



Giant Mine Environmental Assessment

IR Response

Round One: Information Request - Review Board #26

May 31, 2011

INFORMATION REQUEST RESPONSE

EA No: 0809-001

Review Board Information Request #26

Date Received:

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Linkage to Other IRs:

YKDFN IR #15

City of Yellowknife IR #2.3

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May 31, 2011

Request

To evaluate the impacts of the project, the Board needs to ensure that all sources of arsenic have been duly considered. Arsenic trioxide reacts easily with carbon dioxide to form highly mobile arsenite. Any arsenic trioxide in wastes that have been covered or capped with soil can become mobilized by reacting with carbon dioxide in soil gas. Some evidence for this phenomenon comes from the fact that the arsenic levels in pore waters of Baker Creek marsh and pond are much higher than the concentration of arsenic in tailings decant used in loading estimates.

1. Provide an analysis of the redox sensitivity of arsenic minerals in the environment and the related mobility of arsenic after remediation.
2. Describe how this affects future loading estimates.

Reference to DAR (relevant DAR Sections):

ES1 Introduction

The site contains approximately 16 million tonnes of tailings containing arsenopyrite on the surface.

S.5.5.5.1 Tailings

Tailings contain arsenopyrite and soluble arsenic.

Reference to the EA Terms of Reference

S.3.4.2 Human Health and Safety,

S.3.3 (3) Arsenic containment point

S.3.5.1 (3) Water





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Summary

Forms of arsenic that are susceptible to reducing conditions are present in the calcines, mixed tailings, treatment solids and creek sediments. Appreciable changes in redox conditions are only expected to occur during reflooding of the underground mine. The effects of these changes were considered in assessing the potential loadings from the underground mine workings and led to the conclusion that ongoing treatment of water from the underground workings would be required. None of the other remediation activities are expected to result in changes in redox conditions or arsenic loadings.

Response

Arsenic is present in a number of different mineral forms in different materials and storage facilities at the Giant Mine. As a result, the effects of changes in redox conditions will vary. We have prepared a summary explaining the dominant forms of arsenic in the various source materials, and have then reviewed how the remediation plans may affect each of them.

Prior to mining, the ore and surrounding rock contained arsenic bearing sulphide minerals, primarily arsenopyrite (FeAsS) and arsenian pyrite (FeS_2 with trace amounts of arsenic substituting for the sulphur). These minerals are still the primary forms of arsenic present in the mine rock and tailings.

Sulphides present in the ore were concentrated through a flotation process, and were roasted to enhance recovery of the gold. The roasting process oxidized most of the arsenic and released it as a gaseous phase. This eventually precipitated as arsenic trioxide (As_2O_3) in the dust collection system, or as atmospheric fallout, affecting soils, lake sediments and stream sediments in the surrounding area.

Some of the arsenic would have remained in the roaster solids (calcines) either as residual sulphide minerals, or in association with maghemite (Fe_2O_3), an iron oxide mineral that formed following roasting of the concentrates. Subsequent leaching of the calcines to recover the gold may have further liberated some of the iron and arsenic, and resulted in co-precipitation of ferric arsenate minerals (e.g. FeAsO_4) and iron oxyhydroxides ($\text{Fe}(\text{OH})_3$), and/or sorption of arsenate to iron oxyhydroxides.

Small amounts of sulphides would also have remained in the flotation tailings. At various times, the flotation tailings and calcines were stored separately or as mixed tailings. Flotation tailings and mixed tailings were stored in the surface impoundments or were used as backfill in the underground mine.

The majority of the arsenic released to the underground mine is from contact with the arsenic trioxide dust. Some arsenic is also released during oxidation of sulphides present in the backfilled waste rock and tailings. The underground water is collected and this arsenic reports to the treatment plant. The treatment process involves the addition of ferrous sulphate, which results in co-precipitation of ferric arsenates and iron oxyhydroxides, and/or sorption of arsenate to oxyhydroxides. The treatment solids (sludges) are currently allowed to settle from solution in the settling and polishing ponds.

Sediments in Baker Creek also contain elevated amounts of arsenic from historical tailings spills, residual suspended solids from the treatment process, and from direct interactions of the native sediments with





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residual arsenic present in the water column. This arsenic occurs in a variety of forms, including sulphides, maghemite, ferric arsenate, iron oxyhydroxides and arsenic that has been adsorbed on the surface of the solids.

A summary showing the dominant forms of arsenic present in the different source materials and where they are found at the Giant mine site is provided in Table 1.

Table 1: Dominant Forms of Arsenic Present in Different Waste Materials at the Giant Mine

| Source | Storage Area | Arsenic trioxide | Sulphides | Maghemite | Ferric arsenates | Sorbed to iron oxyhydroxides | Sorbed to other minerals |
|---------------------------|---|------------------|-----------|-----------|------------------|------------------------------|--------------------------|
| Mine Rock | <ul style="list-style-type: none"> Underground backfill Underground wall rock Three waste rock piles by B2 pit Surface pads or road fills | | x | | | * | |
| Arsenic trioxide dust | <ul style="list-style-type: none"> Underground chambers | x | | | | | |
| Roaster Solids (Calcines) | <ul style="list-style-type: none"> Calcine storage Area Tailings impoundments Underground backfill | | x | x | * | * | |
| Flotation Tailings | <ul style="list-style-type: none"> Tailings impoundments Underground backfill | | x | | | * | |
| Treatment sludges | <ul style="list-style-type: none"> Settling pond Polishing pond | | | | x | x | |
| Stream sediments | <ul style="list-style-type: none"> Baker Creek | | * | * | * | * | * |

Notes: x – dominant forms, * present in trace amounts

The sensitivity of each of these minerals to changes in redox conditions and the specific changes that can be expected as a result of the remediation activities can be summarized as follows:

- Arsenopyrite and arsenian pyrite are stable under reducing or oxygen limited conditions. In the presence of oxygen, these minerals will slowly oxidize, releasing sulphate, acidity, ferrous iron and arsenite to the aqueous phase. The ferrous iron and arsenite will further oxidize forming ferric iron and arsenate. Under neutral pH conditions, the ferric iron will precipitate as an iron oxyhydroxide mineral, and some of the arsenate will be co-precipitated with or sorbed to this mineral. Depending on the iron to arsenic ratios, low to moderate concentrations of arsenic may be released in seepage and runoff that is in contact with these minerals. Under acidic conditions, oxidation rates typically increase, and iron oxyhydroxides are no longer stable, often leading to increased rates of arsenic release and much higher arsenic concentrations. However, at Giant, results of acid base accounting tests have shown that there are sufficient amounts of carbonate minerals to maintain neutral pH conditions in all of the source materials.



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Oxidation of sulphide minerals is expected to occur in unsaturated portions of the flotation tailings, mixed tailings, and calcines. As part of remediation activities, the tailings impoundments will be covered by a simple soil cover and areas re-vegetated, and the calcines will remain encapsulated within the overburden pile. These efforts are not expected to limit the exchange of gas, and will not reduce the amount of oxygen reaching any of these materials. Therefore, remediation activities are not expected to result in any changes in the rates of oxidation and release of arsenic relative to current conditions. However, in some areas, they may result in a reduction in the amount of flow that is in contact with these materials and therefore the total loading from these areas.

Oxidation of sulphides is also expected to occur in mine rock deposits left on surface, and in underground mine wall rock or backfill that remains above the water table. The low surface area of these materials make them relatively small sources of soluble arsenic.

- Arsenic trioxide is extremely soluble over a wide range of pH, redox and temperature conditions, reaching concentration of 4,000 to 10,000 mg/L. The remediation plan is intended to completely isolate the arsenic trioxide storage areas from any interaction with surface or groundwater flows. Therefore, the arsenic trioxide storage areas will not be affected by changes in redox conditions. Historically, arsenic trioxide was also dispersed from the roaster stack and soluble arsenic may now be present in contaminated soils, particularly in the mill area. These will be excavated and placed in the B1 pit, where they will be frozen and again isolated from any further interaction with surface or groundwater. The removal of contaminated soil that was affected by historical deposition of arsenic trioxide is also expected to result in reduced concentrations and loadings in some areas of the site, particularly in the mill area.
- Forms of arsenic that occur as co-precipitates of ferric arsenates and iron-oxyhydroxides, sorbed to iron oxyhydroxides or associated with maghemite are known to be susceptible to changes in redox conditions, particularly in settings where organic substrates are present. Some examples of this process in the literature include tailings at the Campbell Mine in Ontario (McCredie *et al* 2000, Stichbury *et al.* 2000) and Cheni Mine in France (Roussel *et al.* 2000) where tailings with these types of minerals were deposited on top of peat. Microbial activity associated with these processes is also expected to result in the release of carbon dioxide.

As summarized in Table 1, arsenic associated with these secondary iron minerals are the dominant forms of arsenic found in the calcines, mixed tailings, and treatment sludges. Trace amounts may also be present in flotation tailings and waste rock that have been exposed to oxidation and weathering.

- The only materials that will be subjected to a major change in redox conditions are the backfilled tailings and waste rock in the parts of the underground mine that have been or will be flooded. The potential for reductive dissolution of arsenic associated with iron oxide minerals in the underground mine was considered in predictions of arsenic concentrations from other sources of arsenic in the underground workings, as documented in "*Giant Mine – Geochemical Characterization of Other Sources*" (SRK 2005). The potential for ongoing release of arsenic from





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these materials is the main reason why the remediation plan assumes that water in the underground workings would continue to be pumped to surface and treated over the long term.

- As discussed previously, the tailings impoundments will be closed in place with a soil cover, and some areas will be re-vegetated. The soil cover is not expected to limit the amount of oxygen reaching the tailings, the amount of carbon dioxide released from the tailings, or the redox conditions in the tailings. Therefore, arsenic concentrations in the tailings porewater are not expected to change as a result of these processes. However, arsenic loadings will be reduced as a result of decreased flows through these materials.
- The treatment sludges in the settling and polishing ponds will be closed in place and will be covered with a soil cover. These sludges are currently saturated with water, and are expected to remain close to saturation once these remediation measures are implemented. Therefore, redox conditions are not expected to change appreciably from current conditions.
- The remediation plan for Baker Creek is being developed in consultation with other stakeholders, and include a variety of options to reduce arsenic concentrations in the sediments. If any of the contaminated stream sediments are left in place, they would continue to be susceptible to seasonal changes in redox conditions, as is currently observed in some areas of the creek during low flow conditions. However, the future estimates of arsenic loading from this area of the site are conservatively based on the current loadings from these areas which reflect the current sediment quality and the current range of redox conditions in the creek.

In conclusion, the only location where appreciable changes in redox conditions and therefore loadings are expected to occur are the flooded mine workings. The effects of changing redox conditions in the underground mine on mine water quality have been considered in the assessment of long-term treatment requirements.

References:

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Roussel, C., H. Bril, and A Fernandez, 2000. Arsenic Speciation: Involvement in Evaluation of Environmental Impacts Caused by Mine Wastes. *Journal of Environmental Quality*, Vol 29, No.1, Jan-Feb 2000.

