Increasing Mine Backfill Replacement Ratio Beyond Traditional Limits to Minimize Environmental Impact in Mining

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Abstract

In the mine backfill industry, the typical replacement ratio, a number that measures the ratio between the mass of the ore mined and the mass of tailings placed underground, is ~ 50%. In other words, approximately half of the tailings cannot be returned underground. The remainder of the tailings not returned underground are most commonly stored on the surface within a tailings management facility (TMF). NexGen Energy has proposed an innovative solution for its Rook I Project (the "Project") which would enable placing 100% of the process waste solids underground. Through constructing purpose-built underground chambers, the replacement ratio can be further increased beyond the traditional limits. This method also requires designing a backfill system that can reliably handle all streams of waste solids from the process plant regardless of the particle size and mineralogy. Utilizing a systematic set of material experiments and engineering studies, multiple paste backfill mixes have been designed in consideration of the geotechnical and geochemical requirements for supporting mining operations, ground stability and permanent storage. This paper discusses the considerations, the approach, and the lessons learned from advancing a Project with zero process waste on surface.

Key words: paste, uranium, tailings, radioactive, zero

Background

NexGen's Rook I Project, based on the Arrow deposit discovery in Feb 2014, is a proposed uranium mine with a process plant located in northwestern Saskatchewan, Canada approximately 150 km north of La Loche. Measured and indicated mineral resources total 3754 kt grading 3.10% U_3O_8 containing 256.7M lbs supporting an initial mine life of ~ 11 years. The deposit starts approximately 250 m below the surface level. The selected mining method for the uranium ore body is a combination of transverse and longitudinal longhole stoping with a 30 m of sill to sill spacing.

As with all underground mining operations, the tailings produced by the process plant cannot be entirely placed in the underground stopes due to the 'swell' phenomenon (ie, the density of the ore is generally higher than that of the tailings.) To determine how much tailings materials can physically 'fit' underground, the comparison in densities is between the *in situ* density of the ore and the bulk density of tailings when consolidated underground. By the law of conservation of mass, a decrease in material density results in an increase in the total tailings volume. While some percentages of ore mass are extracted during processing, the tailings still have a substantially larger volume than the void space resulting from mining the ore. Generally, the ratio between the mass of ore mined and the tailings returned underground, referred to as the replacement ratio, is ~ 50%. The remaining tailings, ~ 50% of the total, are typically stored on the surface in various forms (eg, slurry form in a tailings pond, dry-stacked filter cake). It is worth noting that this upper limit of the replacement ratio is due to simple physics of swelling, and also to a lesser extent due to a mine designer's choice to not fill all of the available void space created underground to facilitate ore extraction.

NexGen Energy has proposed to develop a mine with zero process waste on surface, which requires going beyond the traditional replacement ratio's upper limit. In this context, the process waste includes not only the tailings (ie, leach residue), but also the gypsum produced in the neutralization process and solids from the effluent treatment plant precipitation process. To exceed the traditional limits of the replacement ratio, purpose-built underground chambers will be strategically constructed to manage the process waste that would otherwise not fit within the mined-out underground ore stopes. More specifically, the process waste will be delivered underground as cemented paste backfill (CPB). In comparison to hydraulic fill, CPB enables including a higher percentage of fine particles in the tailings in the paste mixes. This is important in that a large fraction of the process waste is expected to be very fine in particle size. Furthermore, CPB generally produces only minimal bleed water after its placement and has a low hydraulic conductivity. These are desirable properties for both mining operation and long term storage considerations. This paper discusses the novel approach to allow all processing waste streams to be managed underground, and the associated engineering work conducted to demonstrate this safe, long-term waste management strategy for the Project.

Materials Characteristics

Due to the very high density of uranium, the density of the ore varies greatly depending on the grade of the ore. Over the Project life of mine, the average ore density for the Project is estimated to be ~ 2.5 tonne/m^3; however, the density may vary substantially based on the mineralized grade. Typically, as grade increases, density is observed to increase and can reach > 4.0 tonne/m^3 in higher grade ore.

From the uranium extraction process, three types of waste materials are generated: neutralized leach residue (NLR), effluent treatment plant precipitates (PPT), and gypsum. The average solids densities of the materials are 2.6, 2.5 and 2.6 tonne/m^3 respectively. Of all the waste materials, NRL contains the highest radiation. With 36% passing 20 µm, NLR material is the most suitable to make an effective paste backfill.

PPT contains precipitates from two separate stages, and the solids are very fine in particle size distribution (PSD) with ~ 35% passing 10 µm. Similarly, gypsum has a very high fraction of fines, also ~ 35% passing 10 µm. The PSDs are illustrated in Figure 1 below.

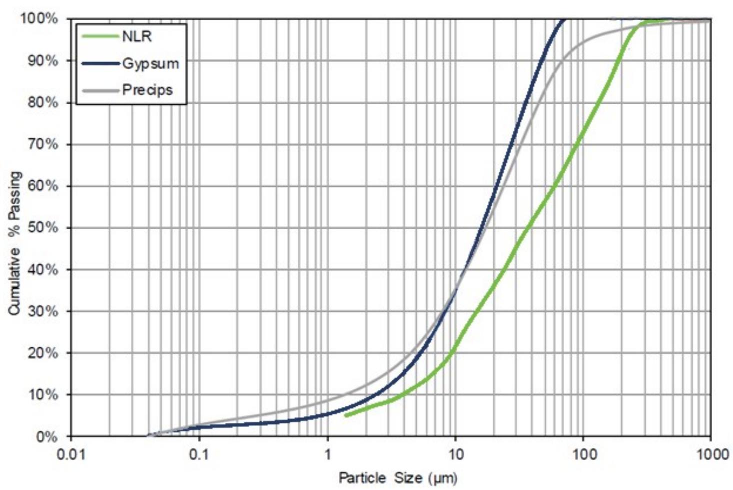

Figure 1. Particle Size Distributions of NLR, PPT, and Gypsum.

The very high fine fractions in the PPT and gypsum make the materials difficult to achieve high percent solids in the paste mix design while having desirable flow characteristics. Also, the fine PSDs generally require a high binder content to achieve the target paste strength.

The requirements and the proposed engineering strategies

The requirements

The concept and the nature of the waste materials demand very high plant availability.
Backfill plants are often designed between about 50–80% utilization. When the backfill plant is not running, the tailings are either sent to a surface TMF, or filtered and stockpiled for later use. These two options provide the time for the backfill system to be temporarily shut down for maintenance and other activities such as process improvement.

NexGen is focused on having zero process waste on the surface; therefore, managing the waste in a surface TMF is not an option. Considering a temporary stockpile, the radioactive nature of uranium process waste requires design and management processes for applications in which large surge stockpiles are utilized. Of particular note, given that the radioactivity is proportional to the quantity of radioactive materials, there is an elevated risk of radon gas emission when the materials are allowed to dry and accumulate. Therefore, the backfill plant would ideally be capable of processing all the waste materials as soon as they are produced by the process plant. In other words, the backfill system must have an availability that matches the processing plant's availability, which is much higher than the industry's typical 50–80% utilization.

All materials will be processed and backfilled
In general, tailings with undesirable characteristics (in terms of PSD, or metallurgical properties) can be engineered to improve the properties for making paste. For example, hydrocyclones are sometimes used to 'deslime' tailings. There are also examples where high sulphides materials are purposely removed from the feed to the backfill plant. Avoiding the use of these challenging materials to make paste in the first place is usually a highly effective strategy. However, the downside to this approach is that the thickener and the surface TMF would receive the problematic materials rejected by the backfill system.

As NexGen plans to place all of its process waste underground, there is not an option to reject unfavourable materials. As a result, the backfill system must be able to process all three streams of waste materials regardless of materials characteristics. The requirement to dispose of all waste streams presents a challenge as the plant design and the paste mix designs must account for both the very fine PSDs and radioactive nature of the materials.

Optimizing cost, and operability
Managing the overall cost and reducing the complexity are part of the focus in the design philosophy. While some designs are effective at the benchtop scale, the solutions may be impractical or cost prohibitive in the real world. For example, paste with exceedingly high yield stress is difficult to transport in pipeline, or has poor pumpability. Moreover, the plant design needs to be simple in order to be practical and operation friendly.

The engineering strategies

Underground tailings management facility (UGTMF)
As discussed earlier in this paper, the replacement ratio is generally ~ 50% across the mining industry. In order to send 100% of Project's process waste materials back underground, additional volume to that crated during ore extraction must be developed. NexGen plans to achieve this by developing a UGTMF composed of purpose-built chambers dedicated for the placement and storage of the process waste

streams. The UGTMF will fundamentally function like a surface TMF. With processing waste streams utilized to produce paste backfill to fill ore production stopes, the remainder of the waste will be placed underground in these dedicated UGTMF chambers for permanent storage.

The UGTMF chambers are planned to be 25 m wide, 25 m long, and 60 m tall to maximize storage per chamber without requiring extensive and costly ground support due to the very favourable geotechnical conditions in the region of the facility. Another advantageous feature of the location of the UGTMF is that the Project's host rock mined is generally more geochemically stable than the processing waste, and thus safer and less costly to manage than tailings. Chambers will be developed progressively over the life-of-mine (LOM) to ensure that there is always sufficient space developed that all processing waste not used for production stope backfill (ie, in areas of ore extraction) can be placed underground. The Rook I mine plan as of the Feasibility Study is shown in Figures 2 and 3 below.

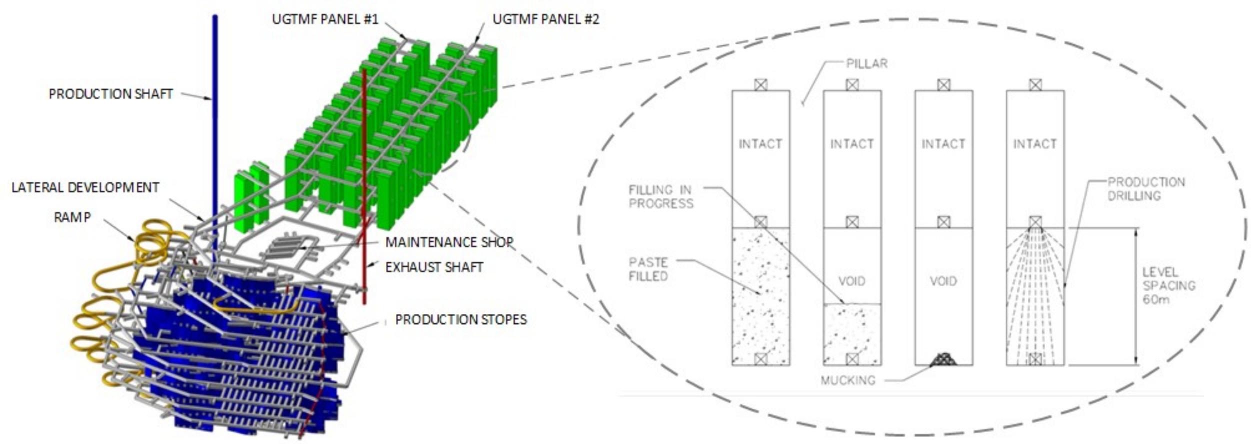

Figure 2. Rook I Mine layout with UGTMF cross sectional view.

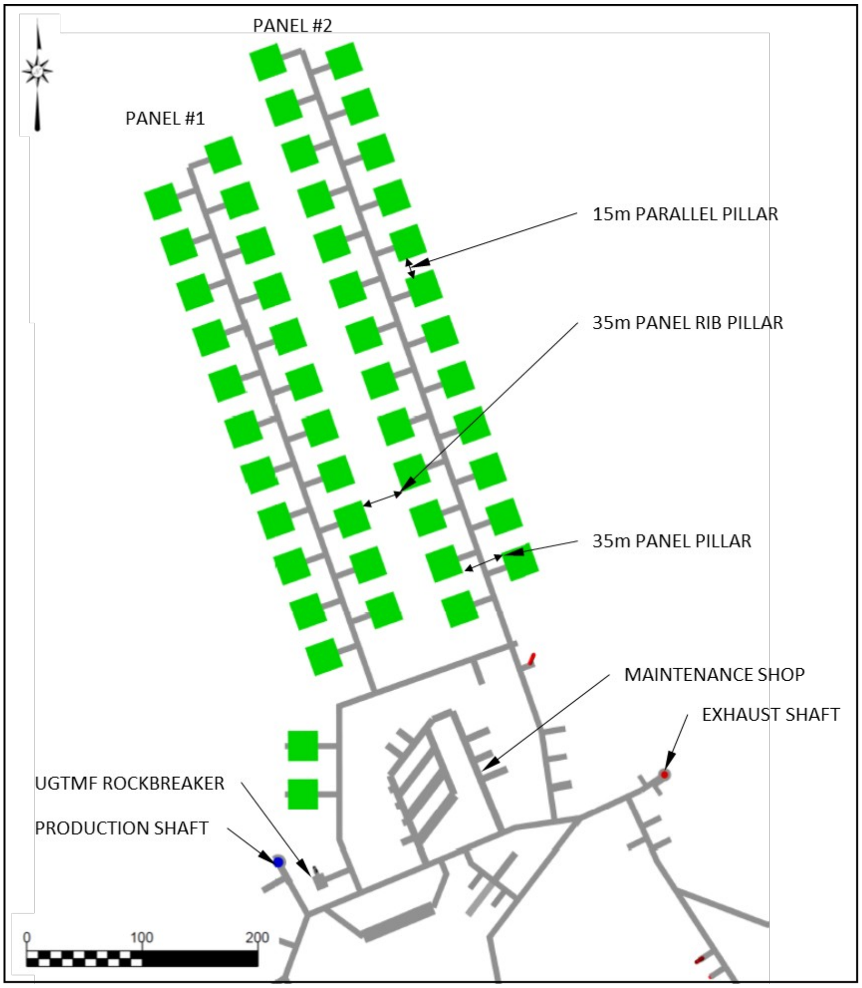

Figure 3. Plan view of the UGTMF.

Multi-recipe approach

It is common for a mine to generate materials with a spectrum of properties, with some being more desirable for making paste than others. Put simply, the materials can be categorized into 'favourable,' and 'unfavourable' for making paste. As discussed, examples of unfavourable materials are tailings containing high concentration of sulphides or with a very fine PSD. One strategy to optimize the mix design is to use the favourable portion for making structural backfill, where the quality of the backfill is critical for ongoing mining operations. On the other hand, the unfavourable materials will be processed into low quality backfill. This low quality backfill can be placed in areas where the backfill is contained, and therefore low structural requirements.

With the Rook I Project, the favourable waste material is the relatively coarser NLR. The finer PPT and gypsum are less desirable for making paste. Therefore, two different mix designs are developed. The first one is CPB, made exclusively with the NLR. The mass balance calculation indicates that there will an excess of NLR for making CPB. Therefore, the second is cemented paste tailings (CPT), which includes PPT, gypsum and the remainder of NLR not used in making CPB.

The relatively coarser NLR provides CPB a higher strength at a given percent solids and cement binder. This will be used in the production stopes, as well as the caps and the plugs in the UGTMF. The very fine PSD in CPT results in low percent solids in the practical yield stress range for pumpability consideration. Thus, CPT is used only in the body of UGTMF, where the backfill is contained. Figure 4 below provides a summary of the material flows.

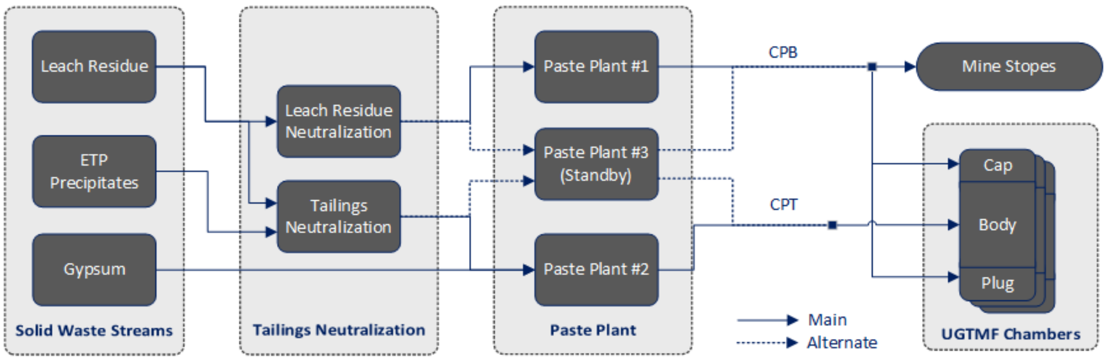

Figure 4. Flow of materials from the production to placement.

Cement Binder selection

General use (GU) cement, fly ash cement and slag cement (ground granulated blast furnace slag) are commonly used in mine backfill. The availability of fly ash cement is expected to decrease in the coming years as the use of coal power generators declines in Canada. While slag cement generally produces lower early strength, the backfill UCS made with slag cement typically surpasses the backfill made with GU by 28 days. This means using slag cement will require a lower binder percentage than when using GU cement for achieving the same target strength. Lowering cement added to the backfill is beneficial not only in decreasing the cost of cement, but also in decreasing the overall volume of UGTMF.

Analysis

Paste Mix Design

Due to the fine PSDs, both CPB and CPT have relatively low percent solids in the range of practical yield stress (for pumpability). Figure 5 below shows the yield stress of both CPB and CPT as a function of the percent solids. Note that the weight percent solids are just over 55% and 62% at 200 Pa yield stress for CPT and CPB, respectively.

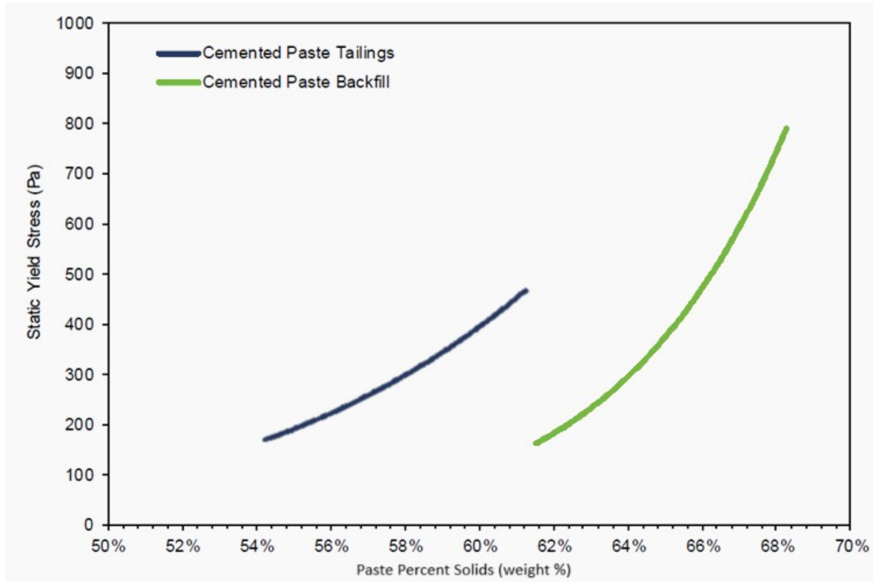

Figure 5. Static yield stress as a function of percent solids of paste materials (CPT and CPB).

Considering the pumpability of the paste materials, the mix designs are expected to have low percent solids. Consequently, a relatively high cement binder contents are required. Based on the lab test data, CPT and CPB can achieve target strength (200–1500 kPa for various applications) with slag cement between 4–10% by weight.

Also, due to the low percent solids the paste slurry specific gravity of CPB and CPT are ~ 1.62 and 1.50, respectively. These are low when compared to the uranium ore density. As a result, even if all the void space created in the stope are filled with CPB (the higher density backfill), the replacement ratio is only ~ 36.5%. Much of the waste materials will need to be placed outside of the production stopes. Therefore, UGTMF will be constructed to manage the remainder of processing waste streams.

Backfill System

NLR, PPT and gypsum will be dewatered to produce filter cakes for making paste. The filter cakes will be mixed at the pre-programmed ratio to make CPB and CPT when mixed with the cement binder. In order to minimize downtime, the Project's backfill system will have three independent paste production processes, which each consist of a set of filter cake conveyors, three cement feeders, and three twin-shaft mixers. Of the three systems, two are dedicated for producing CPB and CPT, while the third is a redundant system for either product. The paste pumps will deliver CPB and CPT underground via boreholes. A network of underground distribution system (UDS) will be used to direct CPB and CPT to the designated areas programmed by the operator.

Given that there will be no surface TMF to receive waste materials, this arrangement is designed to provide sufficient redundancy to minimize the backfill plant's downtime. By having the backfill system with high availability reduces the required feed materials surge capacity. Furthermore, the backfill plant is designed to safely handle the radioactive nature of the waste materials.

Optimization Opportunities

There are opportunities to further optimize the backfill system. Ideally, increasing percent solids will allow placing more solids in a given void. Generally, increasing percent solids in the paste also improves backfill UCS, and thereby decreasing the required cement content. Moreover, reducing the cement content requirement translates to reduction in binder OPEX as well as the number of UGTMF chambers.

One possibility is to either develop a more efficient UDS (ie, shortening flow path) or increase the pressure rating of the UDS. This will allow a higher friction loss per meter, and therefore a higher percent solids paste mix design. Another opportunity is to develop new mix designs that allow high percent solids through experimenting different blends of the three streams of waste material. If successful, having a higher percent solids would translate to a higher replacement ratio, further reducing the number of UGTMF chambers as well as the cost of the project.

Conclusion

NexGen has proposed to develop the Rook I Project with zero process waste on the surface. This novel concept can be achieved by going beyond the traditional 50% limit of the replacement ratio. By constructing a UGTMF, additional space will be created to receive the waste materials that would otherwise not fit in the underground mined out ore stopes.

Two paste materials, CPT and CPB, were developed using the three waste streams; NLR, PPT and gypsum. This strategy was found effective in reaching a target UCS at binder contents between 4–10% for the various mix designs. Additionally, redundancy in the backfill system design has been incorporated to achieve very high system availability, which will minimize the size of the surge capacity in the plant.

While there has been substantial progress in engineering this design, there are further optimization opportunities to improve the backfill system design. Optimizing the UDS or developing paste mix designs that allow high percent solids will be very effective in reducing the number of UGTMF chambers, reduce the Project's backfilling cost and potentially improve the operability of the system.