Environmental Arsenic in a Changing World –
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Permanent remediation of toxic arsenic trioxide in Canada's North

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ABSTRACT: The former Giant Mine is North America's largest and most technically challenging arsenic contaminated site. During the operational phase of the mine, some 237,000 metric tons of arsenic trioxide dust were stored in underground vaults within the mine. An interim mine site remediation plan has been approved for a maximum of 100 years, subject to a number of pre-conditions and regulatory approvals. Among these conditions is the requirement for a research program to identify methods to permanently eliminate the risks posed by the arsenic trioxide dust. As a first step, the independent Giant Mine Oversight Board initiated a comprehensive review of potentially promising methods.

1 BACKGROUND

Located in Canada's sub-arctic, the former Giant Mine is adjacent to the City of Yellowknife on the shores of Great Slave Lake, approximately 300 km south of the Arctic Circle. Gold ore at the Giant Mine is associated with an arsenic-bearing mineral known as arsenopyrite. The process used to release the gold from the arsenopyrite led to the production of arsenic-rich gas as a by-product. Operators of the mine captured this gas in the form of arsenic trioxide dust which was transferred to large underground rock chambers within the mine. Throughout the 50-year operational life of the mine, a total of 237,000 metric tons of arsenic trioxide dust was produced. The arsenic trioxide dust, which is approximately 60% arsenic, is hazardous to both people and the environment (Arcadis Canada Inc., 2017).

2 REMEDIAL STRATEGY

During mining operations, it was originally assumed that the naturally frozen rock surrounding the dust chambers would immobilize the arsenic waste. However, mining activities resulted in the thawing of the rock and the waste is no longer effectively contained. Of particular concern, arsenic in the dust is water soluble and has the potential to contaminate groundwater and downstream surface water bodies. Arsenic concentrations of up to 4,000 mg L^{-1} have been measured in the mine water.

2.1 *Interim remediation*

Following the bankruptcy of the mine operator, the Government of Canada became responsible for managing the risks associated with the mine. After conducting a comprehensive review of alternatives, it determined that the preferred method for managing the arsenic trioxide dust was to freeze it in place. Referred to as the "frozen block" method, the approach involves artificially cooling the surrounding rock using refrigeration and passive thermo-syphons. A pilot test of the technology was successfully performed and full-scale implementation of the frozen block method is projected to begin in 2020, subject to regulatory approvals.

2.2 *Requirement for a permanent solution*

While the Mackenzie Valley Environmental Impact Review Board approved the frozen block method, it was accepted only as an interim solution for a maximum of 100 years, primarily because the approach requires active long-term care and is not considered to be permanent. There is, therefore, a requirement to develop a remedial strategy that will *permanently* mitigate the risks associated with the arsenic trioxide dust.

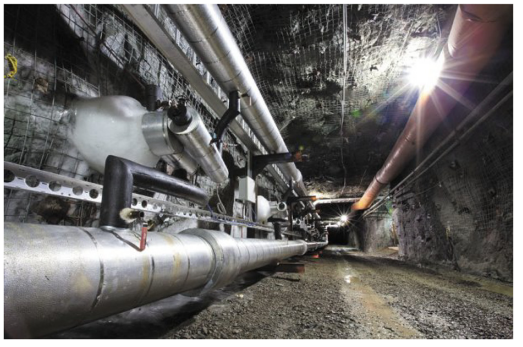

Figure 1. Testing of the Frozen Block method.

2.3 *Independent oversight and research*

An independent body (the Giant Mine Oversight Board – GMOB) was established to oversee the remediation of the Giant Mine, including the implementation of the frozen block method. GMOB is also responsible for designing and managing a research program to identify and evaluate technologies that could lead to a permanent solution for the arsenic trioxide waste currently stored at the site.

3 TECHNOLOGY REVIEW

Prior to initiating the design of its arsenic trioxide management research program, GMOB commissioned a "State of Knowledge" (SOK) review of potentially promising technologies. The review was performed to establish a technology baseline that would inform the design of the research program.

3.1 *Research methods*

The SOK review assessed a wide range of management options and technologies that can be broadly grouped into the following categories: 1) *in situ* management; 2) arsenic trioxide dust extraction; 3) *ex situ* waste stabilization/processing; and physical isolation and disposal. Each technology was assessed against a set of weighted criteria that included but were not limited to the following: permanence (i.e., long-term waste stability); technical maturity; occupational risks; operation, maintenance and mon-itoring requirements; compatibility with future land use; contingencies; and cost

GMOB recognizes that individual technologies are unlikely to resolve the problem on their own; instead, it is likely that a combination of technologies may be required, e.g., extraction followed by *ex situ* treatment and disposal.

3.2 *Research findings*

In situ methods

To establish a baseline for comparison, the SOK review evaluated the approved 'frozen block' method (Fig. 1). The method performed well for both technical soundness and safety but scored poorly in the critically important criteria of permanence. An alternative *in situ* technology, nano-scale zero-valent iron which involves injection of very small iron particles to create a barrier to arsenic movement was also evaluated. The technique, which has been used effectively at other contaminated sites, was determined to be impractical as a primary mitigation at the Giant Mine.

Arsenic trioxide dust extraction

Dust extraction or mining would remove the arsenic trioxide dust from underground for processing. To be effective, a high degree of removal efficiency (i.e., >98%) would be necessary to minimize the risk of residual arsenic contamination. In an effort to limit occupational risks, remote mechanical mining methods were evaluated. While recent technology advances have increased the effectiveness and safety of remote mining, the occupational risks have not been eliminated. As a result, mining of the dust generally scored low in the safety category. However, hydraulic borehole mining, which uses high-pressure liquid or steam to remove the dust was assessed to be the safest and most effective of the mining methods.

Ex situ waste stabilization/processing

Multiple *ex situ* waste stabilization technologies were assessed including cement stabilization, vitrification, cement paste backfill, mineral precipitation and biological precipitation. The most promising of the *ex situ* techniques was vitrification which involves encasing the arsenic trioxide dust in a glass matrix. Key advantages of the technique include long-term stability of the resulting glass and moderate overall costs.

Physical isolation and disposal

Physical containment or disposal of untreated arsenic trioxide dust was not considered due to the ongoing risks associated with the dust. However, long-term storage of the treated arsenic would be required for all ex situ methods. Under the current review, only one potential method was reviewed. The technique would involve placing the treated product underground in the mine within concrete vaults surrounded by sand and/or gravel to provide protection from ground movement.

4 CONCLUSIONS

The SOK Review evaluated a wide range of technologies, some of which show potential for the effective and long-term management of arsenic trioxide dust. There is, however, a need for targeted research to further assess the viability of the approaches that were reviewed, other emerging technologies, and the integration of technologies. GMOB is using the findings of the SOK Review to assist with the design of this research program.

REFERENCE

Arcadis Canada Inc. 2017. *Giant Mine State of Knowledge Review: Arsenic Dust Management Strategies*.