Success Criteria for Ground Freezing

Parties to the EA have expressed an interest in the criteria by which the performance of the proposed ground freezing will be evaluated. One participant in the June 2012 Workshop with Parties succinctly stated the issue as "how will a person on the ground in 25 years know that the freeze is still successful?"

Further discussion at that workshop helped elucidate both the reasons why the Parties want to see firm criteria at this stage of the environmental assessment, and the Developer's reluctance to specify a single number or set of numbers at this point in the system design. Agreement was reached that the Developer would summarize the currently available criteria and describe the process by which any further criteria would be defined.

Currently Available Criteria

The Developer has committed to criteria for the completion of the initial freezing process. These are illustrated in the DAR Figure 6.2.1. In words:

- The freeze wall around each chamber or stope will be judged complete when the chamber or stope is surrounded on all sides and below by a 10 m wide zone of rock that is -10 ^{o}C or colder.
- The frozen block will be judged complete when the dust within the chamber or stope reaches -5 ^{o}C or colder.

Criteria Needing Further Definition

Development of criteria to evaluate the adequacy of freezing over the long term is a more complex question. A much broader range of factors will need to be considered, including:

- The spatial extent of any changes in conditions;
- Temporal trends in measurements and their relationship to normal seasonal fluctuations;
- The amount of time needed to confirm changes or trends;
- The amount of time needed to implement mitigation measures (as outlined in the DAR Section 6.2.9.4, the range of mitigation actions includes investigating causes, replacing defective components, modifying the ground surface to reduce heat flux, installing shallow thermosyphons to counteract surface heat flux, and installing additional full-depth thermosyphons to counteract sideways or upwards heat flux);
- The management and oversight regime (who needs to be notified and when).

The complexity of these factors makes it dangerous to rely on simple numerical criteria. An example of more appropriate long-term performance criteria would be something like:

- A temperature increase of 1°C in thermistor A2, located at the base and outside of the freeze wall around Chamber 2-12, indicates a possible problem with thermosyphons N6 through N12, and mitigation will take up to 18 months. Therefore changes greater than 0.1^{o}C will require immediate notification of the geothermal engineer, and any change greater than 0.25^{o}C sustained over one year or 0.5^{o}C sustained over one month will require immediate investigation.

- Temperature increases of 0.5 °C sustained over one year in five or more thermistors are likely to indicate a significant change in ground conditions and may require mitigation actions that could take up to five years to be fully effective. Therefore, the geothermal engineer will provide an annual report including an analysis of annual average temperatures in each thermistor, and any year- to-year change of greater than 0.5°C average temperature in five or more thermistors will require immediate initiation of mitigation.

The criteria are expressed here in words only to demonstrate the thinking that will need to underlie each one. In practice, every monitoring rule would be reduced to a simpler format for ease of implementation and oversight. An example would be a control chart; i.e. a plot of a particular thermistor's temperatures over time, with a series of lines indicating actions required should the measured temperatures exceed certain levels. The complete monitoring plan would include many criteria like the above, and in addition would have requirements for reporting, notification, public announcement, etc.

<u>Recommended Process for Further Criteria</u>

The Developer believes that the more complex criteria needed for assessing long-term performance of the frozen blocks would best be defined by working together with interested parties through the EMS process.

The following inputs would be required:

- A freeze system design at a preliminary engineering level, including locations and depths of thermosyphons around each chamber and stope;
- Modeling of the effects of various system deficiencies or unexpected conditions on ground temperatures around the frozen blocks, to identify where temperature changes would first be noticeably different from natural fluctuations;
- Modeling of mitigation measures to verify the timelines required to effect "repairs" to any under-performing frozen blocks ;
- Agreement on oversight, inspection and operations systems, to know who would be notified and what responses could be expected over what time frames.

Once those inputs are available, the Developer would ask the EMS team to discuss and propose guidelines for the long-term freeze monitoring system, including specific objectives for detection of changes.

Those guidelines would then be forwarded to the design team to develop a proposed instrumentation and monitoring plan. Further modeling would undoubtedly be required at this stage, both to simulate alternative proposed systems and to demonstrate effectiveness of the recommended design.

The recommended instrumentation and monitoring plan, and the associated performance modeling, would then be returned to the EMS team for review.