Selection of Remediation Measures for Abandoned Mine Sites

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NATO, CCMS, Non-Ferrous Mining Sector,
Baia Mare, Romania 2003

Outline

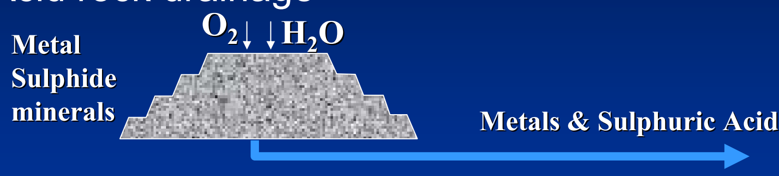
- Uniqueness of mine closure
- Mine closure evaluation approaches
- “Top Down” approach
- Case studies

Why are mines different?

- Large volumes of relatively uniform waste
  - Waste rock
    - Millions of tonnes
    - Somewhat uniform composition
  - Tailings
    - Millions of tonnes
    - Highly uniform composition
  - Other
    - Processing wastes (e.g. arsenic trioxide dust)
    - Hydrocarbons
    - Other hazardous wastes

Why are mines different?

- Delayed reactivity
  - Acid rock drainage



  - Cyanide → SCN → NH_3
    - Cyanide toxic to fish, birds and animals
    - Thiocyanate not very toxic
    - Ammonia toxic to fish only

Why are mines different?

- Contaminated water streams
  - Mine water
  - Tailings ponds
  - Waste rock drainage

Why are mines different?

- Physical hazards
  - Mine openings
  - Water-retaining structures
    - Large dams
  - Water-conveyance structures
    - Ditches, pipelines and pumps
  - Buildings

Canadian Mine Closure Management

- “Contaminated Sites” methods
- “Risk Management” approach
- “Bottom up” or “Guideline” methods
- “Top Down” approach

Contaminated Sites Approach

- Commonly used for contaminated properties outside of mining industry
- Clearly defined phases designed to identify and delineate contaminants
- CCME Guidance Documents
  - Phase I - Identify possible contaminants
  - Phase II - Locate contaminants
  - Phase III - Delineate contaminants
  - Phase IV+ - Select remediation methods

Contaminated Sites Approach

- Direct usefulness is limited to hydrocarbons and building wastes
  - About 10% of liabilities on most mine sites
- About 90% of liabilities are associated with waste rock, tailings and minewater management
- Why put 100% of the planning through a process that is only set up for 10% of the liability?

Risk Management Approach

- Commonly used in industry for environmental management
- Semi-quantitative methods:
  - Define site elements and hazards
  - Select consequence severity definitions
  - Select probability definitions
  - Locate all site elements on a risk ranking table
- Fully quantitative methods
  - Very complex analyses and data needs

Risk Management Approach

Probability	Consequence Severity				
	Low	**Minor**	**Moderate**	**Major**	**Critical**
Almost Certain	High	High	Extreme	Extreme	Extreme
Likely	Moderate	High	High	Extreme	Extreme
Possible	Low	Moderate	High	Extreme	Extreme
Unlikely	Low	Low	Moderate	High	Extreme
Very Unlikely	Low	Low	Moderate	High	High

Risk Management Approach

Probability	*Consequence Severity*				
	Low	Minor	Moderate	Major	Critical
Almost Certain					
Likely					
Possible	Waste Rock Slope Failure		Tailings Dam Slope Failure		
Unlikely					Tailings Dam Flood Failure
Very Unlikely					

Risk Management Approach

- Most useful in management of ongoing liabilities
  - Creates inventory of risks and identifies priorities
- Some use in mine closure planning
  - Can help to determine “what” needs to be done
  - Does not lead directly to a decision about “how” to do it
- Therefore not suitable as overall framework for mine closure planning

Bottom Up Approach

- “Bottom up” and “top down” come from software development
- Bottom up approach in a nutshell:
  - Start doing numerous scientific and engineering studies
  - Hope they will add up to a clear decision
    - Often leads to “further study required”, ie. Don’t stop until every question answered

Bottom Up Approach

- Literal interpretation of regulatory guidelines
  - Follow the Table of Contents
  - Prescriptive
- Loss of focus on objectives of the planning process

Bottom Up Approach

- Inefficient use of investigation dollars
- Difficult to control schedule
- Driven by specialist’s opinion of what is enough, rather than by need to make a particular decision

Top Down Approach

- Elements of method selected from good mine closure projects
- Successfully applied in mine closure projects of different complexity:
  - Survey of abandoned Yukon mines
  - ➔ Arctic Gold & Silver tailings (Yukon)
  - ➔ Colomac Project (NWT)
  - ➔ Giant Mine (NWT)

Top Down Approach

- Define alternatives
- Define evaluation factors
- Create initial evaluation matrix using available information
- Make decisions where results are clear
- Initiate investigations where not clear
- Continue investigations only until decision is clear

Case 1 - Arctic Gold & Silver

Small size and moderate complexity

A number of alternatives to be considered

Phases of investigation, analysis and selection

Case 1 - Arctic Gold & Silver

1968-69 operation

Mill + tailings (300,000 m^3)

Tailings contain several % arsenic

Paste pH 1.8 - 3.0

Case 1 - Arctic Gold & Silver

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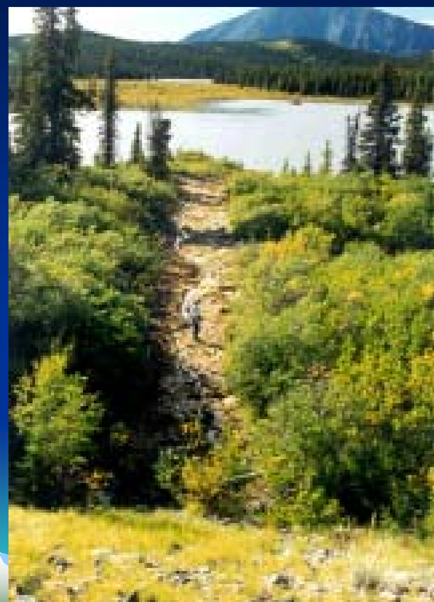


Arsenic in seepage up to 28 mg/L

Tailings plume in lake

Case 2 - Arctic Gold & Silver

Mill structures

Health and safety issue

Case 1 - Arctic Gold & Silver

Physical stability concerns

Case 1 - Define Alternatives and Evaluation Factors

Alternatives	Evaluation Factors		
	Physical Stability	Human Health	Water Quality
Do nothing	no	no	no
Control access	no	yes	no
Cover tailings	yes	yes	?
Consolidate sources	no	?	?
Reduce contact w water	no	no	?
Chemical amendment	no	yes	?
Reprocessing	yes	yes	?

Case 1 – Design Investigations

Studies	Phase 1	Phase 2
Topographic survey	y	
Surface water quality survey	y	
Tailings characterization	y	y
Delineation of other arsenic sources	y	
Groundwater investigation	y	y
Delineation of in-lake tailings	y	
Metallurgical properties	y	y
Borrow sources	y	y
Cost estimate	y	y

Case 1 - Investigate & Re-evaluate

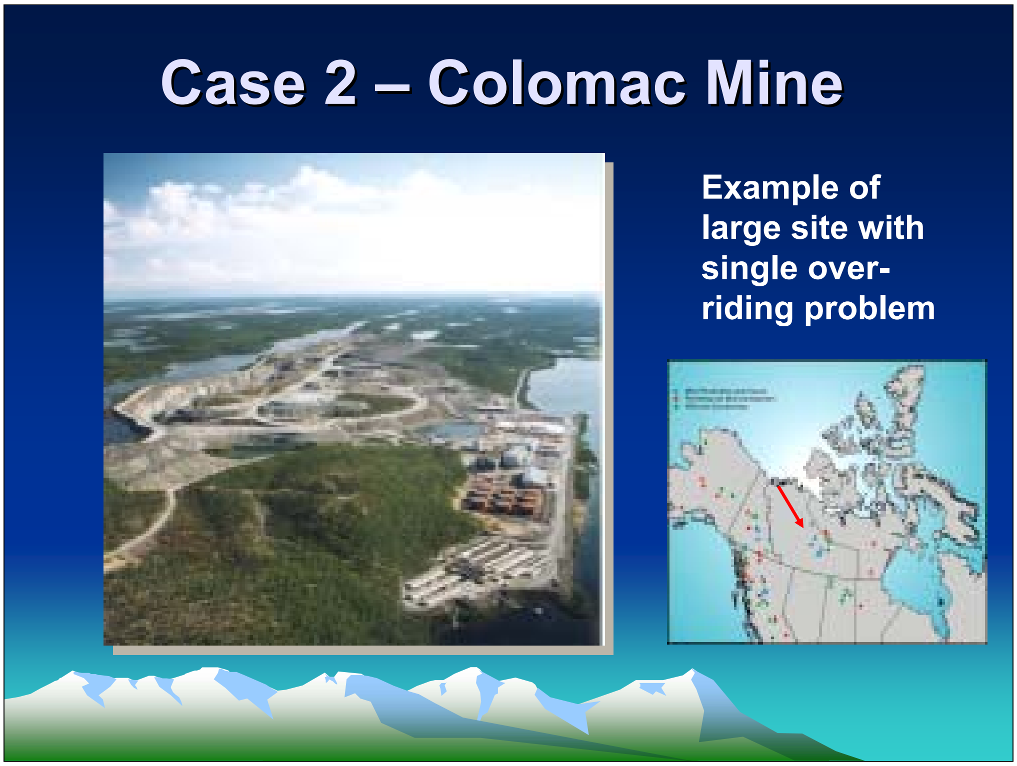
	Phase 1	Phase 2
Topographic survey	y	
Surface water quality survey	y	
Tailings characterization	y	~~y~~
Delineation of other arsenic sources	y	
Groundwater investigation	y	~~y~~
Delineation of in-lake tailings	y	
Metallurgical properties	y	~~y~~
Borrow source delineation	y	y
Cost estimate	y	y

Case 1 - Select Alternative

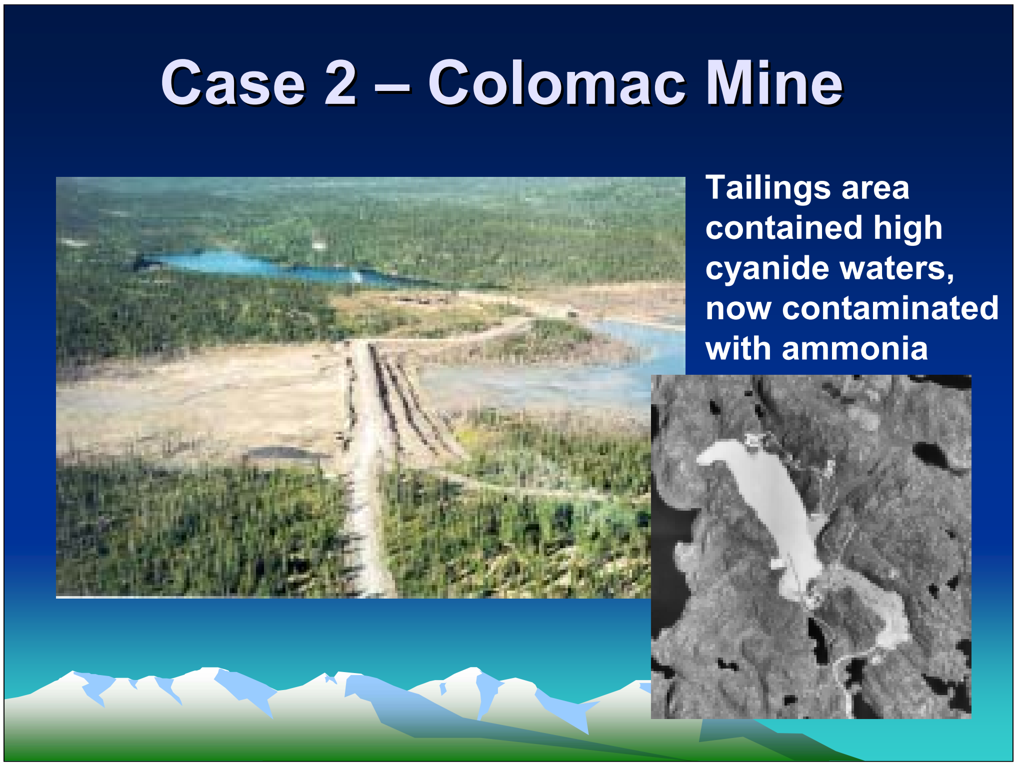
- Investigations showed that best alternatives were:
  - Consolidate and cover tailings
  - Reprocess tailings
- Stakeholder working group selected consolidate and cover because:
  - No need for multi-year funding
  - No risk of changing gold price

Case 1 - Implementation

- Covers constructed in 1999
- Monitoring shows good results



The third case is an example of a very large and very complex mine closure. The Giant Mine near Yellowknife NWT operated from 1948 to 1999. The gold ore at Giant was associated with the mineral arsenopyrite. To liberate the gold, the ore was roasted at high temperature. The roasting resulted in the production of arsenic gases, which were captured in an electrostatic precipitator. The resulting arsenic trioxide dust was then stored underground.



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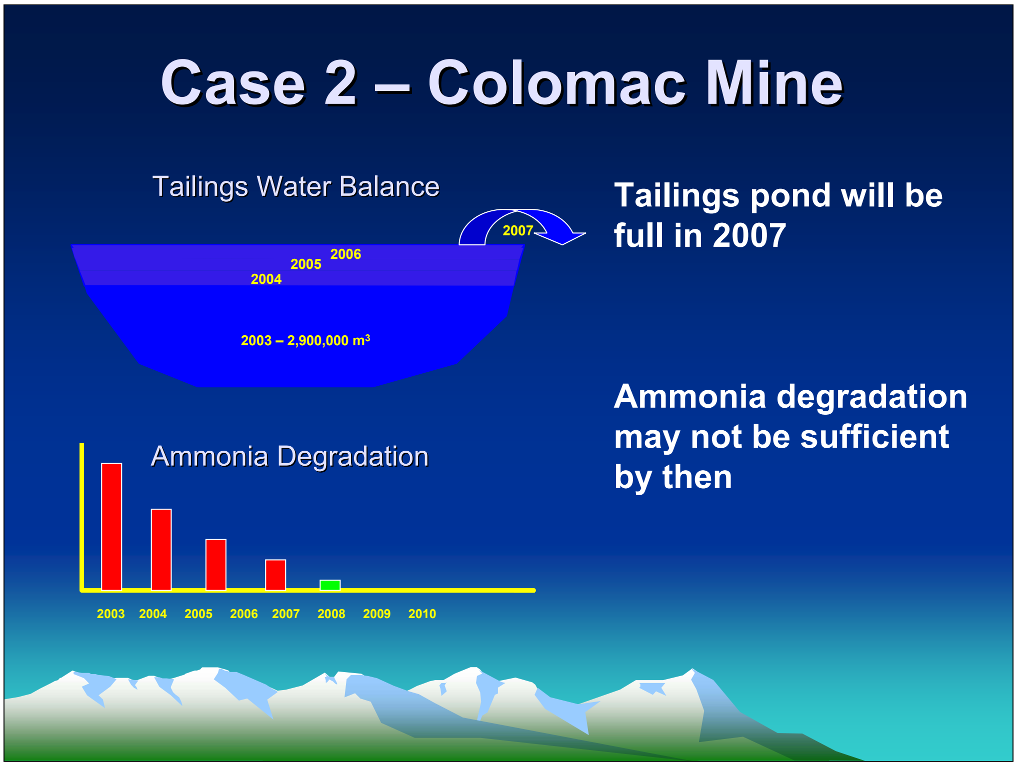

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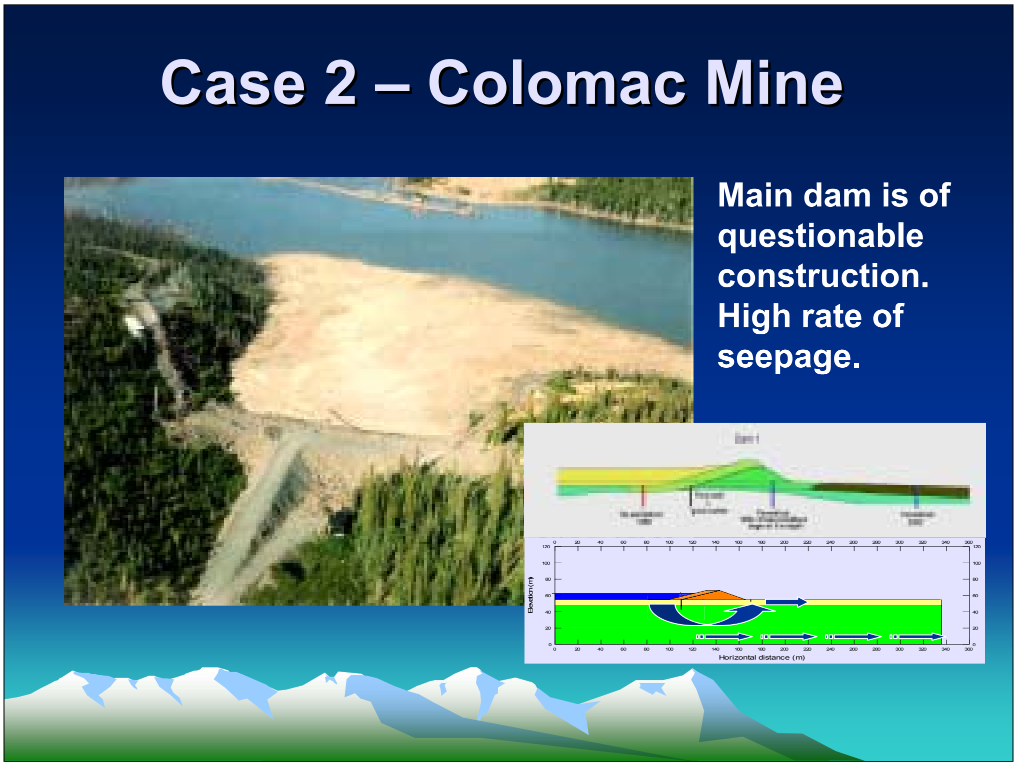

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Case 2 – Evaluation Factors

- Environmental protection
- Human health and safety
- Local Aboriginal acceptance
- Other public acceptance
- Cost
- Long-term effectiveness
- Technical certainty
- Corporate (Can.Gov.) objectives

Case 2 – Water Management Alternatives & Investigations

- Literature review paper
- Expert and stakeholder workshop to brainstorm options – select studies
- Lab study selection of treatment methods
- Second workshop to select short list:
  - Enhanced natural removal
  - Active treatment of water
  - Complete relocation of tailings to Pit

Case 2 – Phase 2 Investigations

- Detailed water balance – schedule, inputs
- Field test of enhanced natural removal
- Pilot testing of best water treatment methods
- Predictive modeling
- Diversions / Pits
- Engineering / Costs

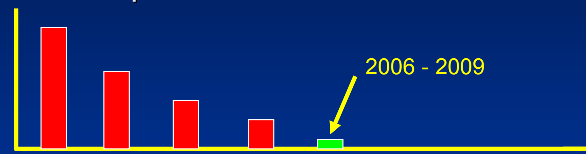
Case 2 – Alternatives Evaluation

- Enhanced Natural Removal ($8 - $20 Million)
  - Good field evidence
  - Some questions, but many mitigation options
- Rapid Treatment ($38 - $50 Million)
  - Good pilot plant performance data
  - Proven technology
- Tailings Relocation ($30 - $100 Million)
  - Not been done in the north
  - Many questions and uncertainties

Case 2 – Alternative Selection

- Preparation of simple graphics to present alternatives to stakeholders
- Rating of alternatives in stakeholder meetings

Ammonia prediction



Additional water management measures

Case 2 – Alternative Selection

- Federal government and Aboriginal community agree that enhanced natural removal plus water management is the preferred alternative
- Project Description in preparation

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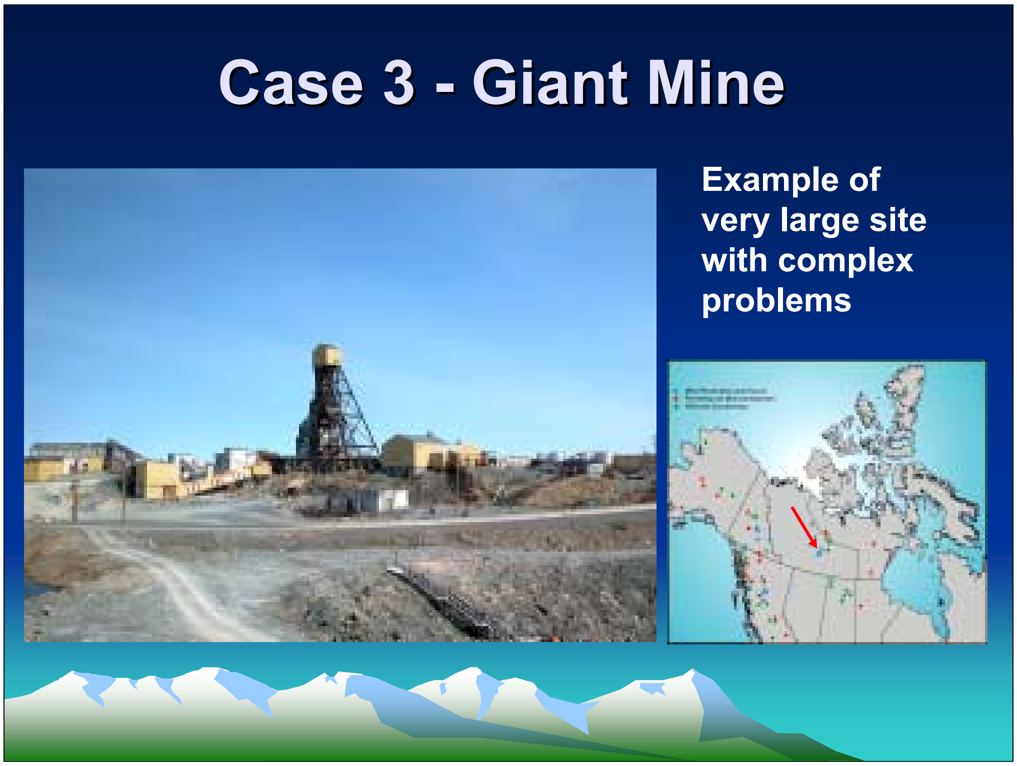

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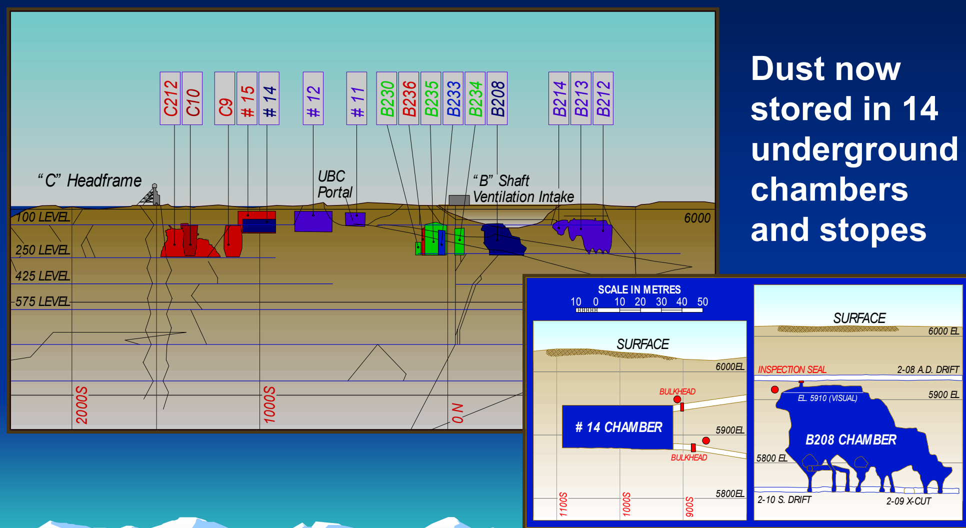
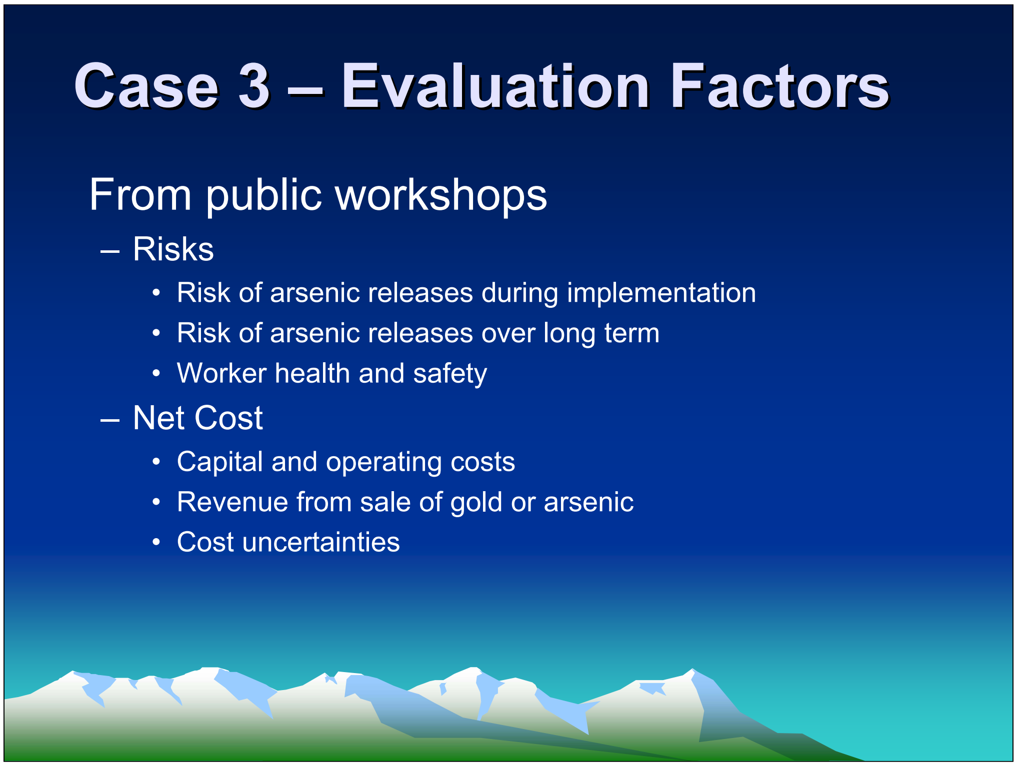
Case 3 – Giant Mine



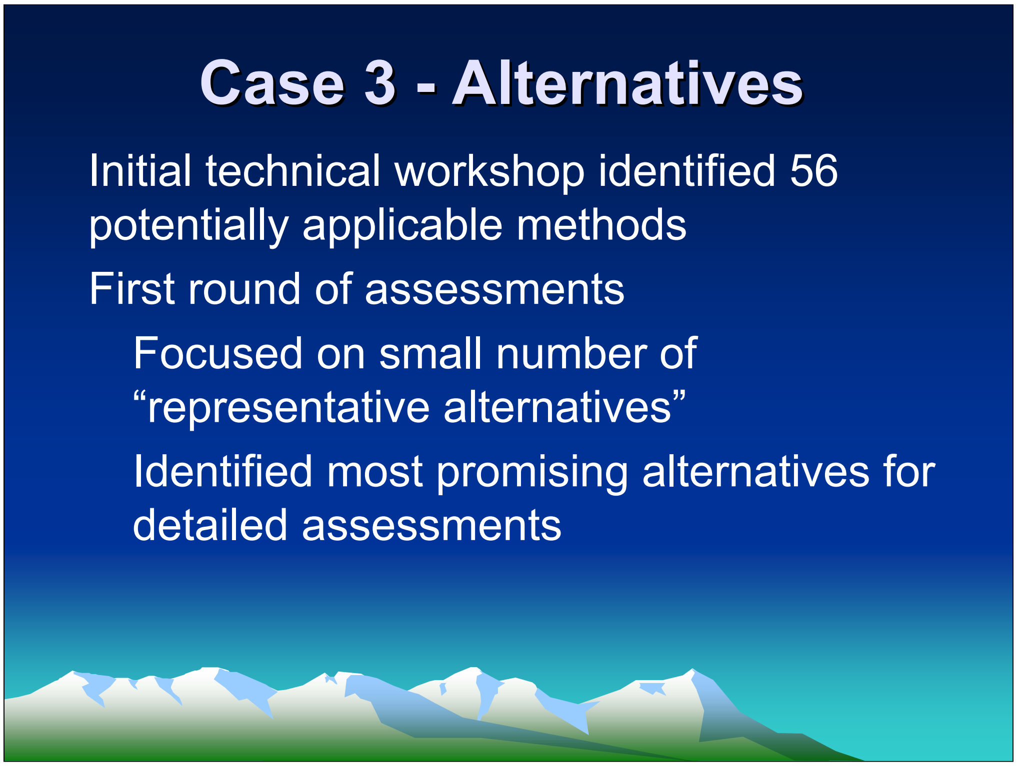
Dust now stored in 14 underground chambers and stopes

Case 3 – Giant Mine

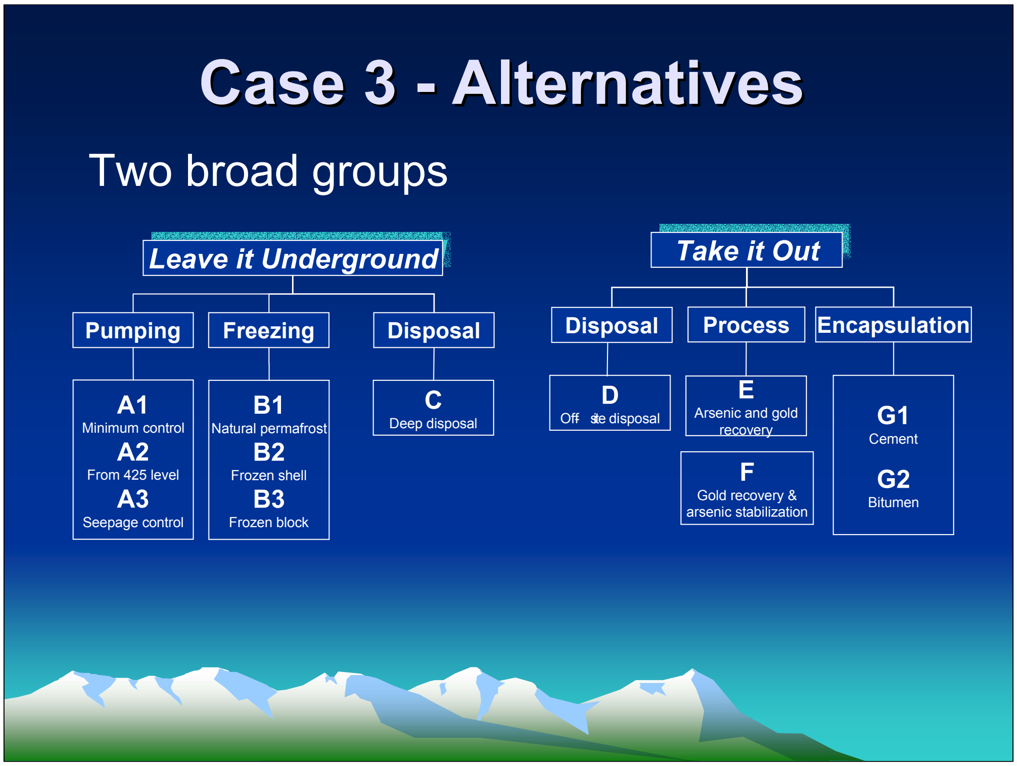
- Dust is very soluble
  4000 mg/L arsenic
- Also contains gold
  ~ 0.5 oz/ton



Evaluation criteria for assessing the four alternatives were selected at a series of public workshops held in 1999 and 2000. They included the different types of risk associated with each process, and costs.



To addresss this complex problem, we put together a group of engineers and scientists and started by listing all of the potentially applicable management or remediation methods. That list included over 90 methods. We then put together groups of methods and selected "representative alternatives" to represent each group. The next steps were all done on the four representative alternatives you see listed here.



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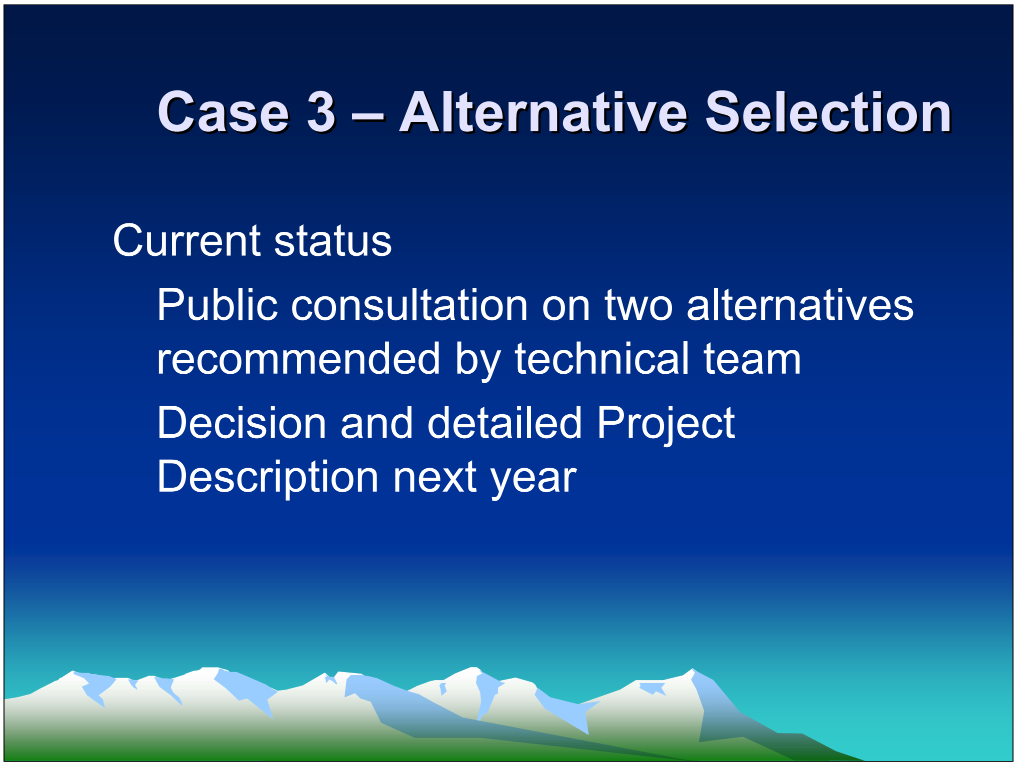
The investigations to fill in the blue area of the matrix took about six months. We started by developing pre-feasibility level engineering designs for each alternative. The engineering designs were then used as a basis for risk assessments and cost estimates.

Case 3 – Alternative Selection

"Leave it Underground" Alternatives	Overall Risk	Dominant Risk Category	Net Cost Range ($Million)
A1. Water Treatment & Minimum Control	High	Long term	30-70
A2. Water Treatment & Drawdown	Moderate	Long term	80-110
A3. Water Treatment & Seepage Control	Moderate	Long term	80-120
B2. Frozen Shell	Low	Long term	90-110
B3. Frozen Block	Low	Long term	90-120
C. Deep Disposal	Moderate	Worker H&S	190-230

Case 3 – Alternative Selection

"Take it Out" Alternatives	Overall Risk	Dominant Risk Category	Net Cost Range ($Million)
D. Removal & Surface Disposal	High	Short term	600-1000
F. Removal, Gold Recovery & Arsenic Stabilization	Moderate	Worker H&S	400-500
G1. Removal & Cement Stabilization	Moderate	Worker H&S	230-280



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I would now like to pull together the three case histories and suggest a "unifed top down approach" to this type of work.

The first step in all cases is to start with the end in mind, i.e. define complete alternatives. The process of doing that will depend on the scale of the project. For small sites and simple projects, a standardized list of alternatives might be applicable. For medium-sized projects, a site specific list will be needed. For the very large projects, a lot of work is required to define all possible methods and select representative alternatives for further assessment.

2. Select Evaluation Criteria

Project Cost	Typical Evaluation Criteria		
	Cost	Risk	Acceptance
$100,000	Scoring on unit costs	Scoring by risk type	Experience-based scoring
$1,000,000	Site specific investigation and design	Screening level risk assessment	Consultation with stakeholder group
$10,000,000	Phased investigation and design	Human health & environmental risk assessment	Public hearings & review process

The next step is to define the evaluation criteria and the level of detail required to assess each alternative with respect to each criteria. Again, the level of effort needs to vary depending on the complexity of the project. Looking at the cost column for example, simple unit cost approaches might be adequate for small projects, but multi-phased investigations with lab, bench, and pilot scale studies may be needed for very large projects. The point is to let the top down process direct investigation efforts to key uncertainties.

3. Analyze & Select

Project Cost	Investigations and Evaluation Sequence
$100,000	Screening investigation Matrix
$1,000,000	Screening investigation Alternatives definition Follow-up investigation Limited consultation
$10,000,000	Initial studies Confirmatory investigations Feasibility level design Project Description Public review

Finally, the process of selecting alternatives can be a single step in small projects, but will probably be iterative and involve significant public interaction in the larger projects.

End

Questions?

Risk Management Process

Consequence Severity Definitions

Categories	Very Low	Minor	Moderate	High	Very High
Injury and Disease	Low-level short-term subjective symptoms. No measurable physical effect. No medical treatment.	Objective but reversible disability/impairment and /or medical treatment injuries requiring hospitalization	Moderate irreversible disability or impairment to one or more persons.	Single fatality and /or severe irreversible disability or impairment to one or more persons.	Short or long term health effects leading to multiple fatalities. Catastrophic event leading to multiple fatalities
Environmental Impacts	No lasting effect. Low-level impact on biological of physical environment	Minor effects on biological or physical environment	Moderate effects on biological or physical environment but not affection ecosystem function. Medium term widespread impacts.	Serious environment effects/some impairment of ecosystem function. Widespread medium-long term impacts.	Very serious environmental effects with impairment of ecosystem function. Long-term effects on the environment
First Nations Impacts	No impact to traditional lands	Minor or perceived impact to traditional lands	Some mitigatable impact to traditional lands or lifestyle	Significant impact to traditional lands. Short-term impact to harvest rights	Irreparable (permanent) damage to traditional lands. Long-term impact to harvest rights.
Legal	Low-level legal issue. Fines not likely	Regulatory warning likely. Fines possible.	Fines likely.	Large fines expected.	Major fines expected
Community, Media, NGO's	No local complaints or press coverage	Public concern restricted to local complaints and press coverage	Heightened concern by local community. Local /regional media and NGO attention.	National press coverage, Globe and Mail CBC Newsworld. National NGO's involved.	International press coverage, CNN. International NGO campaign
Mitigation Costs	< $100,000	$100,000 - $500,000	$ 500,000 - 2.5 Million	$2.5-$10 Million	>$10 Million

Risk Management Process

Likelihood Definitions

Assigned Likelihood	Description	Frequency	
		Human Health	Safety, Environment and Community
Almost Certain	…expected to occur in most circumstances	1 case / 100 person-year	High frequency of occurrence – occurs more than once per year
Likely	…will probably occur in most circumstances	1 case / 1000 person-year	Event does occur, has a history, occurs once every 1 – 10 years
Possible	…should occur at some time	1 case / 10^4 person-year	occurs once every 10 – 100 years
Unlikely	…could occur at some time	1 case / 10^5 person-year	occurs once every 100 – 1000 years
Very Unlikely	…may occur under exceptional circumstances	1 case / 10^6 person-year	occurs once every 1000 – 10 000 years