INFORMATION REQUEST RESPONSE

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Linkage to Other IRs

Review Board IR #7

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Request

Preamble:
The DAR makes reference to the FOS (see IR 1 above), but does not clearly state how the frozen block is created and controlled. In particular, the creation of a frozen (not sub-zero) curtain in the surrounding rock is still unclear. The DAR states:

"Step 1 Creating the Frozen Wall […]
The objective of the first step will be to create a frozen zone around each storage area that is wide enough to prevent any outflow of water or soluble arsenic trioxide when the chamber or stope is flooded".

"Step 2 Wetting the Dust
Complete […] saturation of the dust is not required; the "frozen block" concept only requires that a large mass of frozen water be developed somewhere within each chamber or stope. […] The dust is thought to be quite open, with porosity estimated at up to 60%. The high porosity and the high latent heat of freezing water means that if water at even 1 or 2°C is added to the dust, it will infiltrate before it freezes. On the other hand, tests to date indicate that the dust has a relatively low hydraulic conductivity, estimated at 7x10-7 m/s. Based on these estimates, simply adding water to the surface of the dust and allowing it to infiltrate would be feasible but slow, taking up to several months in the larger chambers".

Question:
1. The frozen wall concept appears to be based on the assumption that potential water will freeze in situ if it reaches the -10°C curtain as the chambers and stopes are wetted. Please clarify why the creation of the frozen wall appears to be based only on temperature and not on the existence of actual ground ice.

2. Please clarify why the "frozen block" concept only requires that a large mass of frozen ground, and provide any references to potential models, concepts or laboratory investigations that would support this statement. Please clarify the meaning of "large" in this context.

3. There seems to be a contradiction between the high porosity requirement for non-saturated conditions and the low hydraulic permeability. The DAR states that water will infiltrate before it freezes because of the latent heat effect, but on the other hand, the hydraulic conductivity is relatively low. Please present analytical data, numerical models or laboratory investigations to support this assumption.

Reference to DAR (relevant DAR Sections):

S.6.2.6 Initial Freeze

Reference to the EA Terms of Reference

S.3.3 Arsenic Containment, Point 2

Summary

Measurement of ground ice in bedrock with a low porosity is impractical, while temperatures can be monitored easily and reliably.

Thermal modeling initially presented in the Remediation Plan shows that complete and uniform saturation of the arsenic trioxide dust is not required. Requirements and methods for distributing water within the dust remain subjects of ongoing investigation and detailed design.

The calculations and supporting statements in the DAR regarding the rates of wetting and freezing are presented.

Response 1

Details of the initial freeze criterion can be found in Supporting Document J1 of the Remediation Plan - Conceptual Engineering for Ground Freezing (SRK, 2006).

The -10^{o}C frozen shell is situated in the bedrock around the chambers. This bedrock has a very low porosity, estimated to be in the range of 0 to 1% based on the recovered rock cores and available literature. Measurement of ground ice in a medium with such low porosity is impractical, while temperatures can be monitored easily and reliably.

Ground freezing projects commonly adopt a series of temperature criteria to determine when the ground is adequately "frozen". Water in the ground begins to freeze at 0^{o}C, but can remain unfrozen or partially unfrozen at several degrees lower, due to the effects of solutes in the water and the capillary forces exerted by matrix pores. For example, saline water with a NaCl concentration of 30% will freeze at -2^{o}C instead of 0^{o}C for pure water and the capillary force of a fissure of 1 micrometer will depress the freezing temperature by 0.05^{o}C. Furthermore, it is impractical to monitor all of the frozen area, and allowance must be made for variability. Therefore, it is good engineering design practice to adopt temperature criteria that are significantly below 0^{o}C, and to specify a distance over which such temperatures must be measured before the ground can be considered to be adequately frozen.

The initial frozen shell criteria of a -10^{o}C temperature over a width of 10 m were selected to be conservative. They are the same criteria as were adopted at the McArthur River uranium mine in northern Saskatchewan, where ground freezing is used to provide a ‘freeze curtain’ that isolates the mine working from an adjacent rock layer containing high pressure groundwater. Section 3.2 of the Conceptual Engineering for Ground Freezing (SRK 2006) report provides a list of bullets comparing the McArthur River Mine to the Giant Mine providing additional rationale as to why the initial freeze criteria selected for the Giant Mine project are conservative.

Response 2

The wording in Section 6.2.6 of the DAR is intended to draw a distinction between “wetting” and “saturation” of the dust. Both the Remediation Plan and the DAR Terms of Reference had used the term “saturation”, implying a complete and uniform distribution of water to fill all of the pore space within the dust. The use of the word “wetting” in the DAR is intended to imply that complete and uniform distribution of the water is not essential. That intent is clearer when the entire paragraph is quoted. For example, the last sentence clarifies the paragraph’s intent by adding the caveat “However, it would be desirable to distribute the water as much as possible throughout each chamber and stope prior to freezing”.

Similarly, the use of the term “large” in Section 6.2.6 is in the context of a plain English description, rather than an engineering specification of a particular size.

The basis for these statements is a series of modeling results such as were presented in Table 3.3 of Supporting Document J1 of the Remediation Plan - Conceptual Engineering for Ground Freezing (SRK, 2006). Those simulations provided predictions of thawing times assuming that the freezing system, either active or passive, is removed after 25 years. The table is repeated below. The second and third rows compare thawing times for cases where the dust in Chamber 12 is fully saturated and 10% saturated. Both rows indicate that it will take a very long time for the outer edge of the dust to reach 0^{o}C. Complete saturation appears to provide little benefit in this analysis.

A similar pattern is expected in other cases. However, there are combinations of frozen zone distributions and thawing locations that show more rapid thawing. For example, the top surface of the dust is predicted to thaw more quickly in cases where the water is assumed to fill only the bottom 80% of a chamber than in cases where the water is uniformly distributed. These considerations are being taken into account in the later phases of design and will lead to a better definition of the “wetting” or “saturation” requirements.

Table 3.3 Time predictions of thawing

Area	Stope	Dust	Thaw Index n_t	Thawing time for outer edge of dust to reach threshold temperature after the removal of artificial freezing at year 25 -10 °C Time (years)	-5 °C Time (years)	-1 °C Time (years)	0 °C Time (years)
1	12	saturated	1	4.5	14	> 50	> 50
		saturated	2	3.1	8.2	18.1	26
		unsaturated deg. sat. 10%	2	3	7.8	18	21
2	C212, 10	saturated	2	10	28	> 50	> 50
3	B230, B233, B234	saturated	2	12	27	> 50	> 50
4	B212	saturated	2	4.8	12	30	41

Response 3

Section 6.2.6 of the DAR clearly states that alternative methods of wetting the dust remain under consideration. Rather than trying to test or model the details of a particular implementation, the DAR seeks only to examine the fundamental limitations provided by the low hydraulic conductivity of the dust and the thermodynamics of freezing.

The section states that adding water to the surface of the dust and allowing it to infiltrate would be "feasible but slow, taking up to several months in the larger chambers". Table 1 provides the calculations for the chamber filling time assuming ponded infiltration for a range of different chamber sizes. The calculations assume that the water is injected uniformly across the top of the dust and infiltrates downward under a unit hydraulic gradient. The calculations indicate filling times ranging from 3-7 months. But it is recognized that the process of infiltration into an unsaturated medium is more complex than this simple calculation. So the DAR states only that the process would take "several months".

Table 1: Calculations of Chamber Filling Time Assuming Ponded Infiltration

Chamber dimensions			
Chamber	**10**	**B212**	**B230**
Length, (m):	26	52	23
Width, (m):	11	31	9
Total Volume, (m^3):	5700	25700	2800
Porosity:	0.59	0.59	0.59
Void Volume, (m^3):	3336	15040	1639
Darcy's Law assuming unit hydraulic gradient			
Hydraulic Gradient, (m/m):	1	1	1
Maximum Area, (m^2):	286	1612	207
Flow Rate, Q (m^3/s):	2.00E-04	1.13E-03	1.45E-04
Filling Time (s):	1.67E+07	1.33E+07	1.13E+07
Days:	**193**	**154**	**131**

Source: Arsenic_Dust_Wetting_Calculations.xlsx

Table 2 summarizes the calculations used to compare the amount of heat required to warm arsenic trioxide dust to the latent heat required to freeze the infiltrating water.

Scenarios 1 to 3 assume a range of dust heat capacity values, representing dry, saturated frozen and saturated unfrozen dust. Each of these scenarios assumes that the dust is initially at -10°C. Scenario 4 uses worst case properties for the dust: the typical dry bulk density is doubled, the porosity is lowered by half to 0.3, the highest heat capacity is assumed, and the initial temperature is set to -15 °C. Even under the extreme scenario 4 assumptions, the heat required to freeze the water is greater than the heat required to warm the dust to 0°C. These calculations indicate that the dust will warm before the water will freeze or, in other words, the dust is not cold enough to freeze the infiltrating water.

Once again it is recognized that a full analysis of the infiltration of water into unsaturated cold dust is more complex than the simple calculations indicate. A full treatment would require, amongst other things, laboratory testing of the dust's unsaturated hydraulic and thermal properties. The project team is not against embarking on such a program if the need is clear, but currently a number of wetting methods remains under discussion. The testing requirements associated with each method form part of that discussion.

Table 2: Numerical Comparison of Heat Required to Freeze Water Vs. Heat Dust

	Scenario 1: Dry Heat Capacity	Scenario 2: Saturated Frozen Heat Capacity	Scenario 3: Saturated Unfrozen Heat Capacity	Scenario 4: Extreme Worst Case	Units
Dust properties					
Bulk Dry Density, ρ_b	1402	1402	1402	2800	kg m^{-3}
Specific Gravity	3380	3380	3380	3380	kg m^{-3}
Porosity, ϴ	0.59	0.59	0.59	0.30	
Heat Capacity, c_g	0.6	1.06	1.71	1.71	kJ kg^{-1} $°C^{-1}$
Initial As Temperature, T	-10	-10	-10	-15	C
Heat required to raise dust to 0^o C					
Heat	**8,412**	**14,861**	**23,974**	**71,820**	**kJ m^{-3}**
Heat required to freeze the water					
Saturated water content, γ_f	585	585	585	300	kg m^{-3}
Latent heat of freezing, L_f	-334	-334	-334	-334	kJ kg^{-1}
Heat reqd to freeze sat. dust	**-195,459**	**-195,459**	**-195,459**	**-100,200**	**kJ m^{-3}**

Source: Arsenic_Dust_Wetting_Calculations.xlsx

- In Table 2, the heat required to raise dust to 0^oC is calculated as: $H = \rho_b \times c_g \times \Delta T$
  where ΔT is the change in temperature from its initial temperature to 0^oC.
- The heat required to freeze the saturated dust is calculated as: $H = \gamma_f \times L_f$