Giant Mine Oversight Board
Strategic Research Plan Development

FINAL REPORT (DRAFT)

Institut national de la recherche scientifique

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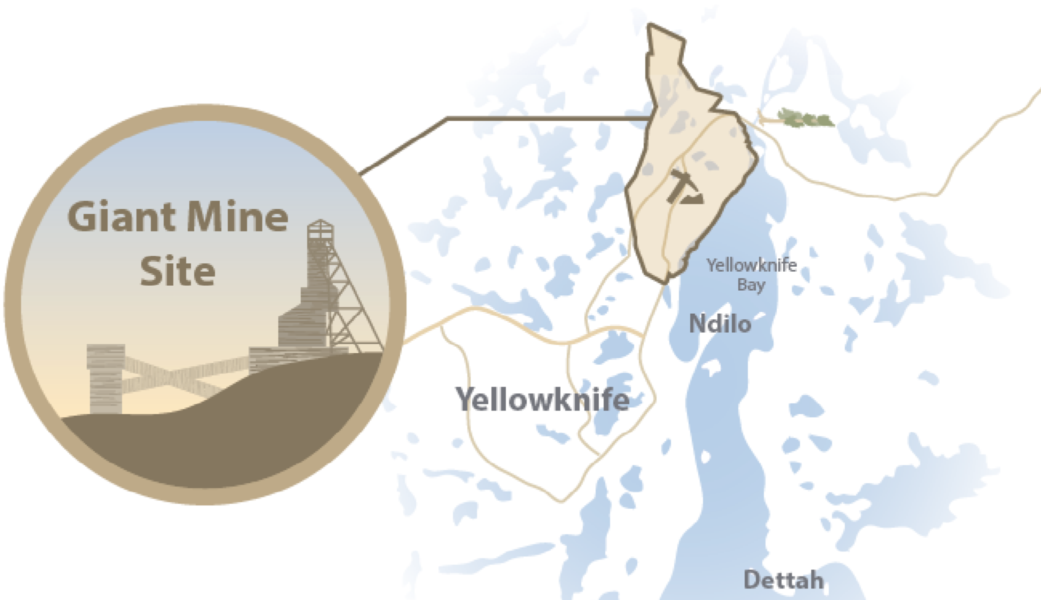
Strategic Research Plan Development

Final Report (Draft)

René Lefebvre, Ph.D., Professor at INRS



Submitted to the

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SUMMARY

The Giant Mine is located just north of Yellowknife in the Northwest Territories, and it produced gold from 1948 to 1999. Ore processing generated arsenic trioxide dust, of which 237,00 tonnes were collected and stored underground at the mine site in “chambers” built for that purpose as well as in open mine “stopes”. The Proponents of the Giant Mine Remediation Project are the Governments of Canada and of the Northwest Territories. The “Frozen Block”, involving freezing outside and within the dust storage chambers and stopes, was selected as the arsenic trioxide dust remediation alternative to be implemented. The Environmental Assessment judged appropriate the remediation alternative, but it was considered an interim solution for a maximum of 100 years and required its periodic review every 20 years. The Giant Mine Oversight Board (GMOB) was established as an independent entity to ensure the responsible management of the remediation of the Giant Mine site and to manage a research program to seek a permanent solution to the arsenic trioxide dust. This document was produced to guide GMOB in the development of a formal research strategy.

Section 1 of this report describes the context and purpose of the research strategy, which is to provide GMOB with a rational framework to carry out its mandate to manage a research program to seek a permanent solution to the arsenic trioxide dust at the Giant Mine site. Section 2 provides an overview of the characteristics and storage of arsenic trioxide dust at the Giant Mine site. The process followed for the selection and implementation of a remediation alternative is described because it provides an analog for the process of developing a permanent solution. This process also involved the definition of criteria for the selection of a remediation alternative that could also be relevant regarding a permanent solution (Table 2.2). Furthermore, the conditions under which the arsenic trioxide dust is found after the implementation of the Frozen Block remediation alternative must be considered for the implementation of a permanent solution.

Section 3 provides a vision of the desired nature of a permanent solution for the remediation of arsenic trioxide dust. As the remediation alternative, the permanent solution would have to minimize the risk of long-term arsenic release, but its nature should not require monitoring and maintenance, so that it would have a “perpetual” nature. The Environmental Assessment indicates that it would be the responsibility of the Proponents of the Remediation Project to design and implement a permanent solution. Section 3 also describes the components of a permanent solution that would involve 1) the removal of dust from the underground mine, and 2) the stabilization of the dust in a form that prevents arsenic leaching, so that 3) storage of the stabilized dust would require no, or minimal, monitoring and maintenance. The development of a permanent solution must thus consider each of the components, which present specific constraints and challenges requiring scientific and technical developments (Table 3.1). Finally, based on the historical timelines of the Giant Mine Remediation Project, potential timelines are established for the processes related to the search for and the implementation of a permanent remediation solution for arsenic trioxide dust (Table 3.2).

Section 4 briefly describes the previous studies and the current research activities supported by GMOB. Research activities and studies were first carried out for the selection and design of an arsenic trioxide dust remediation alternative and these studies covered a wide range of topics. However, most of these studies were carried out 20 years ago. Recently, GMOB thus sponsored a State of Knowledge (SOK) Review "to provide an assessment of technologies, methods, or integrated combinations of technologies and methods that are potentially relevant to arsenic trioxide management" (Table 4.1). One of the findings is that advances in hydraulic borehole mining imply "that dust extraction could be performed effectively and safely" at the Giant Mine site. Finally, the top-ranked dust stabilization and processing method was Vitrification, and it was recommended to devote further research to vitrification-based technologies. GMOB is currently supporting seven (7) studies through the TERRE-NET research network (Table 4.2). Their emphasis is on the development of a better fundamental understanding of the nature of arsenic trioxide dust and on potential methods to achieve its passivation by transforming the dust into another form. One of these studies notably looked at the leaching behavior of vitrified Giant Mine dust using a commercial process. This is a key study to further assess the potential of vitrification for the transformation of arsenic trioxide dust. These studies should be completed in 2023.

Section 5 specifically describes the potential content of the GMOB Strategic Research Plan, which aims to define 1) the role of GMOB in the development of a permanent solution for the arsenic trioxide dust present at the Giant Mine site, 2) the strategic actions that will structure the development of a permanent solution that would meet the hopes of the community, 3) the topics to be covered by the studies sponsored by the Research Program and their priorities, and 4) the process that will be followed to carry out the Research Program and the criteria that will be used to measure the progress made. The report outlines the issues needing to be addressed regarding roles of GMOB and the Proponents, the permanent solution development process, the criteria to be used to assess a potential permanent solution, and the timeline to develop and implement a solution. An initial step would thus require GMOB to seek an agreement with the Proponents regarding these issues. In priority, it would also be important to take actions ensuring the full involvement of the community in the development of an acceptable permanent solution. Another step would be to secure adequate funding for the Research Program. Whatever the level of financial resources available to carry out the Research Program, GMOB could strive to leverage its research spendings by supporting proposals to research granting organizations. GMOB could also adopt a long-term continuous research approach to ensure coherent development of the components of a permanent solution. This "continuity" could be achieved by the support of a research chair at a local education institution. GMOB could also ensure the development of local "capacity" and the training of Highly Qualified Personnel from NWT. Section 5 provides indicators that could be used to measure progress regarding the orientation of the Strategic Research Plan (Table 5.1). The priority of research topics previously identified is also provided to guide the allocation of funds. Finally, potential initial steps for the development of a Research Strategy are provided at the end of Section 5.

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1 CONTEXT AND PURPOSE OF THE RESEARCH STRATEGY

1.1 Arsenic trioxide dust at the Giant Mine site

The Giant Mine is located just north of Yellowknife in the Northwest Territories. The mine produced gold from 1948 to 1999. The gold ore is associated with pyrrhotite, which is a mineral containing arsenic. Ore processing produced arsenic trioxide dust, of which 237,00 tonnes were collected and stored in “chambers” built for that purpose as well as open mine “stopes” generally located within the vertical extent of the permafrost originally found at the site (SRK, 2002). In late 1999, the Department of Indian Affairs and Northern Development (DIAND) assumed responsibility of environmental liabilities at the Giant Mine.

A Technical Advisor (SRK, 2002) was mandated to assess remediation alternatives and it proposed the best *in situ* and *ex situ* alternatives that were reviewed by an Independent Peer Review Panel (IPRP) and discussed with the community (Terriplan, 2003). From 2001 to 2003, after three years of extensive scientific and technical research as well as consultation with the community, the “Frozen Block” was selected as the arsenic trioxide dust remediation alternative to be implemented at the Giant Mine (Government of Canada, 2023). The selected *in situ* remediation alternative involves freezing the ground around and within the chambers and stopes storing the arsenic trioxide dust to isolate it from water infiltrating into the mine (SRK, 2007).

The Mackenzie Valley Environmental Impact Review Board (MVEIRB, 2013) issued its *Report of Environmental Assessment and Reasons for Decision* on the *Giant Mine Remediation Project* in 2013. The Frozen Block remediation alternative for the arsenic trioxide dust was judged to be the most appropriate management approach currently available. However, it was considered an interim solution for a maximum of 100 years requiring periodic review every 20 years (Arcadis, 2017).

While the Environmental Assessment concluded the frozen block method was the most appropriate technical solution currently available, it also determined that emerging technologies should continue to be investigated. The Giant Mine Oversight Board was tasked with supporting research into technical approaches that could serve as a permanent solution (Government of Canada, 2023).

1.2 The Giant Mine Oversight Board and Other Parties

The Mackenzie Valley Environmental Impact Review Board (MVEIRB, 2013) identified measures to assist in identifying a better long-term management solution, including the periodic review of arsenic management technologies, and the allocation of funds to support arsenic management research (Arcadis, 2017). In June 2015, the Giant Mine Oversight Board (GMOB) was established as an independent entity to ensure that these measures are implemented (Arcadis, 2017).

As stated in its 2021 Annual Report, GMOB (2021) has two purposes:

- Independently monitor, promote, advise, and support the responsible management of the remediation of the Giant Mine site; and

- Manage a research program to seek a permanent solution to the arsenic trioxide dust stored underground at the Giant Mine.

GMOB envisions that the remediation of the Giant Mine site, including the subsurface, will be carried out in an environmentally sound, socially responsible, and culturally appropriate manner (GMOB, 2021). GMOB is governed by a six-member Board of Directors representing the six Parties to the Giant Mine Remediation Project Environmental Agreement. The parties are 1) Government of Canada (GC), Crown-Indigenous Relations and Northern Affairs Canada (formerly DIAND) (Government of Canada, 2023), 2) Government of the Northwest Territories, Environment and Natural Resources (GNWT-ENR, 2023), 3) Yellowknives Dene First Nation (YKDFN, 2023), 4) North Slave Métis Alliance (NSMA, 2023), 5) Alternatives North (AN, 2023), and 6) City of Yellowknife (2023). The Governments (GC & GNWT) are co-proponents of the Giant Mine Remediation Project and form the Giant Mine Remediation Project Team ("Project Team"). In 2017, Parson was awarded the responsibility of the Main Construction Manager (MCM) of the Giant Mine Remediation Project (Parson, 2023).

1.3 PURPOSE OF THE GMOB RESEARCH STRATEGY

The purpose of the GMOB Research Strategy is to provide a rational framework to carry out its mandate to manage a research program to seek a permanent solution to the arsenic trioxide dust at the Giant Mine site. The Research Strategy is described in section 5 of this report, and it defines 1) the respective roles of GMOB and the proponents in the development of a permanent solution, 2) the research goal and strategy to be implemented by GMOB, 3) the options and priorities identified to develop a permanent solution, and 4) the process to be followed to support research and the indicators considered to assess the Research Program.

Prior to the description of the Research Strategy, this report provides important information about the conditions that constrain the Research Program to develop a permanent solution to arsenic trioxide dust. Section 2 describes the characteristics of the dust and the selected remediation alternative. The Giant Mine Remediation Project will be leaving the mine site in a state that will affect the conditions under which to implement a permanent solution. Section 3 provides more information about the desired nature of a permanent solution, the components forming the solution (dust recovery, dust stabilization, and storage), the criteria to be considered in the assessment of a potential permanent solution and in the decision to implement it, and the expected timeline for the implementation of a permanent solution. Section 4 summarises previous research efforts related to the development of a permanent solution, which defines the main achievements and the important remaining gaps towards a permanent solution.

2 ARSENIC TRIOXIDE DUST REMEDIATION ALTERNATIVE

2.1 CHARACTERISTICS AND STORAGE OF ARSENIC TRIOXIDE DUST AT THE GIANT MINE

As described by SRK (2002) and Terriplan (2003), the process of roasting was used to recover the gold associated with the arsenopyrite, an arsenic-bearing sulphide mineral, associated with the ore at the Giant Mine. The process converted the arsenopyrite into an arsenic-rich gas, which was captured in the form of arsenic trioxide dust. The arsenic trioxide dust is approximately 60% arsenic, which can be leached by contact with water and is hazardous to both people and the environment. In total, 237,000 tonnes of dust were stored in 10 purpose-built underground chambers in the mine as well as in five mined-out stopes. These chambers and stopes are located between depths of 20 to 75 metres below the ground surface. The dust storage areas are sealed off from the rest of the mine with concrete bulkheads.

2.2 SELECTION AND IMPLEMENTATION OF A REMEDIATION ALTERNATIVE

The assessment of remediation alternatives for long-term management of the arsenic trioxide dust at the Giant Mine involved two phases. In Phase 1, the Technical Advisor for the project proponent first identified over fifty technologies that were potentially applicable as part of complete alternatives for long-term management of the arsenic trioxide dust (SRK, 2002). Table 2.1 summarizes the steps or processes involved in the remediation of arsenic trioxide dust and the potential methods that could be applicable for these purposes, which were considered in Phase 1. The applicable processes were assessed and compared by considering their relative risks and costs. Three categories of risk were considered: 1) the risk of arsenic release in the short term during the implementation of alternatives; 2) the risk of arsenic release in the long term after implementation; and 3) the worker health and safety risks that would be faced during preparation, implementation, and post-implementation activities (SRK, 2002).

After consultation with the community (DIAND, 2001), the Phase 2 of the assessment of remediation alternatives considered seven (7) measures in more detail, including 3 *in situ* and 4 *ex situ* measures. The *in situ* measures involve operations that keep the arsenic trioxide dust in the mine, whereas *ex situ* measures require the removal of the dust from the mine. These alternatives are summarized in Table 2.1. Out of these 7 alternatives, the Technical Advisor identified the preferred *in situ* and *ex situ* alternatives that were examined by an Independent Peer Review Panel (IPRP) and discussed with the community (Terriplan, 2003). This assessment, selection and consultation process led to the choice of *in situ* alternative B (Dust Isolation by Ground Freezing) as the preferred remediation option. The “Frozen Block”-variant of that alternative was considered more appropriate, notably because it was more “robust”, in the sense that it could be maintained over the long-term.

Table 2.1: Steps or processes considered in the management of Arsenic trioxide dust and the potential methods that could be used (based on SRK, 2002).

Steps or processes	Potential methods applicable
Phase 1 assessment of remediation alternatives	
In situ management	• Pump and treat methods • Isolation methods • In situ modifications • Relocation underground
Removal of dust	• Bulk mining methods • Methods of retrieving dust in a pipe • Other mining methods
Re-processing to recover gold and/or arsenic values	• Direct shipment of crude dust • Production and shipment of refined dust • Arsenic metal production • Manufacture of added value products • Stabilization of As_2O_3 and preparation of refractory gold values for recovery • Cyanidation and gold recovery • Water treatment
Waste stabilization and disposal	• Isolation and containment • Physical stabilization • Chemical stabilization
Phase 2 assessment of remediation alternatives	
Phase 2 *in situ* measures considered	• A: Long-Term Water Collection and Treatment • B: **<u>Dust Isolation by Ground Freezing</u>** (of area around or within each chamber and stope; Frozen Shell & Frozen Block variants) • C: Removal and Deep Disposal of the dust in specially excavated caverns at the base of the mine
Phase 2 *ex situ* measures considered	• D: Removal and Surface Disposal of the dust in an off-site hazardous waste disposal facility • E: Removal, Gold Recovery and Arsenic Trioxide Purification to recover gold and produce a high purity arsenic product • F: Removal, Gold Recovery and Arsenic Stabilization • G: **<u>Removal and Encapsulation</u>** with cement or bitumen and on-site storage in disposal facility

Note: the Technical Advisor considered that alternatives B3 (Frozen Block) and G were the preferred *in situ* and *ex situ* alternatives, respectively (highlighted in bold and underlined).

Table 2.2 summarizes the criteria that were considered at different steps from the screening, assessment, selection and implementation of a remediation alternative for arsenic trioxide dust at Giant Mine. The aspect of applicability or feasibility was implied by the Technical Advisor in its screening and assessment of alternatives. The IPRP was more explicit about applicability, as it used as criteria the technical viability, namely the use of proven technology, and the availability of enough data to test the alternatives. The IPRP also insisted on the need for the alternative to be robust in the long-term, acceptable (socially and relative to regulations) and be verifiable through monitoring.

During the consultation on the remediation alternatives, the Government of Northwest Territories (GNWT) "focused on the importance of minimizing the risk of arsenic release in the long term, stating that the long-term eco-system and human health risks are considered by the GNWT to be the highest-ranking decision-making criteria" (Terriplan, 2003). Regarding the preferences among the alternatives expressed by the community, Terriplan noted a general support for *in situ* management and apparently no support for *ex situ* management. Also, the freezing option was the most widely preferred *in situ* management alternative, but the GNWT requested further consideration of deep disposal in order to make a comparison with freezing (Terriplan, 2003). Overall, "worker health and safety, technological feasibility and environmental and human health are seen as the most important factors in choosing an alternative. Some stakeholders do not regard cost as a key consideration" (Terriplan, 2003). So, overall, Table 2.2 and the previous discussion show that **reduction of the long-term arsenic risk** is regarded as the most important criteria for the management of arsenic trioxide dust.

In the implementation of the selected remediation alternative, the Technical Advisor formulated the remediation objectives as follows: "To manage the underground arsenic trioxide dust in a manner that will prevent the release of arsenic to the surrounding environment, minimize public and worker health and safety risks during implementation, and be cost effective and robust over the long term (SRK, 2007)". So, in the implementation of an alternative, worker health and safety were also considered important criteria. Cost-effectiveness was considered important in the implementation of the selected remediation alternative by the Technical Advisor and the Governmental authorities involved (Government of Canada, 2023). The Technical Advisor also adopted the criteria of robustness proposed by the IPRP for the implementation, which led to some modifications of the initial proposed design, notably the attainment of a lower temperature for the Frozen Block alternative (-10 °C around the dust and -5 °C in the dust versus -2 °C originally proposed; SRK 2007, p. 143 vs SRK, 2002, p. 96).

Table 2.2: Compilation of criteria considered for the assessment, selection, and implementation of Arsenic trioxide dust remediation alternatives (based on various sources indicated in the note below the table).

Criteria	Technical Advisor (Assessment)	IPRP (Selection)	GNWT	Community	Technical Advisor (Implementation)	Governments (Canada / DIAND & NWT)
Applicability / feasibility	X			X		
Short-term As release risk	X					
Long-term As release risk	X		X	X	X	X
Worker health & safety	X			X	X	X
Relative costs	X					
Cost-effective				Not “relevant”	X	X
Technically viable		X				
Proven technology		X				
Testable (data available)		X				
Robust		X			X	
Acceptable	X	X	X	X	X	X
Verifiable (monitoring)		X				

IPRP: Independent Peer Review Panel. GNWT: Government of Northwest Territories.

Sources: Technical Advisor (Asssement): SRK (2002); IPRP, GNWT, and Community: Terriplan (2003); Technical Advisor (Implementation): SRK (2007). Governments (Canada / DIAND & NWT): SRK (2007) and Government of Canada (2023).

2.3 THE FROZEN BLOCK REMEDIATION ALTERNATIVE AND GIANT MINE SITE CONDITIONS

As mentioned, regarding the arsenic trioxide dust, the Giant Mine Remediation Plan (SRK, 2007) retained the alternative of the Frozen Block, which involves freezing around the chambers and stopes containing the dust (down to -10 °C) as well as within the dust itself (down to -5 °C). The chambers and stopes storing dust are mostly within the vertical extent of permafrost (frozen ground) at the site, which is from 100 feet (30.5 m) below surface to more than 250 feet (76 m) below surface (SRK, 2007, p. 24), although the top of some chambers is shallower than 30 m.

Freezing will be done by pumping a coolant (carbon dioxide, CO_2) in thermosyphons, which cool the ground without any input of energy, below and around the chambers and stopes (https://www.youtube.com/watch?v=E4nZDSLdIiM). The Technical Advisor's studies concluded that even under an extreme global warming, the thermosyphons are supposed to maintain frozen conditions in and around the chambers and stopes. The thermosyphons are intended to operate indefinitely, with only periodic maintenance and occasional replacement (SRK, 2007).

The IPRP (Terriplan, 2003) had considered the Frozen Block as a robust remediation alternative for many reasons: freezing from underneath, as well as from the sides, eliminates the possibility of "windows" in the frozen block; the frozen block option takes advantage of the wet dust to create even more ice; supplementing the active freezing method with cold air pipes from the surface gives added protection from thawing; the option is flexible and can be monitored, and if there is a concern about thawing, the freezing mechanism can be reactivated to refreeze the blocks; very little energy is required to maintain the frozen blocks once they are frozen solid, which reduces the long-term cost of the option and the extent of the long-term maintenance required.

In the perspective of implementing a permanent solution requiring the removal of the arsenic trioxide dust, the Frozen Block alternative was considered "reversible": "It is possible to mine the frozen material, bringing it to the surface to use this new technology", but thawing the dust was considered to lead to potential problems (Terriplan, 2003, p. 10-11).

The Frozen Block remediation alternative is not a "walk away" solution. Like all other remediation alternatives, after the implementation of the Frozen Block it will be necessary to maintain a water collection and treatment system at the site (SRK, 2007). The pumping of water out of the mine has lowered the local water table and completely changed groundwater flows near the mine. Deep groundwater between the lake and the mine is flowing towards the mine workings, so that no arsenic has escaped the underground workings through groundwater flow (SRK, 2007). The proposed storage of contaminated water underground will require that the water level be kept below the bottom of the deepest pit that will remain open (SRK, 2007). The water level in the mine will be maintained below the bottom of the open pits, which will also prevent any release of contaminated groundwater to the surroundings (SRK, 2007). Since arsenic concentration in water from the underground mine will depend on the exact flow path through the various underground sources, the mine water may not be acceptable for direct discharge for many years (SRK, 2007).

An extensive monitoring program must also be implemented regarding surface water, treated water, mine water, groundwater, air, environmental effects, and frozen ground, as well as the physical monitoring and inspections of the site and facilities (SRK, 2007). Also, maintenance of the ground freezing system would continue indefinitely, as would mine water treatment and long-term monitoring (SRK, 2007). So, continued management of the site over the long term (decades) is required, which was recognized by the Member of the Legislative Assembly commenting that "our city, and the federal government, must acknowledge that we have a perpetual management issue" (Terriplan, 2003).

3 DEVELOPMENT OF A PERMANENT SOLUTION

This section aims to describe the desired nature of a permanent solution for the remediation of arsenic trioxide dust stored underground at the Giant Mine site, and which is presently controlled by the implementation of the "Frozen Block" remediation alternative. The nature of the permanent solution would guide the GMOB Research Strategy in its development of such a solution.

Based on the outcome of the Environmental Assessment of the Giant Mine Remediation Project (MVEIRB, 2013), subsection 3.1 states the goal of a permanent solution, identifies its proponents, and explains its foreseen implementation process. Then, subsection 3.2 describes the components that must be developed to form a complete permanent solution (dust removal, dust stabilization, storage and perpetual management of stabilized dust, and management of residual dust). Next, subsection 3.3 proposes criteria that could be used for the selection of a permanent solution and as a basis for the decision to implement this permanent solution by the proponents. Finally, based on the historical process followed to implement the Frozen Block remediation alternative, subsection 3.4 provides a timeline that could be expected for the development and implementation of a permanent solution.

3.1 OBJECTIVES, PROPONENTS, AND IMPLEMENTATION OF A PERMANENT SOLUTION

Based on the selection process that led to the implementation of the Frozen Block remediation alternative (Section 2.2; Table 2.2) and the Environmental Assessment of the Giant Mine Remediation Project (MVEIRB, 2013), the main objectives of a permanent solution to the arsenic trioxide dust can be stated as follows:

- Minimize the risk of long-term arsenic release.
- Does not require monitoring and maintenance.

The first objective is the same as the main objective of the screening study of remediation alternatives (SRK, 2002) and the Remediation Plan (SRK & SENES, 2007). The second objective is based on the Environmental Assessment, which stressed the importance of the "permanent" or "perpetual" nature of the needed solution, which imposes important constraints on the nature of the solution (MVEIRB, 2013; p. 159). These constraints imply that any element of the solution should be coherent with the need for the absence, or at least the minimization, of monitoring and maintenance.

The Environmental Assessment showed that it will be a challenge to get the Developer to implement a permanent solution (MVEIRB, 2013; p. 62): "The Developer stated that it believed it was unlikely that there would be a "markedly superior" option in the future, because of the thoroughness of the Developer's 2000-2003 investigation of alternatives, and because of the challenges inherent in excavating the arsenic even if a better treatment were available (…). The Developer's view is that, considering the amount that would have been previously spent on the initial Project implementation, "the thresholds for any new options are going to be very high" (…)". This was further emphasized as follows (MVEIRB, 2013; p. 64): "In the DAR the Developer emphasized that the proposed Project is not intended as a temporary measure, and views the frozen block method as the long-term solution for Giant Mine arsenic trioxide. The Developer added that it remains open to improvements in technologies but has no intention of adding a long-term search for a better solution to the Project (…)". Despite these statements, at the request of the Environmental Assessment Board, the Developer agreed to support a research program aimed at the development of a permanent solution.

The Environmental Assessment also clearly indicates that it would be the responsibility of the Developer to design and implement a permanent solution (MVEIRB, 2013; Measure 2): "If the periodic review identifies a better approach that is feasible and cost-effective, the Developer will further study it, and make the study and its results of the study public". It thus appears that the role of the GMOB Research Program is to develop the components of a permanent solution up to a level that provides strong evidence that it would meet the criteria, which would require the Developer to initiate a formal detailed assessment, engineering design, and fund appropriation for the implementation of a permanent solution.

The Environmental Assessment also defines the process to be followed for the implementation of a permanent solution (MVEIRB, 2013; p. 62):

"Measure 2: Every 20 years after the beginning of Project implementation, the Developer will commission an independent review of the Project to evaluate its effectiveness to date, and to decide if a better approach can be identified. This will:

1. consider results of the ongoing research
2. be participatory in nature
3. follow the requirements of procedural fairness and be transparent in nature.

If the periodic review identifies a better approach that is feasible and cost-effective, the Developer will further study it, and make the study and its results of the study public."

The 20-year reviews of the Giant Mine Remediation Project thus offer the opportunity to 1) verify the effectiveness of the implemented Frozen Block remediation option, but also 2) to compare the remediation option to alternatives that could be considered sound candidates for a permanent solution. The following Section 3.2 provides and overview of the components that such a permanent solution should include. Section 3.3 will discuss the criteria that could be used to judge if an arsenic trioxide dust remediation alternative developed through the GMOB Research Program represents a potential permanent solution that must be further studied by the proponents.

3.2 COMPONENTS OF A PERMANENT SOLUTION

The Environmental Assessment of the Giant Mine Remediation Project considered that the proposed Frozen Block remediation option did not qualify as a "permanent solution" to the arsenic trioxide dust stored underground at the mine site (MVEIRB, 2013). The main limitations of this remediation option are that 1) the dust remains in place, 2) the dust is in its original form that could release arsenic if contacted by liquid water, and 3) that the control of arsenic release relies on active monitoring and maintenance of the Frozen Block. It was thus concluded that in the very long term, beyond the 100-year horizon, a risk of failure of the remediation option could be foreseen. Thus, the arsenic trioxide dust can still be considered as a "threat" to the surrounding environment and communities after the implementation of the Frozen Block.

Consequently, by opposition to the implemented remediation option, a permanent solution would have to involve 1) the removal of dust from the underground mine, and 2) the stabilization of the dust in a form that prevents arsenic leaching, so that 3) storage of the stabilized dust would require no, or minimal, monitoring and maintenance. The development of a permanent solution thus involves a paradigm change relative to the implemented remediation option, by stressing the requirement for the "perpetual" or "permanent" efficiency of the remediation, even if no active management were carried out in the very long term. Such a permanent solution would be a return to the "*ex situ* measures" considered in Phase 2 of the assessment of remediation alternatives (Table 2.1). As illustrated in Figure 3.1, a permanent solution would require the development of various operational components: dust removal, dust transformation to stabilize it, and the storage of stabilized dust. The permanent solution would also have to consider site management, including non-removed dust from underground storage and the stored stabilized dust.

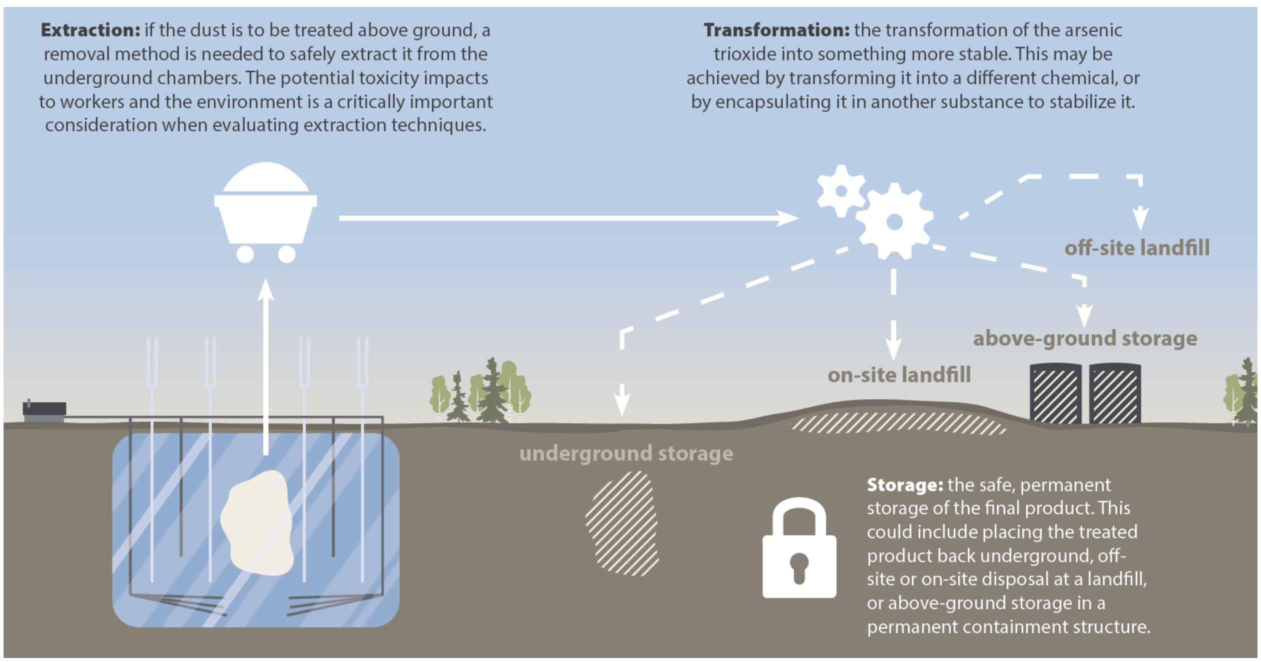

Figure 3.1 : Main components of a permanent solution for arsenic trioxide dust at the Giant Mine site (dust extraction, dust transformation and storage of transformed dust) (GMOB, not dated 2).

The development of a permanent solution must thus consider each of the components or operations required to achieve a successful implementation of the solution. Each of these components presents some specific constraints and challenges requiring scientific and technical developments that must be considered by the GMOB Research Program. Some of the more apparent issues related to these components are stated in the following text (summarized in Table 3.1). The GMOB-sponsored State of Knowledge Review by Arcadis (2017) provides more details about potential methods or technologies that could be applied to the components of a permanent solution and highlight remaining gaps (more details are provided in Section 4.2).

Dust extraction

So far, no technology has been considered suitable for the *in situ* transformation of the arsenic trioxide dust into a form that would prevent the leaching of arsenic if liquid water flows through the dust. Dust transformation thus requires its prior extraction from the underground chambers and stopes where it is stored. As stated previously, the Frozen Block remediation alternative allows later extraction of the dust. In Phases 1 and 2 of the assessment of remediation alternatives, some applicable dust extraction methods were considered (Table 2.1; SRK, 2002). More recently, a State of Knowledge Review has indicated that advances in mining methods provide further options for dust recovery, notably hydraulic borehole mining (see Section 4.2; Arcadis, 2017).

In terms of issues, even though potential dust extraction methods have been identified, their applicability to the nature of arsenic trioxide dust and the specific conditions of dust storage at the Giant Mine has not been the object of a detailed study. A key issue about dust removal is the required completeness of the removal process to avoid arsenic leaching of remaining dust and its consequences on the water treatment system. Furthermore, besides the non-extracted dust, consideration will have to be given to the other potential sources of arsenic leaching present in the mine workings (rocks containing arsenopyrite, stored waste rock, wastes containing arsenic, etc.). A key question regarding this component of a permanent solution is the potential need to maintain mine water pumping and treatment after the extraction of trioxide arsenic dust. The presently implemented remediation option of the Frozen Block requires such pumping and treatment. Furthermore, Arcadis (2017) states that “all integrated remedial alternatives must also have a form of long-term water treatment to capture any remaining arsenic that is not treated by the method implemented.” However, what is the meaning of “long-term” in the “perpetuity” perspective of a permanent solution? Moreover, can a permanent solution be implemented as long as there is a need to maintain mine water pumping and treatment that require continuous monitoring and maintenance, which is contrary to the principle of a permanent solution?

The questions regarding the performance of dust recovery and the potential need to maintain mine water pumping and treatment could represent a “go/no go” criterium for the implementation of a permanent solution. These questions are thus important and deserve research efforts, notably about 1) the applicability and expected performance of dust extraction methods, 2) the prediction of the very-long term leaching of arsenic from mine workings over decades and centuries following the extraction of the dust and under differing mine water pumping conditions, and 3) the trends in mine water arsenic concentrations over the decades following the implementation of the Frozen Block that could provide indications about the effect of the “passivation” of the dust.

Dust transformation (stabilization)

The availability of a suitable technology for the transformation of arsenic trioxide dust into a “stable” form that prevents the leaching of arsenic by flowing liquid water is the key component, and actually a prerequisite for the development of a permanent solution. Some potentially applicable methods were identified during the assessment of remediation alternatives (Table 2.1; SRK, 2002). The recent State of Knowledge Review has identified vitrification as having an interesting potential applicability (Section 4.2; Arcadis, 2017). Vitrification has thus been the focus of GMOB-sponsored research efforts (Section 4.3).

The performance of transformation methods in terms of arsenic leachability and very long-term stability of transformed dust has important implications on the storage requirements, notably the need or not to isolate the transformed dust from atmospheric conditions and to prevent or not contact with infiltrating precipitations. If the stabilization performance were poor, the storage facility could require monitoring and maintenance and even the recovery and treatment of infiltrating precipitation, which would go against the principles of a permanent solution.

Key issues about dust transformation technologies is their applicability to the arsenic trioxide dust and their performance in terms of arsenic leaching and very long-term stability. Also, the capability to apply methods in the context of the Giant Mine must be verified. Finally, as required by the Environmental Assessment (M MVEIRB, 2013; Measure 2; Section 3.1) are these methods should be “cost-effective” both in relative terms (methods compared to one another) and in absolute terms.

The research needs regarding dust transformation involve 1) the screening of potentially applicable technologies, notably based on results of GMOB-sponsored studies (Section 4.3), 2) further testing of most promising methods to verify if the transformed dust is stable and minimizes arsenic leaching, and 3) scoping engineering and cost estimation for the implementation of the most promising technology. Considering the potentially high cost of dust transformation, the pilot testing of the retained processes could possibly provide some of the required answers about issues related to dust transformation.

Dust storage

As stated previously, the requirements for dust storage largely depend on the performance of the dust transformation technology. Generically, storage could be considered offsite, on-site at the surface (with tailings, in open pits, in a new built-for purpose storage) and on-site underground (back to chambers and stopes, or deep storage in the mine). In all cases, it would be necessary to assess the available storage volume relative to the material produced by dust transformation and the operations involved to use the different storage options. Even if storage may be seen as a component whose development will be required after the other components of a permanent solution, it would be necessary to have initial studies at least about 1) the potentially suitable storage options at the Giant Mine site, 2) foreseeable storage designs, and 3) required long-term monitoring and maintenance of the different storage options. These studies should provide an idea of the relative advantages and costs of storage options, including the key aspect of the need to monitor and maintain a storage facility, which is contrary to the concept of permanent solution.

Table 3.1: Overview of the components that must be considered for the development of a permanent solution.

Potential Methods / Technologies	Issues to Consider	Research Needs
Dust Extraction		
• Methods cited by the Technical Advisor (Table 2.1; SRK, 2002) • Hydraulic borehole mining (Section 4.2; Arcadis, 2017)	• Technical applicability to arsenic trioxide dust stored at the Giant Mine • Expected performance (% recovery) in the conditions of the Giant Mine • Implications of partial extraction • Potential need to maintain mine water pumping and treatment	• Engineering study of the applicability of extraction methods and their expected dust recovery efficiency • Very long-term As leaching from mine workings (decades and centuries) • Trends in mine water As concentrations over decades following the implementation of the Frozen Block
Dust Transformation (Stabilization)		
• Cementing • Vitrification • Ceramic encapsulation • Potential other methods	• Applicability to arsenic trioxide dust • Performance (very long-term stability and As leaching) • Implementation capability to the Giant Mine site • Cost effectiveness	• Screening of potentially applicable technologies (notably based on GMOB-sponsored studies) • Testing of most promising technologies (including long-term As leachability) • Scoping engineering and cost estimate of most promising technologies
Dust Storage		
• Offsite • On-site at surface (with tailings; in open pits; in purpose-built facility; etc.) • On-site underground	• Surface and volume availability for transformed dust • Operations required to use the potential storage options	• Suitable storage options at the Giant Mine site (or need for offsite storage) • Potential storage designs • Required long-term monitoring and maintenance of storage facilities
Site Management		
• Non-recovered dust • Storage facility	• Monitoring needs • Maintenance needs	• To be studied based on selected options for dust extraction, transformation and storage

Site management

Event more so than storage, the requirements for site management related to the implementation of a permanent solution is dependant on all other components of a solution. Site management regards the monitoring and maintenance needs of the mine site and infrastructures related to the implemented permanent solution. As discussed previously, such management operations could be required for the non-recovered dust (covered under extraction) and storage facility. Consequently, site management is an issue that must be studied as part of the development of all other components of the permanent solution (dust extraction, dust transformation, and transformed dust storage). Furthermore, as part of the development of all components for the implementation of a permanent solution, worker health and safety would have to be ensured by appropriate measures. If dust is to be stabilized, the issues related to health and safety could be mostly related to the recovery and transformation operations if the stabilized dust has minimal arsenic leaching potential.

3.3 CRITERIA FOR THE SELECTION AND IMPLEMENTATION OF A PERMANENT SOLUTION

This section provides a potential list of criteria that could be considered for the selection of a permanent solution. These criteria also represent the conditions that would have to be met to consider the implementation of a proposed solution. Since GMOB's Research Program aims to develop such a solution that would be implemented by the proponents of the Giant Mine Remediation Project, the proponents would also have to adhere to these criteria and to the process leading to the decision to initiate work on the implementation of a permanent solution.

The Environmental Assessment did not define the criteria that would be applied to the decisions to select or implement a permanent solution by the Developer, but an emphasis was placed on the importance of the "permanent" or "perpetual" nature of the needed solution, and the proposed solution would have to be "feasible and cost-effective" (MVEIRB, 2013; Measure 2). As a starting point for the definition of criteria to be applied to a potential permanent solution, the criteria used for the selection of the remediation alternative can be looked at. Table 2.2 compiles the criteria that were considered important for the screening, assessment, and selection of a remediation alternative for the arsenic trioxide dust at the Giant Mine. It is suggested that a permanent solution should at least meet these criteria and even significantly go beyond them to justify an implementation. Furthermore, the permanent solution should be coherent with the vision of GMOB regarding the remediation of the Giant Mine site, which is that it will be carried out in an environmentally sound, socially responsible, and culturally appropriate manner. A list of potential criteria is proposed on the basis of Table 2.2, the Environmental Assessment and GMOB's vision. The criteria are classified in two groups: general criteria and site-specific criteria. GMOB's Research Strategy and Research Program must be defined in a way that general and specific criteria would be met in the development process of a permanent solution and in the characteristics of such a solution.

General criteria for a permanent solution

- Socially acceptable: meets the wishes of the community regarding what would be acceptable and non-acceptable for a permanent solution. Based on the Environmental

Assessment (MVEIRB, 2013), social acceptability about the different components of a permanent solution should be sought prior to the development of the solution.

- Scientifically supported: the solution is demonstrated to be capable to minimize arsenic release from the trioxide arsenic dust in the long-term.
- Technically feasible: the solution can be implemented with existing technologies, parts of which could have been developed through the GMOB Research Program.
- Financially responsible: there is a major gain regarding the reduction of the long-term risk of arsenic release relative to the implemented remediation alternative, the Frozen Block, or the minimization of the requirements for monitoring and maintenance of the solution provides such a reduction in environmental risk, that it justifies the costs involved in the implementation of the identified permanent solution.

Specific criteria to be considered in the decision to implement a permanent solution:

- The permanent solution would at least match the performance of the Frozen Block remediation alternative in terms of long-term arsenic release risk, but without the requirement to maintain active operations (monitoring and maintenance), which would provide a truly “perpetual” minimization of risk.
- The permanent solution would “stabilize” the arsenic trioxide dust by converting the dust into a form that minimally releases arsenic when in contact with water.
- The permanent solution is scientifically proven to be effective and can be technically implemented in the specific context of the Giant Mine site.
- The implementation of the permanent solution involves measures to ensure the worker health and safety.
- In itself, the permanent solution would require no or minimal long-term care involving active operations, maintenance, repairs or monitoring to ensure minimal arsenic release from the arsenic trioxide dust. On-going care at the Giant Mine site, which may be done at perpetuity, is separate from care of the arsenic trioxide dust remediation.
- The permanent solution would meet regulatory requirements.

3.4 POTENTIAL TIMELINE FOR THE IMPLEMENTATION OF A PERMANENT SOLUTION

The timeline for the implementation of a permanent solution must consider several issues. Table 3.1 compiles the historical timelines of the Giant Mine Remediation Project, which provides potentially representative times required to complete the steps for the development of that project, but also a view of the steps that will be required for the implementation of a permanent solution. Accordingly, the implementation of the permanent solution must consider the following aspects:

- The time required for the implementation of the Giant Mine Remediation Project, including the Frozen Block and other surface and underground actions.
- The periodic reviews of the implemented Remediation Project (every 20 years), which would provide an opportunity to assess the performance of the implemented option and consider the potential of an alternative permanent solution.

Table 3.2: Timelines related to the Giant Mine Remediation Project and the processes related to the search for and the implementation of a permanent remediation solution for arsenic trioxide dust.

Issues	Schedules	Implications
Remediation Project Development	● Screening of methods for the remediation of the Giant Mine site by Technical Advisor: 2000-2004 ● Public consultation and Independent Review Panel: 2003 ● Engineering design for the Remediation Plan: 2005-ongoing ● Regulatory process (Environmental assessment: 2007-2014, including the acceptance by AANDC) and licensing (obtained Water Licence MV2007L8-0031 and Land Use Permit MV2019X0007)	● The historical timeline for the steps related to the selection of the remediation option applied to the arsenic trioxide dust provides a realistic perspective on the process to be followed to develop a permanent remediation solution ● The conditions at the Giant Mine site following the implementation of the Remediation Project involve constraints and opportunities to be considered in the implementation of a permanent solution
Remediation Project Implementation	● Project implementation: 2021-2037 ● Freezing completed: 2035 ● Water Treatment start: 2026	● The decision to select a permanent solution is not likely to take place during the implementation of the Remediation Project
Remediation Project Licences	● Project Water Licence: 20 years (September 18, 2020, to September 17, 2040) ● Project Land Use Permit: 5 years (August 7, 2020, to August 6, 2025)	● In a very long-term perspective, a permanent solution could replace the implemented dust remediation option at the end of the licence ● Long before the end of the licence a choice must be made between retaining the implemented option or replace it with a permanent solution
Remediation Project Reviews	● 20-year project reviews: 2040, 2060, 2080, 2100	● Project reviews allow assessment the performance of the implemented dust remediation option and its comparison to a potential permanent solution
Permanent Solution Development (**GMOB Research Program**)	● Community consultation on the desired nature of a permanent solution ● Development of definitive criteria for the decision to implement a permanent solution ● Identification and testing of a dust stabilization method ● Identification of components of a permanent solution (dust recovery, disposal method and site management)	● The GMOB Research Program is to support studies for the identification, development, and testing of the components of a permanent solution ● The assessment criteria and submission process of a permanent solution have to be defined with "proponents" during its development phase ● An acceptable, scientifically proven, and technically feasible

	• Definition of a process for the submission and acceptance of a permanent solution by "proponents" (Gov. Canada & NWT) • Submission of the permanent solution to governmental proponents	solution is to be submitted to the governmental "proponents" of the Giant Mine site Remediation Project
Permanent Solution Selection and Acceptance by Governmental Proponents	• Permanent solution acceptance process involving an independent assessment • Preliminary engineering selection of the components of the permanent solution (dust recovery, dust stabilization, storage, workers H&S, monitoring, management) • Consultation with the community regarding the acceptability of the envisioned permanent solution and of its components • Final engineering design of permanent solution components • Funding for the implementation of a permanent solution	• Governmental proponents of the permanent solution have to assess the proposed solution, verify its acceptability, finalize the design and assess costs, and secure the funding for the implementation • That process went from 2007 to 2020 for the Giant Mine site remediation project, but the permanent solution for arsenic trioxide dust is a more focused issue
Regulatory Approval Process	• Environmental assessment of the proposed solution (4 to 7 years based on Giant Mine Remediation Project's EA process) • Licensing of the proposed solution	• The environmental assessment and licensing of the Remediation Project went from 2007 to 2014

- Based on the GMOB Research Program, the development of a permanent solution may involve numerous steps: community consultation, the testing of the dust stabilization method, the identification of suitable other components of the solution (dust recovery and stabilized dust storage). A potentially suitable permanent solution will have to be proposed to the Developer based on acceptability criteria for a permanent solution and according to a submission process that could be part of the 20-year reviews of the Remediation Project or following another process agreed upon with the community and the Developer.
- Once accepted by the Developer, a permanent solution would have initially to go through an assessment, preliminary engineering of the components of the solution, consultation with the community, final engineering design and fund appropriation.
- The permanent solution would then have to go through an Environmental Assessment and regulatory approval (licensing).

4 PREVIOUS STUDIES AND RESEARCH ACTIVITIES

4.1 HISTORICAL STUDIES

Research activities and studies were carried out for the selection and design of an arsenic trioxide dust remediation alternative (SRK, 2002; Terriplan, 2003; SRK, 2007). These studies covered a wide range of topics, including mining methods to recover arsenic trioxide dust, worker safety, groundwater flow, risk assessments, arsenic trioxide dust passivation (using cement and bitumen), underground access to stopes, field testing of a deep thermosyphon, conceptual design of deep disposal, identification of possible residue disposal sites. SRK (2007) refers to "over forty supporting documents (…) of scientific and engineering studies".

An important initial step in the development of a permanent solution would be to create a repository that would host an electronic copy of all studies carried out to support the Giant Site remediation. Such a repository would ensure the conservation and accessibility of previous studies.

4.2 STATE OF KNOWLEDGE REVIEW

Arcadis (2017) completed a State of Knowledge (SOK) Review "to provide an assessment of technologies, methods, or integrated combinations of technologies and methods that are potentially relevant to arsenic trioxide management at the Giant Mine site, with a specific focus on underground arsenic trioxide". Ten methods were evaluated in more details using the following scoring criteria: Effectiveness, Operation, Maintenance and Monitoring Requirements, Short-Term/Health & Safety and Cost. Table 4.1 summarizes the methods evaluated by Arcadis (2017) that could be considered for the management of arsenic trioxide dust at the Giant Mine.

Table 4.1: Methods evaluated by Arcadis (2017) that could be considered for the permanent remediation of arsenic trioxide dust at Giant Mine.

Category	Method
In Situ Management	• Frozen Block (baseline for other methods) • Nano-Scale Zero-Valent Iron (reactive barrier around dust storage areas)
Dust Extraction	• Remote Mechanical Mining Methods • Hydraulic Borehole Mining
Ex Situ Waste Stabilization / Processing	• Cement Stabilization • Cement Paste Backfill • Vitrification • Mineral Precipitation • Biologically-Mediated Reductive Arsenic Precipitation • Biologically-Mediated Oxidative Arsenic Precipitation
Physical Isolation and Disposal	• Sand-Shell Purpose-Built Vault

Arcadis (2017) mentions that significant advances have been made in hydraulic borehole mining and "that dust extraction could be performed effectively and safely". The Frozen Block method also performed very well according to the same criteria. Finally, the top-ranked dust stabilization and processing method was Vitrification, and it was recommended to devote further research to vitrification-based technologies based on its “potential for long-term stability of the resulting glass, moderate overall costs, and potential for gold recovery”. However, Arcadis (2017) states that the complex nature of arsenic trioxide dust is such that different technologies would need to be integrated to “provide effective treatment”. Arcadis (2017) states that “all integrated remedial alternatives must also have a form of long-term water treatment to capture any remaining arsenic that is not treated by the method implemented.”

4.3 GMOB-SPONSORED RESEARCH

GMOB directly supported scientific studies carried out by scientists participating in the research network TERRE-NET (2022) (Table 4.2). The goals of these projects were “to provide an enhanced understanding of the physical and geochemical properties of the roaster waste; and screen for potentially viable remediation alternatives that may warrant additional research (e.g., long-term laboratory experiments, pilot-scale trials)” (TERRE-NET, 2022).

Table 4.2: Main results of the TERRE-NET studies supported by GMOB.

Project	Main results
Project 1: Examination of arsenic trioxide dust composition and solubility	● Composition of arsenic trioxide dust and its solubility under varied environmental conditions. Dust solubility is limited relative to pure product and varies widely due to variations in dust characteristics.
Project 2: Stability of iron arsenate phases	● Long-term stability of iron-arsenate phases subjected to abiotic (Project 2a) and biological (Project 2b) redox reactions under anoxic environmental conditions.
Project 3: Sulfidation of As_2O_3 to low-solubility arsenic sulfide (As_2S_3)	● Explores sulfidation methods to transform As_2O_3-rich dust to a low-solubility As_2S_3 material, which would be stable under anaerobic conditions such as those found deep in the mine. ● Also looks at As_2O_3 extraction from the dust.
Project 4: Biogenic sulfide precipitation	● Efficacy of biologically-mediated sulfate reduction and precipitation of As-bearing sulfides (e.g., FeAsS).
Project 5: Leaching behaviour and geochemical stability of vitrified arsenical glass	● Leaching properties of vitrified arsenical glass produced with the process of Dundee Sustainable Technologies. ● Also looking at mineralogy and microstructure of the glass.
Project 6: Incorporation of As_2O_3 into cemented-paste backfill	● Potential incorporation of the dust into cemented-paste backfill (mixture of tailings, cement & water) to ensure its passivation. ● Includes the characterization of the dust and the assessment of diverse paste-backfill preparations.
Project 7: Implementation and application of Sb isotope systems	● Assess whether antimony (Sb) stable isotopes can be used to characterize sources of As and Sb across Giant Mine. ● Application to mine site waters and solids and to laboratory experimental systems.

The emphasis of these studies was placed on the development of a better fundamental understanding of the nature of arsenic trioxide dust and on potential methods to achieve its passivation by transforming the dust into another form. Study 1 looked at the leaching properties of the dust and it could be of interest to assess the effect of non-complete dust recovery from storage chambers and stopes on arsenic leaching and mine water composition. Studies 2, 3 and 4 looked at the transformation of the dust under other chemical forms. These transformations appear to reduce the leaching of arsenic, but final results will have to be looked at to find out if the new forms are stable and provide a material that could be permanently stored with minimal long-term risk of arsenic leaching. The extraction of As_2O_3 from the dust looked at in Study 3 could also be of interest for other dust transformation technologies. Study 5 looked at the leaching behavior of vitrified Giant Mine dust using a commercial process. This is a key study to further assess the potential of vitrification for the transformation of arsenic trioxide dust. Study 6 assessed the possibility to incorporate the dust into cemented-paste backfill that could be injected into the underground workings of the Giant Mine. The material looked at through Study 3 would also have to be stored deep in the mine workings. Finally, Study 7 provides a novel tool to identify the sources of arsenic in materials (water and solids) found at the Giant Mine site. The method could also help the interpretation of results from laboratory experiments carried out with arsenic trioxide dust from Giant Mine.

To date, the focus of GMOB-sponsored research activities have been on 1) the characterization of arsenic trioxide dust, and 2) the search for a "stabilization" method. The implied assumptions of this focus are 1) that a better knowledge of arsenic trioxide dust could help develop a suitable "stabilization" method, which implies also that 2) "stabilization" of arsenic trioxide dust is considered a requirement for permanent solution. In the wider perspective of developing all components of a permanent solution, Table 3.1 has provided a summary of issues related to each component and of the studies that could be carried out regarding those issues. Table 5.2 indicates a potential order of priorities for the studies that could be supported by GMOB's Research Program.

5 GMOB STRATEGIC RESEARCH PLAN

5.1 RESEARCH PERSPECTIVE AND RESEARCH PROGRAM NAME

The Strategic Research Plan aims to define 1) the role of GMOB in the development of a permanent solution for the arsenic trioxide dust present at the Giant Mine site, 2) the strategic actions that will structure the development of a permanent solution that would meet the hopes of the community, 3) the topics to be covered by the studies sponsored by the Research Program and their priorities, and 4) the process that will be followed to carry out the Research Program and the criteria that will be used to measure the progress made.

First and foremost, the GMOB Research Program must meet the mandate defined by the Environmental Assessment of the Giant Mine Remediation Project (MVEIRB, 2013). The process of carrying out the Research Program also must meet the general criteria defined in Section 3.2, the first of which is the social acceptability of a permanent solution, which implies the full involvement of the community in the development of a permanent solution. The permanent solution also must meet the specific criteria defined in Section 3.2 that would have to be agreed upon by the proponents. Since the process of developing a permanent solution may be viewed as important as the finality of the Research Program, the following name could be adopted for the Program:

“A community-driven search for a permanent solution for arsenic trioxide dust at Giant Mine”.

The following sections further define the respective roles of GMOB and the proponents in the development of a permanent solution (Section 5.2), outline the actions of the research strategy (Section 5.3), identify the topics to be covered by the Research Program and their priorities (Section 5.4), and describe the research process and criteria (Section 5.5).

5.2 RESPECTIVE ROLES OF GMOB AND THE PROPONENTS

As previously mentioned, the Environmental Assessment of the Giant Mine Remediation Project (MVEIRB, 2013) has defined the respective responsibilities of GMOB and the proponents regarding the development of a permanent solution for the arsenic trioxide dust stored underground at the Giant Mine site. GMOB has the responsibility to carry out a research program aiming to develop the components of a permanent solution. The Environmental Assessment also specified that such a solution would be submitted at 20-year periodic reviews of the Remediation Project. The Environmental Assessment states that the proponents (Developer) would have to further study a potential permanent solution: “If the periodic review identifies a better approach that is feasible and cost-effective, the Developer will further study it, and make the study and its results of the study public” (MVEIRB, 2013; Measure 2, p. 62).

Even though the Environmental Assessment defines these general roles of GMOB and the proponents in the development of a permanent solution, many aspects will have to be further defined between GMOB and the proponents:

1) **Roles**. How far should the GMOB Research Program develop the components of a permanent solution? In terms of general criteria (Section 3.3), would GMOB be responsible of the "social acceptability" and "scientific soundness" of a solution, whereas the proponents would have to carry out the engineering studies to assess the "technical feasibility" dans "cost-effectiveness"? How detailed should be the study of a potential solution by the proponents? More specifically, would "Phase 1" engineering design be the responsibility of GMOB (to show "technical feasibility" and "cost-effectiveness"), whereas the detailed "Phase 2" engineering design would be carried out by the proponents once a potential permanent solution has been shown to have adequate potential?
2) **Process**. The Environmental Assessment envisioned that the performance of the Remediation Alternative and potential permanent solutions would be assessed at regular 20-year reviews of the Remediation Project. Perhaps GMOB and the proponents could agree on a process that could allow the initiation of studies by the proponents on potential permanent solutions, or specific components of a solution, prior to the 20-year reviews. This would allow the continuous development and assessment of potential permanent solutions prior to 20-year reviews.
3) **Criteria**. Section 3.3 has identified potential general and specific criteria that could be considered to assess the relevance of a potential permanent solution. It would be preferable if GMOB and the proponents could agree on the applicable criteria prior to the assessment of a potential solution, rather than discuss both the criteria and the solution components at the 20-year reviews.
4) **Timeline**. Section 3.4 (Table 3.2) provides a perspective on the timeline that could apply to the development, assessment and regulatory approval of a permanent solution. A common understanding of the timeline between GMOB and the proponents would be required so that the key steps and respective responsibilities could be defined. Ideally, specific dates (years) could be identified for the different steps of the timeline.

The importance of the aspects of the development of a permanent solution requiring a common understanding by GMOB and the proponents shows that the proponents have to be actively involved in the process, rather than be confined to a "reactive role" at 20-year reviews of the Remediation Project. This involvement of the proponents is also required to ensure the recognition of the process that would lead to the development, assessment and implementation of a permanent solution. Accordingly, the Strategic Plan should include the development of an agreement with the proponents regarding the process to be followed to "further study" a potential permanent solution developed through GMOB's Research Program. That should include 1) criteria, 2) nature of study (Phase 2 engineering), 3) duration of study, 4) independent review, 5) public nature, 6) community involvement, etc. Beyond such "further study", the agreement would also have to cover the criteria to be considered for the decision to implement the permanent solution.

5.3 RESEARCH STRATEGY

The main outcome of the Research Program would be the development of a potentially applicable permanent solution for the remediation of arsenic trioxide dust at the Giant Mine. However, a Research Strategy can be developed so that the Research Program would also have a wide positive impact. Strategic elements of the Research Program are briefly mentioned in this section.

Permanent solution development process. The previous section has highlighted several issues requiring the development of a consensus between GMOB and the proponents. The first step of the research strategy would thus require that GMOB seeks an agreement with the proponents regarding their respective roles, the steps of the development process, the criteria to be used to assess a potential permanent solution and the timeline for the development and assessment of a permanent solution.

Resources allocated to the Research Program. The strategic orientations of the Research Program and the issues needing to be covered appear to require more funding than what is currently available to carry out the Research Program. Accordingly, the second step of the research strategy would be to secure adequate funding for the Research Program. For that purpose, GMOB will detail the costs of the foreseen activities of the Research Program and will seek a level of funding that is appropriate.

Community involvement. As mentioned before, the Environmental Assessment has stressed the need for and importance of fully involving the community in the development of an acceptable permanent solution for arsenic trioxide dust at the Giant Mine site. To ensure community involvement, GMOB could first support a study to identify the best means to reach and involve the community. GMOB could also seek the views of the community on what would be an acceptable permanent solution GMOB and what is not *a priori* acceptable. GMOB could also directly involve community representatives in the oversight of the Research Program, perhaps as members of a steering committee. Finally, GMOB could further develop its outreach and information program aimed at the community so that the community can follow and comment the development of a permanent solution.

Aim at a full solution for the first 20-year periodic review. A key element of the Research Strategy would be to ensure the develop of the components of a permanent solution that could be presented at the first 20-year periodic review of the Giant Mine Remediation Project. For that purpose, GMOB would put in place a research process ensuring the production of sound scientific and engineering results (Section 5.4), and it would support studies on priority topics for the development of a permanent solution (Section 5.5).

Leverage Research Program resources. Whatever the level of financial resources available to carry out the Research Program, GMOB could strive to leverage its research spendings by supporting proposals to research granting organizations (e.g. NSERC). With this approach, rather than providing the full financial support of studies, GMOB could provide part of the funding of research proposals submitted to granting organizations (e.g. NSERC) on topics of interest to develop a permanent solution. This was already done for some of the TERRE-NET projects. Such an approach, 1) multiplies the resources dedicated to research of interest for GMOB, 2) ensures the independent scientific peer review of proposals (accepting the possibility that some studies will not be accepted by granting organizations), and 3) does not put on GMOB the full burden of assessing the scientific value of potential studies.

Research continuity. GMOB could adopt a long-term continuous research approach to ensure coherent development of the components of a permanent solution. This "continuity" of research activities could be achieved by long-term agreements with research groups or by the support of a research chair whose focus would be related to the overall goal of the GMOB Research Program. The agreement of GMOB with TERRE-NET reflects such a perspective, but the duration is relatively limited, and the research activities are dispersed among numerous researchers. Having a researcher responsible for or coordinating the orientation of the Research Program would provide more continuity.

Develop local "capacity". GMOB has the possibility to have a positive impact on the community by ensuring that its Research Program involves the development of local "capacity". A long-term Research Program is likely to lead to technological and scientific advances, but it also provides the opportunity for the training of Highly Qualified Personnel (HQP). GMOB could ensure that a significant portion of this HQP training involves local individuals and academic organization. The long-term support of local academic organizations and researchers would lead to the development of capacity, even if there is a limited initial expertise base. To achieve local capacity development, a Research Chair could be created in Yellowknife, scholarships could be awarded to local NWT students to be involved in studies supported by the Research Program, and mandates regarding scientific or engineering studies could require training opportunities for NWT students.

5.4 RESEARCH PROCESS AND INDICATORS

Various options can be considered for the process that could be followed to carry out the GMOB Research Program and for the indicators to be used to assess its advances. Key aspects of the research process regard governance, community involvement, and the local impact of the Research Program. The process can evolve through time as the elements of the Research Strategy described in Section 5.3 are progressively achieved.

Governance. Governance of the Research Program can be defined in such a way that it can achieve multiple objectives. A Steering Committee could be established to involve representatives of the community and the proponents to make sure that their views are considered in the choices of orientations made for the Research Program. Independent scientists could also be part of the Steering Committee, or their views could be obtained through a regular Review Process, perhaps every five years. A process would also be required to assess the soundness of individual studies carried out as part of the Research Program. This issue is discussed later in relation to the production of sound scientific and engineering studies by the Research Program.

Indicators for the attainment of good governance of the Research Program could include the following items:

- A formal regular review process of the Research Program is in place;
- Topics (research & engineering) of studies to be covered by the Research Program are progressively carried out according to their relative priorities;
- Specifically, the effectiveness of at least one dust transformation process is scientifically demonstrated;
- Following the demonstration of a dust transformation method, technical feasibility of other solution components is progressively assessed (dust extraction, storage, site management);
- Progress of the development of the components of a permanent solution is on track for its submission at the first 20-year review of the Giant Mine Remediation Project.

Community involvement. As stated, the Research Program should seek full involvement and support from the community. To that end, GMOB could support a sociologic study to hear the wishes of the community regarding a permanent solution and define the most appropriate process to involve the community in the Research Program. Community representatives could also be part of the Steering Committee. Finally, a communication and outreach program could be developed to inform the community and get feedback. The following indicators could be considered to verify if there is adequate community involvement in the Research Program:

- The community involvement process in the Research Program is well-defined, and it is implemented and considered satisfactory by the community;
- A communication and outreach strategy has been defined and put in place;
- There is active community participation and feedback, and a survey indicates a good level of satisfaction regarding the Research Program and the way it is carried out;
- The community fully participates to activities aiming to define what is the desired nature of an "acceptable permanent solution".

Capacity building and continuous research. The GMOB Research Program offers the opportunity to locally build capacity on mine remediation in a northern environment and more generally on environmental monitoring of various media (soils, water, air, biota). As stated previously, this capacity building could be achieved through training opportunities to NWT students as part of studies supported by the GMOB Research Program. Another way to build strong local expertise would be to support a Research Chair installed in Yellowknife, which could become in some way the "research arm" of GMOB. Carrying out scientific studies through a research chair would provide multiple advantages. It would first ensure the scientific soundness of the studies and results, as the research activities of the chair would go through peer review, both at the onset when the research chair program is proposed to a granting organization, and continually as research proposals are submitted and results are published in peer-reviewed scientific journals. A chair would also offer "continuity" in scientific developments on the topics of interest to GMOB. A chair would also be an ideal mean of local HQP training. Finally, a chair would not necessarily cover all topics required for the development of a permanent solution, but it could be involved in collaborations with other scientist and engineering firms that would cover studies outside of the expertise of the chair. The chair location and research theme would also be attractive to other scientific group, so that visiting scientists could progressively make Yellowknife a dynamic research environment on issues of interest for NWT and its communities.

The following indicators could be used to assess the impact of the Research Program on capacity building:

- There is a steadily increasing number of HQP from the local community that receive training as part of studies supported by the Research Program;
- Funding for the creation of a Research Chair is secured;
- A Research Chair is established with the hiring of a professor heading the chair in one of the NWT higher education institutions;
- The scientific research program of the chair is developed and implemented;
- A research infrastructure is progressively developed;
- Research collaboration agreements are developed between the chair and other scientists.

Sound scientific and engineering studies. It is necessary to ensure that studies supported by the Research Program use sound scientific methods and produce conclusive results. However, it would be a heavy process for GMOB to request a review of each individual study sponsored by the Research Program. This is why the strategy already mentioned to support proposals submitted to granting agencies would ensure the peer review of studies even prior to their start. Supporting a research chair would also imply that the entire research program of the chair has been the object of a detailed peer review carried out by the granting agency supporting the chair.

The following indicators could be used to assess the soundness of scientific and engineering studies supported by the Research Program:

- An adequate process ensures the absence of conflicts in the selection of studies;
- The steering committee of the Research Program includes recognized scientists and engineers who can advise GMOB about the assessment of the quality of studies;
- The majority of supported scientific studies have gone through an independent external review process by granting agencies and have been published in peer-reviewed scientific journals;
- Key engineering studies on the main components of a potential permanent solution are subjected to an independent external review.

Table 5.1 summarizes an initial list of indicators that could be used to assess the GMOB Research Program.

Table 5.1: Summary of potential indicators to assess the GMOB Research Program.

Process	Indicators
Governance	● Formal periodic review process in place ● Scientific and engineering studies are progressively carried out according to their relative priority ● At least one dust transformation process has been scientifically demonstrated ● Feasibility of all solution components is progressively assessed (extraction, storage, site management) ● A permanent solution with all components is sufficiently developed to be submitted at the 1st 20-year review
Community Involvement	● The community involvement process is defined, implemented and satisfactory to the community ● A communication and outreach strategy is in place ● There is active community participation and feedback ● The community participates to the definition of the nature of an “acceptable permanent solution”
Capacity Building & Continuous Research	● There is an increasing number of local HQP training through studies supported by the Research Program ● Funding for the creation of a Research Chair is secured ● A Research Chair is established at a local education institution and a chair holder is hired ● The Research Chair scientific program is developed ● Research infrastructures are locally developed ● Collaboration agreements with outside research groups are established
Sound Scientific & Engineering Studies	● An adequate process ensures the absence of conflicts in the selection of studies ● The steering committee includes recognized scientists and engineers ● Most supported scientific studies have gone through an external independent peer-review process and have been published in scientific journals ● Key engineering studies are subjected to an independent external review

5.5 RESEARCH TOPICS AND PRIORITIES

The permanent solution will require the integration of numerous methods for the different steps involved (dust removal, dust stabilization, dust storage). Based on the wishes of the community, the focus of the Research Program could thus be on technical aspects needed for the implementation of a permanent solution. In that perspective, the components of a permanent solution would be progressively developed. The nature of these components could be “validated” at the periodic 20-year reviews of the Remediation Program. There are potential issues related to each component that need to be addressed through studies. Table 3.1 presents the components of a permanent solution, their issues and their research needs. The following table 5.2 suggests an order of priority of these studies. Not all studies have to be carried out in sequence. Depending on the budget allocated to the Research Program, it could be envisioned to support a number of studies carried out in parallel.

Table 5.2: Proposed order of priority of studies to be supported by GMOB's Research Program.

Priority	Studies
Community engagement	● Sociological study carried out to identify the best ways to engage the community and define the nature of a "socially acceptable permanent solution"
High-priority key studies	● Testing of most promising technologies for dust stabilization (including long-term As leachability) ● Engineering study of the applicability of dust extraction methods and their expected dust recovery efficiency
Important studies following up on key studies	● Phase 1 engineering study of the implementation of a demonstrated dust stabilization technology ● Study of very long-term As leaching from mine workings (decades and centuries) and the need for mine water treatment ● Engineering study of suitable storage options at the Giant Mine site for transformed dust (or need for offsite storage)
Complementary studies (Could be carried out by Proponents as part of Phase 2 engineering study)	● Pilot testing of dust extraction technologies ● Pilot testing of dust stabilization technology ● Phase 1 engineering of stabilized dust storage facility ● Assessment of site management requirements (monitoring and maintenance)

It is proposed that a pre-requisite study would identify the best ways to involve the community in the development process of a permanent solution and actually define what an "acceptable" solution should look like. Successful high-priority key studies are needed to demonstrate the potential for the development of a suitable permanent solution. Without a demonstrated dust stabilization technology and the capability to efficiently recover the dust, initiation of the other studies would not be relevant. However, even though the key studies are essential, they would not provide a complete permanent solution. The "important studies" of Table 5.2 are meant to complete the development. Prior to proposing the application of a dust stabilization technology, it would be necessary to carry out a Phase 1 engineering study of the implementation of the technology to demonstrate its feasibility and assess its cost-effectiveness. Another needed study would be on the assessment of long-term arsenic leaching from mine workings and the present underground dust storage rooms due to the presence of non-recovered dust and other materials containing arsenic already present in mine workings. At this point, it would also be necessary to provide an initial design of the storage facility for stabilized dust. The "complementary studies" listed in Table 5.2 would be needed to further demonstrate the feasibility of key components of a permanent solution (dust extraction, dust stabilization and storage) and asses the site management requirements directly associated with the permanent solution for arsenic trioxide dust. It could be envisioned that such studies would actually be carried out by the proponents as part of a Phase 2 engineering study of a permanent solution concept that has been recognized as meeting the criteria for a detailed study and potential implementation.

5.6 Initial steps for the implementation of the Research Strategy

Besides the definition and implementation of the studies supported by the Research Program, key steps can be identified to put in place a research strategy and implement the Research Program:

- With the Developer (Fed & NWT Gov), develop a process to review the implemented option (Frozen Block) and criteria to compare it to a potential permanent solution as well as decide to implement a permanent solution;
- With developer define the information needs and timeline to start the 20-year review;
- With local academic institutions and in collaboration with expert Canadian research groups, create a research entity (Research Chair) that will ensure local capacity building, both in terms of research capacity and the training of local highly qualified personnel;
- Develop a public knowledge repository to ensure permanent preservation of past studies on Giant Mine. At the research entity, develop the function of "Observatory" to compile and synthesize new research and technologies relevant for the development of a permanent solution to the arsenic trioxide dust found at the Giant Mine site;
- With the research entity created (Research Chair), with the input of the community, define the orientations and priorities of the research program and the research process, including periodic reviews of the technical and scientific advances:
    - Priorities and selection/evaluation criteria
    - Technical and scientific committee (orientation of program)
    - Review process (independent review of research reports)
    - Annual reporting
    - Periodic review and orientation of the program (5 years)
- Systematically develop research on each component of a permanent solution. Start in priority with technologies to stabilize the dust, then technologies to recover the dust, and then options to store and cover stabilized dust.

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