CYANIDE HEAP LEACH AND TAILINGS IMPOUNDMENTS CLOSURE

DRAFT

July 1993

U.S. Environmental Protection Agency
Office of Solid Waste
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Washington, D.C. 20460
DISCLAIMER AND ACKNOWLEDGEMENTS

This document was prepared by the Environmental Protection Agency with assistance from Science Applications International Corporation (SAIC) in partial fulfillment of EPA Contract No. 68-W0-0025, Work Assignment 248. The mention of company or product names is not to be considered an endorsement by the U.S. Government or by the U.S. Environmental Protection Agency (EPA).
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SECTION 1. INTRODUCTION

The predominant method used to beneficiate gold ore is cyanidation. The volume of ore recovered from mines has grown significantly over the last 20 years. Cyanidation mills started in the 1950's and expanded in the 1980's. The expansion in the 1980s was primarily due to favorable economic conditions (increase in gold prices) and to the development of gold leaching methods such as heap leaching, suited to low grade ore. As the first heap leach operations, started in the late 1970's and early 1980's, begin to deplete their reserves, closure and reclamation of these operations are becoming a concern.

The purpose of this report is to provide information on closure activities associated with cyanidation operations. The ultimate purpose, which extends beyond the scope of this report, is to identify appropriate closure practices. Such practices not only prevent environmental degradation but also prevent costly remedial actions under Superfund and other programs.

Cyanidation includes both heap leaching and tank leaching. Spent ore or tailings containing residual amounts of cyanide are generated as wastes. These wastes are typically treated to neutralize or destroy cyanide prior to final closure. This report discusses cyanide detoxification or treatment in terms of chemistry, duration, removal efficiencies, and advantages and limitations. After a discussion of treatment techniques, the report describes typical closure and reclamation activities for heaps and tailings impoundments, identifying issues that are still outstanding.

The report also describes Federal and state requirements that apply to cyanide operations. In addition, selected case studies are presented, including three gold-related Superfund National Priorities List (NPL) sites, as well as active cyanide operations. Sites on the NPL were reviewed to determine how closure and reclamation measures were implemented. The active sites were selected to reflect a range of facility types, including a vat leach operation with INCO treatment of tailings slurry, an a large heap operation with several permanent pads, and a site using biological treatment by bacteria.

The report is based on literature reviews, publicly available documents, and telephone contacts with Federal and state agencies.
SECTION 2. CYANIDE LEACHING

Introduction

Cyanidation uses solutions of sodium or potassium cyanide as lixiviants (leaching agents) to extract precious metals from ore. Cyanidation techniques used in the gold industry today include heap or valley fill leaching, agitation leaching followed by carbon-in-pulp (CIP), and agitated carbon-in-leach (CIL). Cyanidation is best suited to fine-grain gold in disseminated deposits. Heap or valley fill leaching is generally used to beneficiate ores containing less than 0.04 Troy ounces/ton (oz/t). CIP and CIL techniques, commonly referred to as tank or vat methods, are generally used to beneficiate ores containing more than 0.04 oz/t. These cut-off values are dependent on many factors, including the price of gold and an operation’s ability to recover the precious metal (van Zyl et al. 1988). For the purposes of this report, a brief description of both heap and tank leaching is provided below. A more detailed description may be found in EPA’s Industry Profile on Gold (EPA 1992a).

Heap Leaching

Since the 1970’s and early 1980’s, heap leaching has developed into an efficient way to beneficiate a variety of low-grade, oxidized gold ores. Compared to tank leaching, heap leaching has several advantages, including simplicity of design, lower capital and operating costs, and shorter startup times. In many cases, heaps are constructed on lined pads with ore sent directly from the mine (run-of-mine ore) 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 needed for leaching to occur (Bureau of Mines 1986). Agglomeration entails mixing the crushed ore with portland cement, lime, ash, or other materials. In some cases, after crushing, sulfide ores may be treated by roasting, autoclaving, bio-oxidation, or chlorination prior to heap leaching.

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 (Lopes and Johnston 1988).

The reaction of the cyanide solution with the free gold is oxygen-dependent. Therefore, the solution is oxygenated prior to application or during spraying. The solution concentration is generally between 0.5 and 1.0 pounds of sodium cyanide per ton of solution. Cyanide solution is applied using drip or spray irrigation. The cyanide leachate percolates through the ore and is collected by pipes located under the pile or carried on the asphalt or plastic liner directly to ditches around the pile.
significantly higher recovery efficiencies than heap leaching facilities, recovering from 85 to 98 percent of the gold contained in the ore. Generally, CIP or CIL methods are used for high grade ore.

Oxide ores are typically beneficiated by grinding to 65 mesh and leaching with 0.05 percent sodium cyanide over a 4- to 24-hour period with a pulp density of 50 percent solids. Sulfide ores are typically beneficiated by grinding to 325 mesh and leaching with 0.1 percent sodium cyanide for a 10- to 72-hour period with a pulp density of 40 percent solids. (Weiss 1985).

In the CIP method, a slurry consisting of ore, water, cyanide, and lime is pumped to the first series of tanks for agitation and leaching. Gold is leached from the ore in the leach tank train. The slurry containing leached ore and pregnant solution is pumped to the second series of tanks for gold recovery. In the second series of CIP tanks, the slurry is introduced into a countercurrent flow with activated carbon. The slurry enters the first tank in the series containing carbon that is partially loaded with the gold-cyanide complex. In the suspended slurry, the activated carbon adsorbs gold material on the available exchange sites. As the carbon material becomes laden with precious metals, it is pumped forward in the circuit towards the incoming solids and pregnant solution. Thus, in the last tank, the low-gold percentage solution is exposed to newly activated and relatively gold-free carbon that is capable of removing almost all of the remaining precious metals in the solution. Fully loaded carbon is removed at the feed end of the absorption tank train for further beneficiation. Tailings are discharged to a tailings impoundment. (Bureau of Mines 1978, 1986; Stanford 1987).

The CIL technique differs from CIP in that leaching and recovery of values occur in the same series of tanks. Activated carbon is mixed with the ore pulp in the agitated leach tanks. A countercurrent flow is maintained between the pulp (ore and leaching solution) and the activated carbon. In the first tanks of the series, leaching of the fresh pulp is the primary activity. In later tanks, adsorption onto activated carbon becomes dominant as the concentration of gold in solution increases and fresh carbon is added to the system. The loaded carbon is transferred to a stripping vessel while the spent ore is pumped as a slurry to the tailings impoundment (Bureau of Mines 1986; Calgon Carbon Corporation, undated; Stanford 1987). Tailings from tank leaching may be treated prior to discharge to the tailings impoundment. Treatment standards for tailings prior to discharge to the impoundment are often set by the State regulatory authority. As the tailings impoundment becomes dewatered, reclamation may take place.
SECTION 3. CYANIDE TREATMENT TECHNOLOGY

Introduction

This section discusses various treatment methods for neutralizing or detoxifying cyanide solutions, spent leached ores, and tailings. Treatment methods range from rinsing heaps with water to more complex techniques such as alkaline chlorination and sulfur dioxide processes, which treat both solutions (spent cyanide solutions and heap rinsate) and slurries (tailings). Natural degradation of cyanide is also discussed. Where possible, information on chemistry, duration, removal efficiencies, and advantages and limitations has been described, as presented in current literature. Independent field testing or confirmation of these techniques has not been conducted by EPA.

Rinsing of Heaps

There are three fundamental approaches to the decommissioning of cyanide-contaminated ore heaps. The first is to leave the heap alone and allow the cyanide to degrade, perhaps slowly, but without any human intervention. The second is to dismantle the heap and treat the ore in smaller batches. This approach may be necessary when sections of the heap have become impermeable or when it is desired to reclaim the leach pad area for other uses. The third approach is to rinse the heap to flush out cyanide, with the rinse solution then being treated by any of the methods described below.

Ore heaps may be rinsed with fresh water or with recycled rinse water that has been treated so that it contains little cyanide. The rinse medium may or may not contain chemicals designed to oxidize the residual cyanide as it trickles through the heap.

Mines using cyanide heap leaching will already have equipment available to supply rinse solution. The same system used to apply the cyanide solution can be used for rinsing of the heap. At Echo Bay’s Borealis Mine in Nevada, the heaps were rinsed at a rate of about 0.005 gals/min/ft² (Schafer and Associates 1991b) using Rainbird sprinklers. At Brohm Mining’s Gilt Edge on-off heap leach operation in South Dakota, a cyanide neutralization solution containing hydrogen peroxide has been applied at a rate of 0.0043 gal/min/ft² (Damon, Smith, and Mudder 1992).

Rinsing also may be accomplished, or enhanced, by natural precipitation; some facilities have included precipitation as part of their detoxification plans (WGA 1991b). However, many cyanide heap leach operations are located in arid areas of the western United States where precipitation rates aren’t sufficient enough to be a source of rinse water.

The duration of rinsing required to reach a specified cyanide level in water leaving the base of the heap may vary considerably. At the Borealis mine, rinsing continued for several months, with each section of the pad being rinsed for 10-20 days. At the Gold Fields Operating Company’s Mesquite...
Figure 1. INCO Sulfur Dioxide-Air Process
Source: Adapted from Higgs 1992
Limitations to INCO appear to be that the reaction proceeds more slowly at low temperatures. A drop in temperature from 25°C to 5°C can cause a tenfold decrease in reaction rate. Correspondingly larger residence times and tank volumes would be required to achieve the same CN⁻ removal efficiencies at lower temperatures. The INCO process does not remove thiocyanate, cyanate, or ammonia. Cyanate can be transformed into ammonia by microbial action; ammonia is toxic to fish. In addition, removal of toxic metals may not be sufficient to meet permit requirements.

Alkaline Chlorination Process

The alkaline chlorination process is one of the oldest cyanide destruction methods (Higgs 1992). In this process, cyanide in solution is oxidized to cyanate using chlorine or hypochlorite in solution:

\[ \text{CN}^- + \text{Cl}_2 \rightarrow \text{CNCI} + \text{Cl}^- \]

\[ \text{CNCI} + 20\text{H}^- \rightarrow \text{CNO}^- + \text{Cl}^- + \text{H}_2\text{O} \]

Alkaline chlorination can be applied to both clear wastewaters and slurries. One mine in northern Ontario abandoned the use of this process for slurries because the chlorine requirements were excessive (Smith and Mudder 1991).

Equipment requirements for the alkaline chlorination process are similar to those for the other two oxidation processes (hydrogen peroxide, sulfur dioxide). Wastewater to be treated is introduced into a mixing vessel, where it is reacted with chlorine or hypochlorite (Figure 2). The pH is maintained in the alkaline range by addition of lime. Precipitated metals are removed in a clarifier before the wastewater is discharged.

Smith and Mudder (1991) state that the first-stage reaction (cyanide to cyanate) requires approximately 15 minutes at pH 10.5. Hydrolysis of the cyanate to ammonia and carbonate requires an additional 1-2 hours.

The Giant Yellowknife mine reported that the process reduced \(\text{CN}_r^-\) from 7.8 mg/l to 0.05 mg/l. Fifteen days retention in a polishing pond reduced \(\text{CN}_r^-\) to 0.02 mg/l. These data were averages for the 1984 operating year. At the Mosquito Creek mine, total cyanide was reduced from 310 mg/l to 25 mg/l and WAD cyanide was reduced from 226 mg/l to 0.5 mg/l.

Few sites are currently using this technology. The Thunder Mountain Mine in Idaho operated from 1984 to 1991 (Mohr Undated). The mine was operated as an on-off heap leach. Leached ore was treated by alkaline chlorination. This method was also used to treat wastewater generated by rinsing of the pads during decommissioning. Effluent from the treatment process was disposed at a "wastewater land application facility", so that there was no direct NPDES point source discharge.
However, the operator may be required to apply for a NPDES permit to cover stormwater discharges from the site under recently EPA promulgated regulations. Mohr (Undated) does not give any details regarding cyanide destruction efficiency or operating parameters. Generally, wastewaters which can be discharged indirectly through natural or artificial wetlands or land treatment facilities do not need to meet the same requirements as direct discharges, because natural processes in the wetland lead to additional cyanide destruction and metals removal.

Environment Canada conducted a study of this process at three mills in British Columbia and one in the Northwest Territories during the period 1981 - 1983. As of 1992 (Higgs), no mines in Canada were known to be using this technology. The Giant Yellowknife mine used this process followed by an arsenic precipitation step and a polishing lagoon to treat a wastewater which had relatively low CN⁻ values. Reagent costs were very high, about CAN$ 46.50 per kg CN⁻ in 1983. This would correspond to approximately US$ 43.50 at 1992 prices. This was partly due to the additional chlorine loading required to make the arsenic precipitation step operate properly, and partly due to the very remote location of the mine, which resulted in high transportation costs.

Alkaline chlorination’s advantages are that it is a simple process applicable to wastewaters and slurries. Disadvantages are that it does not remove iron cyanides, and chloramines and free chlorine remain in solution; these are toxic to fish.

**Hydrogen Peroxide Process**

In the hydrogen peroxide process, cyanide in solution is oxidized to cyanate using hydrogen peroxide in the presence of copper ion:

\[ \text{CN}^- + \text{H}_2\text{O}_2 \rightarrow \text{CNO}^- + \text{H}_2\text{O} \]

Cyanate ion hydrolyses to form ammonia and carbonate:

\[ \text{CNO}^- + 2\text{H}_2\text{O} \rightarrow \text{CO}_3^{2-} + \text{NH}_4^+ \]

This process can be applied to wastewaters. Reagent requirements become excessive when applied to slurries.

Equipment requirements for the hydrogen peroxide process are similar to those for the INCO process. Wastewater to be treated is introduced into a mixing vessel, where it is reacted with hydrogen peroxide (Figure 3). Copper sulfate is added as a catalyst. The pH is controlled by addition of lime. Hydrogen peroxide is a strong oxidizer, which can give rise to violent explosions and fires if brought in contact with combustible organic material (wood, old cloth rags). Specially designed storage tanks and handling equipment must be used.
Griffiths (Degussa 1988) reported that a mine in northern Ontario was planning to use this process. Under these cold conditions, batch tests indicated that 27 hours would be required to reduce total cyanide from 25.7 mg/l to 0.94 mg/l. Higgs (1992) indicates that retention times should be in the range of 45 minutes to 2 hours, but bench scale tests are needed for each individual waste stream.

An example of removal efficiencies is provided by the Annie Creek Mine (McGrew and Thrall, cited in Brooks 1992). At this mine, effluent from a heap was reduced to 0.57 mg/l CN\textsuperscript{-} and 0.09 mg/l CN\textsubscript{wad} after 97 days of rinsing with H\textsubscript{2}O\textsubscript{2} solution.

The hydrogen peroxide process was applied at the Timberline mine in Utah (Brooks 1992). This gold mine operated as a heap leach operation from 1984-1986. In 1989, the operator declared bankruptcy and forfeited the bond to Tooele County. The sheriff's department arranged for the placing of 800 pounds of calcium hypochlorite in the solution pond, but this was found not to be sufficient to neutralize the cyanide leached from the pile, especially after heavy rainfall events. The county, the State, and the U.S. Bureau of Land Management decided to treat the leached ore in lifts consisting of layers one foot thick, using 0.01 gallons of H\textsubscript{2}O\textsubscript{2} per ton of ore. After treatment, the ore averaged 6.3 mg/kg CN\textsubscript{wad} and 24 mg/kg CN\textsuperscript{-}. By 1991, the cyanide levels were 2.12 mg/kg CN\textsubscript{wad} and 8.46 mg/kg CN\textsuperscript{-} in the leached ore, and 1.11 mg/l CN\superscript{-} in rinsate samples. The state considers the heap to be neutralized. This project was completed on a very low budget (the $20,000 bond) using BLM personnel and equipment and volunteers from a nearby mining company.

The limitations of hydrogen peroxide treatment include handling and costs. Hydrogen peroxide is a hazardous material, and can be expensive. Special equipment for hydrogen peroxide service may increase the total capital cost. The treatment process generates ammonia, which is toxic to fish. Information on the treatment's effect on metals was not obtained.

**AVR Cyanide Recovery Process**

In the handling of cyanide solutions, significant efforts are taken to ensure that the pH is always kept in the alkaline range so that toxic hydrogen cyanide gas will not be released. The Acidification-Volatilization-Recovery (AVR) process runs directly counter to this principle. The pH of a cyanide solution is lowered by addition of sulfurous acid so that HCN gas is formed. This gas can then be absorbed into a NaOH solution:

\[
\text{CN}^{(-)}(\text{aq}) + \text{H}^{+}(\text{aq}) \rightarrow \text{HCN(g)}
\]

\[
\text{HCN(g)} + \text{NaOH(aq)} \rightarrow \text{NaCN(aq)}
\]
Figure 4. AVR Cyanide Recovery Process

Source: Adapted from Higgs
Cyanide Heap Leach Closure

It is unclear if natural processes can generally be used to meet Federal or state closure standards. One site in Colorado (Battle Mountain Resources, Inc.) planned solely on using natural degradation to reduce cyanide levels in its tailings slurry, tailings impoundment, and collection pond. Natural degradation, however, was unsuccessful in reducing cyanide to levels required in the permit (4.4 ppm total or 3.8 ppm wad cyanide). In 1991 and 1992, elevated cyanide concentrations (up to 260 ppm total, 240 ppm free and 110 ppm wad) led to a notice of violation and issuance of an administrative order (Colorado Mined Land Reclamation Board 1992).

The advantages in using natural degradation are that no capital investment or chemical costs are incurred. However, natural degradation may never reduce total cyanide levels to within the limits specified by state agencies. Information on other constituents was not obtained. While natural degradation is occurring, the waste may continue to pose a threat to humans and animals; there is a possibility of bird and mammal kills. Security costs for preventing public access over a period of several years may prove excessive.

Biological Treatment

If cyanide-bearing wastewaters are left untreated, microbial action may eventually cause some transformation of cyanide to ammonia. Metal ions released from metal cyanides will be absorbed by the biomass and thiocyanates may be converted to sulfate:

\[
\text{Cu}_2\text{CN} + 2 \text{H}_2\text{O} + \frac{1}{2} \text{O}_2 \rightarrow \text{Cu-biofilm} + \text{HCO}_3^- + \text{NH}_3
\]

\[
\text{SCN}^- + 2 \text{H}_2\text{O} + 2\frac{1}{2} \text{O}_2 \rightarrow \text{SO}_4^{2-} + \text{HCO}_3^- + \text{NH}_3
\]

Further microbial action will convert the ammonia to nitrate:

\[
\text{NH}_4^+ + 1\frac{1}{2} \text{O}_2 \rightarrow \text{NO}_3^- + 2 \text{H}^+ + \text{H}_2\text{O}
\]

\[
\text{NO}_2^- + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_3^-
\]

The purpose of biological treatment processes is to greatly increase the rate at which these natural transformations occur.

Until recently, known applications of this technology were confined to barren solutions. Since microbes tend to adhere to solids, it may be possible to make this process work for slurries and even directly on heaps. Bench-scale lab tests conducted by Gold Fields Mining Corporation indicate that in situ remediation of cyanide-contaminated heaps may be possible. (Thompson and Gerteis 1990)
Figure 5. Biological Treatment Process
Source: Adapted from Higgs 1992
SECTION 4. CLOSURE AND RECLAMATION OF WASTE UNITS

Introduction

Environmental closure entails those activities conducted after a cyanide leach unit ceases operating, in order to prepare the site for reclamation. Closure essentially consists of those activities that remove a hazard or undesirable component, whether it be chemical or physical. It can entail detoxifying a heap, neutralizing waste, treatment and/or evaporation of rinse liquids and pond water, dismantling associated equipment and piping, removal of waste, treatment of waste, reconstruction, grading or stabilizing, and chemical testing. Closure must meet state or Federal environmental statutes.

Reclamation consists of those activities that are undertaken to return the site to a condition suitable for future use, and to minimize adverse impact to the environment and surrounding community, whether that use is grazing, wetlands, park land and recreational, water shed or commercial. Reclamation may involve regrading; site drainage control such as diversions, channels, riprap, and collection basins; and revegetation to establish ground cover and protect against erosion.

The preceding section focused on the detoxification of cyanide in tailings and heaps in terms of applicability and effectiveness; this section identifies other activities that might take place during closure and reclamation, focusing on those factors that are unique to cyanide heaps and tailings, and discussing issues associated with closure and reclamation of cyanide operations.

To date, very few, if any, cyanide operations have been completely reclaimed, consequently, closure and reclamation measures are not yet well established. According to regulatory personnel in both Nevada and California (two of the major gold supplying states), industry and state experience with heap closure and reclamation is limited.

Closure and Reclamation of Heaps

After a heap has been detoxified, additional steps may be necessary prior to closure or reclamation. Typical decommissioning activities include dismantling and removal or disposal of buildings and other structures and stabilization of permanent structures such as heaps and tailings impoundments.

After rinsing or treatment of a heap, core samples may be taken to analyze the residual waste to determine the effectiveness of decontamination. Core samples, such as those analyzed by the Meteoric Water Mobility Test\(^1\), provide a more detailed picture of a waste's potential to leach in the future than do effluent samples.

\(^1\) The Meteoric Water Mobility Test is used to simulate the effect of fresh water percolating through the heap. Core samples of the heap are collected for analysis, usually by drilling, after a heap has drained.
acceptable to State or other authorities (BLM, USFS, NPS, etc.), it may be closed in place, or further treated and/or disposed of offsite. (It is not known how many mine sites may have disposed of pond sludge off-site, however.)

Land application of solution rinses is used at many mine sites as a means of treatment/disposal of solution water. Land application may accelerate natural degradation of cyanide through volatilization and oxidation; however, metals and nitrates may persist. It is not clear what procedures or standards are required for land application, including the amount, if any, of prior treatment.

At sites with a history of liner integrity problems, samples of the subsurface soils may be analyzed prior to closure. Closure of ponds in-place often involves folding the synthetic liner over the remaining, if any, sludge or residue and backfilling the pond with soil followed by regrading and revegetation. (WGA 1991b)

Closure and Reclamation of Tailings

Because cyanide mill impoundments containing cyanidation tailings are reclaimed in a manner similar to other impoundments, the available literature primarily deals with tailings in general and does not focus on cyanide operations. While States have issued guidance on heap operation and effluent detoxification levels, closure and reclamation usually are addressed on a site-specific basis, through a reclamation plan that is typically filed with the State. When reclamation of cyanide units are mentioned in the literature, the discussion primarily addresses general reclamation activities such as drainage control, grading, and revegetation and does not focus on aspects unique to cyanide operations, such as the persistence of cyanide and cyanide-metal complexes in tailings or the fate and transport of cyanide and other constituents in the spent ore or tailings.

The two principal concerns with closure of tailings impoundments are: 1) its structural stability and 2) its potential to leach contaminants. As with other types of tails, grain size (percent slimes vs sands), uniformity and method of tailings deposition all affect tailings stability and subsequent closure.

Tailings may be treated or detoxified as they are generated before disposal in the tailings impoundment, which may or may not be lined. Because tailings impoundments typically operate as zero discharge units under the Clean Water Act, the impoundment may have a pumpback system to move water from the impoundment back to the milling process system. Pump back allows the water balance to be maintained. When the impoundment is closed, it may be allowed to dewater or a pump system may remain to continue draining the impoundment as part of closure. Climatic conditions determine in large part the availability of these options; in arid regions where evaporation exceeds annual precipitation, dewatering is the usual choice. Information was not available on how long facilities continue to use pump back systems after closure. For closure, sampling of solids and
for the Part 440 guidelines does indicate that EPA was aware of specific sites where laboratory methods were effectively being used to quantify cyanide removal (but does not describe the methods). The document further suggests these methods could be used by permit writers to establish cyanide limits in individual NPDES permits on a site-by-site basis.

Analytical methods used to determine cyanide concentrations in tailings, heap effluents, and pore water are still being debated. At low concentrations, testing is inaccurate and measurements of cyanide may not be good predictors of actual cyanide concentrations in the field. (Durkin 1990; Colorado 1992a; ORD 1993)

Cyanide is generally measured as one of three forms: free, weak acid dissociable (WAD), and total. Free cyanide refers to the cyanide that is present in solution as CN⁻ or HCN, and includes cyanide-bonded sodium, potassium, calcium or magnesium. Free cyanide is very difficult to measure and its results are often unreliable, difficult to duplicate, or inaccurate. WAD cyanide is the fraction of cyanide that will volatilize to HCN in a weak acid solution at a pH of 4.5. WAD cyanide includes free cyanide, simple cyanide, and weak cyanide complexes of zinc, cadmium, silver, copper, and nickel. Total cyanide measures all of the cyanide present in any form, including iron, cobalt, gold and platinum complexes. (Colorado 1992a)

Many states are continuing to debate over the proper test methods for measuring cyanide (WAD, free, or total). A South Dakota hydrologist with the State Department of Environment and Natural Resources (DENR) points out that many of the commonly used test methods for cyanide leaching yield questionable results for certain parameters. (Durkin 1990)

Mudder & Smith point out that historically, cyanide was regulated as "free" cyanide, but that newer standards specify weak acid dissociable (WAD) cyanide. "Free" cyanide has been shown to be analytically inexact at desired regulatory levels and WAD cyanide levels are more easily determined below one part per million (ppm) and more relevant from an environmental standpoint. (Mudder and Smith 1992)

EPA’s Office of Research and Development (ORD) is currently evaluating cyanide test procedures and methods, and is investigating a proprietary, privately developed, distillation method that appears to be successful for cyanide analysis. One of ORD’s activities includes revising the current methods for measuring and detecting cyanide fractions and eliminating interferences. ORD is also reviewing performance data and problems of 17 currently used methods. Future efforts of ORD in FY 1994 will involve continued evaluation of cyanide species. (ORD 1993)
TABLE 2. Relative Stabilities of Cyanide Complexes in Water

<table>
<thead>
<tr>
<th>Cyanide Species</th>
<th>Examples present in gold and silver processing solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Free cyanide</td>
<td>CN-, HCN</td>
</tr>
<tr>
<td>2. Simple compounds</td>
<td></td>
</tr>
<tr>
<td>a. Readily soluble</td>
<td></td>
</tr>
<tr>
<td>b. Relatively insoluble</td>
<td></td>
</tr>
<tr>
<td>3. Weak Complexes</td>
<td></td>
</tr>
<tr>
<td>4. Moderately strong complexes</td>
<td></td>
</tr>
<tr>
<td>5. Strong complexes</td>
<td></td>
</tr>
</tbody>
</table>


TABLE 3. Some Metal-Cyano-Complex Ions and their Stability Constants

<table>
<thead>
<tr>
<th>Metal</th>
<th>Complex Ion</th>
<th>Stability Constant at 25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt (III)</td>
<td>hexacyanocobaltate</td>
<td>[Co(CN)₆]³⁻</td>
</tr>
<tr>
<td>Iron (III)</td>
<td>ferricyanide</td>
<td>[Fe(CN)₆]³⁻</td>
</tr>
<tr>
<td>Iron (II)</td>
<td>ferrocyanide</td>
<td>[Fe(CN)₆]⁴⁻</td>
</tr>
<tr>
<td>Nickel (II)</td>
<td>tetracyanonickelate</td>
<td>[Ni(CN)₄]²⁻</td>
</tr>
<tr>
<td>Cadmium (II)</td>
<td>tetracyanocadmiate</td>
<td>[Cd(CN)₄]²⁻</td>
</tr>
<tr>
<td>Manganese (III)</td>
<td>hexacyanomanganate</td>
<td>[Mn(CN)₆]³⁻</td>
</tr>
</tbody>
</table>


Although the reasons for incomplete or variable rinsing have not been confirmed, Durkin (1990) proposes that non-uniform neutralization or dilution may be factors. A number of facilities have had to switch treatment methods after a chosen method failed to reach the desired concentrations. Thus, in practice, rinsing may take many seasons, or years, to complete.

Climatic conditions effect the amount of time needed for closure and reclamation. Cold weather effectively shuts down many operations. Natural and biological treatment methods cease naturally at low temperatures over the winter months. (Schafer and Associates 1990; McGill & Comba 1990; BLM 1992; Higgs 1992)

According to a Nevada Bureau of Water Quality representative, the cyanide rinsing standard of 0.2 mg/l WAD cyanide has been difficult for many operators to achieve, and the mining community would like to see the standard changed. Agglomerated heaps are more difficult to rinse because aggregating the material (lime, etc.) keeps the pH elevated, which in turn makes reduction of pH and detoxification of cyanide more difficult. The Trinity mine near Lovelock, Nevada operated an agglomerated heap; at closure initial WAD cyanide concentrations were 400 - 500 mg/l. The facility proposed using natural degradation to reduce the cyanide concentrations, but has had little success to date at lowering the cyanide levels via natural degradation. A final decision on the Trinity mine was not available; the amount of time since operations ceased also was not obtained. In several instances, the State has issued or is considering variances from the rinsing criteria. (Nevada 1993c)

Water Balance

Water balance can be a concern at some sites. In arid regions, with limited water resources, the amount of water that is necessary to rinse heaps to a required standard may be a significant concern. Conversely, in wet climates like South Carolina, excess water from heavy precipitation can place a strain on system operations and may make draining or revegetating a heap or impoundment very difficult. (ELI 1992) South Carolina has experienced severe problems as a result of weather conditions, such as heavy and persistent rainfall causing flooding, leaks, dam compromises, etc., making closure difficult. South Carolina has also had trouble with revegetation at the Brewer mine facility heap leach pad; details were not available for this report. (South Carolina 1993). Sudden snowmelt also can affect operations.

Percolation of Solution through Heaps

The presence, or potential for "blind-offs" in heaps may cause incomplete neutralization or treatment. Blind-offs are less permeable lenses or isolated areas of a heap that affect percolation and flow through the heap, leading to preferential paths for fluid migration. Research suggests that preferential flow paths and blind-offs increase with time and volume of liquid. These preferential flow paths can
SECTION 5. REGULATORY PROGRAMS

Introduction

The following section provides a brief overview of those Federal and state requirements that are specific and unique to waste management at cyanide leach operations, such as programs related to cyanide tailings impoundments, spent heaps and pads, and solution wastewater. The section is not a comprehensive summary of all the regulatory requirements that apply to a cyanide facility but rather, introduces some of the key Federal and State programs involved in the oversight of cyanide operations.

Federal Requirements

Environmental Protection Agency - NPDES Program

The Environmental Protection Agency’s (EPA) National Pollution Discharge Elimination System (NPDES) program requires permits for all point source discharges to surface water. For most industries, technology-based discharge effluent limits have been established using best available technology.

The standard established in 40 CFR 440 Subpart J for mills that beneficiate gold or silver by cyanidation is zero discharge: such mills may not discharge process wastewater unless they are in areas where net precipitation exceeds net evaporation. In such areas, mills may discharge the difference between annual precipitation and evaporation, subject to National effluent limitations for total suspended solids, copper, zinc, lead, mercury, cadmium, and pH, and subject to other standards established on a case-by-case basis.

Because tailings dams often, or usually, leak, the point at which the zero discharge limitation is applied may be downgradient of the impoundment. In such cases, seepage from the impoundment is collected in ponds and pumped back to the impoundment during the active life of the facility.

It should also be noted that the effluent limitation guideline was developed for mills that use cyanide and predates the widespread use of heap leaching to recover gold. However, the zero discharge standard has been universally applied to heap leach operations. Although there are provisions for permit applicants, on a case-by-case basis, to seek different limits based on "fundamentally different factors" that apply to their discharges relative to those studied by the Agency in setting the standards, to date there have been no known requests for different limits.
Cyanide Heap Leach Closure

solutions are to be collected from open containment and transfer structures. Additional details on implementation and enforcement are not provided in the policy.

On August 14, 1990 BLM issued a Modification of Bonding Policy for Plans of Operation Authorized by 43 CFR Part 3809. This modification requires operators who use "cyanide/other leachates" to post a bond equal to 100 percent of estimated closure costs. The bonding policy modification was applicable to leach heaps, pads, and cyanide-bearing tailings impoundments and ponds, but did not apply to vat leach facilities using cyanide.

Since the original August 1990 cyanide policy and bonding modification, BLM has issued two additional changes to its cyanide policy. The first change, issued on October 9, 1991, was an additional modification of the Bonding Policy. It removed the vat leach exemption from the 100 percent estimated closure cost bonding requirement. The second change, issued on October 10, 1991, recommended rotation of trained BLM personnel in an effort to improve cyanide inspections.

BLM policy requires bonds for the full cost of reclamation, including heap and solution detoxification and neutralization to State and Federal standards, for all cyanide operations on Federal lands. BLM requires that cyanide solutions and heaps be neutralized or detoxified prior to solution release to the environment. Neutralization of cyanide solutions is also required for any prolonged period of inactivity and for temporary or final closure. Specific concentrations for neutralization or detoxification levels are not specified in BLM policy. Heaps must be neutralized upon completion of each heap. Flushing alternatives may be used, but heap materials and/or discharges must meet the appropriate state and EPA discharge limits. The conditions necessary for release of bond were not addressed in the BLM policy.

Monitoring of groundwater and surface water through closure and final reclamation is required. Specific monitoring requirements such as the frequency, location, chemical parameters, and analytical methods were not outlined in the policy and are left to the discretion of the state and BLM district offices. Additional details on detoxification, closure, and reclamation of cyanide operations are not addressed in the BLM policy.

In 1992, BLM issued its Solid Minerals Reclamation Handbook with guidance on reclamation of mining sites on Federal and Indian lands (BLM 1992). The manual specifically addresses cyanide heap and vat leach systems and provides general reclamation guidance and approaches. According to the BLM, the mine reclamation plan should cover cyanide detoxification of residual process solutions, ore heaps, tailings impoundments, and processing components. BLM strongly encourages laboratory and pilot test studies of selected/proposed detoxification. Concurrent reclamation during active mining also is recommended. In the Handbook, BLM does not require any specific metal or cyanide concentrations that must be achieved. Criteria are established on a site-specific basis reflecting any special concerns of the area, such as sensitive resources. The Handbook is written as a general "how
the Handbook with any additional cyanide guidance. The National Park Service appears to defer to
individual states, or other local authority, for specific cyanide guidance and regulatory authority, but
may be involved on a case-by-case basis depending upon site-specific concerns. (National Park
Service 1986)

State Requirements

In the following paragraphs, a summary of applicable state requirements for cyanide operations are
reviewed. This discussion does not include a complete characterization of all applicable mining
programs. An attempt has been made to highlight those factors that are unique to cyanide operations
that may vary from state to state, such as rinsing criteria. Construction design and operating
standards for heaps and tailings are briefly discussed, as they affect closure and reclamation.

States do not have prescribed technologies that must be used for detoxification, but rather rely on
performance standards requiring detoxification to specific criteria. If a site is unable to meet criteria,
a state will often issue a variance based on an alternative treatment method or treatment standard.
Alternatives are typically supported by pathway fate and transport analysis or modeling. For
detoxification and closure, monitoring parameters typically include WAD, free and/or total cyanide,
pH, and metals.

Table 3 provides a comparison summary of various state treatment or detoxification criteria for wastes
and highlights unique reclamation and/or bonding requirements. The table illustrates that there is not
a uniform standard in terms of concentration or constituent specie. Many states use these levels as
guidelines and may issue site-specific variances if a facility is unable to meet these levels. Several
states are debating between WAD cyanide and free or total cyanides, thus, the cyanide species/levels
presented in Table 3 may be subject to change in the near future. Typically, once detoxification
levels are met, and approval is received from the State, final closure begins, followed by reclamation
of the site. Various methods of treatment/detoxification are described in Section 3 of this report.
Section 4 describes closure and reclamation of cyanide operations.
<table>
<thead>
<tr>
<th>State</th>
<th>Treatment Criteria</th>
<th>Reclamation/Bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montana</td>
<td>Water Quality Act requires no discharge from cyanide operations into State waters. Metal Mine Reclamation Act (includes new standards for small cyanidation facilities):</td>
<td>Same as other mining operations, except cyanide operations that would normally qualify for the small miner's exclusion are subject to operating and reclamation requirements.</td>
</tr>
<tr>
<td></td>
<td>• Based on permit writer's discretion.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• to levels considered acceptable based on under applicable water quality standards.</td>
<td></td>
</tr>
<tr>
<td>Nevada</td>
<td>General Performance Standard that facilities may not degrade the waters of the State. Surface water quality is set by NRS 445.253. Groundwater is set at Federal or State drinking water standards and WAD cyanide at 0.2 mg/l. Heaps: Spent ore must be rinsed until effluent reaches²:</td>
<td>Pond sludges, heap solids must be tested using Meteoric Water Mobility Test during closure prior to reclamation.³ Reclamation similar to other mining operations.</td>
</tr>
<tr>
<td></td>
<td>• WAD cyanide: 0.2 mg/l</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• pH: between 6 and 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Remaining solids tested using Meteoric Water Mobility Test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tailings (vat leaching)⁴: For impoundments that do not have underdrainage collection systems, solids must be tested using Meteoric Water Mobility Test.</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td>Based on permit writer's discretion. Current criteria:</td>
<td>Closure required as part of reclamation.</td>
</tr>
<tr>
<td>Carolina</td>
<td>• free cyanide: 0.2 mg/l⁵</td>
<td>Under Mining Act, bond for &quot;affected area&quot; is approximately $1000/acre. However, under Pollution Control Act, (which does not specifically provide for bonding), one mine in the State was required to post $10 million financial assurance.</td>
</tr>
<tr>
<td></td>
<td>In practice, level to which constituents (including CN) are reduced determine how post-closure leachate and wastes may be managed.</td>
<td></td>
</tr>
</tbody>
</table>

⁷ In Nevada, variances are available.

⁸ Cyanidation tailings generated from tank or vat leaching are not specifically called out in the Nevada regulations. The treatment standard for cyanidation tailings prior to discharge to the tailings impoundments has not been obtained.

⁹ In Nevada, units that have a history of liner integrity problems may be required to test underlying soils using the Meteoric Water Mobility Test.

¹⁰ South Carolina is currently considering changing limit from free cyanide to total cyanide.
Monitoring requirements for each site are typically addressed in Water Discharge Requirement (WDR) permits. These permits are required from the Regional Water Quality Control Boards for all discharges. Monitoring requirements are site-specific, depending on site conditions.

Colorado

The Colorado guidelines do not require specific methods for rinsing, neutralization or detoxification. Detoxification standards for cyanide (heaps and ponds) are established on a site-by-site basis between the applicant and the Division of Minerals and Geology. Factors taken into consideration during the permit review process include water balance of process and detoxification solutions, ambient water quality, characteristics and uses of the water in the area, and projected effluent characteristics. If residual metals are anticipated to be a problem, then appropriate treatment standards are also developed for those constituents. (Colorado 1992a)

Specific practices for cyanide leaching are addressed in a Colorado-issued guidance manual for State staff entitled "Guidelines for Cyanide Leaching Projects" (March 1992). The cyanide guidelines manual requires (actually, it would have permit writers require, since it is not regulatory) double liners on all surfaces that will potentially come in contact with a cyanide solution, including all pads, ponds, piping and conveyance systems, and pretreatment areas. Soil layers are allowed as double liners if the soil meets the "impermeable" standard of $1 \times 10^{-6}$ cm/sec; however, to be used as a lower liner in a pond, a soil liner must have a maximum permeability of $1 \times 10^{-7}$ cm/sec. Colorado has not set a permeability standard for synthetic liners. (Colorado 1992a; ELI 1992)

Colorado has approximately 17 active cyanide leach sites, the majority (12) of which are permanent heap leach pads. There are three vat leach operations and one each of valley and on/off pads. (WGA 1991b)

For cyanide operations, Colorado requires surface and groundwater quality monitoring, three to four times annually, during reclamation as well as during active operations. (Colorado 1992a)

Bonding requirements for cyanide operations are the same as for other mining activities, but calculation of the costs must address detoxification of the ore and process solutions by including: an estimation of the volume of solutions in ponds during detoxification, the average residual cyanide in ore for each rinsing, and calculation of the amount of detoxification agent for each rinse until the detoxification standard is reached. (Colorado 1992a)

It should be noted that (as of Spring 1993) the Colorado legislature is considering a major revision to the Mined Land Reclamation Act. In addition, the Mined Land Reclamation Board placed a moratorium on approval of new cyanide operations in early 1993 (the status of the moratorium was not determined).
recovery*, however, tailings structures more than 30 feet high are exempt from the impoundment requirements (subject to Idaho Code Title 42, Chapter 17). (ELI 1992) Leach pads and impoundments are required to have a hydraulic liner designed for a maximum coefficient of permeability of \(10^{-7}\) cm/sec; clay liners are also to have a minimum thickness of 12 inches.

Idaho requires a monitoring strategy in each cyanide operation plan addressing baseline water quality (surface and groundwater), proposed monitoring, leak detection, and emergency response procedures. Ground water, and if applicable, surface water, monitoring is required at all cyanide operations. Duration of monitoring through closure, reclamation and post-reclamation is not identified in the regulations. (Idaho Title 1 1992)

Proposals for land application or economic reuse of cyanide solutions must be included with the permit application. Details on land application are not specifically addressed in Idaho's Rules and Regulations for Ore Processing by Cyanidation.

Several seasonal heap leach facilities operate in Idaho. The State has separate requirements for seasonal, temporary and permanent closure. Seasonal closure requires an increase in freeboard to allow for seasonal runoff and snowmelt. Cyanide concentrations are to be reduced and pH controlled (6.5-9.0) in solution and process waters during seasonal closure. A temporary closure plan is submitted for temporary closure; it details the procedures and schedule for treatment and drainage control. Permanent closure activities are to be included in the operation permit application. (ELI 1992)

Prior to disposal or abandonment of the spent ore, process-contaminated water drained from leached ore must be stabilized at a pH of 6.5 to 9.0, or WAD cyanide levels are to be reduced to 0.02 mg/l. If WAD cyanide is used as the determining value, then other pollutants must be reduced to an appropriate level based on disposal criteria. The other pollutants include those addressed by surface, drinking or other water quality standards that the State deems appropriate on a site specific basis. (Idaho Title 1 1992) Financial assurance for cyanide operations is released when the facility completes permanent closure in accordance with an approved plan. (Idaho Title 1 1992)

Montana

In Montana, all cyanide operations are subject to the general regulations for mining operations adopted in 1980. Each mine must obtain an operating permit that addresses operations, practices, closure and reclamation. In addition, Montana has a permitting program for small cyanide mines less than five acres. The regulations for small mine cyanide operations are more detailed than the general operating permits standards. (WGA 1991b)
Nevada requires (by permit) the Meteoric Water Mobility Test for pond closure at cyanide operations, and requires sites with a history of liner integrity problems to collect subsurface soils for analysis. Closure of ponds in-place often involves folding the synthetic liner over the remaining sludge/residue, backfilling with soil followed by regrading and revegetation.

Closure is considered complete when the facility and mined areas have been stabilized and no longer have the potential to degrade waters of the state. Variances may be granted if the rinsing standards cannot be met by a facility and the facility provides alternative measures to inhibit migration of runoff. Once a heap or pond has been chemically stabilized (as demonstrated by the Meteoric Water Mobility Test), then the State staff sends a letter to the facility allowing them to proceed with reclamation.

In the Evaluations for Closure, Nevada specifies that for tailings impoundments, the saturation and permeability of the tailings be determined and for underdrainage collection systems, the quality and quantity of the underflow solution are to be defined before final closure. Tailings without underdrainage collection systems are to be cored and analyzed by the Meteoric Water Mobility Test. The extent of capping and drainage control methods will be based on the results of the underdrainage analysis. (Nevada 1990) Approximately ten cyanidation sites have been satisfactorily closed and are ready for, or have started, reclamation. (Nevada 1993a)

Reclamation standards are site-specific; no design standards are prescribed in the law or regulations. Heap leaches and tailings may be regraded to enhance structural integrity, reduce runoff, reduce infiltration, and control erosion, or they may be covered with waste rock, topsoil, or growth medium, revegetated, and runoff diverted. (ELI 1992)

The Nevada Department of Wildlife began a permit program for industrial ponds, including tailings impoundments and all cyanide process ponds. The program was created in order to substantially reduce, or eliminate, wildlife mortality associated with mining ponds. (GAO 1991) Numerous birdkills during the 1980s from cyanide ponds prompted enactment of the State law to protect wildlife (effective 1989). The required Department of Wildlife industrial pond permit (also referred to as the toxic pond permit) requires either fencing and covers on all ponds or use of dilution/neutralization. Nevada Department of Wildlife frequently accepts dilution or neutralization of free cyanide to below 50 ppm as sufficient to avoid mortalities. (WGA 1991b; ELI 1992)

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14 The state's Meteoric Water Mobility procedure is used to determine the potential to degrade waters of the state. ELI 1992.
South Dakota

Concerns over the impacts of surface mining led to a State moratorium on new large-scale gold and silver mines in South Dakota, effective in 1992. One of the instituted reforms was a requirement for large-scale cyanide operations to develop contingency plans and obtain sufficient financial assurance to cover releases to the environment, and submit annual reports listing annual cyanide use. (ELI 1992)

Permitting for a typical heap leach facility would involve pre-submission meetings, submission of the permit application, a socio-economic study, a completeness review, technical review, a public notice and a public hearing before the South Dakota Board of Minerals and Environment. (WGA 1991b)

South Dakota mining laws, regulations, and permit conditions require that spent ore be adequately neutralized and designated as suitable for disposal before off-loading from heap leach pads. Heaps must be rinsed until treatment standards are reached. (Durkin 1990)

Prior to detoxification, effluent or pore water from the ore must be characterized for cyanide, metals, anions, cations, pH, radioactivity and total dissolved solids. The South Dakota Department of Environment and Natural Resources (DENR) then uses these results to designate key parameters for an individual site to monitor throughout the treatment/neutralization cycle. Spent ore is considered suitable for disposal when the effluent meets the criteria listed in Table 3.

South Dakota DENR requires that neutralization and off-load criteria be based on effluent samples collected at the toe of the spent ore heap or analysis of leachate extracted from a representative solid sample (pore water) taken from the spent ore heap. (Durkin 1990)

If detoxification (treatment) of tailings is not successful and the operator wishes to try a new treatment method, a new treatment plan must be submitted to DENR. In cases where the treatment criteria cannot be achieved, DENR may develop alternate, site-specific criteria, or tailings may be reclaimed such that infiltration, percolation, and discharge are minimized, as indicated by appropriate pathway and fate analysis. (Durkin 1990)

The South Dakota Water Pollution Control Law has set a regulatory groundwater standard for WAD cyanide at 0.75 mg/l. Concentrations detected at or above this level prompt remedial groundwater investigations. (ELI 1992)

The State has five leach operations, of which three are on/off pads. The fourth is a permanent heap pad and the fifth is a vat leach operation (WGA 1991b). With detoxification of heap leaches, the State's experience has shown that 2.5 pore volumes are required before effluent concentrations are within the required standards. (South Dakota 1993)
SECTION 6. CASE STUDIES

Introduction

Selected case studies are presented in this section. First are three gold-related Superfund National
Priorities List (NPL) sites with cyanide operations that resulted in releases to the environment. A
brief summary of facility operations, releases and constituents, and response actions of concern are
provided. NPL sites can provide an example of what may happen if cyanide (and other) operations
are not managed with care. In contrast to the NPL sites, several active or recently active sites are
presented as case studies. The active sites selected as case studies were not selected as either good or
bad models, but rather to examine a range of cyanide treatment techniques. The three active case
studies highlight a vat leach operation with INCO treatment of tailings slurry, a large leach heap
operation with several heap pads, and a site using biological treatment by bacteria. Material for the
case studies came from publicly available documents, and file materials collected from the respective
State regulatory offices.

Sites on the NPL

Cimarron Mining Corporation Site, Carrizozo, New Mexico

The Cimarron Mining Corporation Superfund Site is located on 10.6 acres of privately owned land
east of Carrizozo, New Mexico, and approximately 100 miles south-southeast of Albuquerque. The
site was a conventional agitation cyanidation mill used for the recovery of precious metals. The mill
was closed in July 1982, and the owners of the facility filed for bankruptcy in July 1983. As a result
of disposal of cyanide contaminated wastes, both groundwater and soils have been contaminated with
elevated levels of cyanide and heavy metals. The Cimarron site was added to the NPL on October 4,
1989.

Precious metal milling at Cimarron consisted of vat leaching ore with a cyanide solution in two
separate tanks to produce a pregnant solution bearing precious metal values for electrowinning.
Various stages in this operation produced cyanide laden waste streams. Tailings were sent to a series
of four thickeners where residual pregnant solution was skimmed off the top. The thickeners also
produce two waste streams, a fluid fraction containing cyanide solution for recycling, and tailings or
solids to be disposed of onsite. The fluid fraction and small-sized solids were apparently gravity fed
to two cement block trenches and eventually recycled back into the cyanidation operation. The
tailings were pumped through a solid separator and transported to the tailings piles by truck.

Barren solution generated from electrowinning operations containing free cyanide and metal-cyanide
complexes of copper, iron, nickel, cobalt, zinc, and other impurities was also pumped to the cement
to neutralize leachate from the heap that collected in the pond were completed, however cyanide solution containing heavy metals continued to discharge from the heap. In each case, cyanide in the leachate ponds was effectively detoxified, however, the heap, which was not rinsed or otherwise remediated, continued to produce contaminated leachate.

In June 1985, the heap leach pile was stabilized by removing liquids and residue from the leachate pond, and both the heap and collection pond were covered with geotextile fabric and a 33-mil hypalon liner. No sampling of the heap or spent ore material was performed prior to capping. (References do not indicate whether the heap was rinsed prior to draining, just that it was allowed to drain.) According to the EPA Regional Project Manager (RPM), the final cap on the heap consists of a 2-foot clay liner, topped with 3 feet of topsoil which has since been vegetated.

The leach heap, mine dump, mine drainage, and bedrock were identified as four potential sources of elevated levels of arsenic, cyanide, and antimony in soils and groundwater at the site. Grab and composite soil samples were obtained in 1992 from areas around the heap, and underneath waste piles and other "spoil" piles. Materials from these piles were removed and consolidated on the heap prior to sampling, and prior to capping the heap. No heap or consolidated materials were sampled. Soils were only sampled for cyanide and arsenic, and no elevated levels of cyanide were detected. According to the RPM, EPA is currently nearing completion of the remedial action design.

Whitewood Creek Site, Lawrence, Meade, and Butte Counties, South Dakota

The Whitewood Creek Superfund Site is a mine tailings contaminated site located in Lawrence, Meade, and Butte Counties, South Dakota, on an 18-mile stretch of Whitewood Creek. Homestake Mining Co. (Homestake) began gold mining near Lead, South Dakota in the late 1870's when gold was recovered by gravity or by amalgamation with mercury. Approximately 21.6 million tons of tailings have been generated by these operations, most of which were disposed of in Whitewood Creek. The Whitewood Creek site was listed on the NPL in early 1984.

Tailings disposal to Whitewood Creek ceased in the mid-1970s following results of a study finding elevated concentrations of mercury in groundwater. In 1977, Homestake constructed the Grizzly Gulch tailings impoundment to contain residual tailings and process waters. The impoundment is unlined and intersects the groundwater table during the wet season. From 1977 on, cyanide tank leaching was used exclusively to extract gold values from the ore. A wastewater treatment system was installed in 1984 to treat waters generated from the tailings impoundment and water pumped from the bottom of the mine.

Carbon-in-pulp vat leaching methods of precious metals recovery are used at this site. Two size fractions of milled ore are treated separately, each subject to cyanide leaching, followed by precious metal recovery by activated carbon filter methods. Approximately 1.5 to 2.0 million tons of tailings...
Active Sites

The following are active, or recently active cyanide leaching operations (not on the NPL) that have begun closure activities. The discussion of these three facilities focuses on closure and/or reclamation activities at the sites.

Hecla, Yellow Pine, Idaho

Hecla Mining Company completed gold extraction from its heap leach pad at Yellow Pine, Idaho in 1992 (Minerals Today). Currently, the facility is detoxifying the cyanide in the spent ore by applying a bacterial biological treatment method to the heap.

The bacterial solution is applied to the spent heap using sprinklers to spray the top of the heap. The solution then percolates through the spent ore with bacteria consuming the cyanide as it progresses. After the solution passes through the heap it is collected in a process pond and then recycled back through the heap. At the end of treatment, the solution pond will be allowed to evaporate, materials (sludges) will be sampled and analyzed, and the unit will be closed in place by folding the pond liner over any remaining sludge, contouring, and revegetating. Information on the type of bacteria, additional nutrients required, and the developer of the process used by Hecla have not yet been obtained. (Idaho 1993)

After treatment, effluent from the heap reached the 0.2 mg/l state standard for cyanide during the fall of 1992. The Idaho DEQ wants to review cyanide levels through one wet rainy season prior to approving the start-up of reclamation activities. The facility planned to collect effluent samples during spring sampling. Depending on the results of this sampling, the state may approve initiation of reclamation for Fall 1993. (Idaho 1993)

The detoxified heap may not require capping. The fourth (top) tier of the heap will be removed and used to regrade and contour the heap. A berm will be constructed around the top of the heap to prevent runoff erosion from destroying the steep slopes of the heap. The liner beneath the heap will not be broken with numerous perforations, but approximately three spots will be used to drain any percolated material to the ground. The state will require 5 to 10 years of groundwater monitoring of onsite wells (for cyanides and metals). (Idaho 1993)

An Idaho representative (Idaho 1993) stated that the biological cyanide destruction process has appeared to work well at the Yellow Pine facility. The site has been able to meet the 0.2 mg/l WAD cyanide standard for heap effluent, although the state is still waiting to see the results after a wet season, before it approves closure. Metals have not been a problem at the site, although the state representative credits this to the composition of the ore rather than the result of the biological treatment process.
Periodically, Landusky land applies neutralized solution to a specified parcel of land at the site. In 1987, during one round of land application four million gallons were applied during a five day period. Cyanide concentrations of the water applied to the ground were above 3 mg/l (exact concentrations were not obtained for this report).

McCoy/Cove Mine, Echo Bay Mining Company, Nevada - INCO process

The McCoy/Cove Mine, near Battle Mountain, Nevada, operates a vat leach operation for extraction of gold. The facility added an INCO cyanide treatment system in 1990 to its operations after experiencing more than 1000 water-fowl deaths caused by migratory birds drinking out of its cyanide tailings impoundment (such deaths are in violation of the U.S. Migratory Bird Treaty Act).

At the McCoy mine, the INCO process is used to remove cyanide from the tailings pulp after gold has been recovered from the milling process. Prior to the use of INCO, the spent tailings were discharged directly to a tailings pond. The liquid fraction of the tailings was reused as make-up in the leaching process. The cyanide-containing liquid in the 145 hectare tailings pond attracted the migratory birds in a desert area with few open bodies of water.

The system treats tailings pulp (thickener) underflow containing 268 kg WAD cyanide/hour in two parallel reactors (40 percent solids; 8,500 stp mill throughput) to reach a target residual cyanide level of 25 mg/l WAD cyanide (it can reach 5 mg/l WAD cyanide, if necessary). Other INCO references suggest that the McCoy/Cove effluent has total cyanide levels below 10 mg/l. Periodic WAD cyanide analysis, as well as SO₂ feed, slurry flow rate, pH, and percent solids, are monitored. Tailings are disposed of in a tailings impoundment where WAD cyanide levels are monitored daily, ranging from 4 to 7 ppm. (Devuyst 1992; INCO 1992) The facility has cut its cyanide consumption by reusing cyanide recovered from the INCO process.
Because cyanide leaching dramatically expanded in the 1980s, many facilities are now facing closure and reclamation. A number of cyanide treatment techniques, ranging from rinsing with fresh water to bacterial treatment to sulfur dioxide methods are available today. Issues facing states and the industry include effectiveness of neutralization methods, treatment or stabilization of non-cyanide constituents, accuracy of sampling and analysis, bonding and long-term monitoring, and appropriate regulatory controls.

Cyanide treatment methods have varying degrees of effectiveness, depending not only on operating parameters, but also characteristics of the spent ore or tailings, and on geography and climate. In many cases, treatment has not effectively lowered cyanide to the required levels. The effectiveness of rinsing agglomerated heaps in particular, has not been well established. Thus, the existing rinsing and treatment techniques have not yet proven to work for all cyanidation wastes at all sites.

Measurements of detoxification have shown examples of elevated spikes in cyanide and other constituents after rinsing has ceased. This raises concerns regarding the quantity/amount of residual cyanide, and other constituents remaining in the ore. Until the causes for the spikes are well established, doubt remains over the effectiveness of treatment or rinsing of heaps and tailings impoundments.

Although treatment may reduce cyanide levels, existing treatment methods may not be effective for other constituents, such as metals, present in the spent ore or tailings. The potential for acid generation may also exist at many mine sites. Section 4 discussed several sites that were able to reduce cyanide concentrations but encountered difficulties with other compounds such as arsenic or mercury.

Because of the relative newness of the technology, there is little State experience with closure and reclamation of cyanide leaching operations. Standards are not uniform from one state to the next. Federal agencies (BLM, USFS, and NPS) are following the state leads, for the most part, and defer to States for specific contaminant criteria. Many operating sites have been "grandfathered" in because they existed prior to the development of State cyanide programs and thus are not subject to more recently developed standards. It is not known whether grandfathered sites will use current best available technology for closure and reclamation or adhere to their original, usually brief, reclamation plans.

States have set various treatment/detoxification standards for cyanide, but the standards and required test methods vary. In part this is due to the difficulty in measuring cyanide and the inaccuracy that accompanies the test results. Research on cyanide test methods is ongoing.
SECTION 8. REFERENCES


Carson Hill Undated. Excerpts from the geology and climate sections of the Feasibility Study on the Carson Hill Mine Project. (Full citation, including date, not provided.)


Idaho Title 1 1992. Idaho Title 1, Chapter 13: Rules and Regulations for Ore Processing By Cyanidation, January 6, 1988, revised April 23, 1992. (Sections 01.13000 to 01.13999)


Cyanide Heap Leach Closure


