July 30, 2012

## REPORT ON

# Feasibility Study for Paste Backfill Avalon Rare Metals

**Submitted to:**
David Swisher, Vice President Operations
Avalon Rare Metals Inc.
6165 Hwy 17, Unit 330
Delta, BC  V4K 5B8



REPORT

**Report Number:** 11-1900-1060

**Distribution:**

1 Copy - Avalon Rare Metals Inc., Delta, BC

1 Copy - Golder Associates Ltd., Sudbury, ON

Golder Associates

# 1.0 INTRODUCTION

Avalon Rare Metals Inc. (Avalon) has retained Golder Associates Ltd. (Golder) to undertake a feasibility level design of a mine backfill system in support of Avalon's current work on the Thor Lake Project located in the Northwest Territories.

The Thor Lake Project is located approximately 100 km southeast of Yellowknife. The project is an undeveloped rare earths elements (REE) deposit with an estimated 8.9 and 63.8 million tonnes of measured and indicated mineralized resources of REE, zirconium, niobium and tantalum at a $260 net metal return cut-off grade.

The processing of the ore from the 2,000 tonnes per day (tpd) underground mine will be performed on site. Metallurgical testing indicated that the metal values can be recovered in a flotation circuit after crushing and grinding to 80% passing 40 microns. The processing circuit also includes magnetic and gravity separation stages. The current Avalon design basis is that 18% to 22% of the feed will report to the flotation concentrate. The concentrate will be shipped to the hydrometallurgical facility located across the Great Slave Lake at Pine Point.

## 1.1 Objective

The engineering services for the feasibility study follow a preliminary laboratory test program and pre-feasibility study report (Golder Project 10-9002-0059 "Pre-feasibility Study for Paste Backfill – Avalon Rare Metals) issued October 14, 2011.

The current study advances the pre-feasibility engineering design to a feasibility level accuracy by finalizing the process flowsheet, design criteria and equipment specifications, as well as performing the basic engineering design of the paste backfill plant. The engineering design includes the mechanical, plant layout, piping and electrical and structural layouts, in addition to obtaining pricing for the major equipment from vendors.

## 1.2 Scope

In order to meet the above objective, the scope of services addressed within this study can be summarized as follows:

- Reviewing the applicability of the engineering design considerations used in the pre-feasibility study;
- The engineering design itself which included:
  - Selecting the location of the paste backfill plant;
  - Developing a firm process, operating design criteria and mass balance of the paste backfill plant;
  - Developing a flowsheet and piping and instrumentation diagram (P&ID);
  - Identifying and sizing the major process equipment items;
  - Developing a preliminary operating philosophy;
  - Designing a preliminary paste backfill plant layout; and
  - Designing preliminary plant piping.

- Underground Distribution System (UDS):
  - Conducting hydraulic modelling of the UDS based on the location of the backfill drifts; and
  - Developing preliminary UDS operating strategies based on location of the backfill drifts.
- Developing a capital and operating cost estimate to a +/-15% level of accuracy; and
- Appraising the design and providing conclusions and recommendations for advancement.

### 1.2.1 Battery Limits

The battery limits considered in the development of this study can be summarized as follows:

- Tie-in to the thickener underflow cone in the flotation plant;
- Tie-in to the flotation plant's process and freshwater lines (tie in location at the paste backfill plant);
- Tie-in to the flotation plant's compressed air (tie-in location at the paste backfill plant);
- Tie-in to the step down transformers in the flotation plant's electrical rooms;
- Tie in to the flotation plant's PLC system. Tie in location at the paste backfill plant;
- Design of communication system between the paste backfill plant and the flotation plant by others;
- Binder loading: tie-in at loading nozzle on binder silos; and
- Transport of cemented paste fill down the backfill drift at the boundary of the mining stopes.

## 2.0 DESIGN CONSIDERATIONS

A paste backfill plant is typically designed to handle tailings at the rate they are generated at the processing plant. In the case of the Thor Lake Operation, metallurgical test work performed by Avalon estimated the mass of the concentrate to be in the order of 18 to 22 wt% of the mill feed. For a 2,000 tonne per day (tpd) operation, roughly 1,600 tpd of tailings would be produced. Not considering the concentrate mass, roughly 60% of the tailings can typically be returned underground to fill the voids created by mining. When taking into account the concentrate mass, in the case of the Thor Lake operation, this would be closer to 75% of the tailings generated, with a backfill plant utilization rate of around 85%. This level of utilization is high for a normal paste backfill plant operation since there is a considerable amount of time lost to start-up and shutdown as well as waiting for stopes to be ready, pipe movements, etc. However, the development of permanent backfill drifts as envisaged by Avalon should help the operations keep the paste backfill plant utilisation rate closer to a more normal 70%.

Avalon is no longer considering deferring the cost and construction of the paste backfill plant by several years as it was considered at the time of the pre-feasibility study. At the time, Avalon was planning to initially mine only the primary stopes for the first 60 months of operation which would have required a higher than normal filling rate to make up for the shortfall. This change negates the need to consider a tailings storage and reclaim system. Nonetheless, the backfill plant was designed with some internal surge capacity to increase the utilization rate of the plant. This and the efficient operation of the plant should bring the overall utilization close to those of most paste backfill plants.

## 2.1 Design Criteria Summary

Key design criteria are reported in Table 1, with further more detailed criteria included in Appendix A and reported as necessary within the report.

**Table 1: Design Criteria Summary**

| Criteria | Value | Data Source |
|---|---|---|
| Life of mine | >20 years | Avalon |
| Underground production | 2,000 tpd | Avalon |
| Paste backfill plant design capacity | 1,738 tpd | Calculated |
| Paste backfill plant design capacity | 72.4 tph | Calculated |
| Design uplift | 10% | Golder recommendation |
| Tailings specific gravity | 2.83 | Avalon |
| Thickener underflow | 65 wt% solids | Golder testing |
| Vacuum filter cake | 80 wt% solids | Golder testing |
| Paste (250 mm, 10" slump) | 75.0 wt% solids | Golder testing |
| Binder type | Normal Portland cement | Golder |
| Binder dose (design) | 7 wt% (primary stopes) | Golder testing |
| Underground distribution | Backfill drifts | Avalon |
| Design codes | North American unless stated otherwise | |

# 3.0 PLANT DESIGN

## 3.1 Introduction

The paste backfill plant has been designed to prepare a 250 mm (10" slump) backfill using mill tailings. The paste backfill plant is developed around the dewatering of tailings and then adding cement before the mixture is pumped to the stopes. The paste backfill plant can be summarised as follows:

- Thickened tailings are pumped from the tailings thickener underflow to an agitated filter feed storage tank.
- From the filter feed storage tank, the thickened tailings can be split, with a large portion directed to the vacuum disc filters and a small portion sent directly to the conditioning mixer for slump adjustment.
- Filter cake from the vacuum disc filters is conveyed to a conditioning mixer while the filtrate is directed to a seal water sump and back to the thickener feed box. The filter drain as well as clean up of the paste backfill plant area is collected in a separate sump and also directed back into the thickener feed box.
- The continuous mixer discharge and normal Portland cement are weighed and fed into a batch mixer to which process water is added so that the mixer discharge is of a consistent paste slump.
- Normal Portland cement will be delivered to site, more than likely in isotainers and discharged into one large capacity silo, designed to offer capacity for approximately one day of continuous operation at the highest binder consumption rate.

- The discharge of paste from the batch mixer will be delivered to the stopes via a pipeline in the ramp down to backfill drifts.
- Distribution of the paste will be via pumping as a result of the long distances and the flow characteristics of paste.

The following supporting information is appended to this report:

- Process flowsheet and mass balance – Appendix B;
- Major mechanical equipment list – Appendix C; and
- General arrangement drawings – Appendix D.

## 3.2 Mass Balance

The mass balance has been completed using the following assumptions provided either from Avalon or from laboratory testing performed as part of the pre-feasibility study (Report 10-9002-0059):

- Tailings solids have a specific gravity (SG) of 2.83;
- Thickener underflow is 65 wt% solids;
- Tailings filter cake is 80 wt% solids;
- Average binder consumption is 4.2 wt% with approximately 7 wt% solids for the primary stopes to achieve the target strength and 2.5 wt% in the secondary stopes to prevent liquefaction based on a 250 mm (10") slump; and
- Mixer discharge for a 250 mm (10") slump is 75.0 wt% solids.

## 3.3 Tailings Classification and Additives

The possible classification of the tailings to remove the ultrafines in order to improve the dewatering and strength characteristics was reviewed as part of the pre-feasibility study. However, the material balance for tailings is already tight since approximately 20% of the mill feed reports to concentrate. Removing the ultrafines would further reduce the amount of tailings available for backfill, making it difficult to meet the underground fill volume requirements.

The addition of waste rock was considered but rejected due to the harsh climate and the desire to keep the plant design as simple as possible. It is quite likely that the addition of waste rock will substantially improve the cement requirements and hence the operating cost of the plant; however, the extra complexity of adding a waste rock crushing circuit was considered to be a significant risk to the operability of the plant and would not markedly improve the project economics. This option was discarded.

## 3.4 Plant Location

The location of the paste backfill plant was examined as part of a trade-off study looking at different options. The three options examined for the paste plant were as follows:

- Option 1: Paste backfill plant on surface adjacent to the mill building (base case);
- Option 2: Paste backfill plant on surface as a stand-alone building above the underground workings; and
- Option 3: Paste backfill plant underground closer to the mine workings.

For the above options, Golder compared the possible advantages and disadvantages and provided an estimate of the associated capital and operating costs.

**Table 2: Plant Location Capital Cost Comparison**

| Description | Option 1 Cost ($CDN) | Option 2 Cost ($CDN) | Option 3 Cost ($CDN) |
|---|---|---|---|
| Process Mechanical Costs | 4.9 M | 5.0 M | 4.9 M |
| Direct Plant Costs (building / underground excavation) | 8.1 M | 10.3 M | 7.7 M |
| Slurry / Paste Distribution System Costs | 1.4 M | 1.0 M | 1.1 M |
| Indirect Costs | 5.9 M | 6.5 M | 5.6 M |
| Contingency (20%) | 3.9 M | 4.4 M | 3.7 M |
| **Total Capital Cost** | **$24.2 M** | **$27.2 M** | **$23.0 M** |

**Table 3: Plant Location Operating Cost Comparison**

| Description | Option 1 Cost ($CDN) | Option 2 Cost ($CDN) | Option 3 Cost ($CDN) |
|---|---|---|---|
| Consumables | | | |
| Power | 2,488,000 | 3,277,000 | 3,085,000 |
| Binder | 6,627,000 | 5,744,000 | 5,744,000 |
| Other | 669,000 | 815,000 | 718,000 |
| Labour | 1,586,000 | 1,979,000 | 1,696,000 |
| **Total Operating Cost** | **$11,370,000** | **$11,815,000** | **$11,243,000** |
| Equivalent Cost per Tonne of Ore Mined | $30.88 | $32.09 | $30.54 |
| Equivalent Cost per Tonne of Backfill | $15.58 | $16.18 | $15.40 |

There was a gain both the capital and operating costs in having the paste backfill plant located underground. Typically, there is a more pronounced financial driver for locating the plant closer to the mine workings with the two main drivers being the reduction in binder consumption and the reduction in power requirements. However, the gains in the Thor Lake Project appear to be more marginal. The following two factors help explain this:

- The first factor is the configuration of the ore deposit. The Thor Lake REE deposit is relatively flat-lying and comprised of three main ore zones. The paste delivery distances required to provide backfill to these different areas are significant. As a result, it is not possible to provide low slump material to all the stopes and take full advantage of lower binder consumption without incurring significantly higher capital costs (due to the provision of pump booster stations). Locating the plant underground improves this situation somewhat; however, it does not completely eliminate the requirement to pour higher slump paste to the stopes (resulting in a higher binder content to reach the target strength).
- The second factor is the difference in binder requirement to achieve the 0.59 MPa target strength. Based on Golder test work carried out as part of the pre-feasibility study, there is less than a 1% cement difference in binder requirements between a 175 mm and 250 mm slump (typically the difference in binder content to reach the target strength is more than 1%). Also based on the selected mining method (a combination of long hole stoping / drift and fill stoping), the primary stopes need to achieve the 0.59 MPa target strength with the secondary stopes only requiring sufficient binder to prevent liquefaction. This, in combination with the first factor, results in lower cost savings than typically observed in other projects.

Following a review of the trade-off study (Appendix E), Avalon made the decision to proceed with Option 1 with the paste backfill plant located on surface, adjacent to the flotation plant.

## 3.5 Plant Process Description

The paste backfill plant process will be designed to prepare a backfill product using dewatered tailings. The plant will operate on a batch type process system. Continuous monitoring of the process through a PLC system by on-stream instrumentation allows the plant control to adapt process flows and conditions in real-time, maintaining control of the final product.

A batch mixing system was selected vs. a continuous system for the following reasons:

- The paste slump is moderately sensitive to water addition compared to other tailings materials and to achieve precision slump control (and therefore precision control over pipeline friction losses); it is required to control the batch constituents as accurately as possible. Batch systems allow a greater degree of control over the final paste output.
- The filter cake was seen to be very cohesive and there is some concern that when the filter cake is blended in a continuous mixer, it will be difficult to completely mix the filter cake to produce a 250 mm (10") slump paste. The concern is that unmixed chunks of filter cake in a low viscosity matrix like a 250 mm (10") slump, do not get sheared and mixed in at the same rate as they would in a higher viscosity matrix like 175 mm (7") slump. With the batch system, the filter cake can be mixed in the conditioning mixer to a 250 mm (10") slump consistency which will fully mix all the chunks and then the discharge from the conditioning mixer can be mixed to its final consistency in the batch mixer. Chunks of unmixed filter cake are not

desirable since they are zones of weakness in the fill. Some of the chunks will be mixed in the pipeline; however, the degree of mixing is unknown and may not be sufficient to completely blend the filter cake into the paste.

### 3.5.1 Dewatering

All tailings will be received from the high compression thickener where the dewatering process begins. The thickener underflow reports to an agitated filter feed storage tank which offers a means to split the thickener underflow to the downstream process, and provides sufficient residence time to manage fluctuating flows and brief stoppages. Furthermore, the agitation enables homogenization of the slurry before the filtering process.

A portion of the tailings will be directed to the vacuum disc filter with the remaining sent directly to the conditioning mixer. The proportion of thickened tailings sent to the filter and by-pass sent to the mixer is determined based on the desired backfill slump and target solids content. This minimizes both the amount of filtration that needs to be performed and additional water, while still getting the desired outcome of the mixer.

The vacuum disc filter creates a filter cake that is discharged through a chute onto a weigh conveyor sending it to the conditioning mixer. The filter cake is removed from the rotating filter sectors by the snap air system. A snap air receiver contains a reservoir of air that is released according to the filter disc rotational position and blows the cake off the filter cloth. Overflow and drain from the filter is returned to the filter feed tank via gravity while the filtrate is directed to the thickener feedbox via sump pump.

The weight of filter cake passing along the conveyor will be continuously monitored, allowing control of the amount of thickened tailings sent to the filter by-pass to achieve the desired slump. The slump will be fine tuned by adding more or less slurry in order to achieve the target power draw on the mixer motors to obtain a 250 mm (10") slump.

The continuous mixer will mix the filter cake in a low slump matrix such that the mixer contents' viscosity is high enough that adequate shearing takes place to blend the filter cake into the paste.

The conditioning mixer discharge is collected in a tailings surge hopper from where the tailings will be transferred to a tailings weigh hopper in batches. The weight of the tailings in the weigh hopper is monitored and is proportional to the amount of binder addition in the binder weigh hopper.

### 3.5.2 Backfill Preparation and Transportation

A batch mixer is used to combine the various batch constituents into the final paste product where the conditioned tailings are mixed with normal Portland cement and water so that the discharge from the mixer is of a consistent paste slump. The binder is added in proportion to the measured mass of the conditioned tailings in the tailings weigh hopper. The batch mixer power draw is constantly measured and water is added to the mixer in order to adjust the actual power draw required to obtain a 250 mm (10") slump. The paste is then discharged from the batch paste mixer where it is retained within a paste hopper. The paste hopper is the final receptacle for the paste prior to entering the underground distribution system, and is essential to ensure proper operation of the positive displacement pump. Load cells on the paste hopper ensure that the level of material in the hopper is maintained above a minimum level to prevent the risk of air entering the distribution system.

A wet, dynamic dust collector attached to the batch mixer will prevent the release of any cement dust from the mixer, with the resultant dilute waste slurry flowing to the clean-up sump.

As described in Section 4.0, the underground distribution system cannot be designed to operate by gravity, therefore pumping is required. A service or standby piston pump will pump the paste through the distribution pipeline to the stopes.

### 3.5.3 Binder System

One large storage silo has been included adjacent to the backfill plant, allowing for the storage of 150 tonnes of cement. The 150 tonnes capacity offers approximately one day of storage when the plant is operating continuously at the highest binder content. Isotainers of cement will be transported to site and will serve as secondary storage buffers as well as the transport method for the cement. Isotainers are standard container sized frames with a suitable sized cement containment vessel suspended inside the container. Isotainers will be loaded on the back of a flat bed truck and shipped to the barge loading area. They will be barged across the lake and then trucked directly to the cement silo for offloading or trucked to a laydown area where the containers will be stored. The quantity of containers will be such that there is adequate surge capacity to endure outages in transportation facilities.

The binder silo is equipped with a dust collector and fan that will exhaust and transport compressed air through a ducting exhaust system. A monitoring system will continuously monitor the level in the silo. A high level switch and a low level switch provide indication of binder levels. The silos are also equipped with a pressure relief valve which opens if the silo is pressurised excessively.

The cement silo cone will be fluidized using aeration and will discharge through a rotary valve into a binder weigh hopper via a screw conveyor. The rotary valve and screw conveyor control the flow rate of binder into the weigh hopper in order to achieve the desired weight on the load cell. The weigh hopper discharges the binder to the mixer.

## 3.6 Paste Plant Infrastructure and Layout

The backfill plant will be split over several levels, allowing a gravity feed system with the vacuum filter installed at the highest elevation. Beneath the filter, the filter cake conveyor will be installed, feeding into the conditioning mixer. The conditioning mixer discharge will be collected in a surge hopper before feeding the weigh hopper and then the batch mixer. The batch mixer will also receive cement from the binder weigh hopper, itself fed by the binder silo via a screw conveyor. The paste hopper into which the batch mixer will discharge, will be in an elevated position above the ground level, from where it can feed the positive displacement pumps on the ground level. The ground level will also include sump pumps and vacuum pump.

Since the paste backfill plant is located adjacent to the flotation plant the electrical rooms are combined with those of the rest of the mill. The plant building is entirely clad and insulated, given the cold weather experienced at the site, and provision has been made for room in the building to allow the maintenance of equipment and delivery of supplies. This paste backfill plant will have a hoisting bay which enables the vertical movement of equipment via an overhead crane at the top of the building.

## 3.6.1 Structural

A preliminary structural design using Limit States Design, and a material take-off was performed as part of the feasibility study. The design was completed in accordance with the design criteria set forth in the following documents provided by Avalon as well as local regulatory codes:

- 509051-00000-42EC-0001 – "Structural Design Criteria" by SNC-Lavalin Group Inc.;
- 509051-00000-41EG-0001 – "Geographic, Climatic and Seismic Data" by SNC-Lavalin Group Inc.; and
- NB11-00527 – "Thor Lake Site – Phase 3 Site Investigations" by Knight Piésold Ltd.

Design drawings representing the structural design are included in Appendix F. The following is a description of the building and foundation designs.

### *3.6.1.1 Building Design*

The building has a footprint of approximately 15 m x 37 m, and an eave height of roughly 31 m from grade. Of typical industrial design, the building is a braced frame design, with the roof supported by steel trusses. The interior has 5 internal platforms with grating or concrete decking. The building also supports a 5 tonne crane, which spans the entirety of the short direction of the building, and runs the entirety of the length of the building.

A 3D structural analysis model was developed in RISA-3D. The building was designed to carry the process equipment loads, operating loads, crane loads, wind loads and seismic loads, combined in accordance with the National Building Code of Canada, 2010 Edition. Equipment loads were determined either through correspondence with a supplier, or with data taken from past project experience with similar equipment.

Steel elements were designed to current Canadian design practices as outlined in CSA S16-09 - Design of Steel Structures. The steel for the project was assumed to have a minimum yield stress ($F_y$) of 350 MPa according to CSA G40.20 / G40.21 Grade 350W specifications.

### *3.6.1.2 Foundation Design*

Foundation sizes and depths were chosen based on removal of overburden to bedrock, and founding shallow footings and pedestals on rock capable of supporting an allowable bearing capacity of 1,000 kPa. It was assumed that after construction of the foundations, the plant would be backfilled with a competent engineered granular fill material, capable of supporting an allowable bearing capacity of 250 kPa. An 8" slab-on-grade would be founded on this backfill to support operating loads such as forklift traffic.

Concrete elements were designed to current Canadian design practices as outlined in CSA A23.3-04 - Design of Concrete Structures. For the purposes of this study, the concrete was assumed to have a minimum 28-day compressive strength ($f'_c$) of 30 MPa.

### 3.6.2 Electrical

A preliminary electrical design and material take-off was performed as part of the feasibility study. The low voltage motor control centers (MCC) with integral VFDs, medium voltage starters and switchgear has been excluded from the Golder scope of work as per SNC Lavalin (Avalon's representative). The paste backfill plant motors will be supplied from MCCs in the main Flotation Plant building. Golder's estimates cover the lighting, grounding, tray and cable estimates for unit costs and labour. The motor list and single line diagram were developed just prior to receiving the quotations from vendors. Considering that the difference in the overall horsepower requirement between the equipment vendors and those anticipated was in the order of 15% they were not updated.

The total rated capacity for the paste backfill plant is 1.8 MW, whilst the anticipated operating load should not exceed 1.4 MW. The electrical single line along with the motor list is presented in Appendix G.

### 3.6.3 Instrumentation

Instrumentation design was developed from the P&IDs and the Operating Philosophy of the plant. Both these documents are provided in Appendix H.

The paste backfill plant will have stand-alone distributes control system (DCS) that will communicate with the main mill DCS. The paste backfill plant DCS will have a separate processor, I/O cards, power supply, associated equipment and internal wiring provided by the vendor. The DCS estimated pricing includes Factory Acceptance Testing but excludes commissioning costs and is based on a preliminary I/O count. There will be no field mounted junction boxes for field instruments in the paste backfill plant, all instrumentation cabling to the DCS will be home run individually. The labour for cable pulls and routing is included in the cable estimate.

The labour estimate for instrument installation excluded installation of in-line instruments (valves, magnetic flowmeters, regulators, etc.) which are installed by the piping contractor. The labour estimate for these instruments includes terminations, tubing and mounting labour only. Where possible, multiple prices were considered for instrumentation, and an average was calculated for the purpose of budgetary costing.

The instrumentation associated with the thickener underflow pumps will be wired to the main mill DCS set points, process values and valve positions will be transmitted to the paste backfill plant DCS digitally.

### 3.6.4 Compressed Air

Compressed air will be provided by a compressor located within the flotation plant which will be used to feed the paste backfill plant as well as feeding the snap air receiver for the vacuum disc filter. Peak demand for compressed air will be 1090 $Sm^3$/hr (545 / disc filter) during operation of the paste backfill plant. Compressed air (560 $Sm^3$/hr) will also be required during shut down when the main paste line is being flushed with air. This peak demand for the flushing of the main paste line assumes:

- The main distribution line will be 3,000 m in length;
- A 17 $m^3$ volume of air is retained in a receiver/reservoir in the plant; and
- Compressed air will be developed at 860 kPa.

Instrument air will also be required for use in the paste backfill plant and sourced from the same compressor within the flotation plant, but retained within a separate receiver after passing through an air dryer to remove entrained moisture.

### 3.6.5 Clean-up

Centrally located in the backfill plant are three clean-up sump pumps. One sump will collect seal water and filtrate with the material redirected to the thickener. The second sump will receive material from drained mixers as well as flows from the dust collectors. Material collected within this sump will also be pumped back to the thickener via the first vertical centrifugal sump pump. The third sump will receive material from clean-up and drained equipment to be pumped back to the thickener.

### 3.6.6 Process Water

Process water will feed to the paste backfill plant from the process water tank located within the flotation plant.

### 3.6.7 Fresh and Potable Water

Fresh water within the paste backfill plant for use as pump gland seals and emergency safety showers will be piped in from the flotation plant. This water will not be considered as potable, with potable water provided though stand-alone systems.

# 4.0 UDS SYSTEM DESIGN

## 4.1 Overview

The UDS system presented for the Thor Lake Project has been designed with the paste backfill plant located adjacent to the mill and the need to pump the cemented paste fill down the main ramp in order to reach the different ore zones.

### 4.1.1 Flow Modelling

The flow model was created using estimated pressure loss based on the material characteristics of the tailings samples tested. The model is used to determine the available head pressure generated due to the elevation change vs. the friction losses in the pipeline and calculates the pressure required to deliver the paste to the voids on each production level. Ideally, the system would be run with a 175 mm (7”) paste slump, which requires a lower binder content than higher slump paste for achieving the desired cured strength within the production scheduled duration.

For the Thor Lake operation, the mill (paste backfill plant) location requires that there will be a considerable horizontal distance between the paste plant and the stopes. This, in conjunction with the shallow geometry of the orebody, means there is no excess available head pressure and pumping will be required to reach the extent of the orebody. While running at 175 mm (7”) slump would reduce binder consumption, it requires operating with a higher friction factor which would require a number of booster pumps to reach the stopes. Considering the distances that need to be covered and the fairly low binder requirements needed to reach the required backfill strength, Golder has selected a 250 mm (10") slump paste for the Thor Lake operation. The flow model results and views of the piping layout are shown in Appendix H.

### 4.1.2 Pipeline Design

The preliminary pipeline design will be composed of 6" Schedule 80 carbon steel pipe. The grade of pipe will likely be an API 5L Gr.X52 or higher to support the pipeline stresses while providing enough wear thickness to accommodate some loss of internal pipe wall thickness.

Based on the fine nature of the tailings, it is not anticipated that ceramic lined or induction hardened piping will be required. It is possible that there could be some benefit to using those materials at key locations such as elbows or the bottoms of boreholes; however, at this time it is considered likely that carbon steel will be the most cost effective solution. Further optimization of the wear materials in the pipeline could be done during the first few years of operation.

The underground piping will be hung from the back using dywidag and channel hangers. Bracing will be installed at all changes in direction and will consist of a rigid pipe clamp with angles welded to anchor plates that are bolted to the back.

Provision for cleanouts, pressure transducers, flush points and rupture spools will be made at regular intervals along the pipeline length.

The design of the final runs of pipe from the backfill drifts to the stopes is still under evaluation by Avalon. A preliminary evaluation of four different options, titled "Review of Backfill Drift Location" was performed by Golder (Appendix J):

- Option 1: Backfill access drift located at end of stope and parallel to orebody strike (same end as stope access drift);
- Option 2: Backfill access drift located toward the middle of the stope and parallel to orebody strike;
- Option 3: Multiple backfill access drifts with one located at the end of the stope (parallel to orebody) and the second drift located along the secondary stope (perpendicular to orebody); and
- Option 4: Multiple backfill drifts located similar to Option 3, except fewer drifts located along the secondary stopes.

Avalon will be evaluating the different options in the context of the final overall mine design. For the current evaluation, the UDS system estimate considered only the cost to bring piping the length of the various backfill drifts. The costs of the backfill drifts and the final development from the backfill drift to the stopes (including piping and boreholes) have been excluded. Avalon has advised Golder that these costs would be covered by the mining operations.

# 5.0 UNDERGROUND BACKFILL STRENGTH REQUIREMENT

The underground backfill strength requirements were evaluated during the pre-feasibility report. The Avalon ore deposit is relatively flat-lying and is expected to be mined using two different mining methods. The first stage (lower orebody) would be cut-and-fill (CAF) and the next stage (upper orebody) would be longhole (LH) stoping. Both methods would use primary and secondary stopes. The reason for using two different methods is that the footwall of the orebody is irregular. Therefore, a selective mining method is required. CAF is used for selective mining to reduce dilution and ensure high recovery near the footwall. The first three levels benching down will be cut-and-fill, while the other levels going up will be LH stoping.

Prior to secondary stope removal, the primary stope is to be filled with cemented paste backfill. Once the paste backfill has reached sufficient strength, the secondary pillar can be mined. The required backfill strength for primary stopes is dependent on the maximum opening height of the adjacent secondary stope. In order to determine the required backfill strength to be self supporting for the primary underground stopes, an empirical assessment of the backfill strength was completed based on Mitchell et al (1982). This assessment considers a wedge-type style failure of the backfill. The parameters required for the assessment are the stope dimensions, density of the fill, and the internal angle of friction, as follows:

- Length of the stope: 50 to 100 m
- Height of the stope: 5 CAF to 20 m LH
- Primary stope width: 15 m
- Secondary stope width: 16 m
- Density of fill: 2163 kg/m$^3$
- Internal angle of friction: 30°
- Factor of safety: 1.3

The work carried out by Golder's mining group as part of the pre-feasibility study (Appendix K) formed the basis for the following UCS strength requirements:

- Primary stopes with heights >18 m UCS strength of 0.59 MPa;
- Primary stopes with heights <18 m UCS strength of 0.36 MPa; and
- Secondary stopes to prevent liquefaction UCS strength of 0.17 MPa.

Based on the UCS test work performed, the binder requirements for a 250 mm (10") slump material would be would be 7%, 5% and 2.5 wt% binder addition, respectively, for the strength requirements shown above.

The average cement content required on a yearly basis will be between 4 and 5%.