In accordance with the Terms of Reference, which instructed the developer to provide a comprehensive analysis of the key line inquiry, Tyhee should put more emphasis on the questions related to the key line of inquiry. To facilitate this, the information requests in part one contain short descriptions of the information gaps that the Review Board identified in the DAR.

IR Number: 1-1-2

Source:	*Mackenzie Valley Review Board*
To:	*Tyhee*
Issue:	***Cyanide Attenuation***

Background

For cyanide Tyhee appears to rely on natural attenuation through volatilization, leaching, and bacterial activity. In the DAR Tyhee identifies temperature, aeration, UV light availability and bacterial growth as factors determining the rate of attenuation. Yet it does not provide evidence that these factors will allow sufficient attenuation at the Yellowknife Gold Project's sub-arctic location, or an explanation how leaching of cyanide will mitigate environmental effects. In addition, the DAR does not contain an analysis of concentrations of cyanide breakdown compounds.

Request

1. *Please submit studies, or relevant excerpts, that support Tyhee's reliance on natural attenuation of cyanide under the conditions prevailing at the proposed mine site.*
2. *Please provide an explanation how leaching of cyanide will mitigate environmental impacts and a description of where leached cyanide will likely end up and any environmental effects associated with it.*
3. *Please provide an analysis of cyanide breakdown compounds, their toxicity, and their concentrations and distribution.*

Tyhee NWT Corp Response (Revised May 31, 2012)

Request

1. Please submit studies, or relevant excerpts, that support Tyhee's reliance on natural attenuation of cyanide under the conditions prevailing at the proposed mine site.

Tyhee does not plan to rely exclusively on natural attenuation to reduce cyanide in mine effluent water. As stated in Section 4.11.7 of the DAR, a sulfur dioxide (SO_2)-Air cyanide destruction circuit will be used to reduce cyanide concentrations to MMER required concentrations before discharge to the TCA.

Cyanide Destruction Circuit

A sulfur dioxide (SO_2)-Air cyanide destruction circuit (commonly referred to as the INCO process) will be used to reduce cyanide concentrations to MMER required concentrations before discharge to the TCA. The INCO process is based upon conversion of free and WAD cyanides to cyanate using a mixture of SO_2 and air in the presence of a soluble copper catalyst at a controlled pH. In the INCO process, the forms of cyanide are removed by different processes. One process involves the conversion of free and WAD cyanides to cyanate. Iron complexed cyanides are reduced to the ferrous state and precipitated as insoluble copper-iron-cyanide complexes. Residual metals liberated from the WAD cyanide complexes are precipitated as their hydroxides.

The INCO process has been used at over 80 mining operations worldwide and is the process addressed in this section. A primary application of the sulfur dioxide and air process is in treatment of tailings slurries, but it is also effective for the treatment of solutions for the oxidation of free and WAD cyanides. The process has a track record of being able of reducing total cyanide in leach effluents to less than 1 mg per liter (Mudder et.al, no date). Examples include Lac Mineral's Colosseum (0.4 mg/L), Westmin's Premier Gold (< 0.2 mg/L), and Homestake Chevron's Golden Bear (0.3 mg/L).

Free and weakly complexed metal cyanides (i.e., WAD cyanides) are oxidized to cyanate by sulfur dioxide and air in the presence of a soluble copper catalyst.

$$CN^- + SO_2 + O_2 + H_2O \;\mathit{Cu\ Catalyst}\; = \; OCN^- + SO_4^{-2} + 2H^+$$

$$M(CN)_4^{-2} + 4SO_2 + 4O_2 + 4H_2O \;\mathit{Cu\ Catalyst}\; = \; 4OCN^- + 8H^+ + 4SO_4^{-2} + M^{+2}$$

The reaction is normally carried out at a pH of about 8.0 to 9.0, and due to the formation of acid in the reactions, lime is added for pH control. Decreases in process performance can occur if the pH fluctuates outside this optimal range. The optimal pH must be determined experimentally, since maximum cyanide and metals removals occur at different pH values.

Temperature has little effect on process performance between 5°C and 60°C. The SO_2 required in the reaction can be supplied either as liquid sulphur dioxide, sodium sulphite (Na_2SO_3) or as sodium metabisulphite ($Na_2S_2O_5$).

Trace metals remaining in solution following oxidation of the weakly complexed metal cyanides are precipitated as their hydroxides according to the following generalized reaction:

$$M^{+2} + 2OH^- = M(OH)_2 \text{ (solid)}$$

Metallurgical work has been conducted to determine the reagent usage in the beneficiation process for Ormsby ore. Initial testing of the cyanide destruction circuit using the INCO process has been completed.

As discussed in Attachment B, the testing program produced residual total cyanide concentrations after the destruction process ranging from <0.05 mg/L for sample DT-6 to 6.43 mg/L for DT-2. The final total CN concentrations for samples DT-3 through DT-6 were all below 1 mg/L. The final total CN concentration for DT-1, the continuous test system, was 2.88 mg/L. Optimization of the process during operation is expected to produce a supernatant with less than 1 mg/L. The leach tailings represent approximately 6 % of the total tailings material.

Natural Attenuation

Natural attenuation within the TCA is expected to further reduce TCA concentrations below those produced after the detoxed leach solution mixed with the supernatant from the flotation tailings. TCA discharge, when it occurs, will mix with meteoric external water, further reducing cyanide concentrations.

The surface effluent testing on flotation tailings (DAR Appendix J) had a pH of 7.99, indicating that the waters in contact with flotation tailings is likely to be approximately pH 8. That result is similar to that obtained after the cyanide destruction process. The process water will, to some extent, mix with local runoff waters. The average pH of Round, Winter, and Narrow Lakes were 7.43, 7.03, and 7.03, respectively based on monitoring from 2004 through 2010 for water license MV2002L2-0017. If pH in the TCA is maintained below a pH of 8, which is achievable through pH adjustment before discharge, more than 90 percent of the cyanide anion (CN^-) present will be present as hydrogen cyanide (HCN) (Logsdon et al., 1999, available online).

Examples of Cyanide Natural Attenuation

Natural attenuation of cyanide in tailings ponds is a function of the environmental conditions and has been shown to be effective. Lupin Mine and Colomac Mine, both in Canada's North, are excellent examples of natural degradation of cyanide in climates similar to Tyhee's Yellowknife Gold Project.

Lupin Mine, NWT (Logsdon et al., 1999); this mine relied solely on natural degradation of cyanide within the TCA, with CN^- entering the TCA at a concentration of 184 mg/L and being discharged from the TCA at a concentration of 0.17 mg/L. This now-closed mine, currently owned by Elgin Mining (formerly MMG, Kinross and Echo Bay Mines) is located approximately 350 kilometers (km) north of the Yellowknife Gold Project.

The Colomac Mine, NWT, mill was not equipped with a cyanide destruction circuit because the TCA was intended to be a zero discharge facility; however; due to faulting and poor construction, the facility was not zero discharge. Historic sampling over the period of 1998 through 2001 logged the degradation of cyanide, thiocyanate, and ammonia. Total cyanide concentrations in the Colomac Mine Tailings Lake decreased naturally without any intervention from 38 mg/L in September 1998 to 1 mg/L in September 2001 (Chapman et al., no date, available online). Enhanced Natural Removal was successfully used through the addition of phosphorus as a limiting nutrient to bring cyanide and its breakdown compounds (i.e., thiocyanate, ammonia) down to concentrations acceptable for release to the environment. This mine is located within 50 km west of the Yellowknife Gold Project.

Request

2. *Please provide an explanation how leaching of cyanide will mitigate environmental impacts and a description of where leached cyanide will likely end up and any environmental effects associated with it.*

As discussed in Section 1.1.1, the revised estimated of expected TCA water quality was based on the data developed during the characterization of the tailings material produced during the testing of the Ormsby ore. The primary source of the solutes in the TCA are from the supernatant from the flotation process which accounts for approximately 94% of the tailings and supernatant produced by the plant, and the detoxified supernatant from cyanide leaching of the concentrate which account for 6 % of the liquid and solids entering the TCA.

The concentration of the a given solute in the TCA is a function of its concentration in the flotation supernatant, the detoxified leach supernatant, the amount of water reclaimed from the tailings pond, and the amount of makeup water. As no makeup water is used during the first four years of operation, the solute concentrations reach a maximum after the fourth year of operation. To show how the concentrations may evolve during the operation of the facility. Estimates of the concentration of arsenic, copper, cyanide, nickel, lead and zinc in the TCA were prepared for the end of years 1, 4, 8, and 12.

The evaluation indicated the maximum concentrations were present in the TCA in year 4. As shown in the attached report, the estimated concentration of the six parameters in the TCA at the end of year 4 are: arsenic, 59 μg/L; copper, 208 μg/L; total cyanide, 144 μg/L; nickel, 3.3 μg/L; lead, 14 μg/L; and zinc, 2.9 μg/L. These concentrations are all below the MMER guidelines but several exceed the CCME guidance levels.

Impact on Narrow Lake

The impact analysis contained in the DAR was based on the discharge of approximately 900,000 m^3 per year for the life of the project spread over the months of May through October. Approximately two-thirds of this volume was discharged in May and June. Based on the current water balance, no discharge is planned although Thyee expects to need to discharge sometime during the projects term.

As there is no discharge amount required by the water balance, a plausible discharge scenario was needed to evaluate the potential impact of Thyee's expected required future discharge on the receiving water body. The tailings discharge would need to be pumped from the TCA. The available pumps would be the reclaim pumps which have a capacity of approximately 140 m^3/hr. If the discharge lasted for 30 days a total volume of approximately 100,000 m^3 would be discharged. Any discharge would only occur between May and October. The most likely time for a discharge would be in May or June.

An evaluation of the attenuation potential of Narrow Lake for a 30 day discharge at a rate of 140 m^3/hr produced the following expected concentrations in Narrow Lake for a discharge occurring at the end of year 4: arsenic, 4.8 μg/L; copper, 17 μg/L; total cyanide, 11.5 μg/L; nickel; <0.5 μg/L; lead, 1.1 μg/L; zinc, <0.5 μg/L.

Although no routine discharge from the TCA is necessary or planned, future conditions may result in the need for a temporary, limited, discharge. Based on this analysis, the copper concentration in the TCA is the controlling parameter. With specific reference to copper concentrations within the TCA, these would be monitored during operation as part of the water license SNP and the effects of these concentrations on Narrow Lake, including confirmation of water in Narrow Lake meeting CCME guidelines, would be evaluated prior to discharge.

Request

3. *Please provide an analysis of cyanide breakdown compounds, their toxicity, and their concentrations and distribution."*

Free and Dissociable Cyanide

Free cyanide is the toxic fraction (CCREM 1987; Eisler 1991; USEPA 1985) and from a toxicological perspective the distinction between free cyanide and other forms (generally reported as total cyanide or weak acid dissociable [WAD] cyanide) is critical. Free cyanide is defined and measured as the sum of HCN and the CN^-. Total cyanide is the summation of all of the cyanide species including free cyanide, water-soluble salts (e.g., NaCN, KCN), salts of alkali, alkaline earth, or heavy metals (e.g., $Zn(CN)_2$, $Cd(CN)_2$), and less toxic complex metallocyanides (such as $Cu(CN)_2^-$ and $Fe(CN)_6^{4-}$) (Eisler 1991; Exall et al. 2011). Weak acid dissociable (WAD) cyanide is the fraction of bound cyanide that will release the free cyanide anion (CN^-) following the addition of a weak acid. WAD cyanide is often measured in the environment to account for the fraction of cyanide that may become free and toxic with relatively small changes in environmental conditions (i.e., pH). Many factors can affect the form of cyanide, including pH, temperature, salinity, the concentration of metal ions and complexation materials, dissolved oxygen, and sunlight (USEPA 1985). In addition to the various species of cyanide, there are a number of breakdown and by-products that co-occur in the aquatic environment, including cyanates (-OCN), thiocyantes (-SCN), and ammonia in addition to non-toxic forms of carbon and nitrogen.

Cyanide Breakdown Compounds

The breakdown and by-products of cyanide such as cyanates (-OCN), thiocyanates (-SCN), ferrocyanate complexes (e.g., $Fe(CN)_6^{4-}$), and ammonia (NH_3) are considerably less toxic than cyanide itself. Simple thiocyanates, such as the products of cyanide detoxification, are on the order of 12-times less toxic than cyanide (Eisler 1991) and therefore pose considerably less threat to aquatic life (Lanno et al.1996; Exall et al. 2011). The majority of risk associated with the formation of cyanates, thiocyanates, and metal-cyanide complexes is in their potential to re-release cyanide following decomposition by UV or change in pH (Eisler 1991; Calffe and Little 2003). The production of ammonia (NH_3) from the degradation of cyanide is not considered a risk to the aquatic environment at Tyhee's Yellowknife Gold Project. The CCME water quality guideline for the protection of aquatic life is 0.019 mg/L un-ionized ammonia. At 10°C, a pH of 8, and 1.0 mg/L total ammonia, the percent un-ionized ammonia would be 18.25, or a concentration of 0.018 mg/L ionized ammonia (CCME 2010). At the CWQG of 5 μg/L cyanide, negligible amounts of ammonia will be produced, far below the 1.0 mg/L needed to reach the CWQG.

Cyanide Toxicity

Cyanide(CN^-)- can be toxic as it asphyxiates cells by binding to and deactivating cytochrome c. oxidase inhibiting cellular respiration (Eisler 1991). Cyanide toxicosis is rapid following the absorption of a lethal dose, as it can enter the blood stream and cross cell membranes regardless of route of exposure. At sub-lethal concentrations, cyanide can be detoxified and excreted, and is done so by thiosulfate conjugation by specialized liver enzyme rhodenase to produce thiocyanates, which are considerably less toxic and easily excreted in the urine (Eisler 1991). Owing to efficient cyanide detoxification, it has been suggested that sub-lethal concentrations of cyanide can be tolerated in some animals over extended periods of time (Eisler 1991). In the aquatic environment, fish are considered to be the most sensitive organisms to cyanide (USEPA 1985; Sarkar 1990; Eisler 1991).

The CCME guideline of 5 micrograms per Liter (μg/L) for the protection of aquatic life is based on the U.S. Environmental Protection Agency (USEPA) criterion of 5.2 μg/L for the protection of aquatic life (USEPA, 1985), as well as a review of the effects on aquatic organisms carried out in 1987 (CCREM 1987). For example, the lowest concentration to which rainbow trout exhibit an acute response (i.e., mortality) was 27 μg/L (Kovacs and Leduc 1982a), while a 50 percent reduction in performance of cold water fish species was observed following the continuous exposure to 10 μg/L free cyanide (Kovacs and Leduc 1982b; CCREM 1987). The USEPA criterion is based on a calculated value, whereby the Species Mean Acute Value (SMAV) for Rainbow trout (Onchorynkus mykiss) of 44.7 μg/L is divided by an acute-chronic ratio to give 8.1 μg/L; a conservative value of 5.2 μg/L is therefore effective in avoiding chronic toxicity.

A sample of the flotation tailings supernatant was used for whole effluent toxicity testing. The results indicate a 100 percent survival rate for both *Daphnia magna* and *Pimephales promelas* (fathead minnow). These data are consistent with testing conducted on the combined Ormsby and Nicholas flotation tailings which reported 100 percent survival for a 48-hour test using *Daphnia magna* and 100 percent survival for a 72-hour test using rainbow trout.

References

To assist the reader, the copies of following selected references are included in Appendix A: CCREM 1987, Calffe and Little 2003, Eisler 1991, Logsdon 1999, Mudder et.al, no date, and USEPA 1985.