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# Project Summary

# Gold/Silver Heap Leaching and Management Practices that Minimize the Potential for Cyanide Releases

Robert L. Hoye

**This report presents a description of the magnitude and distribution of gold/silver heap leaching, the design and operation leaching facilities, the potential for environmental impact, and management practices that can be used to minimize environmental releases. The information contained in the report was obtained through searches of published and unpublished literature and through contact with knowledgeable individuals involved in the heap leaching industry. Six leaching operations were visited to acquire firsthand knowledge and site-specific information.**

***This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).***

## Introduction

Heap leaching refers to percolation leaching of low grade (approximately 0.05 oz/ton) gold and silver ores that have been stacked on prepared surface (pads). These heaps range from less than 1 to about 50 acres and 15 to over 100 feet in height. The leaching cycle covers a period from several weeks to over a year. The percentage of gold and silver produced by leaching operations has increased over recent years and this trend is expected to continue. An alkaline cyanide solution is used as the lixiviant at all heap leach operations. Currently, there are 78 commercially active gold and silver leaching operations in the United States. Forty-seven of these sites are in Nevada. Additionally, there are numerous inactive and abandoned leaching sites.

Sections 8002(f) and (p) of the Resource Conservation and Recovery Act (RCRA) and its amendments require the U.S. Environmental Protection Agency (EPA) to conduct studies on the "adverse effects on human health and the environment of the disposal and utilization of solid wastes from the extraction, beneficiation, and processing of ores and minerals." The EPA submitted a report to Congress on December 31, 1985, that indicated concern with the cyanide associated with heap leaching. The EPA subsequently issued a regulatory determination on July 3, 1986, that expressed continued concern about mining wastes containing cyanide. Also in this determination, the EPA indicated that it would develop a regulatory program for mining wastes under Subtitle D of RCRA and collect additional information on the nature of mining wastes and management practices and the potential for exposure to these wastes. This report addresses these issues with regard to the development, operation, and closure activities associated with precious metals heap leaching operations.

## Industry Characteristics

The application of heap leaching has increased in recent years because of the relatively low capital investments and fast payouts involved. These techniques allow recovery of low-grade resources that otherwise could not be profitably extracted. The mining industry first became interested in the U.S. Bureau of Mines' developments in gold/silver heap leaching technology in the late 1960s, and the first commercial cyanide heap leaching process was used at the Carlin Gold Mine Company in northern Nevada on mine cutoff material. Since the early 1970s, interest in heap leaching has continued to grow primarily in response to the high prices of gold and silver. Low-grade (e.g., 0.05 oz/ton) gold deposits previously considered uneconomical to recover are now being exploited at a profit. Currently, 78 gold and silver heap leaching operations are active in the United States. The majority (47) of these operations are in Nevada. Ten of the active heap leaching operations are in California, nine in Colorado, two in Idaho, three in Montana, one in New Mexico, nine in Utah, two in South Carolina, and one in South Dakota. In 1984, 525,000 troy ounces of gold was recovered from 19,860,000 tons of ore treated by cyanide heap leaching. The application of cyanide heap leaching has grown in recent years and this trend is expected to continue.

## Operating Practices.

Heap leach operations involve the use of liners and specially constructed leach pads and solution ponds. The basic design and operational layout of heap leach projects are very similar at all facilities. Low-grade ore (typically from a surface mine) is stacked 15 to 50+ feet high in engineered heaps on sloped (1 to 6%), relatively impermeable pads, and a weak alkaline cyanide solution is sprayed over the ore. The solution percolates through the heap and dissolves finely disseminated free metal particles (gold and/or silver). Care is taken during the construction of heaps to ensure that the material is uniformly permeable.

The design, engineering and construction of liners in this industry have reached a high level of sophistication. Pads, 1/4 to 50 acres, are constructed of native or modified clays, synthetic liners (e.g., HDPE, PVC, or Hypalon), or asphalt. This helps ensure that product and reagents are not lost through seepage. The pads must be capable of providing structural support without suffering damage from deflection due to the weight of the ore or equipment traffic. Selection of pad materials and specifications is determined by site-specific parameters such as availability of local materials, slope, geotechnical properties of the sub-base, temperature variations, and operational considerations (i.e., single- or multiple-use pads).

The pregnant solution flows over the pad to a lined collection ditch. The ditch carries the gold-bearing cyanide solution to a lined pregnant solution pond. Pregnant solution is then pumped to a recovery plant, where the metal product is removed by carbon adsorption followed by elution and electrowinning or by precipitation with zinc followed by filtration (Merrill-Crowe zinc dust precipitation). The barren solution is then pumped to a lined holding pond where it is treated with additional NaCN and caustic (e.g., lime or caustic soda). Sodium cyanide is the only commercially proven lixiviant. It is added to maintain a concentration in the barren solution of ~0.5 lb/ton of solution (250 ppm CN). The optimal pH for the gold dissolution is between 10 and 11. From the barren pond, the solution is again pumped to the heap and sprayed over it to complete the closed-loop cycle. Heap leach operations are zero discharge facilities.

The leaching cycle is relatively short (e.g., 20 to 90 days) but may last a year or more. At completion of leaching operations, the leach ore is rinsed with fresh water to remove residual cyanide. With few exceptions, heap leach residue (the barren ore remaining after precious metal values have been extracted) is left in place on the pad. At a very few operations it is excavated, hauled by truck, and disposed of in an on-site disposal area (load-unload operations).

Although the basic process just described is similar at all operations, each site is unique, and several alternative approaches exist. Specific leaching times, reagent use, flow rates, heap dimensions, pad construction, pond capacities, liner materials, and other design and operational parameters vary from site to site, depending on the characteristics and quantity of the ore and the climate, topography, hydrology, and hydrogeology of the site.

## Environmental Concerns

Because cyanide is the lixiviant used in heap leaching of precious metals, there is concern over the potential for release of toxic cyanides into the environment. Because an alkaline pH is maintained in the solution, most of the cyanide is present as free cyanide, as required in the leaching reaction. The barren solution pond typically holds hundreds of thousands of gallons of this solution. The pregnant solution pond contains lesser concentrations of free cyanides because of the destruction and complexation that occur in the heap; however, a significant concentration of free cyanides may be present. The solution in these impoundments represents the greatest source of free cyanide at a leach operation. Failure of the containment system, liner failure, or overtopping of the pond would result in free cyanide in an alkaline solution being released to the environment.

Cyanide in leach residue occurs in combinations of various metallo-cyanide complexes, free cyanides, and cyanates. Cyanide complexes vary from strongly bound forms to others that dissociate more readily. The complexes in a given heap are determined by the mineralogy on the ore. Essentially no data are available on the content and fate of cyanides or cyanates in leach residue. There are no reports of cyanide contamination or migration from properly constructed and operated heap leach operations. However, there have been a few reported incidents involving pond failure or overtopping and contamination resulting from clandestine operations that did not use typical operational practices. The principal transport mechanism is reported to be volatilization of HCN to the atmosphere. Although the toxicity of HCN is well documented, no problems with these atmospheric releases have been documented.

## Management Practices

A limited number of alternative management practices can be applied to minimize the potential for cyanide contamination from heap leach operations. These include alternative liner construction, oxidation of cyanide during post-leach flush-out, and use of reagents other than cyanide. Most heap leach operations are relatively small, their only sources of potential contamination are the heaps themselves and the two process solution ponds. After cessation of operations, only the heap leach residue remains as a potential source of contamination, as the ponds must be emptied during closure. Additionally, most obvious controls, such as pond and leach pad liners, surface water diversions, and post-leach rinsing, are 'eady standard practice in the industry. .though, the need for controls beyond those currently in use has not been demonstrated, the concerns related to potential releases of cyanide may warrant additional controls or overdesign of existing controls. The management practices that were evaluated are listed below.

Most of the controls listed have been incorporated into the design and operation of at least one existing heap leach facility. The feasibility and cost to use these controls at other locations would have to be determined on a site-by-site basis. It would depend on differences in mineralogy, topography, geology, hydrogeology, climate, and design and operational characteristics.

The use of double liners in solution ponds is both technologically feasible and is a demonstrated practice at some heap leach sites. A doubleliner system consisting of two layers of 40- mil HDPE separated by a leachate detection and collection system was evaluated. The pond was assumed to be 300 ft by 150 ft (approximately 1 acre). For the purpose of comparison, the costs associated with a single 40-mil HDPE (High Density Polyethylene) liner system, 'elieved to be common in the industry, 'ere also estimated. The cost comparison indicates the double-liner system increased the cost of the pond by a factor of at least two. The cost of constructing the solution ponds at a site can represent a significant percentage of the total capital cost of the operation.

Cyanide is the only lixiviant currently used at commercial heap leach facilities. Because of the toxicity associated with cyanide, the question of the availability of suitable substitutes for cyanide is raised. The development of alternative lixiviants (e.g., thiosulfate, malononitrile, and thiourea) is still in the laboratory or pilot-scale testing stage, however. If alternative lixiviants are developed, the environmental impacts associated with their use must be fully evaluated. While thiourea can rapidly leach gold from leach ore, it requires a very acidic medium (pH 1) that would be an environmental concern. Additionally, reagent consumption and cost are high and the toxicity and mobility of its degradation products have not been assessed.

The type and sophistication of ground-water monitoring systems vary considerably in this industry. The requirements for these systems are specified on a site-specific basis by State regulatory personnel. The cost for installing a detection monitoring system will vary greatly from site to site. The primary factors that influence costs are the size of the operation and the complexity of local hydrology. The principal factors are the diameter, depth, and components of the wells, the drilling specifications, the geologic material, the sampling and analytical requirements, and site access. Estimates made for an example site indicate that the costs of installing a system of 10 to 13 wells to depths of 25 to 300 feet would range between $12,500 and $195,000. Consultant fees for a qualified hydrogeologist could be expected to range from $6,000 to $50,000. Analytical costs would amount to $12,000 to $16,000 annually plus reporting and recordkeeping. These costs point up the great variability due to site-specific conditions.

During post-closure period, the heap leach residue is the only potential source of cyanide contamination. Current practice is to rinse the leach residue with fresh water for a predetermined time or until some preset cyanide concentration (e.g., 0.2 mg/liter) or pH (e.g., pH 8) in the rinse water is achieved. An additional control option could be the addition of a cyanicide, a strong oxidant, to the rinse water. Alkaline chlorination is a proven technology for cyanide destruction and is the most highly developed of the available methods in terms of experience, simplicity, control, availability of equipment, and engineering expertise. This process destroys most cyanide except iron cyanide and the more stable metallo-cyanide complexes. Treatment of heap leach residue by alkaline chlorination has been carried out at a few operations. When this system is used during the operational period, the facility must incorporate at least one additional pond, a neutralization pond, in its solution management system. If it is used only at closure, the existing process solution ponds would be adequate.

Application of a clay or synthetic cap over leach residue could prohibit infiltration and run-on and thereby preclude formation of leachate. However, it would hinder the natural degradation of

| Operational phase | Management practice |
|---|---|
| Pre-operation | Installation of French drains beneath pads and pond liners<br>Use of RCRA double-liner systems with leak detection in ponds |
| Operational | Use of alternative lixiviants<br>More extensive ground-water monitoring |
| Closure | Flush heaps with cyanicide<br>Recontour and cap heaps |
| Post-closure | Long-term maintenance of heaps and monitoring systems and site security |

cyanide by limiting volatilization and photodecomposition. Forty-seven of the 72 heap leach operations are located in Nevada in arid climates where capping may provide even fewer marginal benefits. In order to place a cap, the side slopes of the heap would have to be reduced to at least 3:1 or more from the 1:1 slopes existing duration operations. Assuming a suitable source of cap material exists near the site, recontouring and capping a 1-acre, 15-foot-high heap would cost about $40,000 and a 50-acre, 100-foot-high heap would cost about $2 million.

## Conclusion

The low production costs, relatively short startup time, and relative simplicity of heap leaching have lead to increased use of this method to recover precious metals that are otherwise not economically recoverable. Current state-of-the-art design, construction, and operation of precious metals heap leach facilities incorporates obvious controls including relatively impervious leach pads, lined collection trenches and process ponds, and closed loop zero discharge solution management. Depending on site-specific considerations, it may be beneficial to incorporate redundancies and overdesigns into these systems. However, the need for additional controls is not currently documented. Additionally, research to determine the presence, fate, and toxicity of cyanide and cyanate in heap leach residue is just beginning.

*Robert L. Hoye is with PEI Associates, Inc., Cincinnati, OH 45246.*
***S. Jackson Hubbard** is the EPA Project Officer (see below).*
*The complete report, entitled "Gold/Silver Heap Leaching and Management Practices That Minimize the Potential for Cyanide Releases," (Order No. PB 88-154 281/AS; Cost: $19.95, subject to change) will be available only from:*
*National Technical Information Service*
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*The EPA Project Officer can be contacted at:*
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