GIANT MINE
Oversight Board

Box 1602 . 5014-50th Avenue . Yellowknife, NT X1A 2P2
Phone 867.675.0788 . **Fax** 867.675.0789 . **Web** www.gmob.ca

State of Knowledge (SOK) Public Presentation

October 11, 2017

What We Heard

Table of Contents

Introduction

The Giant Mine Oversight Board (GMOB) was established in 2015 with a mandate to provide oversight on the Giant Mine Remediation Project (the Project) and to develop and manage a research program towards a permanent solution for the 237,000 tonnes of arsenic trioxide dust that is currently stored in underground chambers at the Giant Mine site. As a first step in the development of the research program, GMOB contracted a consulting company, Arcadis, to conduct a State of Knowledge (SOK) review of technologies that could be used to manage the dust. The SOK report was released on September 11, 2017; GMOB hosted a public meeting at the Northern United Place in Yellowknife on October 11, 2017 to present the SOK results.

This presentation report summarizes the questions and feedback GMOB received during the public presentation.

Structure of the Public Meeting

The presentation was structured as follows:

- The doors opened at 6:30 pm to allow members of the public to talk to GMOB members and to view posters of the plain language summary of the SOK report. Copies of the technical report and plain language summary were available in both paper and electronic format (also available at www.gmob.ca). Models of the Giant Mine site including the arsenic chambers were available at the presentation. Refreshments were provided.
- A formal presentation began at approximately 7:00 pm. Dr. Kathy Racher, the Chair of GMOB, began by providing some background information on GMOB and to explain the purpose of the SOK review. Two consultants from Arcadis, John Vogan and Kathryn Farris, then presented a summary of the SOK review including the main conclusions.
- The Arcadis consultants and GMOB then answered questions and received feedback from the audience on the review and on the research program going forward.
- Additional time was given after the presentation and a question/answer period was provided for members of the public to informally engage with GMOB in the auditorium.
- The presentation ended at approximately 9:00 pm.

A copy of the presentation is appended to this report as Appendix A.

What We Heard

This section of the presentation report provides a summary of what GMOB heard at the public presentation. Instead of listing the questions and feedback in the order they were given, the information has been grouped as follows:

- Questions/answers about the SOK review and results
- Suggestions on the SOK Review methodology
- Suggestions on the SOK Review process
- Next steps for GMOB's research program

Questions/answers about the SOK review and results

- Who were the experts that performed the scoring of the methods?
  - The list of experts can be found in the SOK Technical Report.
- One of the slides on the Frozen Block method said that it would take "15-20 years for water to reach the dust if the freezing stopped working". Did that mean 15-20 years for the dust to thaw or that long for the water to reach it after thawing?
  - At the meeting, the Arcadis consultants clarified that it would take about 20 years for the outer part of the frozen dust to begin thawing in the event that the

thermosyphons failed. The Arcadis consultants provided the following additional clarifications after the meeting:

- In the Developers Assessment Report (DAR) published in 2011, Thawing and Climate change were specifically discussed (Section 6.2.8.2). Simulations were previously conducted by SRK. They determined the following:
    - "It was predicted to take 10 years before the arsenic dust warmed to -5C, and between twenty and more than fifty years before the outer limit of the dust actually began to thaw"
- SRK discussed the chain of events that would need to occur before thawing would lead to an arsenic release.
    - Ineffectiveness of thermosyphons would go unnoticed or unmitigated for at least 20 years, or longer if some thermosyphons are active.
    - Failure of temperature monitoring system
    - Increases in soluble arsenic coming into the water treatment plant would go unnoticed
    - If this went unnoticed, water treatment costs would increase, but the water treatment system would be able to capture the additional arsenic loading.
    - Arsenic release would also require the failure of the mine water collection system (that pumps water out of the underground so it doesn't rise to the level of the dust chambers) and water treatment plant.

- One participant asked about the state of the dust underground and whether there had been any changes in the last 20 years. For example, do we know if any of the dust has leaked out?
    - Board members stated that one way that the dust could move was if it the chambers themselves or the bulkheads that keep the chambers in place shifted. Bulkheads are regularly inspected and monitoring is done check for tectonic activity in the area. GMOB is not aware of any evidence that the dust has shifted. A representative of the Project Team also talked about how all the minewater was collected, treated, and tested prior to discharge; so any arsenic leaks could be detected that way.

- There was a question about how long the vitrified material would last before it devitrified. For example, regular glass will eventually take up some water and this can change the glass structure. Could this happen with the vitrified arsenic dust and in what time period?

    - At the meeting, the consultants said that the glass was very stable but have provided the following information to help answer this question:
        - Based on our discussions with Dr. Don Carpenter, one of the experts that reviewed this technology, this is a very common question that comes up during public meetings. Glass, such as stained glass, does have a limited life-time (Generally around 400 years), as it recrystallizes over that time-period, and eventually breaks down. However, the vitrification process for waste stabilization generates a far more stable glass. Based on models for vitrified radioactive waste, these types of glass are expected to be stable over thousands of years.

- A participant was surprised that there was no evaluation of arsenic trioxide treatment using cerium. He said that a Google search showed at least 40 references for this method.
    - At the meeting, the Arcadis consultants said that in all their discussions with experts in the field of arsenic remediation, the idea of using cerium to treat the dust did not come up.
    - Following the meeting, the consultants did some additional work to provide the following answer to the question:
        - It is true that there has been research conducted investigating cerium and other rare-earths as an absorptive media for water treatment (e.g. http://www.wcponline.com/2015/06/30/a-new-technology-for-arsenic-removal/)
        - These methods appear to focus on relatively low arsenic concentrations in water and waste-water, not methods to process and treat arsenic trioxide dust. In other words, the dust would need to be extracted and dissolved prior to treatment. These types of reagents are typically expensive, large quantities may be needed, and the stability and volume of treated material would need to be evaluated. There has been some research regarding cerium use in contaminated soils, however, these reactions may not apply to arsenic trioxide dust, and it would be extremely difficult to assure complete even mixing within the stopes and chambers.

- A participant asked why the autoclaving process used at Con Mine to treat arsenic trioxide was not also being considered for the arsenic trioxide at Giant.
    - A Board member explained that the autoclave at Con was installed primarily as an alternative to roasting the rich refractory ore - driven by the price of gold - that was present in the older areas of the mine. The arsenic treatment was a bonus of process. The arsenic waste, also containing gold, could only be fed into

the autoclave at a slow rate along with the ore, which contained the sulphur necessary to fuel the reaction. In order to treat Giant's arsenic using Con's autoclave, a feedstock of refractory ore, or an alternative, would be necessary in huge volumes to make the system work. As best as the Board member could recall, the timeline to treat all of Giant's arsenic by this method would be a huge number of years (the exact number is in the environmental assessment documents).

  - After the meeting, the Arcadis consultants provided the following additional information:
    - In Supporting Document 13, Section 3.7, of a 2002 report from SRK, the Con Mine autoclave was evaluated. The vessel volume and material residence time is directly proportional to the feed rate of the arsenic. The timeline to process the arsenic dust using that autoclave was estimated at 36 years. Because of this timeline, the construction of a second would still be needed. It was determined that the added complexity of operating two autoclaves in parallel would be difficult and would not benefit the overall success of the project.

- There was a question as to whether the arsenic needed to be dissolved prior to it being vitrified.
  - The Arcadis consultants said that the dust would have to be dissolved before it could be turned into glass. A representative of Dundee Sustainabilities (who have proposed a vitrification process) stated at the meeting that he did not believe that was the case. However, Arcadis has subsequently re-reviewed the process description provided by Dundee and have confirmed that the arsenic would have to be dissolved prior to vitrification.

Suggestions on the SOK Review methodology

- A member of the public suggested an additional criterion for assessing the different methods that they called a "vulnerability index". The idea was that depending on the type of treatment applied, the arsenic trioxide could be used as a weapon by terrorists or the site could become the focus of an attack. So for example, methods which transformed the dust permanently to something non-toxic (e.g., cement) would make the site less vulnerable to attack or use than methods where the dust is encased in a toxic form (e.g., frozen block).

- A member of the public suggested that methods should be scored based on the amount of carbon that would be released during treatment of the dust. Carbon release would be considered an additional cost of treatment. For example, mixing the dust with cement would release a lot of carbon during the process. The current review did not consider this.

- Another suggestion was to consider alternative energy sources as a way of decreasing the costs of implementing a method. For example, for those methods that scored lower because of high energy requirements (and associated costs), the score may be improved if less expensive forms of energy were considered.

- One audience member questioned whether the implementation of a method in cold climates should have been given a higher ranking, given the site location.

Suggestions on the SOK Review process

- Concerns were expressed that the public wasn't engaged on the criteria or weightings used to score methods in the SOK review. It was pointed out that this was an issue when the first SOK review was done in 2002; in that case, people were left feeling unsure about whether the selected method was appropriate at that time. There was also a concern that notes weren't being taken at the meeting so GMOB might miss the opportunity to benefit from the ideas being raised. GMOB was reminded that it would be best to engage as early as possible so that the concerns and ideas of the public would be considered in future decisions.

Additional Questions

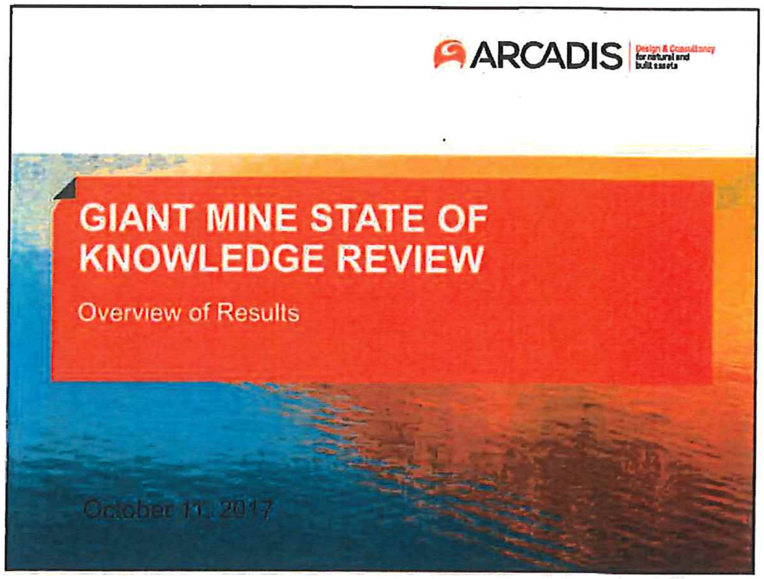
- There was a question as to how samples of the arsenic dust were going to be provided for technology testing. GMOB acknowledged that it would be necessary to provide samples of the dust so that specific methodologies could be properly tested. GMOB stated that only the Project Team had the authority to give out samples; however, GMOB will be working with the Project Team to determine how best to coordinate the provision of samples in future.

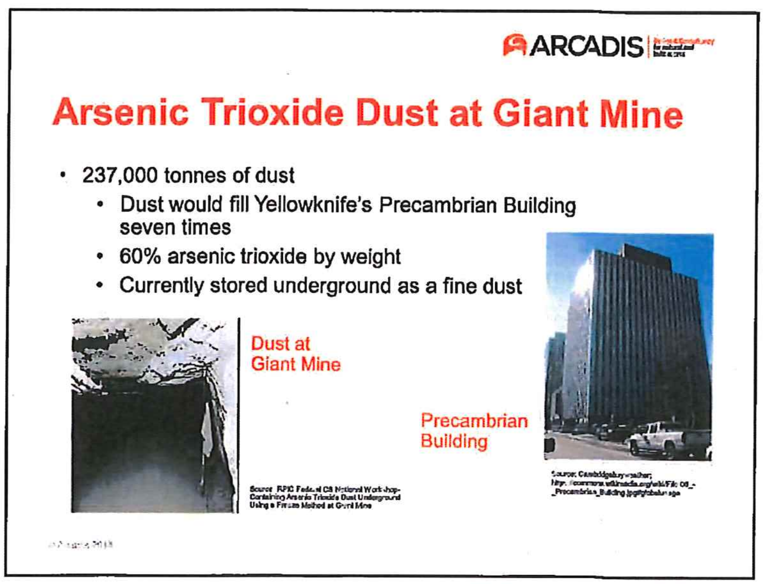
Next Steps

GMOB stated that it has just begun to develop the research program. The SOK review was a valuable first step and GMOB is planning meetings in the fall to figure out the "architecture" of the program. GMOB stated that the public would be engaged on the research program going forward; however, the exact timing and form of engagement is yet to be worked out.

APPENDIX A: October 11, 2017 Public Meeting Presentation

ARCADIS Design & Consultancy for natural and built assets





1

Identifying Options

- In 2000, the Giant Mine Remediation Project Team evaluated 56 methods to manage the arsenic trioxide dust.
- Outcome → Frozen Block

Approved with Conditions:

1. 100 year interim solution
2. Established independent oversight body (GMOB)
3. Facilitate active research in emerging arsenic technologies

© Arcadis 2016

State of Knowledge Review (SOK) (2016-2017)

- Identify and assess any technologies relevant to arsenic trioxide management.
- Re-visit previously considered technical methods (improvements?).
- Evaluate new technologies.
- Focus on underground arsenic trioxide dust.

© Arcadis 2016

ARCADIS Design & Consultancy for natural and built assets

ARCADIS

Arcadis SOK Review Process

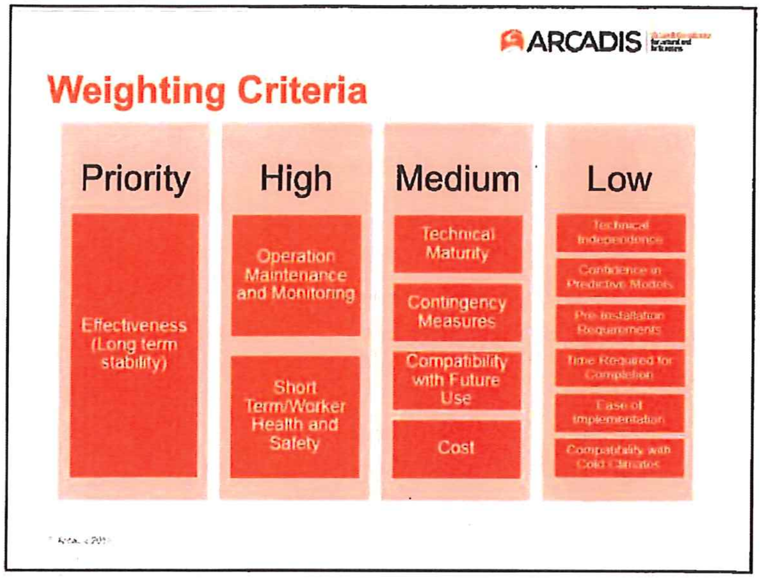
1. **Pre-evaluation Phase**
   a. Review of previous work
   b. Identifying experts (over 20 experts)
   c. Develop scoring criteria
   d. Method Selection
2. **Technical Reviews**
   a. Literature review (100+ papers)
   b. Scored methods with experts
   c. Result write-up and review of scoring by experts
3. **Final Reporting**
   a. Ranked methods based on reviews
   b. Proposal evaluations

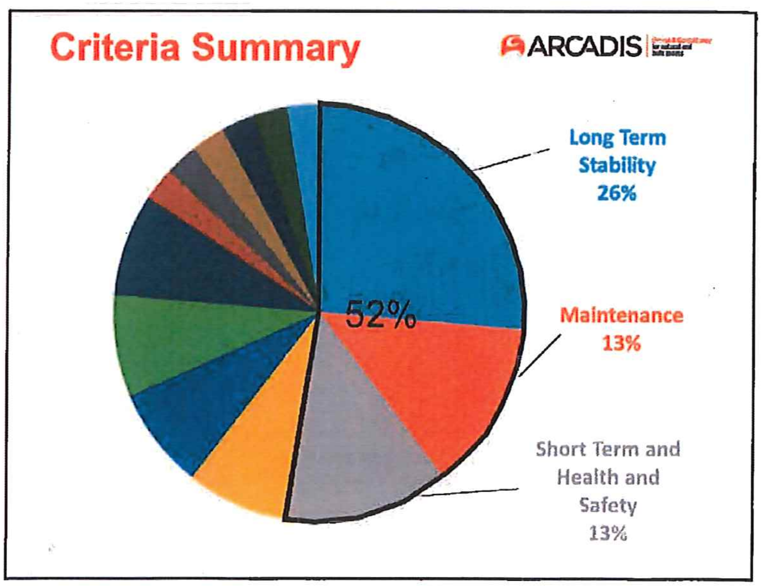
ARCADIS

How do we score a method?

- Scoring system with 13 criteria
  - Long term solution
  - Amount of work involved in maintaining system
  - Health and safety
  - Other design considerations
- Scoring possibilities
  - Very low
  - Low
  - Medium
  - High
  - Very High
- These scores are multiplied by a weighting factor and then added up to a final score

3


ARCADIS
Weighting Criteria
Priority
High
Medium
Low
Effectiveness (Long term stability)
Operation Maintenance and Monitoring
Short Term/Worker Health and Safety
Technical Maturity
Contingency Measures
Compatibility with Future Use
Cost
Technical Independence
Confidence in Predictive Models
Pre-Installation Requirements
Time Required for Completion
Ease of Implementation
Compatibility with Cold Climates

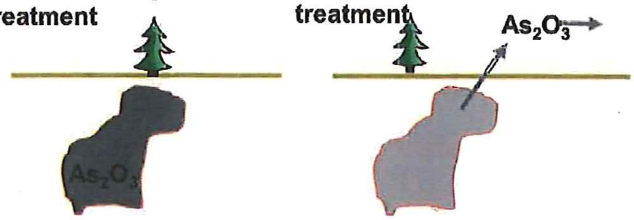

Criteria Summary
ARCADIS
52%
Long Term Stability 26%
Maintenance 13%
Short Term and Health and Safety 13%

4

In Situ vs. Ex Situ

In Situ – Underground Treatment

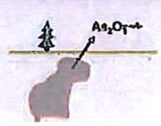
Ex Situ – Above ground treatment



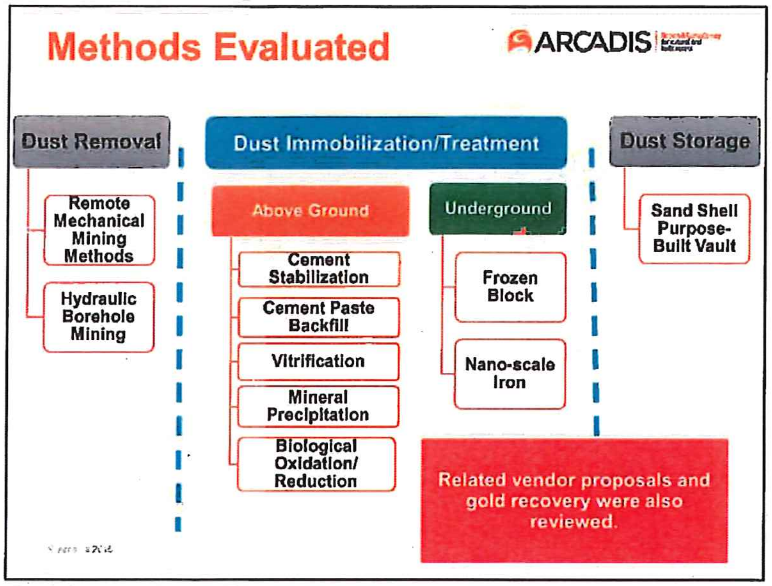
Number of steps needed is different depending on whether dust stays in ground or is removed.

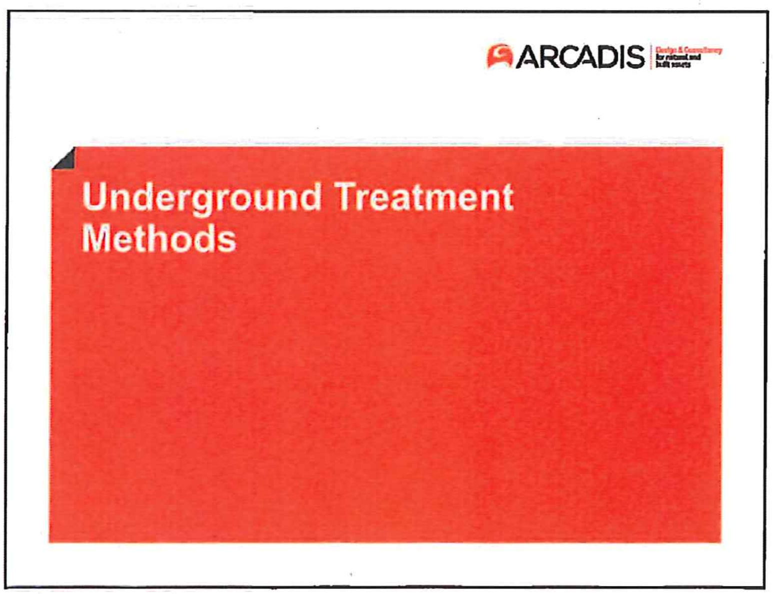
© Arcadis 2015

Steps Required

Treatment Type	Dust Removal	Dust Immobilization/ Treatment	Treated Dust Storage
Underground 	Not Required	Required	Not Required
Above-ground 	Required	Required	Required

© Arcadis 2015


Methods Evaluated
ARCADIS
Dust Removal
Remote Mechanical Mining Methods
Hydraulic Borehole Mining
Dust Immobilization/Treatment
Above Ground
Cement Stabilization
Cement Paste Backfill
Vitrification
Mineral Precipitation
Biological Oxidation/ Reduction
Underground
Frozen Block
Nano-scale Iron
Dust Storage
Sand Shell Purpose-Built Vault
Related vendor proposals and gold recovery were also reviewed.

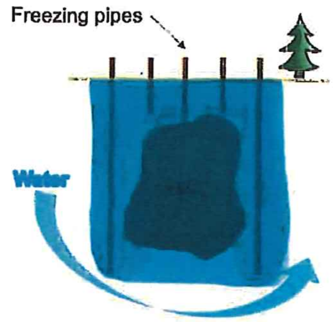

ARCADIS
Underground Treatment Methods

6

ARCADIS Design & Consultancy for natural and built assets

Frozen Block

- Highest scoring underground treatment method.
- Dust and chambers are frozen so water cannot access dust.
- Scored well in technical soundness and safety.



Ground freezing is being tested currently on site

Frozen Block

Advantages:

- Minimal underground disturbance.
- Sustainable (passive thermosyphons).
- Well-studied, well understood and modeled.
- Minimizes chance of arsenic dissolving in the short term.
- It would take ~15-20 years for water to reach the dust if freezing stops working.

Disadvantages:

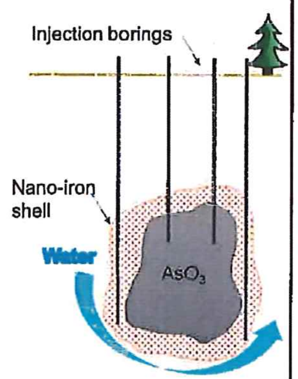
- Temporary solution.
- Could limit future site development.
- Continual maintenance necessary.

ARCADIS Design & Consultancy for natural and built assets

ARCADIS

Nano-Scale Iron

- Injects very small iron particles to create barrier/shell, stopping arsenic trioxide from escaping into groundwater.
- Iron is mixed with liquid and injected into ground surrounding dust storage areas.
- Disadvantages:
  - Hard to fill all cracks in bedrock
  - Hard to monitor long term performance.
  - Numerous re-injections likely.



ARCADIS

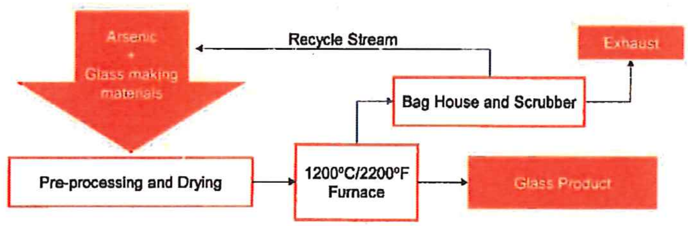
Above-ground Treatment Methods

Dust removal to be discussed later.....

ARCADIS

Vitrification

- Highest scoring above ground treatment method
- Encases arsenic in glass.
- Combines dust with glassmaking materials in a furnace.
- Resulting glass is very stable.



Based on Dundee Sustainable Technologies Flow Chart

ARCADIS

Vitrification

Advantages:

- Glass can be disposed as non-hazardous waste (pending testing).
- Vitrification process could be combined with gold extraction to recover some of the costs.
- Glass is expected to be very stable.

Disadvantages:

- High heat/energy requirements (1200°C/2200°F).
- Dust has to be removed from underground.
- Hazardous gasses possible
- Possible dust release during extraction/processing.
- Dust needs to be dissolved and reacted before processing.

ARCADIS

Cement Stabilization

- Combines cement and dust to stabilize the arsenic.
- Advantages
  - Well studied, common practice for other wastes
  - Long-term stability (storage condition dependent).
- Disadvantages
  - Initial release of arsenic during drying.
  - Large amounts of cement needed (cost).
- Large increase in waste volume vs. dust alone.
  - Over 10x increase in volume possible

A form of calcium-arsenate mineral formed when mixing arsenic with cement.

ARCADIS

Cement Paste Backfill

- Variation of Cement Stabilization where a paste of cement dust is made.
- Similar treatment process as cement except:
  - Advantage: Paste can be pumped (safer dust transport).
  - Disadvantage: Lower strength than solid cement blocks.
  - Large volume produced
- Arsenic release during drying a concern.

Source: http://minewiki.engineering.queensu.ca/mediawiki/index.php/Backfill

Paste is pumpable and would be easier to transport into new storage chambers

Mineral Precipitation

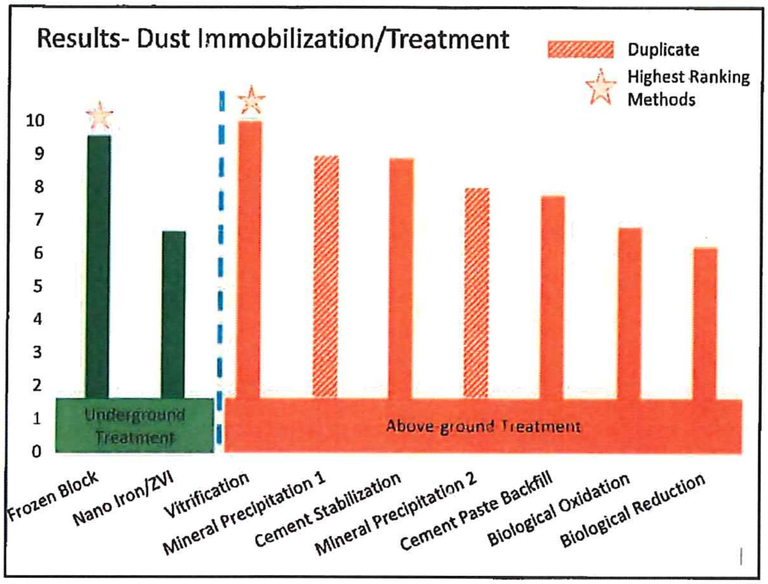
- Converts dust back into more stable minerals.
- Process used at active mines to process arsenic waste.
- Primary method: arsenic mineral formation from liquid solutions.
  - Advantage: Process can be at normal pressure and temperature.
  - Disadvantage:
    - Dust needs to be dissolved before processing
    - very expensive
- Appropriate storage necessary.

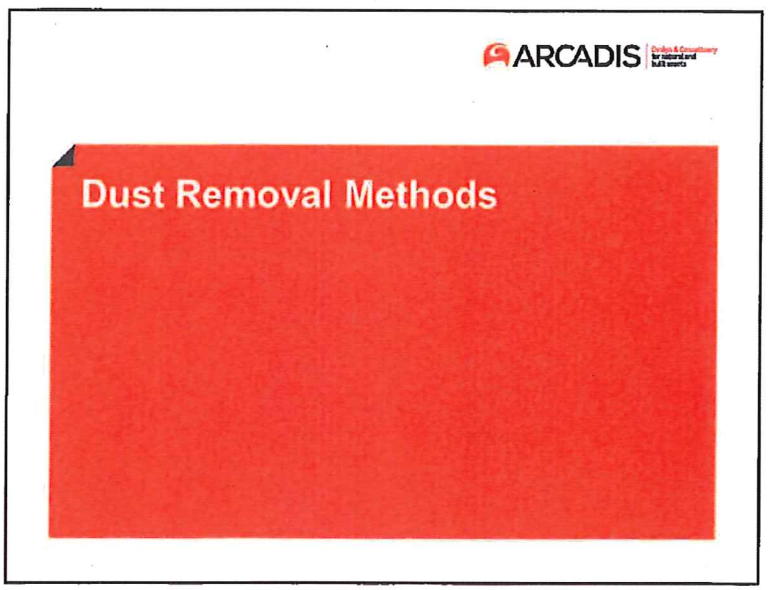
Scorodite: One of the arsenic minerals produced.

Krause & Ettel, 1988

Biological Precipitation

- Newer technology that uses bacteria to produce arsenic minerals.
- Not as well studied as mineral precipitation.
  - Long-term stability less known
- Happens with oxygen present (oxidative) or no oxygen present (reductive).
- Can be more cost effective than mineral precipitation.
- Treatment in large scale aboveground tanks.
- Appropriate storage necessary.

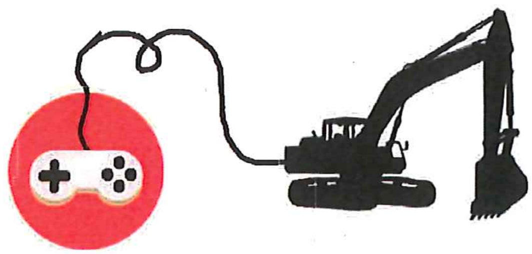

Results- Dust Immobilization/Treatment
Duplicate
Highest Ranking Methods
10
9
8
7
6
5
4
3
2
1
0
Underground Treatment
Above-ground Treatment
Frozen Block
Nano Iron/ZVI
Vitrification
Mineral Precipitation 1
Cement Stabilization
Mineral Precipitation 2
Cement Paste Backfill
Biological Oxidation
Biological Reduction


ARCADIS
Dust Removal Methods

12

Remote Mechanical Mining

- Remote control mining is major technology development since 2002.
- Combination of mining methods is likely required.
- Potential for dust release and worker exposure to dust.
- Unstable underground workings still pose risk.



Hydraulic Borehole Mining

- High-pressure water (water jet) or steam removes arsenic dust. Dust is pumped upwards to surface.
- Significant technology changes since 2000
- Possibly used as sole-removal method.
- Dust would still need to be treated after removal.
- Loss of jetted water would need to be minimized

Source: Kinley Exploration LLC, Hydraulic Borehole Mining

13

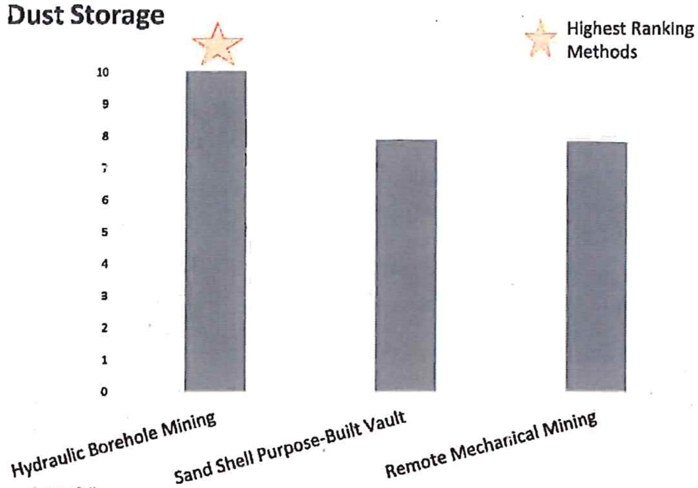
ARCADIS Design & Consultancy for natural and built assets

Dust Storage

Sand Shell Purpose-Built Vault

- Possible underground storage option.
- Treated dust stored in new underground concrete vaults, surrounded by sand and/or gravel.
- Protects dust from ground movement or stress.
- A large number of vaults would be needed to handle the increased volume of treated dust.
- This method has to be combined with an extraction and treatment method to be effective.

Results: Dust Removal and Dust Storage



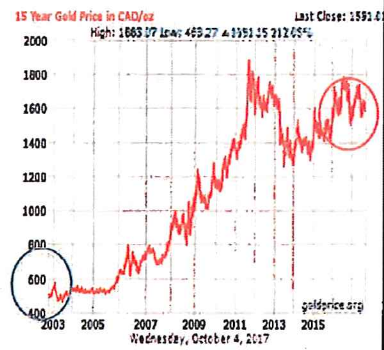
Gold Recovery

ARCADIS Design & Consultancy for natural and built assets

ARCADIS

Gold Recovery

- Arsenic dust contains small quantities of gold.
- Price of gold has increased significantly since previous evaluations.
- Could partially offset cost of treatment by including gold extraction in the management strategy.

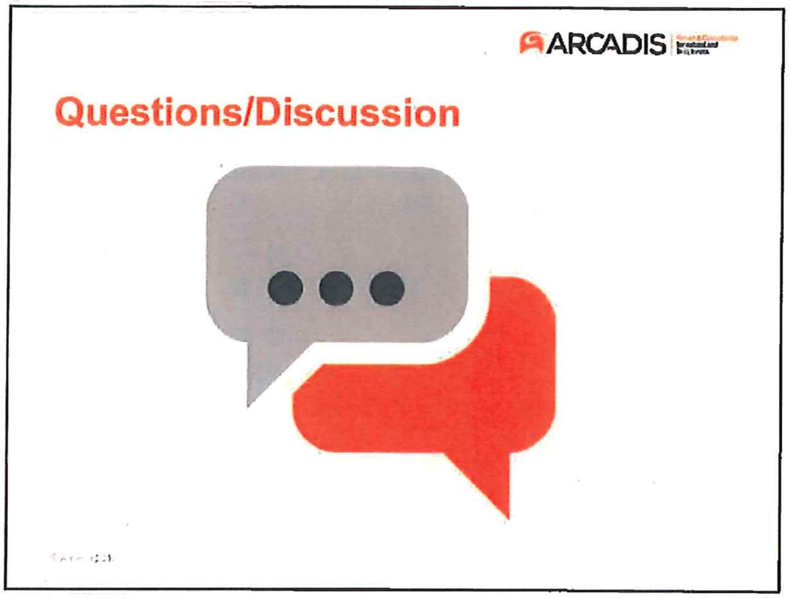


ARCADIS

Summary

- SOK goal review- identify promising arsenic treatment methods
- In-ground treatment – Frozen Block
- Above-ground treatment – Vitrification
- Significant advances have been made in mining and removal.
  - Still poses risks
- Any above ground treatment will need to be combined with extraction and final storage solutions.

16



17