INFORMATION REQUEST RESPONSE

EA No: 0809-001 **Information Request No: Review Board #04**

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Linkage to Other IRs

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Request

Preamble:
Certain additional technical details are required to properly evaluate the freezing properties of the arsenic block and surrounding ground. This freezing is fundamental to the project. The frozen block concept requires that the ground is frozen, meaning that the all pore water in the ground is completely frozen and the hydraulic permeability is reduced to a very small value. The following values can be found in the DAR:

- "Thermal Conductivity, Frozen = 0.093 W/(mk); Unfrozen = 0.100 W/(mk)" (DAR, p. 5-3)
- "Freezing point of saturated solution -0.7ºC" (DAR, p. 5-3)
- "Thermodynamic considerations show that the most important component of that resistance would be the transition from about -1ºC to just above 0ºC (i.e., the point where the ice would have to be melted). Cooling of the block below that range provides little additional benefit. For that reason, the target of -5ºC has been selected as the criterion for declaring the chambers and stopes to be adequately "frozen" and "safe for the environment". (DAR, p. 6-30)

However, the DAR does not present a detailed assessment on temperature dependent hydraulic or thermal conductivities and does not seem to consider that the phase change is likely at a range different than the stated -1ºC to just above 0ºC. Laboratory tests presented by SRK (Memo entitled: "Physical properties of overburden, bedrock and arsenic dust", 5.9.2005) show that at temperatures of -8°C, the unfrozen water content can be as high as 8 Vol.-%, which affects its hydraulic permeability. In addition, a chemical rejection is to be expected, potentially changing the arsenic trioxide concentration as the chambers freeze, further affecting the freezing point of the ground.

This uncertainty is also reflected in the utilization of the term "thaw". It is unclear whether this means unfrozen conditions, i.e. >-0.7ºC, assuming the conditions in the ground are homogeneous everywhere and similar to the ones of the sample tested in the lab, or if thaw simply refers to >0ºC. E.g. in the long-term stability assessment the developer writes: "After 20 or more years of the above conditions, the dust at the top of some of the chambers would just be beginning to thaw" (DAR, p. 6-33). Further, natural changes in groundwater levels may, in combination with thaw of the frozen block (controlled or uncontrolled), result in hydraulic gradients that would allow seepage through the frozen wall and potential contamination of the environment. The temperature dependent, frozen hydraulic conductivity of the materials need to be known in order to assess the long-term behavior.

Question:

1. Please clarify

   a) the potential of change in freezing point depression as a function of freezing rate;
   b) the factor of safety associated with the -5ºC criterion and point of completely frozen conditions (no unfrozen water present);
   c) the change in hydraulic permeability as a function of negative temperature and degree of saturation;
   d) the assessment of the potential seepage through the frozen block assuming best estimates for the frozen hydraulic permeability; and
   e) the use of the term “thaw” within the DAR and a clear definition, which preferentially is defined on an acceptable hydraulic permeability, hence unfrozen water content

Reference to DAR (relevant DAR Sections):

S. 6.2.6 Initial Freeze
S. 6.2.8.2 Thawing and Climate Change
Various other locations in DAR

Reference to the EA Terms of Reference:

S.3.3 Arsenic Containment, Point 1

- “A detailed description of how the frozen block method will be done […]”

Summary

The Information Request preamble implies that the frozen block method is dependent on the arsenic dust providing a frozen hydraulic barrier. However, it is the frozen bedrock shell that provides the impermeable barrier. The ice in the arsenic dust provides an additional benefit as a ‘cooling reservoir’ in the form of stored latent heat, providing greater resistance to thawing.

Freezing rates during implementation will be on the order of months to form the frozen shell and changes in the freezing point depression are not a concern. The -5 ^{o}C criterion for the remainder of the frozen block was chosen as there is very little additional benefit gained by cooling the arsenic dust further as the unfrozen water content will not be significantly further reduced. No hydraulic conductivity tests were completed on the arsenic trioxide, but the potential seepage through the frozen block is estimated to be very, very low as the chambers are surrounded by the frozen bedrock. The term thaw refers to the transition between frozen and unfrozen conditions.

Response A

The freezing rate can cause a change in freezing point depression at very high freeze rates, for example, in the flash freezing of foods. The thermal model simulations in the Conceptual Engineering for Ground Freezing report (SRK 2006) show that freezing will be on the order of months, ex. Figure 3.4 in that report shows that it takes approximately 0.1 years (1.2 months) for the freeze front to advance 3 m from the freeze pipe. The freezing rate will also be lower further away from the freeze pipes, and within the dust material which has a lower thermal conductivity compared to the bedrock.

Freezing point depression can also result from solutes. The testing of saturated arsenic trioxide solutions reported in the DAR, showing that they freeze at -0.7 °C, is clear evidence of that effect and has been accounted for in analyses presented in the Remediation Plan and summarized in the Developer's Assessment Report (DAR).

The information request preamble also raises the question of chemical rejection, i.e. the tendency for solutes to be pushed out of freezing water and concentrated in the remaining unfrozen zones. In saline systems, very high solute concentrations can develop in these unfrozen zones and further depress the freezing point. In the arsenic trioxide dust, the negative effects of solute exclusion will be limited by the fact that the dissolved arsenic trioxide will be at its saturation point. In other words, any freeze concentration effects will cause a precipitation reaction that will remove arsenic from solution. The net result will be that increases in dissolved arsenic concentrations, and changes to the freezing point, will be limited. Other solutes, such as sulphate and magnesium, could be subject to chemical rejection but are present at much lower concentrations than arsenic.

Response B

Following establishment of the frozen shell at a -10^{o}C temperature over a distance of 10 m and wetting of the dust, efforts will then be shifted to the second stage which will target cooling of the arsenic trioxide dust to establish the frozen block. The criterion at that state is a temperature of -5^{o}C or colder within the dust.

Figure 1 of the 'Physical properties of overburden, bedrock and arsenic dust' memo, below, shows the unfrozen volumetric water content curves on arsenic trioxide samples for different degrees of saturation. Between temperatures of -5 ^{o}C and -8 ^{o}C (temperatures at which tests were completed), there was very little change in the unfrozen water content. The -5 ^{o}C criterion was chosen as there is very little additional benefit gained by cooling the arsenic dust below this temperature. It should be noted the unfrozen water content (ranging from 0 to 9% in the tests) will largely be bound by ice and immobile, in addition to being encapsulated by the frozen bedrock shell.

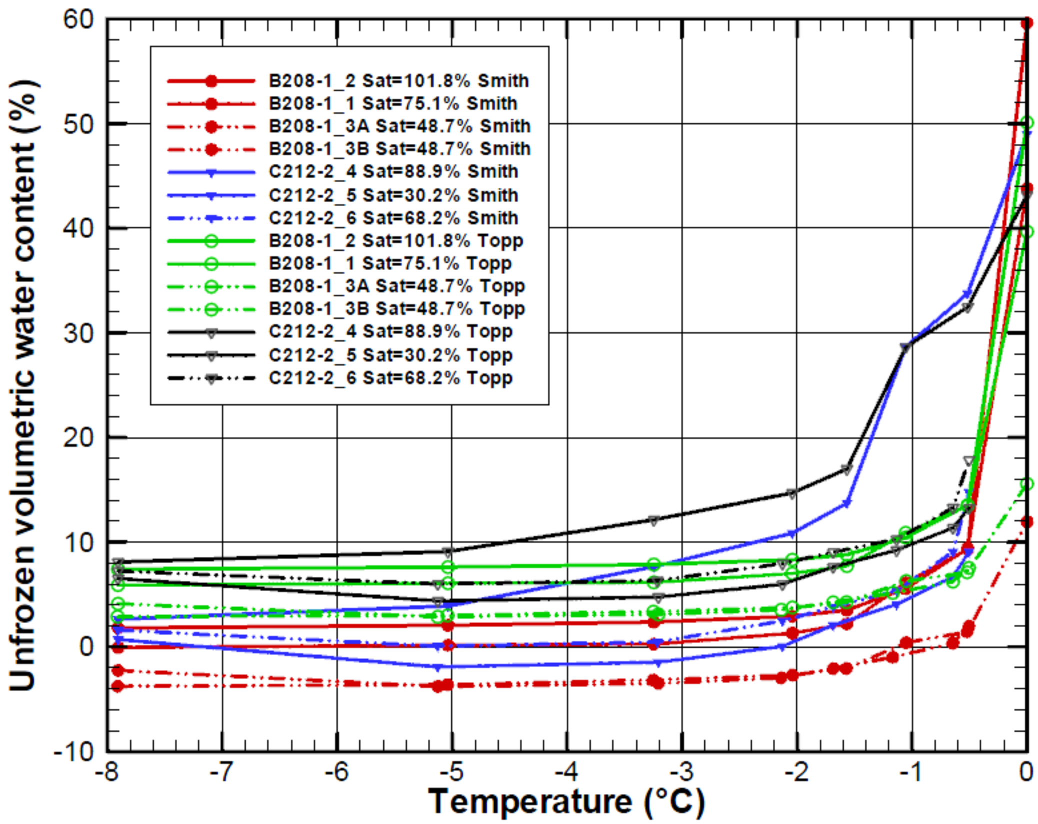

Figure 1 Unfrozen volumetric water content curves on arsenic trioxide samples for different degrees of saturation[1].

Response C

The hydraulic conductivity of the arsenic trioxide dust at negative temperatures was not tested. The frozen block method is not dependent on the low hydraulic conductivity of the arsenic trioxide dust. The frozen shell created during the initial freeze acts as the barrier to groundwater flow. The frozen shell will be created in the bedrock surrounding each chamber or stope, not in the dust itself.

The statement that the “temperature dependent, frozen hydraulic conductivity of the materials need to be known in order to assess the long-term behavior” is partially correct. If, for some reason, the frozen bedrock around a chamber or stope were to thaw completely, it is true that the low hydraulic conductivity of frozen arsenic dust would continue to present an impediment to groundwater flow. However, arsenic trioxide is so soluble that even groundwater flow along the dust-bedrock interface would create high concentrations of dissolved arsenic. For that reason we have conservatively neglected the benefits of the low frozen hydraulic conductivity of the dust, and based the design on keeping the surrounding bedrock frozen.

Response D

The hydraulic conductivity of the bedrock frozen shell will be extremely low. Mine water levels will be maintained below the chambers and stopes and, even in the unlikely event that the mine is subject to complete flooding, very low hydraulic gradients of 0.0002 m/m are expected. We conclude that there will be essentially no seepage through the frozen blocks. We believe the critical design question is how frozen blocks can be created and maintained, and that question is addressed in other part of the DAR and these responses.

Response E

The term thaw is used in the DAR to refer to the transition between frozen and unfrozen conditions. For the arsenic trioxide, as shown in the figure presented above, this transition largely occurs between -0.7 ^{o}C and 0 ^{o}C. For the bedrock material, no unfrozen water content testing was completed. In the thermal modeling simulations described in the Conceptual Engineering for Ground Freezing report, phase change was assumed to occur between temperature of -0.5 ^{o}C and -0.1 ^{o}C.