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EPA

Seminar Series on Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites

August 8-9, 1994—Anaconda, MT

November 15-16, 1994—Denver, CO

November 17-18, 1994—Sacramento, CA

EPA/625/K-94/002
June 1994

Seminars

Managing Environmental Problems at Inactive and Abandoned Metals Mine Sites

U.S. Environmental Protection Agency
Office of Research and Development

Notice

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Contents

Understanding the Reasons for Environmental Problems From Inactive Mine Sites

Dirk Van Zyl
Golder Associates Inc.
Lakewood, CO

Dr. Van Zyl has a B.S. (honors) in civil engineering from the University of Pretoria, South Africa, and an M.S. and Ph.D. in civil engineering from Purdue University. As a researcher, consulting engineer, and university professor, he has over 20 years of civil/geotechnical engineering experience and is a registered professional engineer in 11 states.

Dr. Van Zyl is director of mining in the Denver office of Golder Associates Inc. He is responsible for technical and marketing efforts for mine waste disposal, mine closure, and heap leach projects. He also provides engineering design and regulatory support in negotiations for permits. He has supported regulatory development in the United States and internationally. He is a member of the Society of Mining, Metallurgy, and Exploration, Inc., the American Society of Civil Engineers, and the South African Institute of Mining and Metallurgy. He has published over 50 technical papers, research reports, and books, and served as editor of conference proceedings. He has coordinated and presented numerous short courses for the Society of Mining, Metallurgy, and Exploration, Inc., and the U.S. Forest Service.

"Understanding the Reasons for Environmental Problems From Inactive Mine Sites"

Presented by
Dirk Van Zyl, P.E., Ph.D.
Director Mining
Golder Associates Inc.
Denver, Colorado

"Mining not only produced wealth, power, and fame for the United States; it also attracted world-wide attention and investment to this underdeveloped nation, one that was sorely in need of a financial transfusion".

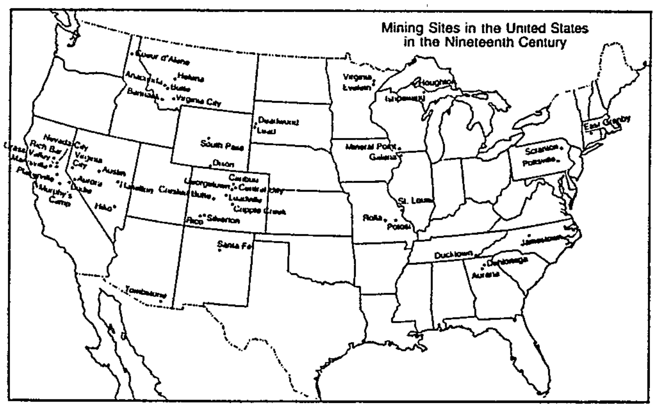
MINING AMERICA
Duane A. Smith, 1987
University Press of Kansas

"Without mining-from coal to iron to gold-the United States could not have emerged as a world power by the turn of the century, nor could it have successfully launched its international career of the twentieth century."

MINING AMERICA
Duane A. Smith, 1987
University Press of Kansas

"All this development did not take place without disturbance-environmental, personal, economic, political and social. Mining left behind gutted mountains, dredged-out streams, despoiled vegetation, open pits, polluted creeks, barren hillsides and meadows, a littered landscape, abandoned camps and burned-out miners and the entrepreneurs who came to mine the miners."

MINING AMERICA
Duane A. Smith, 1987
University Press of Kansas



MINING AMERICA, Duane A. Smith, 1987, Univ. Press of Kansas

Pictorial Slides

Aspects of Mineralization

- Gold and silver in oxidized zones near surface, sulfides at depth
- Sulfide minerals (lead, zinc, copper) in sulfide mineralization
- Other metals can be associated with mineralization, e.g., arsenic, iron, mercury and cadmium

Historic Mine Development

- Prospecting for surface outcrops
- Orebodies close to surface or vein type mining, e.g., lead-zinc in Kansas/Missouri, gold and silver in Rocky Mountains
- Shafts or Adits
- Gravity dewatering important
- Mining activity increased surface area exposed to water and oxygen

Mineral Extraction

- Physical processes - increase surface area
- Amalgamation - mercury introduced
- Smelting - air pollution, firewood consumption
- Cyanidation - introduced in 1890's
- Flotation - no significant chemical residues, increased surface area

Water Quality Data Comparison For Selected Mineralized Areas in Colorado

Parameter	Alum Creek at Mouth (Aug 1991)	Wightman Fork Below Cropsy Creek (Oct 1981)	Wightman Fork Below Cropsy Creek (Oct 1991)	Silver Creek at Bridge Hwy 145 (Mar 1966 to Dec 1968)
pH	NA	3.44	NA	7.9 Mean 8.4 Max 7.4 Min
Arsenic	5.7 9 3	2	NA	NA Mean NA Max NA Min
Cadmium	7 10.2 4.9	5.4	62	NA Mean NA Max NA Min
Copper	259 261 258	3,560	26,000	111 Mean 1,100 Max 0 Min

(All values in ug/l)

Water Quality Data Comparison...

Parameter	Alum Creek at Mouth (Aug 1991)	Wightman Fork Below Cropsy Creek (Oct 1981)	Wightman Fork Below Cropsy Creek (Oct 1991)	Silver Creek at Bridge Hwy 145 (Mar 1966 to Dec 1968)
Iron	126,500 171,500 103,000	6,300	82,000	5,407 Mean 125,000 Max 0 Min
Lead	4.2 6.8 2	18.5	NA	655 Mean 6,350 Max 0 Min
Silver	<0.5	1.02	<0.2	NA
Zinc	652 843 543	770	6,300	855 Mean 2,000 Max 100 Min

(All values in ug/l)

Some Reasons for Environmental Problems from Inactive Mine Sites

- Natural Mineralization
- Mining activities resulted in increased exposure to water and air
- Poor understanding of environmental effects of mining
- Economic incentives driving force
- Chemicals used for hydrometallurgical and flotation extraction typically not a concern

Some Reasons for...

- Problems are now highlighted because:
  - Changes in environmental awareness
  - Changes in regulatory environment
  - Better understanding of environmental processes-multimedia perspective
  - Increased analytical capabilities

Other Issues

- Unrealistic regulatory limits
  - Baseline vs. drinking or aquatic water standards for natural discharge
  - Discharge from treatment plant
- Site-specific risk issues-not always recognized

Conclusions

- Natural mineralization is biggest source of environmental problems
- Mining increased exposure of sulfides and other minerals to oxygen and water
- Present concept: Design for closure

Importance of Characterization in Addressing Environmental Problems From Inactive Mine Sites

Andy Robertson
Steffen, Robertson and Kirsten (Canada) Inc.
Vancouver, BC

Dr. Robertson has a B.Sc. in civil engineering and a Ph.D. in rock mechanics from the University of Witwatersrand, South Africa. After a few years spent working for a mining company as a rock mechanics engineer and for a specialist foundation engineering company doing specialized site investigation and foundation designs and contract supervision, Dr. Robertson became a cofounder of the firm Steffen, Robertson and Kirsten (SRK), Inc., Consulting Geotechnical and Mining Engineers. He has 28 years of experience in mining geotechnics, of which the last 10 years have been devoted extensively to geoenvironmental engineering for mine sites.

Dr. Robertson has been responsible for developing the engineering capabilities of the North American practice of SRK over the past 17 years and has specialized personally in technology for the safe and environmentally protective disposal of mine tailings and waste rock, acid mine drainage prediction and modeling, mine closure plan development, and financial assurance and remediation of abandoned mines. He has been extensively involved in the preparation and writing of a number of manuals on these subjects, which are now widely used in the mining industry. In addition, he gives regular short courses and consults internationally to mining companies and regulatory authorities on these topics. He serves on a number of advisory boards, including the University of British Columbia Board of Studies for the Geological Engineering Program and the Mine Waste Technology Pilot Program (Butte, Montana), as well as on a number of mining project specific review boards.

"The Importance of Characterization in Addressing Environmental Problems from Inactive Mine Sites"

Presented by
Dr. A. Mac.G. Robertson

Steffen Robertson and Kirsten
Consulting Engineers and Scientists

Technical References

Draft ARD Technical Guide
- British Columbia Acid Mine Drainage Task Force Report

Mine Rock Guidelines
- Saskatchewan Environment and Public Safety

Ontario Closure Guidelines
- Ontario Ministry of Northern Development and Mines

Site Characterization Steps

Planning
⇩
Investigation
⇩
Evaluation

All Steps must be considered for appropriate and adequate site characterization

Planning

Definition of Potential Concerns

- *what problems should be considered?*

Methodology for Site Characterization

- *how to look at the site?*

Initial Information Requirements

- *where to start?*

Investigation

Techniques for Initial Reconnaissance

- *what can be seen from the site?*

Evaluation of Existing Information

- *are data sufficient to define concerns?*

Additional Data Collection

- *where do we go from here?*

Evaluation

"Quantification" of Potential Issues of Environmental Liability

- *what are the real problems*

Evaluation of Alternative Control Measures

- *how can these problems be solved?*

Cost/Benefit Evaluation

- *what is the best control measure for the cost?*

Site Characterization for Reclamation

Physical

- *components must be stable, safe and not move*

Chemical

- *materials must not decompose and yield soluble contaminants*

Land Use and Aesthetics

- *site must be useful and look good*

Approach (eg. Rock Piles)

Initial

- initial reconnaissance and evaluation
- geographic comparisons
- lithologic, geochemical units

Approach (eg. Rock Piles)

Detailed

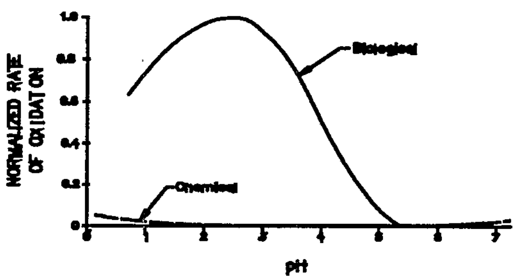
- quantify mine rock units, production
- material distribution and sampling
- laboratory static and kinetic testing
- hydrology and geohydrology
- physical and chemical modelling
- environmental impact

Initial Reconnaissance and Characterization for ARD

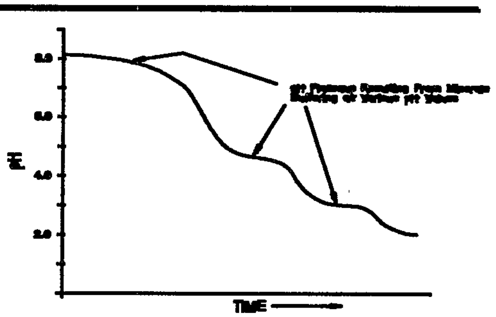
- detect signs of ARD
- assess the factors that control ARD
- evaluate control measures
- evaluate the environmental impact
- assess characterization requirements for subsequent stages

Pictorial Slides

Kinetics of Acid Generation

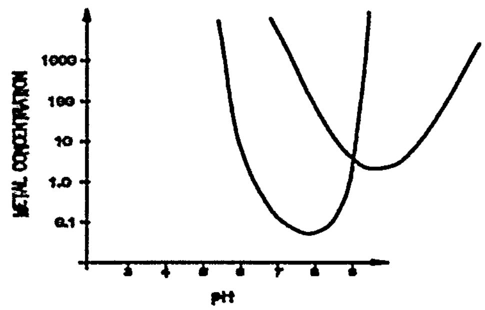


pH Controls During Acid Generation



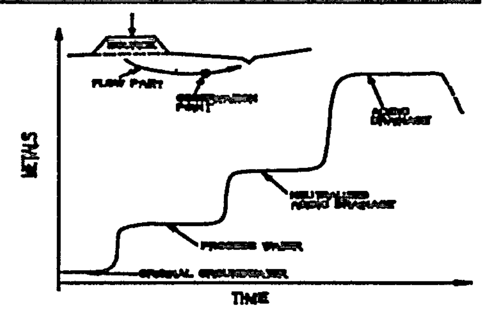
Pictorial Slides

Solubility of Metals



Pictorial Slides

Kinetics of Contaminant Front Migration



Pictorial Slides

Reconnaissance...

What to Bring

- water sampling equipment
- pH paper, meter
- 10% HCl (to test for carbonates)
- sulfate field kit
- hand lens, rock hammer, mineral ID book
- sediment bags

Reconnaissance...

Where to Look

- at and as close to source as possible
- color changes, paste pH
- surface pools
- seeps at toe of waste
- decants and surface runoff
- ground water monitoring wells

Reconnaissance...

When to Look

- spring & fall for water quality (freshet and rains)
- summer for staining and precipitates
- first snowfall for "hot spots"

Reconnaissance...

Field Clues

- visible sulfides
- red, orange, yellow, white, blue staining or precipitates or water
- dead vegetation
- melting snow or steaming vents on wastes
- dead fish and other biota

Reconnaissance...

Water Quality

- low pH in seeps, ground water, decant
- elevated or rising sulfate and metals
- increasing acidity or decreasing alkalinity

Geochemistry

- low paste pH of mine wastes
- high conductivity in field extractions

Identify Site Components

- underground workings
- open pit workings
- mine rock and overburden piles
- tailings facility
- water management and water treatment facilities
- all other infrastructure

Mine Rock Characterization

Physical

- size and layout (topography)
- construction methods and lifts
- grain size distribution and variation
- hydrology (run-on and run-off)

Pictorial Slides

Mine Rock...

Chemical

- mineralogy
- paste pH,
- field extraction's for conductivity
- seep water quality
  - *pH, conductivity, sulfate, metals*
- downstream water quality

Pictorial Slides

Mine Rock...

Land Use

- visual
- soils
- vegetation
- drainage

Tailings Characterization

Physical

- size and layout (topography)
- structures and stability
- deposition methods and zones
- grain size distribution
- surface and subsurface drainage

Pictorial Slides

Tailings...

Chemical

- mineralogy
- paste pH,
- field extractions for conductivity
- seep water quality
    - *pH, conductivity, sulfate, metals*
- downstream water quality

Pictorial Slides

Tailings...

Land Use

- visual
- soils
- vegetation
- drainage

Pictorial Slides

Underground Workings Characterization

Physical

- layout and geometry
- mining methods, stopes and backfill
- openings and subsidence zones
- drainage and flood levels

Pictorial Slides

Underground...

Chemical

- mineralogy of exposed rock and backfill
- drainage pH, conductivity, water quality
- downstream water quality

Pictorial Slides

Underground...

Land Use

- visual
- safety
- subsidence
- drainage

Open Pit Characterization

Physical

- layout and geometry
- contained waste and backfill
- slope stability
- inflow and flooding, groundwater

Pictorial Slides

Open Pit...

Chemical

- wall rock and backfill mineralogy
- paste pH
- field extractions for conductivity
- seep water quality
  - *pH, conductivity, sulfate, metals*
- downstream water quality

Pictorial Slides

Open Pit...

Land Use

- visual
- safety
- subsidence
- drainage

Pictorial Slides

Stages of Sampling and Testing for Site Reconnaissance and Characterization of ARD

Stage	Identify	Test	Question
1 Problem Screening	Geological Units	Static	What we have
2 Source Definition	Geochemical Units	Static (Definition)	What we have
3 Kinetic Characterization	Geochemical Classification	Kinetic	How it will behave
4 Control Characterization	Evaluation of Controls	Kinetic	How to modify the behavior

U.S Bureau of Mines Technology: New Environmental Applications

William Schmidt
Bureau of Mines
Washington, DC

Mr. Schmidt has worked for the federal government for 22 years in areas related to mining and minerals processing. After graduating from the Colorado School of Mines and before joining the government in 1971, he worked for 8 years in the private sector, mostly on assignments related to tunneling and construction engineering.

Mr. Schmidt has managed various government programs related to regulation of coal mining, mining research, and metallurgical research. For the Department of Energy, he served as director of the Office of Coal Technology, where he was responsible for a $70 million per year coal mining and preparation research program. At the Department of Interior's Office of Surface Mining (OSM), he was assistant director for Program Operations and Inspection, responsible for OSM's enforcement, oversight, and Abandoned Mined Lands (AML) programs. Mr. Schmidt has visited Europe and Asia a number of times as a government technical expert. He works for the Bureau of Mines in Washington, where he is chief of the Division of Environmental Technology. In this position, in addition to his research program management responsibilities, he oversees the Bureau's technical assistance to the U.S. Forest Service, EPA, and other agencies in the environmental cleanup arena.

Proven Tools for New Uses

U. S. Bureau of Mines Remediation Technology

William B. Schmidt

USBM Environmental Research

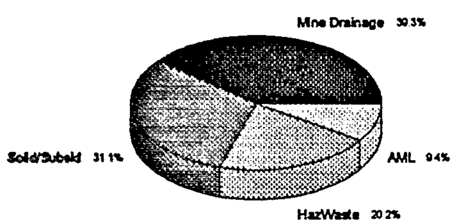
Mine drainage technology
- Acid mine drainage coal
- Acid Mine Drainage metal and non-metal mines

Solid mine waste and subsidence

Hazardous waste treatment technologies
- Characterization
- Treatment

Abandoned Mine Land (AML) remediation

USBM Environmental Technology Distribution of Funding



FY 95 Funding= $19.4M

Mine Drainage Technology

Prediction
- fundamental sulfide reactions
- geochemical models (correlated with static and kinetic testing and field test results)
- host rock and waste rock dumps

Mine Drainage . . .

Mitigation/Control
- seals, grouts, and caps
- passivation

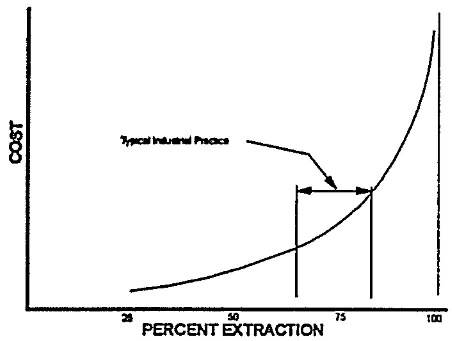
Treatment (Contaminant Removal)
- chemical
- biological

Solid/Subsidence Technology

Reprocessing/process modification
- pyrite removal
- heavy metal removal

Pyrometallurgical treatment (high temp)
- vitrification
- metal extraction

The Problem With Recovering Metals From Wastes



Solid/Subsidence . . .

Waste disposal
- fly ash
- dump stability

Subsidence effects
- prediction
- prevention

Hazardous Waste Technologies (CERCLA/RCRA Wastes)

Characterization
- geophysical
- geochemical
- imaging

Treatment
- electro-dissolution w/ organic acids
- leaching/recovery
- superfund technical support

Abandoned (Coal) Mine Land Technologies

Mine fires
- extinguishment
- containment

Subsidence
- void detection
- subsidence control (backfilling)

Abandoned (Coal) Mine Land. . .

AMD (Coal)
- constructed wetlands
- bacteriacides

Shaft/Entry Seals
- lightweight concrete
- inflatable forms

Hydrologic Controls

ET Customers

USEPA
- ORD/RREL
- Superfund
- Great Lakes Nat'l Program Office

USFS
- Acid Mine Drainage
- Slope Stability

ET Customers. . .

OSM/DOI
- Technical assistance
- Regulatory tech base

NPS/DOI
- Site remediation
- Technical assistance

Targets for ET Technology

Hazardous Sites on Federal Lands

Hazardous Waste Sites

General Mine Waste Problems

Special Studies
- Urban rivers
- Great lakes
- Municipal wastes
- Other (rad wastes, mixed wastes, etc.)

Case Study #2:

An Improved Version of a Constructed Wetland Mine Drainage Treatment System

Ronald Cohen
Colorado School of Mines
Golden, CO

Dr. Cohen received a B.A. degree in biophysics from Temple University in Philadelphia. He also received a Ph.D. in environmental sciences and engineering from the University of Virginia, where he combined disciplines of water quality engineering, water chemistry, hydrology, and applied math. He has worked as a project chief in the National Research Program at the U.S. Geological Survey and currently is associate professor of environmental science and engineering at the Colorado School of Mines. Dr. Cohen has been working on treatment, geochemistry, and transport of mine drainage materials for 5 years. In addition, he has studied the distributions of ^{239,240}plutonium and ^{137}cesium in regions of the front range both affected and unaffected by the Rocky Flats Plutonium Weapons Plant. Also, he has participated in studies of surface runoff, storm runoff, graphic information systems, and stream transport modelling. He has reviewed the Department of Energy's Treatment Plans and Treatment Reports and made suggestions for additional remediation technologies.

Dr. Cohen has received the First Prize for Environmental Projects from the American Consulting Engineers Council for development of treatment systems for acid mine drainage. He is the recipient of a Certificate of Special Recognition from the U.S. Congress for environmental work associated with Department of Energy nuclear weapons plants. He was selected to review the National Five Year Plan for Environmental Remediation of the Weapons Plants. He has published numerous papers in journals such as the Journal of the American Society of Civil Engineers, Limnology and Oceanography, and others. He has worked on contaminant problems in Charlotte Harbor (Florida), Chesapeake Bay, San Francisco Bay, the Potomac River, and Clear Creek and the Eagle River (Colorado). Currently, Dr. Cohen teaches courses on contaminant transport, water quality, water quality modelling, and hydrology at the Colorado School of Mines. He has designed curriculum and coordinated the Hazardous Materials Management Program for professionals dislocated from the energy and minerals industry.

Case Study #2: An Improved Version of a Constructed Wetland Mine Drainage Treatment System

by
Ronald Cohen
Colorado School of Mines
Golden, CO

Wet Substrate Bioreactor for Removal of Metals: Treatment Expanded for Removal of Arsenic and Chromium

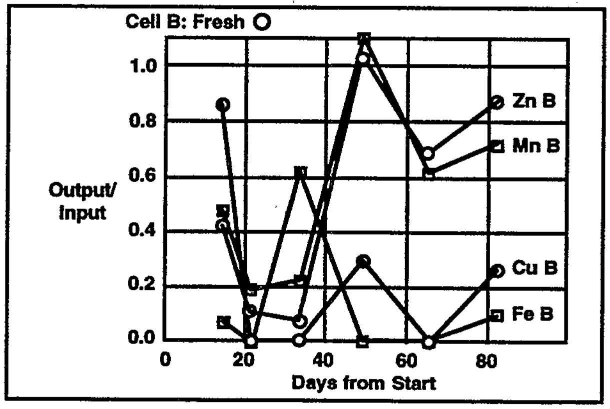
PROBLEM: Remove metals to detection limits inexpensively-low capital costs, low operation and maintenance

- Remove not only Fe, Cd, Zn, Pb, and Cu, but also metals that appear in anionic forms, Arsenic and Chromium
- Raise pH of acidic waters (as low as pH 2) to near neutral
- Minimize the size of the system
- Optimize conditions for bacterial production of sulfides; sulfides react with metals to form precipitates

Wet Substrate Bioreactor for Removal of Metals: Treatment Expanded for Removal of Arsenic and Chromium *(Continued)*

SOLUTION: Upflow reactor filled with composted livestock manure that has been mixed with highly porous calcined clay ceramics

- Removal of Arsenic, Cd, Zn, Pb, and Cu to below detection limits
- Removal of 86-99% of Chromium and Fe
- Reactor life: 3-5 years
- Maintenance: Check for clogged pipes once a week
- Metals can be recycled from spent substrate
- Three, 20' x 20' x 8' systems in operation



Evidence

- Works in winter
- pH increases
- Sulfide in the substrate
- Metal removal
- Sulfate decreases

Simultaneous Isotopic and AVS Analyses on Same Substrate

Samples from Cell B
Rates in nanomoles $S^{-2}/cm^3/day$

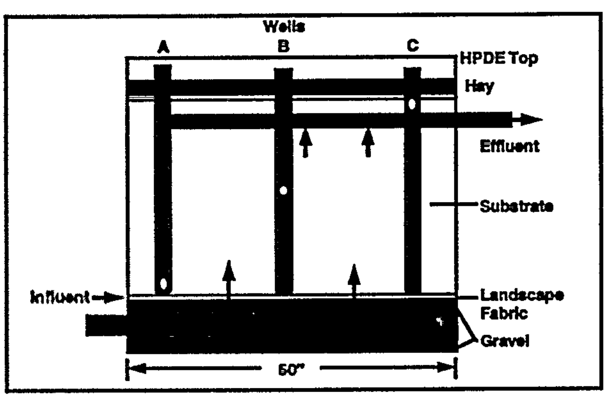
Site	Date	Rate	%DEV
Isotopic			
Surface	10/90	600	10.9 (4)
Bottom	11/90	440	10.4 (3)
Surface	11/90	750	8.6 (6)
Control	11/90	12.2	29 (3)
AVS Method			
Surface	11/90	670	35 (6)

Conclusions

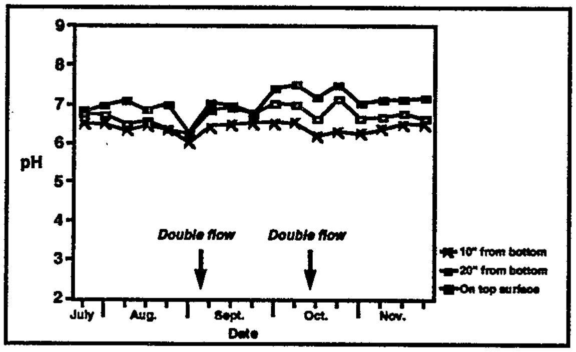
1. Plants did not contribute significantly to metal removal and are not required
2. Loading rate can be estimated using sulfide generation information
3. Major goal is to maximize activity of sulfate reducing bacteria and optimize hydraulic regime

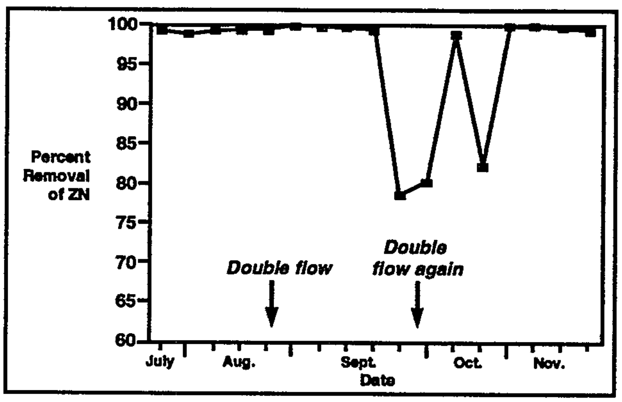
Summary of Design Parameters

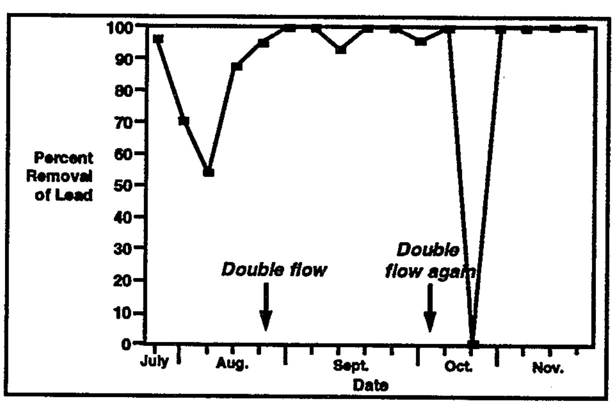
- Upflow configuration
- Size and volume based on:
  1) Minimum hydraulic residence time of 20 - 30 hours or;
  2) Sulphide production rate of 300 - 600 nanoMoles $S^{-2}/cm^3/day$ and metal loading rates, moles per day
- Can use single or multiple stage systems in series as space permits
- Composted livestock manure as organic substrate

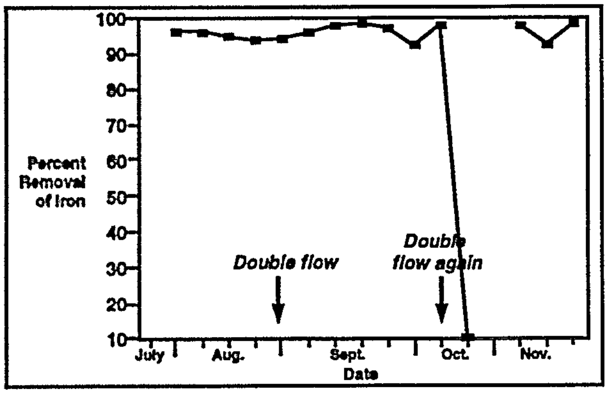


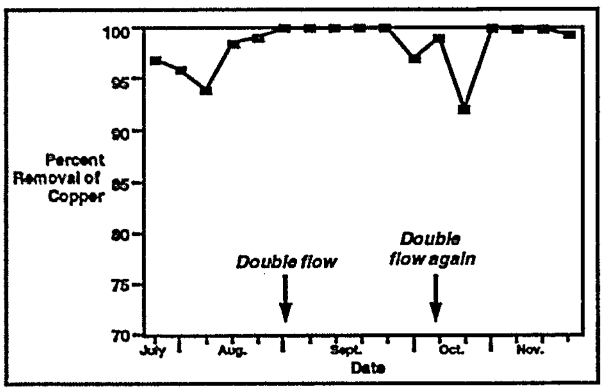
pH in Single Stage Wells

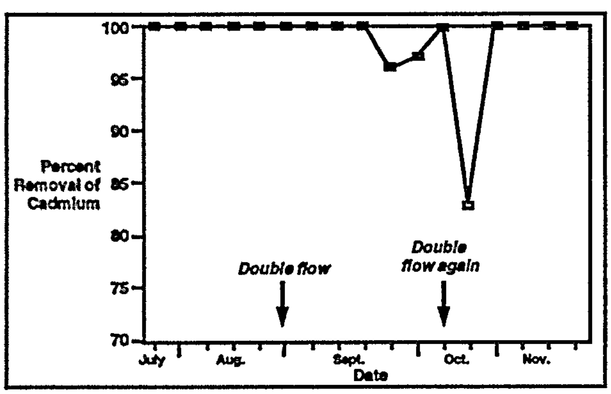


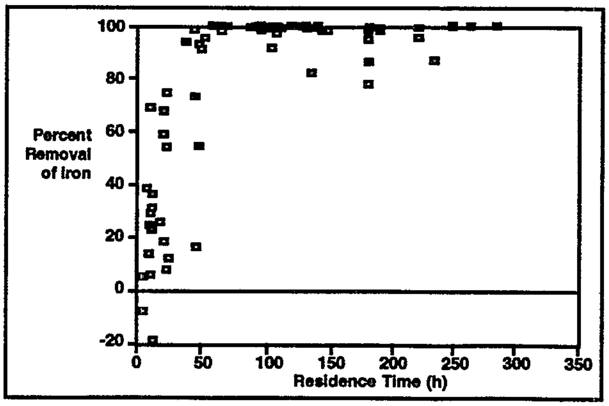




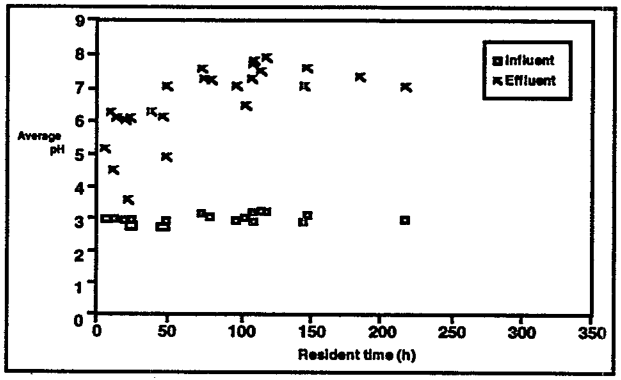

100
90
80
70
Percent Removal of Iron
60
50
40
30
20
10
Double flow
Double flow again
July
Aug.
Sept.
Oct.
Nov.
Date


100
95
90
Percent Removal of Copper
85
80
75
70
Double flow
Double flow again
July
Aug.
Sept.
Oct.
Nov.
Date


100
95
90
Percent Removal of Cadmium
85
80
75
70
Double flow
Double flow again
July
Aug.
Sept.
Oct.
Nov.
Date



Percent Removal of Iron
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
350
Residence Time (h)



Average pH
9
8
7
6
5
4
3
2
1
0
0
50
100
150
200
250
300
350
Resident time (h)
Influent
Effluent

Case Study #3:

Biotreatment at Mine Closure for Alpine and Desert Sites

Leslie Thompson
Pintail Systems, Inc.
Aurora, CO

Ms. Thompson received a B.S. in biology from Purdue University and has continuing education and graduate coursework in geochemistry, environmental engineering, and environmental microbiology. She has worked as a chemist, microbiologist, and chief of research and development of bioremediation processes in mining and engineering companies. She has over 20 years of experience in chemical manufacturing, mining, and waste remediation.

Ms. Thompson is employed at Pintail Systems, Inc., as vice president of research and development. Her responsibilities include management of the environmental research program, oversight of field engineering, and development of innovative biotreatment processes for industrial waste remediation. Under her leadership, new bacterial treatment processes have been developed for control of acid mine drainage, heavy metal wastes, complexed metal cyanides, nitrates, phenolic wastes, and aromatic hydrocarbons from petroleum and coal gasification production operations. Ms. Thompson is a member of the American Chemical Society, the Society of Mining Engineers, the Metallurgical Society, the American Society of Microbiologists, and the Mining and Metallurgical Society of America.

PINTAIL

Mine Operations

Environmental Impact

Mining Waste

Environmental Impact

- Cyanide, heavy metal and nitrate wastes have the potential to impact:
  - *Groundwater*
  - *Surface water*
  - *Soil*
  - *Atmosphere*
  - *Terrestrial and aquatic organisms*

Mining Issues

Issues, Goals and Solutions

- Issue

  Perceived conflict between a strong economy or mining industry and a healthy environment

- Goal

  Create a balance between conservation, resource development and the environment (reclamation and protection)

Mining Issues

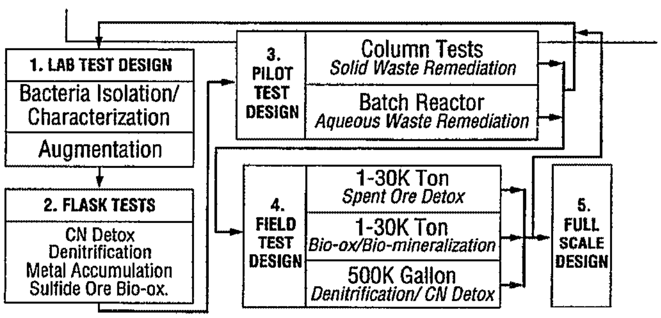
Issues, Goals and Solutions

- Solutions

  Biotreatment of cyanide, nitrate and metal wastes using engineered natural processes

  Conventional chemical/physical treatments for mine wastes

Bio-treatment Development



Laboratory Research and Testing

Cyanide Biodecomposition

Reactions

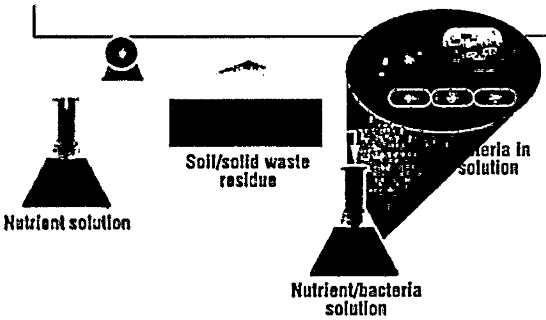
- $M_xCN_y + 2H_2O + 1/2\ O_2 \rightarrow$ M/bacteria + $HCO_3 + NH_3$
- $M_xCN_y \rightarrow NM^{2+} + xCN^-$
- $CN + H_2O \rightarrow NHCN + OH^-$
- $HCN + 2H_2O \rightarrow NHCO_3NH_4$
- $HCN + 1/2\ O_2 \rightarrow NHCNO$
- $HCNO + H_2O \rightarrow NCO_2 + NH_3$

Cyanide Biodecomposition

Reactions

- $NH_3 \rightarrow NH_2OH \rightarrow HNO? \rightarrow NO_2 \rightarrow NO_3$
- $NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow NO_2 \rightarrow N_2$
- CN + bacteria → purines, pyridines, amino acids, proteins

Bacteria Isolation



Pictorial Slides

Bioaugmentation

- Enhancement of a bacteria population's natural ability to use or transform undesirable components of an environment.
    1. *Growth to working biotreatment concentrations*
    2. *Elimination of non-working portions of microbial community*
    3. *Selection of beneficial mutations*

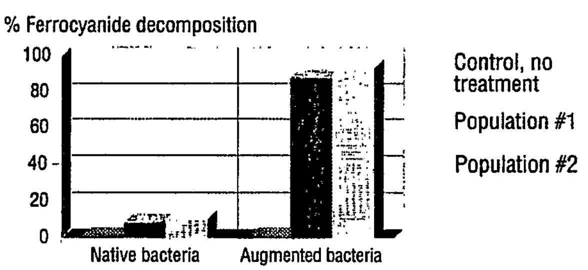
Process Description

Treatment Bacteria Bio-augmentation

- Augment bacteria
    - *Stress in waste infusion media*
    - *Temperature stress*
    - *Eliminate non-working species*
    - *Improve reaction kinetics*
    - *Define optimal growth nutrients*

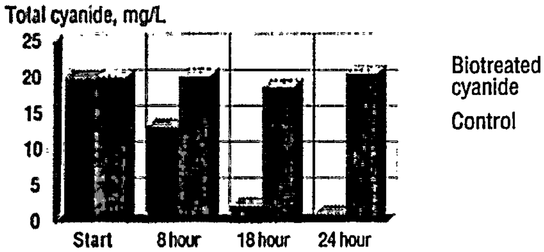
Decomposition of Ferrocyanides

Native Bacteria vs Augmented Bacteria



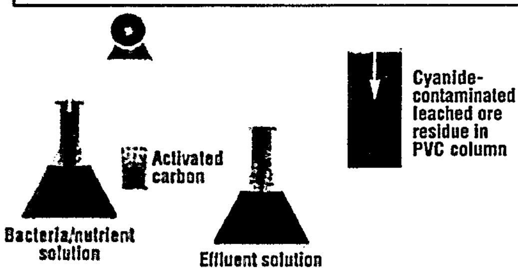
Ferrocyanide Biodecomposition

Total Cyanide (mg/L) vs Time



Cyanide Biodecomposition

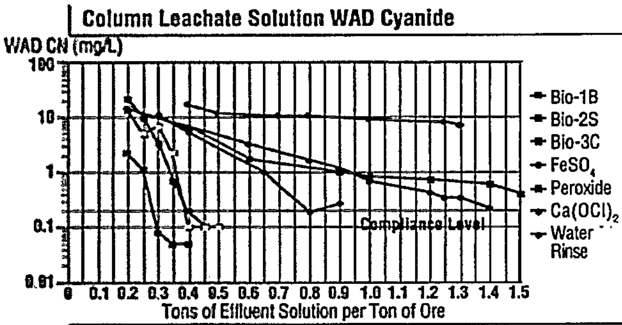
Column tests



Pictorial Slides

Spent Ore Cyanide Treatment

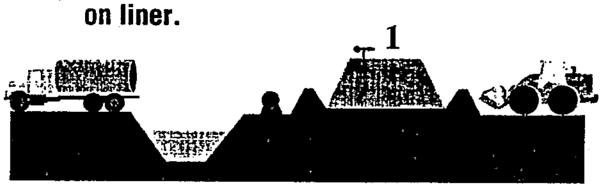
Column Leachate Solution WAD Cyanide



Heap Bio-detox Pilot Test

Biotreatment Sequence

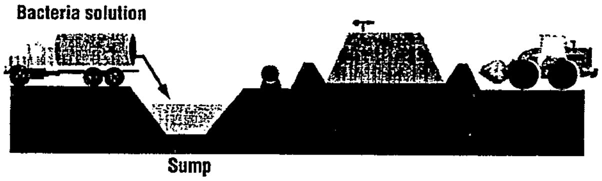
1. Stack 1000 tons of leached ore residue on liner.



Heap Bio-detox Pilot Test

Biotreatment Sequence

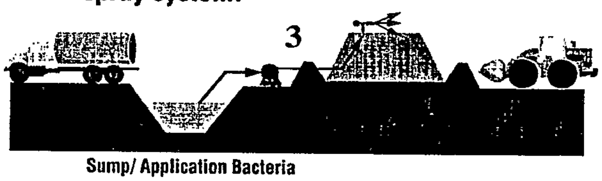
2. Add treatment bacteria concentrate to sump.



Heap Bio-detox Pilot Test

Biotreatment Sequence

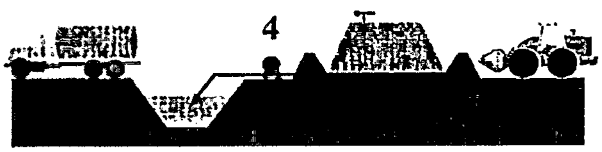
3. Apply bacteria solution to residue with spray system.



Heap Bio-detox Pilot Test

Biotreatment Sequence

4. Collect pile leachate solution in sump.

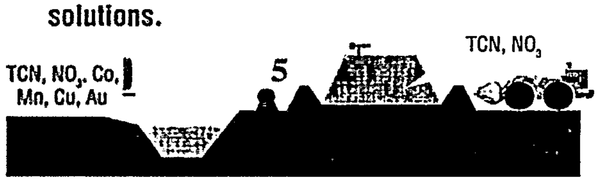


Leachate Solution Collection

Heap Bio-detox Pilot Test

Biotreatment Sequence

5. Analyze leached ore residue and leachate solutions.

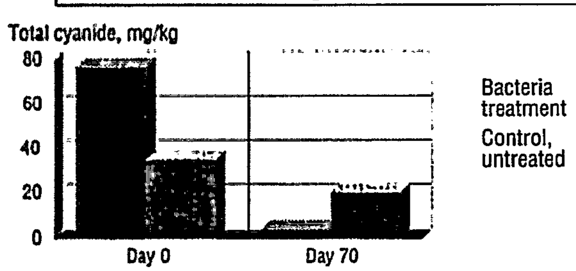


Sump/ Application Bacteria
Leachate Solution Collection

Pictorial Slides

Microbial Cyanide Decomposition

1500 ton Field Test, Average CN Removal



Successful Biotreatment

Requirements

- Establishment of treatment bacteria in environment
- Biodecomposition/bio-mineralization reaction rate improvements
- Physical contact of treatment bacteria with pollutants

Site-specific Design Criteria

Biotreatment Field Test

- Ore/waste geochemistry
- Field bacteria production
- Background waste microbiology
- Application engineering

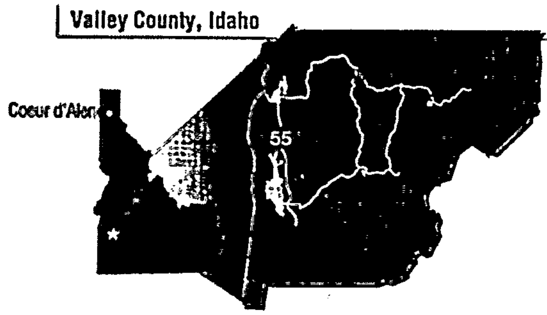
Yellow Pine Unit

Site conditions for heap cyanide bio-detox

- Located near Yellow Pine, Idaho (approx. 50 miles northeast of McCall)
- Elevation ~6500'
- Treatment start: end of March, 1992
- Treatment end: September, 1992
- 1.3 million ton agglomerated oxide ore
- Single leach pad, 114' depth

Yellow Pine Unit

Valley County, Idaho



Yellow Pine Unit

Spent Ore Cyanide Bio-Detox

- Laboratory Phase
  CN oxidizing bacteria isolated/ augmented and tested in flask and column test program
- Field Mobilization
  Bacteria concentrate and nutrients transported to mine
- Field Re-culturing
  Bacteria grown in a 3-stage culturing system

Heap Detox Treatment Goals

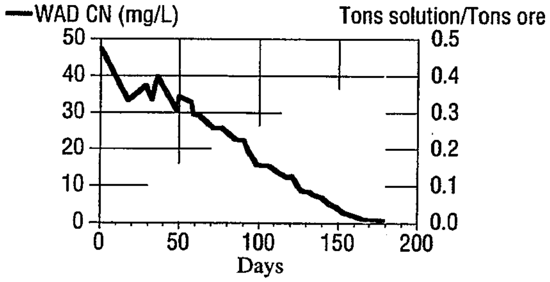
Yellow Pine 1.3 Million Ton Heap

- Reduce WAD CN from 47 to 0.2 mg/l in heap leachate solutions
- Run in situ cyanide oxidation in spent ore to remove cyanide point source
- Complete treatment in *one* operating *season*
- Enhance gold production during detox operations

Pictorial Slides

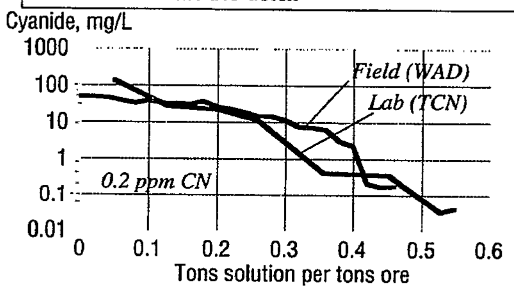
Spent Ore Bioremediation

1.3 Million Ton Cyanide Heap Bio-Detox



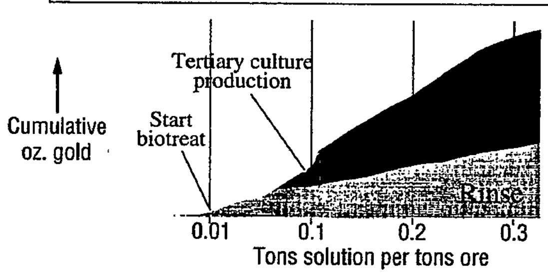
Field vs. Lab Cyanide Biotreat

Hecla Yellow Pine Bio-detox



Field Biotreatment Au Recovery

Biotreatment vs. Water Rinse



Yellow Pine Heap Bio-detox

Spent Ore Cyanide Biotreatment Results

- CN detox complete after 5 month treatment
- Conventional chemical treatment time estimates *greater than* 2 operating seasons
- Enhanced gold recovery during biotreatment

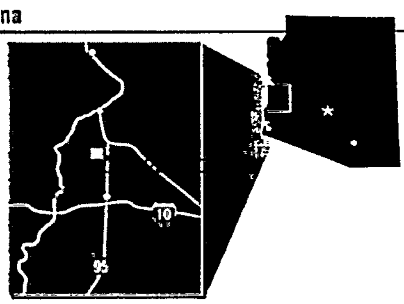
Spent Ore Cyanide Biotreatment

Yellow Pine Unit Environmental Recognition

- Hecla Mining Company received 1992 "Industrial Pollution Control Award" for Idaho from the Pacific Northwest Pollution Control Association.

Cyprus-Amax Copperstone

Arizona



Copperstone Site Conditions

Heap Cyanide Bio-detox

- Located near Parker, Arizona
- Elevation approximately at sea level
- Treatment started in mid-July, 1993
- Treatment completed in December, 1993
- 1.2 million tons ore
- Single leach pad

Detox Treatment Goals

Cyprus Copperstone 1.2 million ton heap

- Reduce WAD and total cyanide from 30 to <0.2 mg/L in heap leachate solutions
- Treat spent ore to remove cyanide source
- Complete treatment in less than 6 months
- Enhance gold production during detox operations

Copperstone Treatment Design

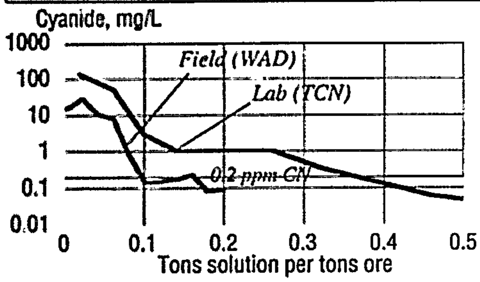
Bacteria Application

- Culture and nutrients applied to heap in a drip irrigation system
- Decrease in WAD and total cyanide measured in pregnant and reclaim solutions.
- Field vs. Lab Cyanide Biotreat

Pictorial Slides

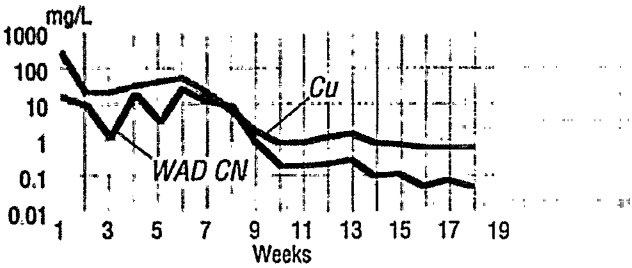
Field vs. Lab Cyanide Biotreat

Cyprus Copperstone 1.2 million ton heap



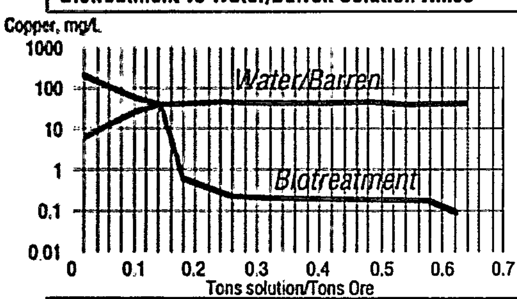
Copperstone Spent Ore Detox

Copper and WAD CN in Leachate Solutions



Spent Ore Detox - Heap Closure

Biotreatment vs Water/Barren Solution Rinse



Bio-detox Treatment Results

Cyprus Copperstone Spent Ore Cyanide Biotreatment

- WAD and total CN detox complete after less than 70-day treatment cycle
- Enhanced gold recovery during biotreatment
- WAD and TCN treatment complete with application of <0.3 tons solution/ton ore

Biotreatment Advantages

Mine Waste Remediation

- **In situ treatment**
- **Natural, non-toxic by-products**

Biotreatment Advantages

Mine Waste Remediation

- **Complete detoxification**
  - Solid and aqueous waste treatment ends long-term liability
  - Shorter duration/fewer pore volumes for spent ore detox

Biotreatment Advantages

Mine Waste Remediation

- **Cost effective compared to conventional treatments**
- **Re-vegetation potential**
  - Site reclamation promotes natural growth on decomissioned heaps, plant areas

Biotreatment Advantages

Mine Waste Remediation

- **Final solution**
  - No continuing liability
  - Eliminate monitoring
- **Establishes corporate environmental commitment**

Pictorial Slides

Case Study #4:

Acid Mine Drainage—Reclamation at the Richmond Hill and Gilt Edge Mines, South Dakota

Thomas Durkin
South Dakota Department of Environment and Natural Resources
Pierre, SD

Mr. Durkin has an A.S. degree in biology from Nassau Community College, a B.S. degree in earth science from Adelphi University, and an M.S. degree in geology from the South Dakota School of Mines and Technology. He is a certified professional geologist. He has worked as a commissioned officer in the U.S. National Oceanic and Atmospheric Administration Corps, and as a mine regulator for the State of South Dakota for the past eight years.

Mr. Durkin is employed by the South Dakota Department of Environment and Natural Resources as a hydrologist in the Office of Minerals and Mining. His duties have involved him with the geochemical aspects of mine wastes and mine waste management issues relating to large scale surface gold mines in the Black Hills. He is concerned particularly with regulating problems associated with acid mine drainage and developing effective prevention, control, and reclamation requirements. He is a member of the Western Governors' Association Mine Waste Task Force and the Abandoned Mine Waste Working Group of the Committee to Develop On-site Innovative Technologies. He is a member of the American Institute of Professional Geologists, the Society of Mining, Metallurgy and Exploration, Inc., and the South Dakota Academy of Science.

Acid Mine Drainage: Reclamation at the Richmond Hill and Gilt Edge Mines, South Dakota

by

Thomas V. Durkin
South Dakota
Department of Environment and Natural Resources
Office of Minerals and Mining

EPA Seminar Series
Managing Environmental Problems at IAM Sites
Anaconda, MT - Denver, CO - Sacramento, CA

GENERAL STATEMENT

The most significant environmental issue that has arisen in the South Dakota mining industry over the last several years is that of Acid Mine Drainage (AMD). The magnitude of the potential environmental impacts and the financial liabilities has only recently been recognized.

History - Richmond Hill Mine

* Historical Perspective
* Property Ownership
* Permitting of Active Mine
* Mining/Processing Method

Pictorial Slides

Site Characteristics

- Elevation - 5,500 to 6,000 ft.
- Climate:
  - Temperature
  - Rainfall
- Geology

History Continued ...

- Discovery of AMD Problem
- Environmental/Economic Assessment of Problem
- Enforcement Action
- AMD Mitigation Plan and Bonding Development and Permitting
- Closure/Postclosure Maintenance and Monitoring Requirements

Discovery of AMD Problem

* Jan/Feb 1992 - Sulfide Ore Stockpile Sulfide Waste in Spruce Gulch Depository
* April 1992 - AMD Detected
* Water Quality Monitoring Results

Pictorial Slides

Environmental/Economic Assessment

- **Descriptive/Predictive Geochemical Tests:**
  Phase I: Static - ABA/NAG Tests, Paste pH's
  Phase II: Kinetic - Humidity Cells, Mineralogical Analyses
  - **Quantification of Problem (Tonnages)**
- **Environmental Impacts**
  - **Hydrologic impact studies**
  - **Mass balance assessments**
  - **Aquatic impact studies**
  - **Investigations of contaminant migration pathways**
- **Short Term / Long Term Mitigation Options**
- **Mitigation Costs -- Reclamation Bonding Environmental Liability**

Pictorial Slides

Geology

Acid Generating	Non-Acid Generating
Altered PC Amphibolite	Unaltered Amphibolite
Tertiary Breccia	

Pictorial Slides

Acid Generating Potential
for various lithologies

- **ABA Values/Static Test Results**
- **Kinetic Test Results**
- **Contaminants (Metals) Generated**

AMD Mitigation Plan
SHORT TERM Control Actions

- Collection and Treatment Surface Runoff
- 10 yr, 24 hr Storm Event Containment Pond
  Below Spruce Waste Dump
- Base Addition
  Soda Ash and Caustic Soda
- Metal Hydroxide (Sludge) Precipitation/Removal
- Pump Partially Treated Dump Discharge
  To Large Lined Stormwater Pond
- Entac Treatment and Lime Addition to Dump
- Anoxic Limestone Drain

Pictorial Slides

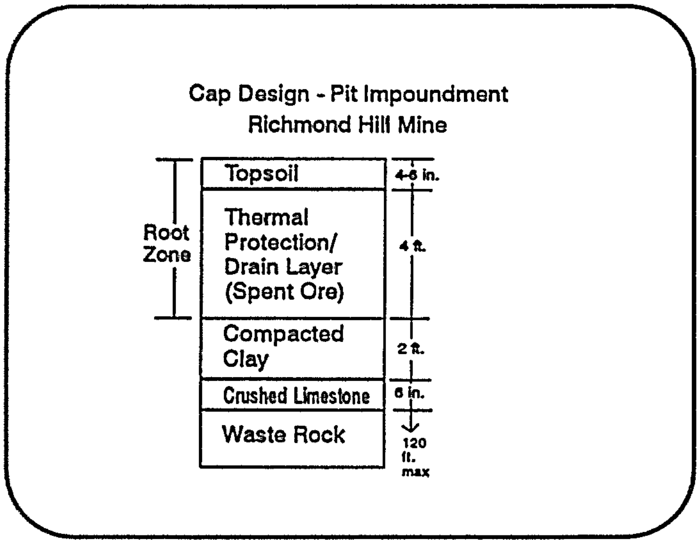
DENR Enforcement Action

- December 1992 Notice of Violations and Order
- $489,000 Penalty
  Mine Permit Violations
  Water Quality Standard Violations
- AMD Control/Mitigation Requirements

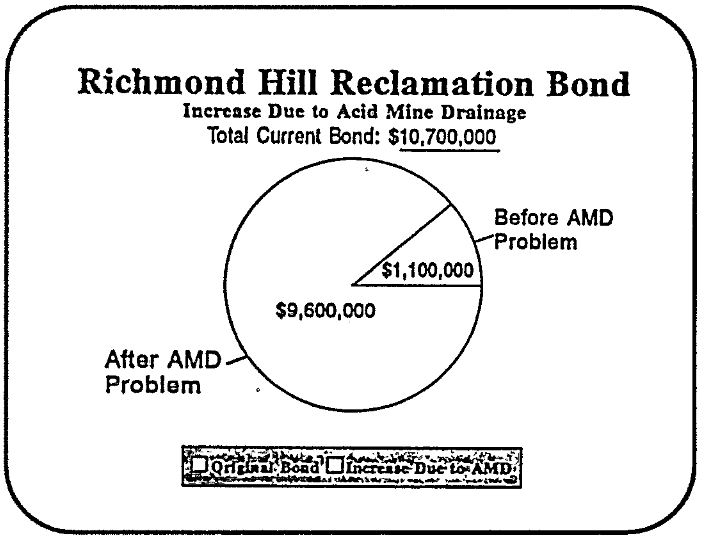
AMD Mitigation Plan
LONG TERM Control Requirements/Actions

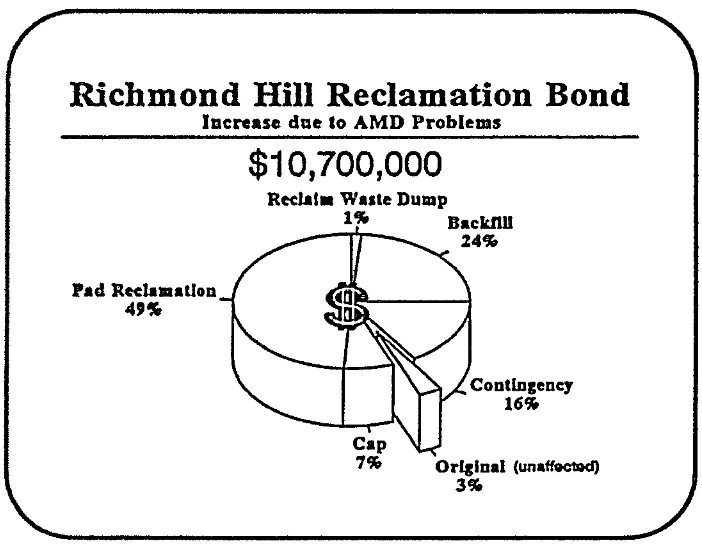
- Remove Acid Generating Material From Dump
  2,700,000 Tons Waste Rock
  Backfilled in Pit Impoundment
- Control Site Water Balance
- Cap Pit Impoundment
  - Covers reactive waste rock
  - Covers reactive pit floor rock
- Reclaim Acid Generating Leach Pads
  - 727,000 tons reactive spent ore
  - Heap decommisioning (neutralization) plan
- Reclaim Ancillary Facilities

(Mine Permit Amendment)



Pictorial Slides





Postclosure

- Postclosure Period Begins at Reclamation Surety Release
- 30 Year Postclosure Period Can Be Extended
- Postclosure Bond Required (Currently Set at $1,700,000)
- Remedial Action Can Be Required (Rebuild Cap, Etc.)

Postclosure Monitoring

- "Performance Monitoring"
- Periodic Monitoring of Water, Air, and Biota at Various Locations Around Reclaimed Facility (Pit, Dump, Pads)
- Lysimeters
  Temperature Probes (Thermistors)
  Oxygen Meters
  Neutron Probes
- Annual Performance Monitoring Meetings

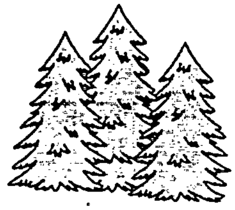
Pictorial Slides

Postclosure Maintenance

- Remove Deep Rooting Vegetation, and Burrowing Animals From Cap
- Ensure Adequate Vegetative Cover
- Repair Erosion Damage
  Maintain Erosion Controls
- Other Remedial Actions (if AMD Reoccurs)

Brohm's Tailings Reclamation Project

Relic Gilt Edge Tailings
Strawberry Creek



Pictorial Slides

Conclusions

Case Study #5

Sharon Steel/Midvale Tailings Superfund Site

William Cornell
Bureau of Mines
Rolla, MO

Mr. Cornell graduated from the University of Missouri—Rolla with a B.S. in metallurgical engineering. He has been employed by the Bureau of Mines for 11 years and has been involved mainly with mineral processing projects. He is a group supervisor in charge of projects in the following areas: beneficiation of rare earth minerals; the remediation of heavy metal tailings; the characterization of heavy metal contaminated tailings, residues, and soils; and the remedial treatment of carbon-contaminated processing wastes. Mr. Cornell has published extensively in the fields of minerals processing and process mineralogy, and was involved with a team that won an RD-100 Award in 1987 for a fine particle beneficiation process to upgrade cobalt values from Missouri lead ores.

- INTRODUCTION & BACKGROUND
- SITE REPRESENTATION
- SITE CHARACTERIZATION
- BENEFICIATION STUDIES
- COST ANALYSES
- CONCLUSIONS

- INTRODUCTION & BACKGROUND
  - Objective of the Study
  - Technical Approach
  - Site Description
  - Site History

OBJECTIVE

Determine if physical beneficiation methods can be us treat the tailings to produce two fractions, one "clean" that can be redosited on site, and one "contaminated" could be dealt with by other means.

DEFINITION

"Clean" material is defined as containing less than 500 ppm Pb, less than 70 ppm As, and passing TCLP.

TECHNICAL APPROACH

1. Review existing data and determine if they suggest a method to represent the site.
2. Conduct studies to characterize the materials on the site.
3. Conduct studies to determine the response of the materials to state-of-the-art beneficiation methods.
4. Assess information and data developed to prepare a report for EPA.

Pictorial Slides

- 1906 to 1927
  - 465 ton capacity gravity mill
  - No Zn recovery
  - Tailings deposited on river bank west of the mill.

- 1927 to 1971
  - Converted to flotation in 1927
  - With upgrades reached final capacity of 1700 tpd.
  - Pb and Zn circuits
  - Pyrite recovery for Au

- SITE REPRESENTATION
  - Review of Production Records
  - Review of Previous Sampling Studies
  - Review of Supplementary Data

- SITE CHARACTERIZATION
  - Chemical Analyses
  - Mineralogical Analyses

Pictorial Slides

- CHEMICAL ANALYSES
  - Drill Hole
  - Bulk Samples

Pictorial Slides

- MINERALOGICAL ANALYSES
  - Drill Hole
  - Bulk Samples

Pictorial Slides

- BENEFICIATION STUDIES
  - Gravity
  - Froth Flotation

- GRAVITY TESTS

Pictorial Slides

FROTH FLOTATION

- **Statistical Design**
- **Bench Scale Flotation**
- **Large Scale Flotation**

Pictorial Slides

CONCLUSIONS

- **A similarity exists between the material in Ponds A & B and the material in Ponds C & D.**
- **In Ponds A & B up to 75% of the material can be treated to below 800 ppm Pb.**
- **In Ponds C & D up to 38 pct of t material can be treated to below 350 ppm.**
- **Total cost of treatment less than $30,000,000.**

Case Study #6

Innovative Approaches To Address Environmental Problems for the Upper Blackfoot Mining Complex

Part 1

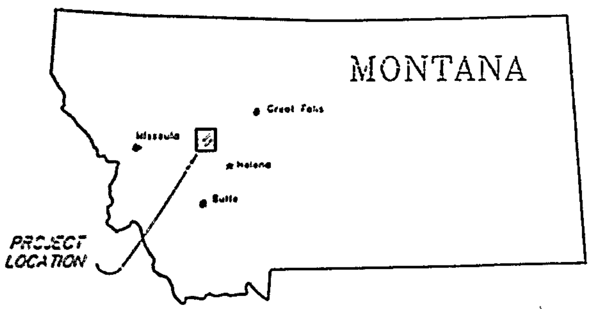
Judy Reese
Montana Department of Health and Environmental Sciences
Helena, MT

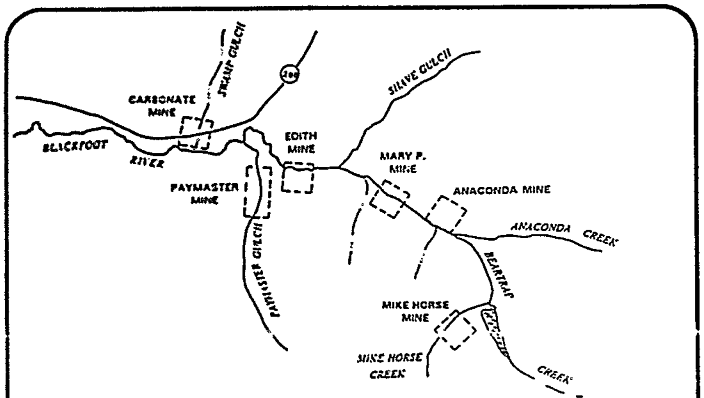
Judy Reese has a B.S. in geology from Wayne State University and an M.S. in environmental studies from the University of Montana. She also has Grades 7-12 teaching certification in earth science and chemistry. Ms. Reese worked in minerals exploration for 8 years for Utah International, BHP-Utah International, Placer Dome, and Meridian Gold Company.

Ms. Reese has worked for the Montana Department of Health and Environmental Sciences Solid and Hazardous Waste Bureau's state Comprehensive Environmental Cleanup and Responsibility Act (CECRA) and federal (CERCLA) Superfund programs since 1991. She is the project manager of the Upper Blackfoot Mining Complex site, and she is responsible for all CECRA related aspects of the site. She also manages a few other CECRA sites and participates on the Clark Fork River Site-Specific Water Quality Criteria committee.

INNOVATIVE APPROACHES TO ADDRESS ENVIRONMENTAL PROBLEMS AT THE UPPER BLACKFOOT MINING COMPLEX

Judy Reese - MDHES, Superfund
Chris Pfahl - ASARCO
Tom McIntyre - MSE, MWTPP





UPPER BLACKFOOT MINING COMPLEX
Lewis & Clark County, Montana

MINING HISTORY
Heddleston District

1889	Ore first discovered
1898	Mike Horse Mine discovered
1919	Mike Horse mill built
1940	First electric power
1945	Purchased by ASARCO
1955	Ceased mining

Total production: 450,000 tons

1962-1973 Exploration of a copper molybdenum ore body

OWNERSHIP

1898-45	Miscellaneous small groups
1945-64	ASARCO
1964-81	Anaconda Company /ASARCO
1979	Anaconda merged with ARCO
1981	ASARCO purchased all of the Anaconda holdings

Department of State Lands
Abandoned Mines Bureau
1987 - 1990

↓

Department of Health and
Environmental Sciences
CECRA
1991 - present

PICTORIAL SLIDES TO FOLLOW

CONTAMINATION SOURCES

Acid Mine Drainage

RockWaste Piles

Tailings

CONTAMINATED MEDIA

Surface Water
Ground Water
Stream Sediments
Soils

PICTORIAL SLIDES TO FOLLOW

MIKE HORSE MINE ADIT
WATER QUALITY mg/L

	Ranges			sMCL
Aluminum	.14	-	1.3	.2
Cadmium*	.02	-	.2	
Copper	.15	-	1.8	1.0
Iron	4.2	-	74.0	.3
Manganese	8.7	-	53.0	.05
Sulfate	346.0	-	2,927.0	250.0
Zinc	26.0	-	90.0	5.0

*MCL = .005 mg/l

GROUND WATER QUALITY mg/L

	Ranges	sMCL
Aluminum	.7 - 10.3	.2
Cadmium*	.2	
Iron	2.2 - 164.2	.3
Manganese	.1 - 105	.05
pH	2.7 - 7.3	6.5 - 8.5

*MCL = .005 mg/l

MINE WASTE mg/kg

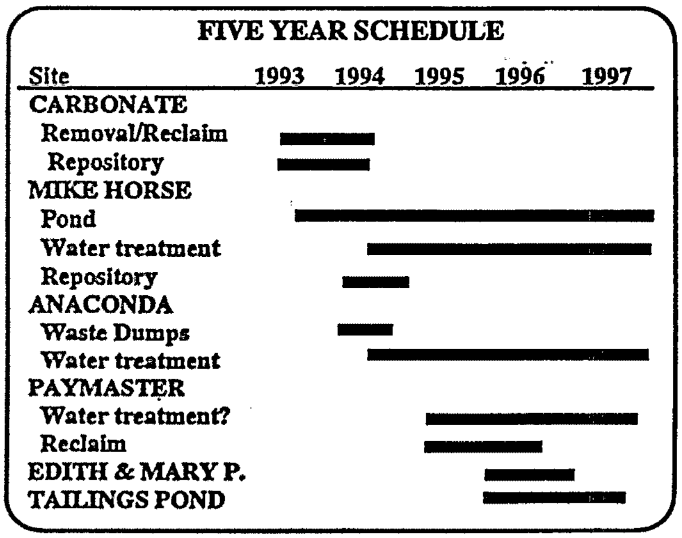
	Ranges		
Aluminum	3,278	-	18,240
Arsenic	42	-	3,555
Cadmium	1	-	134
Copper	59	-	7,405
Mercury	50	-	3,400
Manganese	11	-	8,540
Lead	112	-	21,803
Zinc	23	-	4,333

1993 VOLUNTARY REMEDIAL ACTIONS

- **Lower Carbonate Removal**
- **Upper Carbonate Respository**
- **Mike Horse Creek Stream Diversion**
- **Mike Horse Treatability Pond**
- **Mike Horse Channel Reconstruction**

1994
VOLUNTARY REMEDIAL ACTIONS

- Finish Mike Horse treatability pond
- Remove Anaconda Mine waste
- Construct Mike Horse Repository
- Construct first phase wetland cells



Case Study #6

Innovative Approaches To Address Environmental Problems for the Upper Blackfoot Mining Complex

Part 2

J. Chris Pfahl
ASARCO, Inc.
Wallace, ID

Mr. Pfahl has a B.S. in mining engineering from the Montana College of Mineral Science and Technology. He is a licensed professional engineer in the states of Idaho and Colorado, and a licensed professional land surveyor in Idaho. He has been employed by ASARCO, Inc., in various engineering, supervisory, and management positions for the past 17 years.

Mr. Pfahl is a site manager with ASARCO. He is responsible for all of ASARCO's activities at the Bunker Hill Superfund site at Kellogg, Idaho; the Triumph Proposed Superfund Site at Sun Valley, Idaho; the Upper Blackfoot Mining Complex State Superfund Site at Lincoln, Montana; and several inactive mine site reclamation projects in Colorado, Idaho, and Montana.

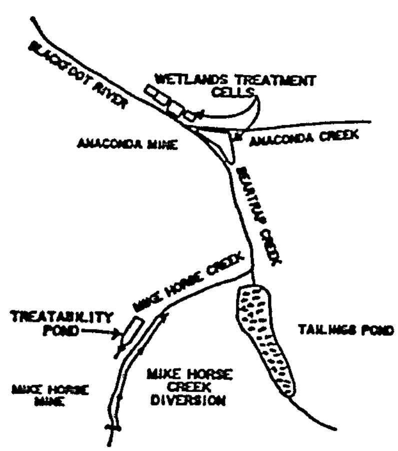
Cleanup Approach

- Perform Cleanup Under Existing Permit System
- Consolidate Mine Wastes
- Permit Discharge
- Treat Discharges Passively

Carbonate Mine

- Consolidate Tailings On Waste Dump
- Problems Associated With Excessive Moisture
- Reclaim As Wetlands

Pictorial Slides To Follow



UPPER BLACKFOOT MINING COMPLEX

Mike Horse Adit Discharge

- Infiltration Control
- Oxidation Pond
- Adit Plug
- Jet Pump Aerator

Pictorial Slides To Follow

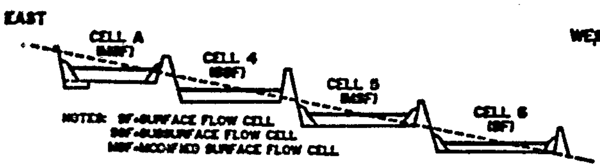
Anaconda Mine

- Consolidate Mine Wastes At Mike Horse Dump
- Blackfoot River Floodway

Pictorial Slides To Follow

Passive Water Treatment

- Wetland Treatment Theory
- Phase I Wetlands
- Phase 2 Wetlands



SECTION THRU TREATMENT CELLS

Miscellaneous Mine Dumps

- Mary P Mine
- Edith Mine
- Paymaster Mine
- Upper Mike Horse Creek

Pictorial Slides To Follow

Mike Horse Tailings

- 1975 Flood Damage
- Subsequent Repairs
- Future Activities

Case Study #6

Innovative Approaches To Address Environmental Problems for the Upper Blackfoot Mining Complex

Part 3

Thomas McIntyre
MSE, Inc.
Butte, MT

Tom McIntyre has a degree in mineral processing engineering from Montana College of Mineral Science and Technology. Since graduating in 1981, Mr. McIntyre has worked in the lead industry with ASARCO, Inc., and in the environmental industry for MSE, Inc. He spent 11 years with ASARCO, working initially as an operations department head for all of the departments within ASARCO—East Helena Primary Lead Smelter. Mr. McIntyre later was put in charge of special projects, which included a stint as plant engineer.

Since leaving ASARCO in 1991, Mr. McIntyre has worked for MSE, Inc., primarily on the staff of the Mine Waste Technology Pilot Program (MWTPP). He is the technical project manager for MWTPP Activity III, Projects 2 and 3. Additionally, Mr. McIntyre is working towards an M.S. in metallurgical engineering with an emphasis on mine waste.

GROUTING AS A HYDROGEOLOGICAL CONTROL
FOR ACID ROCK DRAINAGE REDUCTION
AT THE MIKE HORSE MINE
NEAR LINCOLN, MONTANA

MINE WASTE TECHNOLOGY
PILOT PROGRAM
ACTIVITY III, PROJECT 2

T. MCINTYRE
and
A. L. MCCLOSKEY

MOBILE TOXIC CONSTITUENTS - WATER

- METALS, SEMI-METALS AND SOME NON-METALS
- A RESULT OF, IN PART, ACID GENERATION
- TRANSPORT OF SOLUBLE SPECIES PROVIDED BY WATER INFLOWING INTO MINES FROM THE LOCAL HYDROLOGY

- MINING/MINERAL PROCESSING ROLE
  - INDIRECT MECHANISMS, I.E., CHANGES IN GEOLOGY AND HYDROGEOLOGIC SYSTEM
  - DIRECT MECHANISMS, I.E., REAGENT USAGE, CRUSHING AND GRINDING, ETC.

Photo of Mike Horse Mine Portal Pre-May 1993

CLAY-BASED GROUTING DEMONSTRATION PROJECT

TECHNOLOGY DESCRIPTION

- SITE CHARACTERIZATION
- GROUT FORMULATION
- GROUT PLACEMENT

CLAY-BASED GROUTING DEMONSTRATION PROJECT

SITE CHARACTERIZATION

- PHYSICAL GEOLOGY
- HYDROGEOLOGY
- GEOCHEMISTRY
- PHYSICAL-MECHANICAL PROPERTIES OF ROCK

APPLICATION - ASARCO INCORPORATED'S MIKE HORSE MINE

CLAY-BASED GROUT SELECTION

- ENVIRONMENTALLY SOUND CHEMICAL COMPOSITION
    - KAOLINITIC/ILLITIC CLAYS
    - PORTLAND CEMENT
    - FLY ASH FILLER
    - PROPRIETARY ADDITIVES

APPLICATION - ASARCO INCORPORATED'S MIKE HORSE MINE

CLAY-BASED GROUT SELECTION (continued)

- PAST HISTORY
- LOW MAINTENANCE
- RHEOLOGICAL PROPERTIES
- STRUCTURAL/MECHANICAL PROPERTIES
- COST vs TREATMENT TECHNOLOGIES

APPLICATION - ASARCO INCORPORATED'S MIKE HORSE MINE

COMPLETED SITE CHARACTERIZATION

- SITE SURFACE GEOLOGY
- SITE PHYSICAL GEOLOGY/LITHOLOGY
- AQUIFER TESTING
    - SLUG TESTS
    - STATIC GROUNDWATER LEVEL

APPLICATION - ASARCO INCORPORATED'S MIKE HORSE MINE

COMPLETED SITE CHARACTERIZATION (continued)

- TRACER TESTING
- FLOW MEASUREMENTS
- ROCK MECHANICS

Mike Horse Mine Site Map
Project Site Map
Photo of Site
Photo of Drilling
Photo of Core
Photo of Borehole Plugging
Photo of WellenCo - Geophysical
Photo of WellenCo - Geophysical
Geological Cross Section
Geological Cross Section

APPLICATION - ASARCO INCORPORATED'S
MIKE HORSE MINE

TESTS TO BE UTILIZED FOR EVALUATION

- WATER BALANCE
- AQUIFER TESTING
- TRACER TESTING
- CORE DRILLING

Technologies To Address Environmental Problems at Inactive Mine Sites

Martin Foote
Mine Waste Technology Pilot Program
MSE, Inc.
Butte, MT

Dr. Foote has a B.S. in chemistry and an M.S. in geochemistry from Montana College of Mineral Science and Technology, and a Ph.D. in geology from the University of Wyoming. He has worked as a geologist, geochemist, and consultant to the mining industry for 11 years. He also has worked with both federal and state regulatory organizations in environmental remediation, permitting, and development.

Dr. Foote is employed by MSE, Inc., as a technical project manager for the Mine Waste Technology Pilot Program. This program is funded by EPA and jointly administered by EPA and Department of Energy (DOE) to conduct research and field demonstrations on new and innovative technologies for treating or remediating mine wastes. He has served on the Technology Screening Group for the In Situ Remediation Integrated program and reviewed grant applications for the Small Business Innovation Research program for DOE.

TECHNOLOGIES
TO
ADDRESS ENVIRONMENTAL PROBLEMS
AT
INACTIVE MINE SITES

MINE WASTE TECHNOLOGY PILOT PROGRAM

MARTIN FOOTE
MSE Inc.

SOURCE CONTROL TECHNOLOGIES

Bactericide Addition
Caps and Seals
In-Situ Vitrification
Inundation or Saturation
Reducing Atmosphere

SOURCE CONTROL TECHNOLOGIES (2)

Subsurface Plugging
Sulfide Extraction
Temperature Reduction
Water Control

PATHWAY INTERRUPT TECHNOLOGIES

Alkaline Reagent Addition
Capping and Revegetation
Chemical Addition
Chemical Stabilization
Encapsulation
Plugs and Barriers

TREATMENT TECHNOLOGIES

Adsorption
Anoxic Limestone Drain
Biological Adsorption
Biological Reduction
Chelation Chromatography

TREATMENT TECHNOLOGIES (2)

Chemical Oxidation
Chemical Precipitation
Coagulation, Sedimentation, and Flocculation
Column Flotation
Copper Cementation

TREATMENT TECHNOLOGIES (3)

Dilution
Distillation
Electrochemical Precipitation
Electrocoagulation
Electrodialysis

TREATMENT TECHNOLOGIES (4)

Electrokinetic Osmosis
Electrophoresis
Electrowinning
Evaporation
Filtration and Ultrafiltration

TREATMENT TECHNOLOGIES (5)

Freeze Crystallization
Froth Flotation
Gas Hydrate Formation
Ion Exchange

TREATMENT TECHNOLOGIES (6)

Ion Flotation
Physical Oxidation
Reverse Osmosis
Solvent Extraction

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