive totals, the Tax Board does not publish them in their annual bulletins (Ewell, 2003), and they are apparently not available to the public. Requests for that information were initially unsuccessful do to concerns about proprietary information. However, following a subsequent request in early 2005, these data for the past 3 years were received and indicated that only one company, Newmont, submitted this information on mercury production to the Tax Board for that period. However the information was submitted as either pounds or flasks of mercury produced at individual mines or as dollars received for the mercury transferred to a recycler, and we could not determine the amount of mercury produced. Thus, at present there is apparently no systematic requirement for reporting mercury production in Nevada.

The Nevada Division of Minerals has kept records of mercury by-product production when the information was submitted. In Table D.1, the available Nevada data are provided. For example, in 1990, the total Nevada reported mercury byproduct production was approximately 112 metric tons (plus 504 metric tons of primary mercury). For this same year, all U.S. mines reported producing 114 metric tons of by-product (Sznopek, et al, 1999). Nevada produced approximately 60% of the nations gold in 1990. The mercury estimate for Nevada did not include the Hycroft/Crofoot/Lewis mine, which produced about the same amount of gold in 1990 that it did in 1995 when it reported 24.5 metric tons of byproduct mercury (Nevada Division of Minerals, 2003). Sznopek and coworkers (1999) also reported that 65 tons of U.S. byproduct mercury was produced in 1996, a year when both Paradise

Peak and Hycroft were still producing gold but did not report by-product mercury. In 1992, the EPA estimated that 70 tons of by-product mercury was produced in the U.S. (EPA, July 2002), although at that time both Paradise Peak and Hycroft mines were in full production, and while the mercury production at Paradise Peak was not reported, they produced 74 metric tons mercury in 1991, and up to 120 tons in previous years. Thus, the amount of mercury produced as byproduct mercury in the U.S. in previous years remains uncertain.

At the present time, however, we are unaware of any remaining large producers of byproduct mercury in the gold mining industry. Both the Paradise Peak mine (now closed) and the Hycroft Mine (residual leaching) are no longer significant sources of mercury. Another large producer of gold in California, the McLaughlin Mine, was historically a mercury mine and produced byproduct mercury, although specific production data are not available. This mine is now closed.

Table D. 1. Reported mercury by-product production from Nevada mines (in pounds).

	1988	1989	1990	1991	1992	1993	1994	1995	1996 - 1998	2000	2001
Hycroft								54,000		40,000	7,447
Paradise Peak	237,708	252,000	227,000	164,075							
Alligator Ridge		189									
Newmont	5548	16,264	12,388	8,512	16,872	14,187					14,192
Alhambra	162										
Borealis	1824										
Hog Ranch			7,935	8,208							
McDermitt (primary Hg mine)	846,488		1,008,216	0	0						

*All mines, except for the McDermitt Mine are gold mines. (from the Nevada Division of Minerals files, 2003)

Table D 2 is a breakdown in pounds of the total amount of by-product elemental mercury recovered for sale for the four companies. The by-product production totals, representing years 1999 – 2003 (partial) have been provided directly from Barrick, Placer

Dome , Queenstake (Jerritt Canyon mine, previously owned by Anglo Gold) and Newmont. While most of the mercury byproduct produced is undoubtedly listed in the table below, anecdotal accounts of other mines producing mercury, as well as indications of sales of retorts to mines, suggest that the list below is not complete, although current mercury production data from any additional mines was not available.

Table D. 2. Total Mercury By-Product Recovered for Sale (pounds and metric tons)

	1999	2000	2001	2002	2003
Jerritt Canyon	4,041	4,313	3,709	5,045	
Placer Dome (Pipeline)	831	814	1,068	903	888
Placer Dome (Bald Mtn)	1,203	248	**	**	**
Barrick	13,629	57,573	122,035	182,037	
Newmont (E. Operations)	*N/A*	14,192*	19,484	16,944	16,888
Newmont (W. Operations)	*N/A*		7,986	8,367	11,891
Total pounds		*77,174*	*154,282*	*213,296*	
Total Metric Tons		*35.0*	*70.0*	*96.7*	

* From Nevada Division of Minerals data (total Newmont byproduct mercury)
** Included in Pipeline byproduct production.

As displayed in the Table D.2, 96.7 metric tons of by-product elemental mercury was recovered in 2002 by the four gold mining companies. Approximately 85% of this mercury came from Barrick. Further information provided by Barrick staff (Table D.3.) reveals that the majority of this mercury came from the calomel mercury emission control process on the roasters. Calomel is sold in drums, while elemental mercury is sold in 1-ton flasks.

Table D.3. Mercury (lbs) recovered from various sources at the Goldstrike (Barrick) Mine (reported as mercury)

Year	1999	2000	2001	2002
Elemental Hg, Refinery	13,629	21,600	25,587	20,275
Elemental Hg, Roaster		1,250	29,870	28,933
Calomel, Roaster		34723	66578	132,829

Nevada gold mining companies generally store the by-product mercury for periodic sales to secondary production/recovery companies who receive and, if necessary, further purify the mercury. These companies include Bethlehem Apparatus Co. Inc., Hellertown, PA; D.F. Goldsmith Chemical and Metal Corp, Evanston, IL; and Mercury Waste Solutions, Inc., Mankato, MN (Reese, 2001). These companies also remove mercury from a variety of consumer-based products, including fluorescent lamps, dental amalgams, and a variety of control instruments. The received mercury is purified through further retorting and washing processes as necessary to meet various product standards. Once purification is complete, the recyclers will then sell the refined mercury to various industries, both domestic and international, and it is used in commercial products such as lighting, dental amalgam, thermometers, etc.

Barrick sells their by-product elemental mercury recovered for sale to Bethlehem Apparatus in Bethlehem, PA. Cortez has sold its mercury to Mercury Waste Solutions in Union Grove, WI. and Newmont sells its mercury to the D.F. Goldsmith Chemical and Metal Corp. Phone discussions with representatives of the three recovery companies indicated that Bethlehem Apparatus and D.F. Goldsmith are the largest recipients of by-product mercury. The D.F. Goldsmith representative reported approximately 20 tons of mercury are received annually from the gold mining industry. During March of 2005, the price of a flask of mercury was over $800 per 76 pound flask, up from $200 per flask in 2004. A representative of Bethlehem Apparatus indicated that they receive metallic mercury, mercuric chloride and mercury-containing material from scrubbers and other mercury-trapping process material.

The demand for mercury in the U.S. is larger than its supply, and mercury continues to be imported.

Two of the three representatives were interested in obtaining information about Nevada's mercury by-product production. Each of the representatives, when asked if there were any problems in how mercury was being transported to the secondary production facilities, reported that the procedures worked well and without notable problems.

Management Options: The U.S. demand for mercury is estimated at 150 to 200 tons per year. The demand has been substantially reduced over the past 30 years due to increasing Federal and State regulation on its use in consumer products (Sznopek and Goonan, 2000). The mercury demand in 1996 was 372 tons, down from 720 tons in 1990. The current U.S. demand could fully be supplied by secondary recovery of stored mercury or from the U.S. strategic stockpile, currently reported to be greater than 7,000 tons from U.S. military and chlorine-caustic manufacturing facilities (Brooks, 2003). Because of the concerns about mercury toxicity, keeping mercury out of the environment continues to be a goal of both national and international regulators and scientists. Suggestions have been advanced that mercury should be sequestered in repositories which prevent it from being added to the global burden of mercury (Bender, 2000). Such methods exist, and include conversion to mercuric sulfide, which is stored in permanent repositories (UNEP, 2003).

Should new byproduct mercury be sequestered and removed from commerce? While removal of mercury from the environment is generally recognized as important, there is still a demand for mercury, and the several smaller gold mining sources of mercury need to have method for safe and cost-effective management. Even with a production of over 100 metric tones per year, byproduct production is a minor component of the total mercury presently available. Under the current legal framework, liability for mercury is removed from the mine which produced it when the product is sold to commercial production recovery facilities such as Bethlehem Apparatus. Since byproduct mercury will continue to be produced, there appears to be no compelling reason to establish a process for permanent sequestration of the byproduct mercury. Unless a national (and international) mechanism exists to permanently remove mercury from the market, retention of the present market mechanism for source management of the byproduct mercury appears prudent. Additionally, the significant price

increase in mercury in the recent past is sufficient that primary mercury mines may again become economically feasible. Any mercury management scheme of byproduct mercury that involves sequestration should consider the utility of this approach if the price structure encourages new mercury mine development, either in the U.S. or abroad. Management of metallic mercury is presently under extensive discussions in both the UNEP as well as the European Union, and byproduct mercury should be considered as a component of the larger mercury management plans.

Atmospheric Emissions of Mercury

Because metallic mercury is a relatively volatile liquid, it can escape to the atmosphere, particularly from thermal processes. Several mercury emission points from gold mines exist, and include: roasting or autoclaving, regeneration of carbon used to capture gold cyanide, retorting of mercury during refining, electorwinning cells, and, finally volatilization from waste rock and other mine residue. The amount released to the atmosphere at each point can vary dramatically depending on the ore concentration, the specific process utilized and the effectiveness of the mercury control measures.

For those ores that are unoxidized, the single largest atmospheric source of mercury is from sulfide or carbonaceous ore roasters, autoclaves or other thermal processes that convert reduced (sulfidic or carbonaceous) gold ore to a form that can be more efficiently extracted with cyanide. In these ores, mercury occurs primarily as mercury sulfide (HgS), which is also thermally oxidized and converted to either metallic (mostly) or divalent mercury. The metallic mercury is volatilized and released into the atmosphere, in the absence of any controls.

$$HgS(s) + O_2(g) + heat \rightarrow Hg + SO_2(g)$$

The second major source of atmospheric release of mercury is from the processes that convert gold cyanide to dore bars. Because mercury follows gold through the processing circuit (discussed previously), and several of these processes utilize elevated temperatures, mercury can be volatilized during gold recovery. These processes include carbon regeneration units (reactivate the carbon that was used to capture the gold cyanide)

electrowinning (convert gold to an elemental form), and refining (thermal processes that purify the recovered gold). In years past, anecdotal accounts are common where no retort was utilized during refining, and mercury condensed on the metal roofs of the processing facilities and formed visible droplets on the sides of the building. The charcoal, used to initially capture the gold cyanide and mercury cyanide complexes, is reused. It must be thermally treated for reactivation, and during this process residual mercury on the carbon can be volatilized. This charcoal re-volatilization point can be a substantial fraction of the total amount of mercury released from a specific mine. For each of these sources of mercury, control measures are available to capture a majority of the mercury and are presently being utilized in most Nevada mines. The efficiency of the capture of this form of mercury is variable, depending on the specific processes utilized.

A third type of atmospheric release of volatilized mercury from gold mining is from waste rock dumps, tailings facilities and extracted heap leach piles. This source of mercury is reported to be relatively minor, although methods for measurement of this volatilized mercury do not appear to be well-tested, and direct measurements are scant to non-existent.

Of the releases of mercury into the environment, the most problematic are those where exposure to living systems is most likely. While mercury release to land in a secure land fill may be of a much larger magnitude, this mercury is most often unavailable and carries a relatively low risk. Releases to surface water and to the atmosphere are much more biologically available and these releases, while much smaller, can present much greater environmental risks. Thus, atmospheric emissions are a particular concern for gold mining, since the quantities that have been released from several of the mines are large. Two sets of data have been used to estimate the recent and current amount of mercury released from gold mines in Nevada. The first is the TRI data and the second is the Voluntary Mercury Reduction Program (VMRP). These data should be generally consistent, although some differences have been noted.

TRI Reported Data

The Toxic Release Inventory (TRI), was formulated in 1986 within Section 13 of the Congressional Emergency Planning and Community Right-to-Know Act (EPCRA). This inventory requires specific industries to report releases of particular chemical and chemical

categories released to the air, land and water from industries ranging from energy production to metal mining. The "TRI is designed to provide citizens with information about chemicals being used, processed, manufactured, or released from facilities in their communities. The basic premise of TRI is that citizens have a 'right to know' about toxic chemicals that are handled or released in their community" (State of Nevada, 2000). The EPA, in 1997, changed the TRI reporting requirements to include releases within the metal mining industry.

The section of TRI that is most relevant to this study is the Form-R. Form-R is broken into eight sections:

1. Reporting Year
2. Trade Secret Information
3. Certification
   - This section states who is responsible for the forms authenticity.
4. Facility Identification
5. Parent Company Information and the Quantity of the Toxic Chemical Entering Each Environmental Medium On-Site
   - This section encompasses all data for mercury released to land on-site.
6. Transfers of the Toxic Chemical in Wastes to Off-Site Locations
   - This section gives the name of the off-site location where mercury was sent for further refinement or disposal.
7. On-Site Waste Treatment Methods and Efficiency
   - On-Site Energy Recovery Processes
   - On-Site Recycling Processes
8. Source Reduction and Recycling Activities
   - This section is an accumulative total of data from sections 5, 6 and 7.
   - This section shows columnar references of data from the previous reporting year, the current reporting year, and expected reporting totals for two years in the future.

The data from Form-R is collected on paper copies from the reporting facilities and sent to the appropriate regulatory agency. Within a two year period, the forms are then finalized into electronic copy for public viewing over the web. In this two year period, facilities can change and alter their respective Form-R if, for instance, it is found that there was an initial error in calculating release. It is the understanding in this report that release documented in 2003 TRI paper copies are not finalized until the EPA finalization occurs in the summer of 2005. 2002 TRI reports were published on the web in the summer of 2005, and are therefore finalized. At the EPA's TRI homepage (www.epa.gov/tri/report/trime/), one

can narrow down a search by chemical, facility, or industry using the helpful *TRI Explorer* search engine application.

Because the exact form of mercury is unknown (although assumed to be primarily metallic mercury, Hg^o) that is released into the atmosphere, the total amount of mercury is expressed as "mercury" or "mercury compounds". The atmospheric emissions are presented below in table D.4.

Total Air Emission includes "Stack or Point Source Air Emissions" and "Fugitive or Non-Point Air Emissions". Stack or point source air emissions are from stacks, vents, pipes or ducts, while fugitive or non-point source air emissions is mercury released from less well defined sources. In table D-3, point source emissions are reported for the individual mines, and total fugitive emissions are reported for the entire mining industry in Nevada. Reported fugitive emissions generally are less than 5% of the point source emissions, except for 2000, when Cortez Gold Mines reported 910 pounds of fugitive air emissions. Similar high amounts were not reported from this mine in previous or subsequent years.

The EPA Report to Congress (1997) stated that in the US, the highest concentration of anthropogenic emissions is east of the Rocky Mountains, and that the Great Basin region generally has the lowest emissions rates (ES-10). Furthermore, the Report suggests that combustion point sources, such as utility and industrial broilers make up for 86.9% of 1995 mercury emission in the United States (ES-6).

In 1998, four of the gold mines from Nevada reported (TRI data) individual facility mercury stack emissions totaling 13,560 pounds, making Nevada the second largest mercury emitting state, after Texas based on TRI data in that year. One facility alone, the Jerritt Canyon Mine, reported release of 9,400 pounds of the 13,560 pound totals released by all of the reporting mines. The amount of mercury released by gold mines has decreased since that time, based on TRI data, particularly from Jerritt Canyon (790 lbs in 2003). In comparison with the average coal-fired power plants in the East, emitting an average of 250-400 pounds per year of mercury, the individual Nevada gold mines that have roasters are still relatively large sources of anthropogenic emissions of mercury.

Regulation of mercury releases is complicated by the fact that mercury commonly occurs naturally in the earth and atmosphere. In the Report to Congress in 1997, the EPA estimated that 5,500 tons of new mercury was released world wide into the atmosphere in

1995 from all sources including natural emissions, oceanic emissions, and anthropogenic emissions. In the same year, it was reported that 159 tons (or 3% of total) were emitted into the atmosphere due to US human industrial sources, such as coal-burning utilities, municipal and hospital waste incinerators, industrial broilers, chlor-alkali plants, and cement manufacturers (Report to Congress, 1997). The report did not include emissions originating from mining operations. In 1998, seven Nevada mines reported emission release of approximately 7 tons (or 4.3% of total US) of mercury emitted into the atmosphere (Johnson, 2000). In 2001, TRI data shows that four Nevada mining companies reported releasing 12,121 pounds (or 8.7% of US total) of mercury and mercury compounds as point source (stack) emissions. This amount dropped to 6.5% of the total U.S. emissions in 2002, and 3.6% in 2003, using the TRI data. While the total amount of mercury released by all sources remains uncertain, due to measurement and reporting inconsistencies, the TRI data does suggest a reduction in the total and relative amount of mercury released by Nevada mines.

Table D.4. Mercury Air Emissions from Precious NV Metals Mines (in pounds)

Facility, Point Source Emissions	1998	1999	2000	2001	2002	2003
Placer Bald Mountain			0	0	0	5*
Barrick Goldstrike	1,500	1,400	1,467	1,243	1,287	1,438
Coeur Rochester	0	0	0	1	0	0
Cortez Joint Venture Pipeline			2,200	1,500	1,351	925*
Echo Bay McCoy Cove (Newmont, 2003)			224	363	118	6
Florida Canyon Mine			2	1	1	1
Getchell	0	1	0		0	
Glamis Marigold			4	0	1	0
Jerritt Canyon Joint Venture	9,400	9,400	6,700	7,990	4,740	790
Ken Snyder			11			
Newmont Carlin North			3	3	2	3
Newmont Carlin South	53	71	80	490	513	550
Newmont Lone Tree	0	0	1	5	1	1
Newmont Rain			0	0	0	
Newmont Twin Creeks	2,200	1,200	630	570	530	550
Ruby Hill			0	0	0	0
Smoky Valley Common				0	0	0
Total from Metal Mining (Point source- stack)	13,153	12,072	11,322	12,162	8,544	4269
Fugitive Nevada Total (from mining)	423	95	1,183	212	105	111
Nevada Total (all industries, point and fugitive sources)	13,576	12,167	12,912	12,959	8,992	4,689

Toxics Release Inventory data, U.S. EPA, 9/14/2005)

*This differs from the TRI data slightly due to the Placer Domes finding that they had recovered mercury in a refinery baghouse, which reduced the amount of mercury previously reported on TRI data. This amount is reflected in the totals at the bottom of the table.

Table D. 5. TRI Data: Ranking (2003) of states for atmospheric point source release of mercury and mercury compounds for 2001-2003 from all industries.

Rank (2003)	State	Pounds released (2001)	Pounds released (2002)	Pounds released (2003)
1	Texas	14,766	14,505	13,449
2	Pennsylvania	9,089	9,177	10,001
3	Ohio	11,405	9,625	8,999
4	Illinois	5,963	5,610	7,006
5	Indiana	7,168	7,645	6,246
6	Alabama	5,903	4,641	5,356
7	California	5,668	4,173	4,677
8	**Nevada**	**12,959**	**9,069**	**4577****
9	West Virginia	6,282	4,051	4,295
10	North Carolina	4,164	4,507	3,876
11	Kentucky	5,256	3,670	3,598
All	**States**	**139,021**	**132,022**	**129,849**

* Note that this list does not include fugitive emissions of mercury, which are generally less than 10% of the point source (stack) emissions, except for West Virginia, Ohio and Alabama. ** Adjusted for mercury emissions changes from Placer Dome (see above),

The TRI data in Table D.3 show rather clearly that for the years 1998 to 2003, gold mines were the largest industrial source of atmospheric release of mercury in Nevada. Table D.4 shows that Nevada in 2001 had a #2 U.S. ranking for point source mercury atmospheric discharge and #8 ranking in 2003. Based on discussions with staff at the Cortez Pipeline mine a mercury capture system on the carbon kiln is likely to result in an additional reduction of future mercury emissions at that site. Further reductions in mercury emissions are likely to be less dramatic than in previous years and will depend on the type of ore being mined as well as the improvements in mercury control technology that will be utilized.

Voluntary Mercury Air Emissions Reduction Program (VMRP) data.

As discussed previously, the four companies with the largest emissions agreed in 2001 to participate in the Voluntary Mercury Air Emissions Reduction Program. In lieu of a lengthy regulatory process, the four companies, the Nevada Division of Environmental Protection and the U.S. Environmental Protection Agency all agreed that a voluntary approach for reducing mercury emissions would be a much more rapid process for mercury reduction. During the first 4 years of the TRI program, two of the mines showed substantial reductions in mercury emissions. Other mines had previously installed mercury control equipment prior to the VMRP program, and had already reduced mercury emissions from what was (potentially) previously emitted. Given the focus on the present voluntary program, further reductions in emissions are expected, although less dramtic than in the first four years of the program. The VMRP data are much more extensive than found in the TRI reports, and the VMRP reports are available from the Nevada Division of Environmental Protection (NDEP), but are summarized below in Tables D. 6. through D. 10.

The actual reports provide additional detail and interested persons are referred to staff of the NDEP for a complete copy of the reports. Several issues should be noted regarding these data. First, the methods used to determine mercury emissions are not generally provided, although individual reports discuss (e.g. Jerritt Canyon) issues of how mercury is measured at various heights in the stacks, and how these affect estimates of atmospheric emissions. Second, the estimates of mercury release, are, in some cases, based on actual source test measurements made two years earlier (e.g. Gold Quarry). While the data presented in the VMRP reports are the best available, improved methods for actually measuring mercury release are desirable, as would be increased testing frequency.

Table D 6. VMRP data from Barrick Goldstrike in pounds (NDEP, 2004)

Source	Emissions (2001, Baseline)	Emissions (2002)	Emissions (2003)	Comments
Retorts 1,2,3	11	11	11	
Mill furnace	1,402	161	161	Carbon column added. March 2002
Electrowinning cell	613	Included above	Included above	Emissions sent through mill furnace carbon column
Carbon kiln	4380	4380	1927	Carbon filtration unit added in March, 2002
Autoclave circuit	548	548	548	Controls installed prior to 2001
Roaster	814	814	166	Controls installed prior to baseline year
Total	7768	5920	2819	

Barrick Goldstrike chose to pursue the MACT Equivalent Tract under the VMRP. Many of its controls were installed before the VMRP went into effect. Some controls were installed shortly after the VMRP went into effect. Because the VMRP did not prescribe how the operations were to report, Barrick chose to report in a manner that would reflect the efficiency of the controls, consistent with its election of the MACT Equivalent Tract. Because each emission source does not in reality operate 8,760 hours per year and hours of operation of a given piece of equipment varies from year to year, to normalize data between pre- and post-control periods, and thus slow control efficiency, Goldstike multiplied both pre- and post-control emission factors by 8,760 hours. Thus, Goldstrike's VMRP data reflects the potential to emit of each of its emissions units rather than actual emissions. By contrast, Goldstrike's TRI data reflects actual emissions based on actual hours of operation.

Table D7. VMRP data from Cortez Joint Pipeline Project (Placer Dome) in pounds (NDEP, 2004)

Source	Baseline Emissions (1998)	Emissions (2001)	Emissions (2002)	Emissions (2003)	Comments
Carbon in leach	981.4	249.3	218.3	261	
Carbon in columns	14.7	41.2	67.4	91.1	Carbon column added
Area 28 heap leach pad carbon columns	134.8	234.7	293.9	395	Emissions sent through mill furnace carbon column
Refinery furnaces	3174	160.2	473.3	178	Substantial reductions are due to chemical treatment (see text)
Total	4305	685.4	1053	925	

Table D 8. VMRP data from Jerritt Canyon (Queenstake) in pounds (NDEP, 2004)

Source	Emissions (2001) (Baseline)	Emissions (2002)	Emissions (2003)	Comments
Carbon regeneration kilns	1543	294	0.28	Venturi mercury wet scrubbing/carbon polishing system installed in March
Refinery	365	250	(included above)	Emissions routed to carbon regeneration kiln control system in September
Roaster west	4667	2777	599	Sodium hypochlorite injection system installed in September, 2002
Roaster east	1405	1417	188	Sodium hypochlorite injection system installed in September, 2002
Total	7980	4738	787	

Table D 9. VMRP data from Twin Creeks Mine (Newmont) in pounds (NDEP, 2004)

Source	Emissions (1999) Baseline	Emissions (2001)	Emissions (2002)	Emissions (2003)	Comments
Autoclave phase I	844	119	121	120	Venturi Scrubber
Autoclave phase II	380	112	119	126	Venturi Scrubber
Retorts A,B,C,D	3	3	3	3	Carbon Columns
Juniper kiln	252	253	268	125	Wet scrubber
Electrowinning cells	3	3	3	3	
Pinion kiln	113	67	2	0	Wet scrubber
Induction furnace	4	4	8	4	
Total	1599	561	524	381	

Table D 10. VMRP data from Gold Quarry Mine (Newmont) in pounds (NDEP, 2004)

Source	Emissions (2001) Baseline	Emissions (2002)	Emissions 2003	Comments
Mercury Retorts	24.35	18.54	17.71	Mercury condenser and scrubber previously installed
Furnaces	15.19	15.72	11.43	Carbon adsorption unit previously installed
Carbon kilns	31.23	30.74	55.40	Venturi scrubber; carbon adsorption unit previously installed
Prenant and barren tanks	12.90	12.90	12.90	Carbon adsorption unit and tank scrubber previously installed
Ore Preheater	85.05	90.74	91.33	Baghouses and SO_2 scrubber previously installed
Ore Roaster	23.97	25.75	25.60	Wet scrubber, electrostatic precipitator, SO_2 scrubber and mercurous chloride scrubber previously installed
Mill 6 drying/grinding circuit	291	314	328	Baghouses for particulate
Total	484	508	542	

The differences between the TRI atmospheric emissions data and the VMRP data are, in some cases, significant. In addition to the differences of Barrick's VMRP and TRI data, as discussed above, the Cortez mine reported 1,500 pounds to TRI in 2001 while reporting 685 pounds to VMRP during the same year. Other differences for the 2001 data were relatively small with Jerritt Canyon reporting 7,990 vs. 7,980 lbs, and Newmont Twin Creeks reporting 570 vs. 561lbs. respectively for TRI vs. VMRP data.

As discussed previously, measurements of mercury release are difficult, and the VMRP program appears to have increased the focus on these measurements. As can be observed in the tables above, the amount of information from VMRP data is more detailed than presented in the TRI data. The inconsistent data show the need for agreement on the methods for measurement and the number of actual measurements to ensure that the data provided is consistent and accurate. Reliable methods that will both reduce the cost of analyses and allow much more convenient measurement of mercury in the various emission sources appear to be available. Frontier Geosciences, a laboratory in Seattle, Washington is now routinely measuring mercury emissions at a cost of $100-$150 per sample (Bob Brunette, Frontier Geosciences, personal communication, 2005).

A general concern about the VMRP data that exists is the definition of the Maximum Achievable Control Technology (MACT) standards that have been applied to gold mines. There does not appear to be a rigorous technical definition or comprehensive review of the definition of MACT, and this should be evaluated as part of a larger discussion of mercury regulation in gold mining.

For comparison purposes, the new Clean Air Mercury rule released in March of 2005 (USEPA, 2005) has provided limits for mercury emissions from coal fired power plants in each state. In 2002, TRI data showed that the three Nevada coal fired power plants released 524 pounds of mercury to the atmosphere. The new mercury rule will require the total amount of mercury from these three plants and all new similar power plants to be no more than 570 lbs in 2010 and 224 lbs by 2018. This rule also requires extensive monitoring of power plant emissions to ensure that the reported quantities are being measured on a routine basis. Thus, while gold mining emissions are not regulated under the new rule, the

differences in mercury emissions between coal fired power plants in Nevada and gold mines are likely to be a topic of discussion.

Mercury released to surface impoundments or waste dumps:

Because very large amounts of rock are excavated in gold mines, particularly in open pit mines, the amount of waste rock containing mercury is large and the total amount of mercury in these waste facilities is consequently very large. Waste rock constitutes the single largest release of mercury in the Toxics Release Inventory reports. For example, in 2002 the total amount of mercury released to surface impoundments or other land disposal was 4.68 million pounds. Similar amounts were reported in previous years. We have not included these data in this report, although they are available from the EPA Toxics Release Inventory web site.

While these releases are certainly non-trivial, the large tonnages of mercury released do not provide a realistic sense of the relative risk of these sources of mercury. If the mercury remains in the rock or other waste material and is appropriately contained in waste disposal units, it generally does not present an increase in environmental risk, compared to when that same mercury and rock were geologically isolated before the rock was brought to the surface. Consequently these values, although indeed very large, need to be considered with a perspective of risk.

In certain circumstances, particularly in acidic drainage, release of this mercury can be important in specific watersheds. Additionally, a relatively unknown component is the amount of mercury that is photochemically released from surface rock. Additional research is required to assess this source of atmospheric mercury, and whether it is a significant source, relative to other atmospheric releases. Undoubtedly, however, this risk will not be proportional to the large tonnages reported in the TRI data.

Company Profiles in the Voluntary Mercury Reduction Program (VMRP)

The companies represented in the VMRP include three of the largest gold mining companies in Nevada- Newmont, Barrick, and Placer Dome, and a mid-sized mining company, Queenstake. The gold production of these companies comprises about 80% of the total 7,318,000 million troy ounces of Nevada gold production in 2003 (Nevada Bureau of Mines and Geology, 2003). If Round Mountain Mine is included, jointly owned by Kinross

and Barrick, the number increases to 87-89% of gold production in Nevada. The Round Mountain Mine has not reported significant amounts of mercury released into the atmosphere from the TRI data, and apparently has low mercury content in the ore. Also, based on TRI reports, greater than 90% of the mercury released to the atmosphere is reported by the VMRP companies. A short discussion of each mining company is presented below, to provide a background on the diversity of issues that exist with each mine and mercury. Substantial differences exist in ore type as well as approaches for control of mercury at each mine. Mercury emission controls are driven by both the need to maintain worker environmental health and safety, as well as reduction in mercury released to the atmosphere.

Jerritt Canyon Joint Venture

Gold was discovered at Jerritt Canyon, 60 NE of Elko, NV, in 1973. Mining began in the summer of 1980 on approximately 125 square miles in the Independence Mountain Range. The first gold bar was produced on July 4, 1981. During that first year, operation consisted of producing 23,000 oz of gold. Today, Jerritt Canyon Joint Venture (JCJV) produces approximately 360,000 oz of gold annually.

Until the mid-1990's, JCJV conducted mostly surface mining. Surface mines were planned and permitted with the USFS and NDEP prior to disturbance. Since then, JCJV has mined underground as they have identified ore bodies at increased depths. All underground mines are also planned and permitted with the USFS and NDEP prior to disturbance.

In conjunction with the Voluntary Mercury Reduction Program, Jerritt Canyon has been upgrading their production processes with carbon filter systems. In 2001, JCJV spent $170,000 in carbon kiln upgrades for emission controls. In that same year, they spent $120,000 in a hypochlorite system for emission control in the roasters. Each year forward, JCJV will be spending roughly $60,000 per year in emission analysis of their facility.

JCJV assumes there is approximately 1 million oz of gold remaining in reserves that will keep the facility operational for 3-4 more years. By adding up the total cost of control devices beginning in 2001 until the end of their anticipated reserves (2007), JCJV will have invested in the neighborhood of $1.25 million on environmental compliance upgrades. Average gold production through 2007 is estimated at 300,000 ounces per year. On average, control device spending at JCJV will roughly be $.60 per ounce of gold produced.

The gaseous mercury emissions from Jerritt Canyon's two large roasters of mercury began to be treated with roaster carbon scrubber systems in 2001. The fourth quarter of 2002 was when most of Jerritt Canyon's mercury controls were implemented for control processes. At the carbon regeneration kiln, Jerritt installed a venturi mercury wet scrubbing/carbon polishing system that reduced emissions from a 2001 baseline by 81%. At the refinery, installation of ducting from the refinery to the carbon regeneration kiln system has reduced emissions from the 2001 baseline by 31.5%. Finally, Jerritt Canyon's addition of a hypochlorite injection system in late 2002 produced the cumulative 90+% reduction in mercury emissions from the facility. The aggressive efforts at this mine have been primarily responsible for the substantial reductions in total mercury emitted by Nevada mines. This company mine went from being the single largest source of atmospheric release of mercury in the U.S. in 2001 to the lowest of the VMRP companies in 2003.

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Cortez Pipeline Joint Venture

The Cortez Pipeline mine is located roughly 90 miles South-West of Elko, NV, producing roughly 1 million oz of gold per year. Cortez has experienced elevated mercury in process fluids in the recent past. These concentrations equated to potential hazardous working conditions with potentially elevated exposure levels of mercury to employees, and concerns about employee exposure were a primary driver for implementing reductions in mercury in the process fluids. The majority of ore at this mine is oxide and does not require thermal treatment for gold recovery.

In 1999 and in conjunction with the Voluntary Mercury Reduction Program, Cortez began initiating a chemical treatment using an organic dithiocarbamate mercury trapping agent from the Cherokee Chemical Company called UNR-811. UNR-811 is added to process fluids which then complexes aqueous mercury as a stable organic sulfide precipitate (Upton, 2003). The complexed mercury is attached to either the heap material, or is carried to the tailings impoundment as a complex aqueous slurry. When trapped on heap material or rock, it does not appear to be remobilized, and represents a novel approach to management of mercury whereby employee exposure is reduced while the reduction of mercury in the process fluids is realized. In 2005 a mercury capture system will be added for capture of the

mercury emissions from the carbon regeneration kilns and designed to substantially reduce the mercury release from this primary source.

Barrick Goldstrike

Barrick Goldstrike, located 60 miles North-West of Elko, NV, produces roughly 2 million ounces of gold per year. Barrick is currently the largest single gold mining facility in the United States. In 2001, Barrick completed the development of a new roasting facility. This air pollution control at this facility cost an estimated $45 million (included in this price is the cost of Research and Development). Barrick has estimated that roughly 17 million ounces of their estimated 20 million oz of reserves will pass through the new facility for roasting; the remainder will be processed through the autoclave.

Barrick has several mercury recovery (byproduct) systems within their facility that capture mercury that would potentially otherwise be emitted. The first is at the roaster where mercury is recovered using a calomel mercury capture system and an electrostatic precipitator. The second source of mercury comes from the retort recovery process between the electrowinning cells and the furnace. All mercury collected on carbon scrubbers is is sent off-site. Previous installations of wet venturi scrubbers in the carbon kiln and autoclave circuit, carbon filters in the mill furnace, mercury condensers and carbon scrubbers in the retort units, and process controls in the roaster consisting of wet gas condensers and a mercury absorption tower, all contribute to the reduction in Barrick's mercury emissions. This installation has a large and diverse array of mercury sources, as well as the diverse array of mercury control methods.

Barrick is currently the largest producer of byproduct mercury in Nevada. All of the mercury by-product at Barrick is sold to Bethlehem Apparatus.

Newmont Gold Company

Newmont has been actively mining and recovering gold in Northern Nevada since 1965. In Nevada, Newmont currently mines 14 open pits and 5 underground operations. Combined with all of Newmont's international operations, it is the largest gold producer in the world. Unlike the other companies in the VMRP, Newmont has several sites in Nevada that potentially can produce mercury, although these are generally grouped into the western

operations (primarily Twin Creeks) and the complex near Gold Quarry in the Carlin Trend. At Newmont's numerous operations in Nevada, two general technologies of wet scrubbers and sulfur-impregnated carbon filters are utilized for mercury capture and management. Technologies utilized at Newmont have been in place for many years and many were in place prior to the requirement that mines report under the Toxic Release Inventory reporting program and prior to the establishment of the Voluntary Mercury Reduction program. At one process area at the Twin Creeks mine, a new technology (to Newmont) is being tested that uses a wet scrubber with a hypochlorite solution.

Mercury recovered in the processes is ultimately captured in two refineries at Newmont's operations in Nevada. Newmont's byproduct mercury from Nevada is shipped to DF Goldsmith.

E. Conclusion

Nevada gold mines are a previously unrecognized source of large atmospheric mercury releases, and constitute the largest source of new byproduct mercury in the U.S. Data for estimating mercury released to the atmosphere have been available only since the TRI reporting requirements were applied to mines in 1998 and only sporadically for the amount of byproduct mercury produced. Mercury content in ore is highly variable, and any determination of releases of mercury to the air or byproduct production require direct measurements at each mine. It is apparent, however, that atmospheric mercury releases have decreased in recent years (and also an increase in mercury byproduct production) due, in part, to the efforts applied via the VMRP program.

Byproduct mercury production and mercury emissions are closely related, since most of the byproduct mercury is recovered through atmospheric emission control systems. At present there is no requirement for reporting byproduct mercury produced from each mine, nor is there specific requirements for actually measuring mercury emissions. There is also no requirement for measurement of mercury in the ore that is processed. More complete reporting in all of these categories would allow a better assessment using a mass-balance approach of mercury management from gold mines.

The demand for commodity mercury in the U.S. is decreasing due to a substitution of mercury-containing products to similar functioning non-mercury product. World demand is also decreasing, as manufacturing companies are turning away from its use in common household and industrial products. Ceramic composites are replacing dental amalgams, digitized instruments are replacing mercury thermometers, membrane cells are replacing mercury cells in electrolytic production of chlorine and caustic soda, and indium compounds are being substituted for mercury in alkaline batteries. Governments from many parts of the world are regulating its use and manufactured applications, due to increasing public concerns regarding mercury contamination and health warnings. Given public concerns however, mercury use remains in many products, and a demand will continue to exist for the foreseeable future. Byproduct mercury from gold mines is best processed through recycling facilities that help to meet demand.

A brief comment was made in this report comparing mercury regulations in the coal fired power plants to mercury in gold mining. While mercury releases from gold mines are not included in the new mercury rule for power plants, it is useful to examine how these plants are meeting the new and stringent requirements. The analytical requirements for mercury measurements in power plants are potentially applicable to gold mines, as are its mercury control technologies.

Acknowledgements

We wish to thank the U.S. EPA Region IX for support of this study, and representatives of the State of Nevada NDEP (particularly Jolaine Johnson) and representatives of the VMRP companies for providing valuable contributions and comments on this report.

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Appendix 1, Mercury Supply and Demand in the U.S.

Secondary Production/Recovery

Chlor-Alkali plants are part of a growing source for secondary production/recovery of mercury for U.S. commercial products. In 2002, 15 of the 24 chlor-alkali plants in the U.S. closed their doors. It was estimated in 1996 that an estimated 3,000 tons of recoverable mercury exist in all 24 U.S. sites (Sznopek, et all, 2000). The un-used mercury cells from these plant closures have re-entered the consumer market. Deep discounts are typically given for the sale of scrap mercury. Here again, as in the purchasing of by-product mercury from mining operations, refineries buy mercury cells used in the plants and retort them to produce pure elemental mercury. The refinery then sells this mercury back to the market, creating a source of revenue for their company. The chlor-alkali plants have then removed their liability of mercury, and in the process have gained a percentage share of capital in return. Phase out periods for the remainder of the plants are expected to extend thirty years (Sznopek and Goonan, 2000). Given this time frame and the estimated total of 3,000 tons recoverable, chlor-alkali plant are in a position of supplying the U.S. market with 100 tons of mercury per year for 30 years.

United States Government Stockpile

The U.S. Government stockpile is yet another source for supply of mercury to the United States market. The U.S. Department of Defense and the US Department of Energy owns, as of September 2002, a 4,435 ton stockpile of mercury (Brooks, 2003). This stockpile threatens the price of mercury, both in the US and abroad. If this stockpile is slated for release, then unit supply will magnify while the unit price will decrease. The government sold off quantities of the stockpile through 1994, however, due to environmental concerns, sales has since been suspended (Brooks, 2002).

U.S. and World Sources of Elemental Mercury

The EPA Report to Congress states that US mercury demand of manufacturers in a myriad of product applications can be attained from five main sources:

(1) Primary production
(2) By-product production recoverable for sale
(3) Secondary production/recovery
(4) Government stock
(5) Imports

Primary Production

Primary production of mercury comes from mercury mines. The last primary mercury mine in the U.S. was the McDermitt mine in Northern Nevada. The mine shut down in 1990, after providing 448 metric tons of mercury in that year. U.S. primary mercury production peaked in the late 1970's, producing 2,500 metric tons per year (Jasinski, 1994).

Primary production mercury mines are still in operation in other countries, including Spain, China, Kyrgyzstan, Russia, Ukrane, Slovenia, and Algeria (Brooks, 2002). World production of primary mercury for 2002 was reported to be 1,400 metric tons (Brooks, 2003). Between 1990 to 2000, the average world primary production of mercury was 2,000 metric tons annually (Reese, 2001). World reserves are reported to total roughly 600,000 metric tons, primarily located in Kyrgyzstan, Russia, Slovenia, Spain and the Ukraine (Brooks, 2003).

Decreases in world demand for mercury, in large part due to environmental and health concerns, has been reflected in decreased production of primary mercury over the past two decades. Table A-1 are the production rates of the three largest producers of primary mercury by country, the world production yearly totals, and U.S. primary production totals pre 1991.

Table A-1

U.S. and World Primary Production (metric tons/year)

	1979	1990	1998	1999	2000	2001	2002
Algeria			**224**	**240**	**216**	**320**	**800**
Kyrgyzstan			**250**	**300**	**275**	**300**	**250**
Spain			**675**	**433**	**500**	**500**	**300**
World Total			**1,580**	**1,310**	**1,350**	**1,490**	**1,800**
United States	**2,500**	**448**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

* Source: Brooks, 2002

Supply and Demand

Many legislative events have occurred over the years regarding public health impacts of mercury, however, the single most significant event affecting mercury production and price has been the 1971 U.S. EPA declaration that established mercury as a hazardous air pollutant.

In recent years, Federal and State governments have implemented regulations that decrease the use of mercury in common household and commercial products. These efforts have been driven by the need to prevent mercury from entering our common waste streams. Several states have passed legislation which aim at the reduction of mercury in waste. Such legislation strives to ban the sale of certain mercury-laden products and implement collection and recycling programs for these products. In addition to governmental regulations, a number of industry and non-governmental organizations have been making impressive steps to reduce their use of mercury in the market products.

According to Reese, the USGS reported the total 1998 U.S. demand for mercury was 200 tons. Consumption of mercury in 1990 was 720 tons. Consumption in 1980 was 2,042 tons. Market demand reveals a 90% reduction in mercury use in a twenty year period. 2001 demand totals for mercury are estimated at 200 tons, "estimated at 30% - 50% for chlorine manufacture, 30% - 50% for electronics, and the balance for other uses such as dental applications, lamps, switches, and thermostats" (Brooks, 2002). Historically, the highest domestic annual use of mercury has been in electrolytic production of chlorine and caustic soda, which has since dropped to second highest or 30% of domestic consumption (Reese, 2001). The highest use is reported to be in electrical consumption, 40% of domestic consumption for products such as oscillators, relays, tilt-switches, batteries, and fluorescent lamps (Reese, 2001). The remainder of consumption was used in various application products such as dental amalgams and control instruments (Brooks, 2003). Much progress has been made to reduce the use of mercury in common consumer products. Decrease in demand for mercury can be attributed to federal restrictions on additives in paint and pesticides, voluntary reductions in industries, state regulations on mercury in products, and recycling programs (EPA, Mercury White Paper). Alternative materials and recycling efforts on manufacturer's behalf have been the driving force behind the decrease in demand. Domestic consumption of mercury will continue to decline as mercury is eliminated from products or as substitutes for mercury are made available.

Major contributors to this effort have come from all types of manufacturing companies and industries. In 2001 Ford announced that it had totally eliminated all mercury-containing switches in their new vehicle lines. GM projects that by 2004, all mercury lighting switches in their vehicles will be replaced with non-mercury alternatives. The Mercury-Containing and

Rechargeable Battery Management Act of 1996 severely limited the sale of most mercury-containing batteries in the US. In anticipated response, battery manufacturers have reduced their use of mercury by over 98% since 1980. Battery manufacturers are turning to the use of nickel-cadmium, lithium, and zinc-air batteries as a substitution (Brooks, 2003). Since 1985, mercury in a typical four-foot mercury laden fluorescent bulb has been reduced by 75%. Health Care Without Harm, is currently in the process of a campaign to end the sale of mercury thermometers at major pharmacy chains in the U.S. To date, several of the largest chains have already agreed to remove the product from their stores, including Walgreen, Wal-Mart, Rite-Aid and Albertson's. Many industries are finding substitutes for the use of mercury as well. For instance, chlorine and caustic soda electrolytic production is replacing mercury cells for diaphragm and membrane cells (Brooks, 2003). Dental amalgams are being replaced with ceramic composites and mercury thermometers are being substituted for digitized instruments (Brooks, 2003).

Table A-2 shows the U.S. supply data from years 1993 – 2001. Annual supply totals is a combination of world imports for consumption, industrial secondary recovery production, and up until 1994, shipments from the National Defense Stockpile (Reese, 1997). Brooks reports that on average, the U.S. was supplied with 30% of its imports from the United Kingdom, 15% from Chile, 13% from Kazakhstan, 13% from Germany, and the remaining 29% from other countries.

Table A-2

U.S. Mercury Supply (metric tons/year)

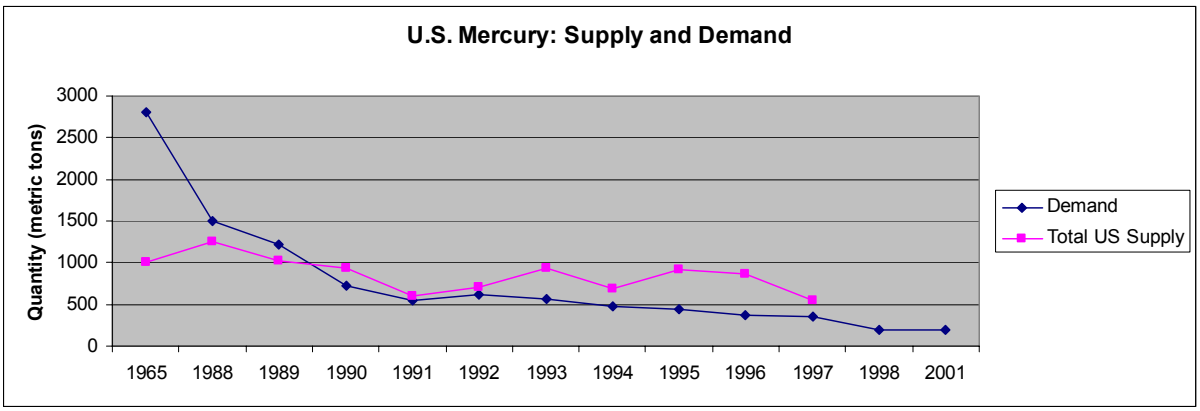
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Imports for Consumption	***40***	***129***	***377***	***345***	***164***	***128***	***62***	***103***	***100***	***209***
Secondary Production: Industrial Recovery	***350***	***466***	***534***	***446***	***389***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***
National Defense Stockpile	***543***	***86***	***--***	***--***	***--***	***--***	***--***	***--***	***--***	***--***
Mercury By-Product from Gold Mining	***N/A***	***N/A***	***N/A***	***65***	***N/A***	***N/A***	*18.9*	*53.6*	*36.1*	***N/A***
Total Supply	***933***	***681***	***911***	***856***	***553***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***
Reported Demand	***558***	***483***	***436***	***372***	***346***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***

* Source: Reese, Mineral Commodity Summary, 1998 – 2001
* Source: Reese, Mineral Yearbook, 1997 – 2001
* Source: Brooks, 2002
* Source: Plachy, 1997

* Source: Given by-product totals by Barrick, Cortez, Jerritt and Newmont

Figure A-1 below graphically depicts the decreasing U.S. supply and demand of mercury in the United States from 1965 – 2001. Total supply data from 1998 to present could not be found. Therefore, in the figure below, the graphical depiction stops in 1997. It is determined that the secondary supply production from industrial recovery is a large enough number to warrant an incomplete total supply from years 1998 to present. Demand totals from 1998 were also difficult to determine, however it was noted that estimated demand for 2001 in the U.S. was 200 metric tons (Brooks, 2002).

Figure A-1

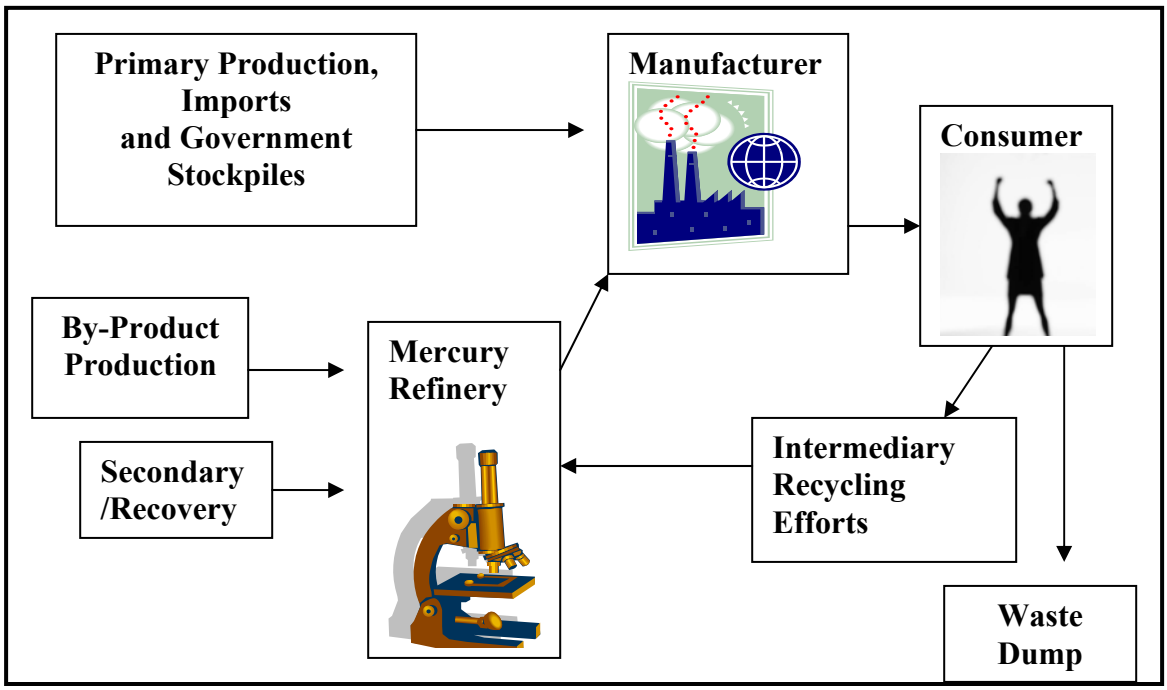


* Source: U.S. EPA 1997 Report to Congress
* Source: Reese, 1997 – 2001
* Source: Brooks, 2002

The price of mercury has been very volatile during the 20th century. There were significant price increases in the high demand periods of World Wars I and II, mostly for munitions production. The price peaked again in 1965, at $575 per flask, and has been in a steady decline since then. The 2002 price was $140 per flask (Brooks, 2003), and represents a 90% drop in price in 35 years. The price of mercury has increased in the last two years up to roughly $800 per flask. Ongoing environmental concerns have resulted in numerous regulatory restrictions and/or elimination of mercury in various commodity applications altogether.

Figure A-2 below, represents the typical supply chain where new elemental mercury will go in a product life cycle. Emissions and releases are not shown in the diagram, however, typical release and emission points occur throughout the supply chain functions.

Economic and environmental liabilities of mercury are released from a company, once a transfer of ownership of mercury has occurred. This transfer might come in the form of the sale of the mercury or by giving it away to a customer. It is unclear as to how many more years a mining company producing by-product mercury will be able to sell the metal and thereby release the liability. In time, continued mercury production will increase the potential liabilities for a mining company should demand fall.

Figure A-2

Mercury-laden Product Supply Chain