Benefits of Rotational, Thin Layer, Air Dried Tailing Deposition after 25-Years of Operation of the Juniper Tailing Storage Facility

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ABSTRACT: From inception in the late 1980s, the Juniper Tailings Storage Facility has been constructed in stages as a massive, compacted, rock fill, modified centerline embankment to retain fine grained predominately silt tailing. The initial cells were designed to contain 8 million tons. Three horizontal expansions and numerous staged raises have been made to the initial facility bringing the planned storage to 150 million tons at a height of 225 feet. Currently additional expansions are being considered. The initial stages of each basin were constructed as downstream embankments and the basins of each initial stage were lined with a 12-inch thick layer of low permeability soils overlain by a 12-inch thick drain layer containing a series of corrugated, slotted HDPE drain pipes. A drain/transition layer was included in the upstream face of the raises so that the fine-grained tailing did not migrate into the rock fill and any seepage was contained within the upstream side of the initial lined embankment where it was collected in the lined basin. Thus, no lining was needed above the initial embankment. This paper discusses the design, construction and operation of the facility including a summary of the benefits realized by the type of embankment constructed and the use of rotational, thin layered, air dried deposition. The features discussed could be considered for inclusion in other projects to provide safety and security, reduce costs and provide efficient operations.

1 INTRODUCTION

1.1 *General*

Newmont USA Limited (Newmont) owns and operates the Twin Creeks gold mining and processing facility located in Humboldt County, Nevada, approximately 35 miles northeast of Golconda. The Juniper Tailing Storage Facility (TSF) provides storage for tailing produced by the processing operations. The current planned storage for the facility is 150 million tons. The TSF currently has a footprint covering 770 acres and a planned height of 225 feet. Additional raises are being evaluated.

1.2 *Topography, Drainage, and Vegetation*

The site itself is plainer and overall it slopes gently to the southeast. The Juniper TSF presently comprises one cell that is the combination of the previous Cells 1, 2, and 3. It has been constructed in numerous stages including both vertical and horizontal expansions. A plan view of the one cell, current configuration, TSF is shown in Figure 1 and the older two cell facility in Figure 2.

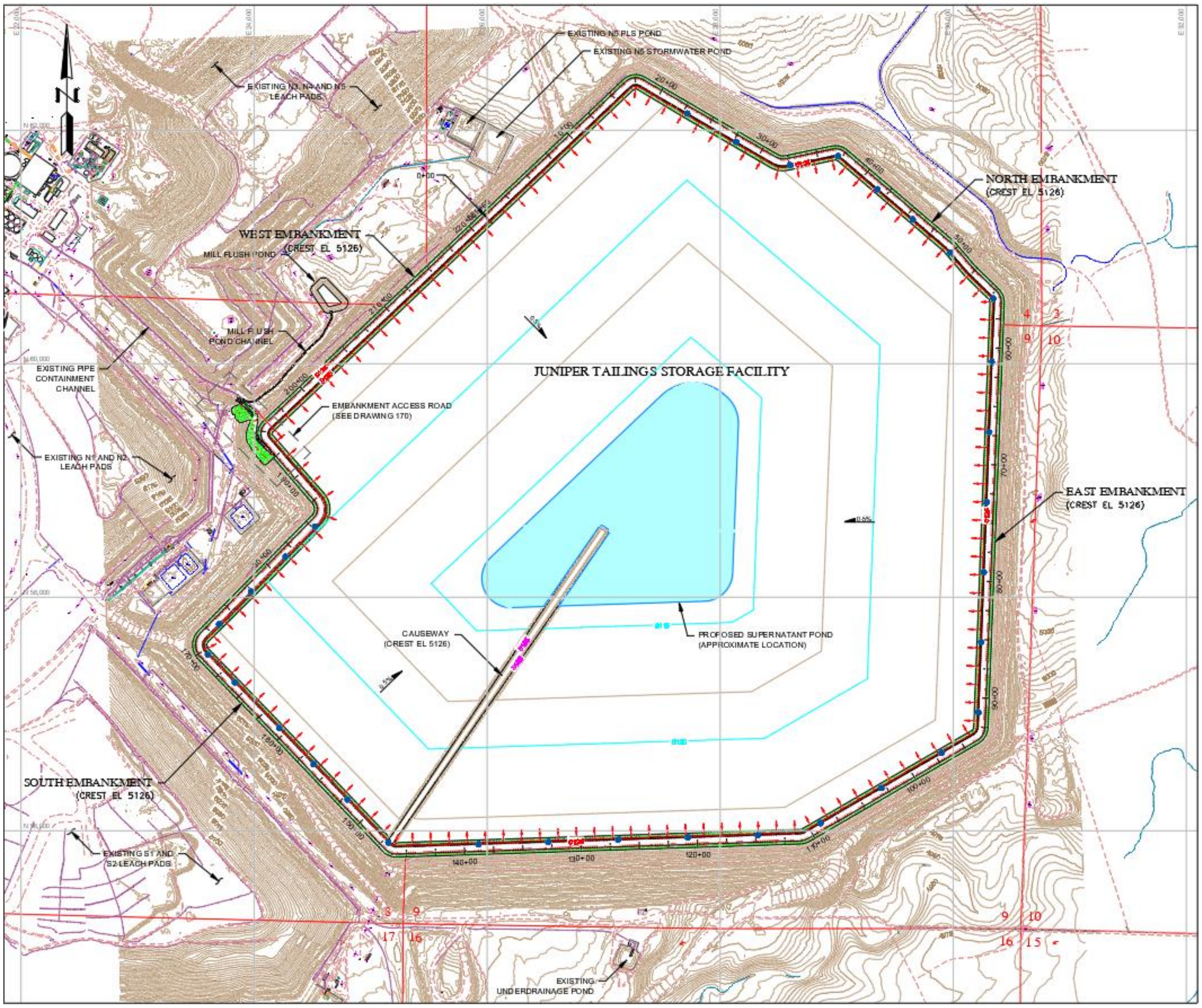

Figure 1. Plan view of current configuration. Combined Cells 1, 2, and 3.

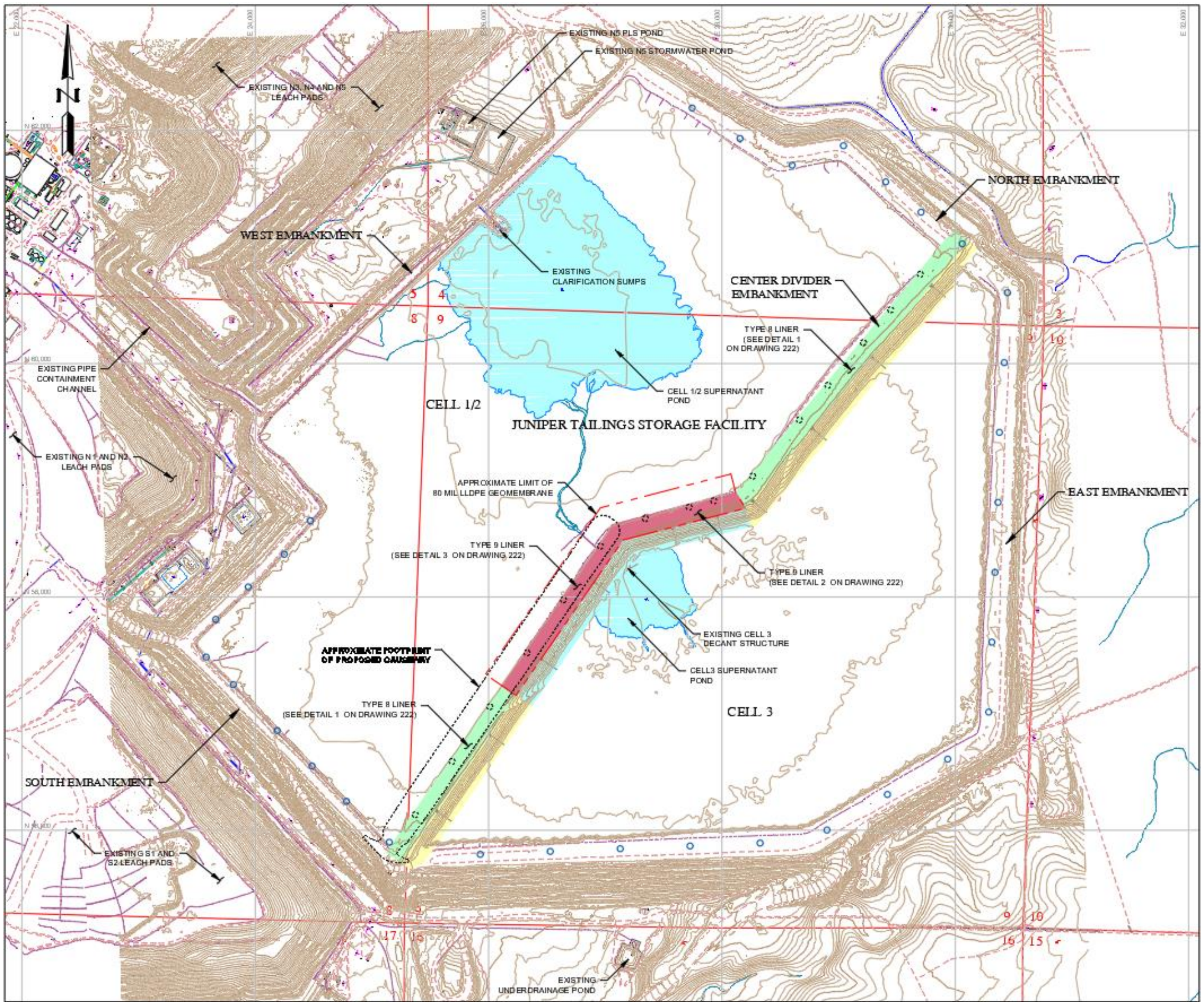

Figure 2. Plan view of Cell 1/2 and Cell 3 configuration.

The primary area wide drainage is generally to the south through Kelly Creek, which flows into the Humboldt River. A secondary drainage tributary to Kelly Creek, which is Rabbit Creek, emanates from numerous small canyons in the Osgood Mountains located to the west and flows to the southeast toward Kelly Creek. Rabbit Creek was diverted around the northeast corner of the TSF prior to joining Kelly Creek as part of the Cell 2 construction. These water courses are generally dry.

The natural vegetation is typical sagebrush and is characterized by Thurber needlegrass, Wyoming big sagebrush, blue bunch wheatgrass, Indian ricegrass, Sandberg bluegrass, and Webber ricegrass. The agricultural potential is low.

1.3 *Project History*

The starter facility was designed in early 1987. It consisted of a two-celled facility comprising a southern Cell A and northern Cell B with impounding embankments and a fully-lined basin with an underdrainage system. When the facility was first commissioned, tailings from oxide ore pulp processed through the Juniper Mill were deposited in Cells A and B that were later combined to form Cell 1 that was constructed in 1988. In the summer of 1989 the Stage 2 expansion was designed. The Stage 2 expansion consisted of raising the embankments using upstream construction methods and expanding the liner and the drainage system in the basin. It was constructed in 1990. The Stage 3 expansion was designed in 1991 and constructed in 1992 to provide storage until the end of 1996. The Stage 3 expansion included an upstream raise to the existing embankment and expansion of the liner and the drainage systems in the basin. Both the Stage 2 and 3 expansions maintained the initial Cell A and B configuration. This portion of the facility had a capacity of 8 million tons.

After construction of Stage 3, plans for a sulfide project were developed, which prompted evaluating the existing facility to estimate the expansion required to adequately store an additional 50 million tons. It was determined that combining Cells A and B into a single cell and construction of an additional cell was necessary to store a total of 58 million tons in the facility. The new cells were denoted as Cell 1, the old Cells A and B, and Cell 2. These components were incorporated into expansions covering Stages 4 through 8.

Stage 4 Cell 1 expansion was constructed during the summer of 1996. Stage 4 Cell 2 was constructed in the spring and summer of 1997 and was the first lateral expansion of the facility. The expansion was to the northeast. The locations of Cells 1/2 and 3 are shown on Figure 2.

In November 1996, tailings from sulfide ore pulp processed in the new Sage Mill and autoclaves were first produced and added to the existing oxide millstream and deposited in Cell 1. Soon afterwards, in May 1997, Newmont commenced processing ore from the Mule Canyon Mine through the Sage Mill. The Mule Canyon ore comprised about 5-10 percent of the sulfide stream. In September 1997, Cell 2 was commissioned using tailings comprised of oxide ore through the Juniper Mill and sulfide and Mule Canyon ore through the Sage Mill. Deposition of this tailings blend continued through February 1999 when processing of Mule Canyon ore ceased. Late in 1997 a change in the tailings behavior was observed, resulting in a significant increase in the time required for solids in the slurry to settle and a decrease in the density of the tailings mass. This led to pulling solids with the solution from the supernatant reclaim system and a more rapid filling rate of the facility than originally envisioned. The addition of Cell 2 and expansion of the supernatant pool in the early stage of filling Cell 2 alleviated pulling solids with the solution from the supernatant reclaim system. Construction of Stage 5 Cells 1 and 2 commenced in October 1997 and was completed at the end of September 1998.

In 1999 the price of gold was low and Newmont wanted to consider viable options for expanding the facility considering two options including (1) a vertical expansion if the price remained low and (2) a horizontal and vertical option if the gold price increased. The price remained low, so Newmont proceeded with the vertical expansion. By 2005 the gold price had increased, Newmont requested the designs be revised to include the Cell 3 horizontal expansion. Cell 3 construction was undertaken in 2004. The plan view of the Cell 1/2 and Cell 3 configuration is shown on Figure 2. The Cell 3 expansion increased the storage capacity to about 115 million tons off tailing.

In 2014 Newmont requested the design of three additional vertical expansions to store an additional 35 million tons bringing the number of stages for vertical raises to 12 and storage capacity to about 150 million tons.

1.4 *Regulatory Considerations*

The designs were completed in accordance with the appropriate State of Nevada regulations. The facility is permitted by the Nevada Division of Environmental Protection (NDEP) and Division of Water Resources (NDWR).

2 EMBANKMENT CONSTUCTION

2.0 *Foundation*

The facility is founded on a sequence of very dense, permeable, alluvial sands and gravels. The alluvial sequence is hundreds of feet thick and the water level in the alluvium is generally deep, typically on the order of 100 feet below ground surface. This provides a very stable foundation for the facility.

2.1 *Embankment*

From inception of the Juniper tailings storage facility in the late 1980's, the facility has been constructed in stages, with a massive exterior compacted rockfill embankment comprised of predominately rock fill or granular alluvium placed in 4-foot-thick lifts compacted to high density by controlled routing of the large haul trucks to retain the fine-grained (predominately silt) tailing. The rockfill is high strength and highly permeable. The rockfill embankment is designed to be dry. A face drain constructed on the upstream face of the rockfill provides a controlled pathway to safely remove water from the tailing placed adjacent to the rock fill and direct it to the base drain, as described below, to collect the seepage and prevent flow into the rock fill and discharges from the facility into the environment. The face drain is also designed as a filter to prevent the fine-grained, very-low-permeability tailing from infiltrating into the rockfill. These key design features maintain the phreatic surface or water level inboard or upstream of the tailing/rock fill interface, thus keeping the rockfill dry to further enhance the stability and safety of the perimeter embankment. Since dry, dense rockfill is not susceptible to liquefaction or strength loss from earthquake loading, it is inherently the most stable type of embankment.

The design of the embankment staging was an intricate process that considered balancing storage needs, mine rock availability, construction timing and costs to develop a cost-effective design. Figure 3 shows the staging for the south embankment. Note that the first major expansion, Stage 4, required starting the embankment on natural ground that greatly increased the needed volume of rock fill compared to that used in Stages 2 and 3. Also note that Stage 5 construction was split into two phases to provide for construction of the base with the mine waste rock available at the time and then the raise later when additional mine waste rock was available.

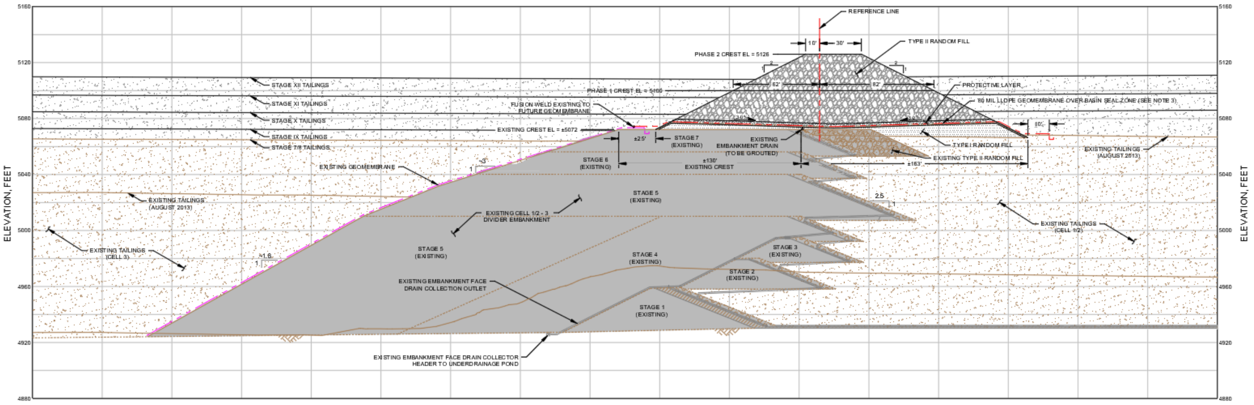

Figure 3. South embankment section showing overall embankment and individual raises.

2.2 *Basin Liner and Underdrains*

A 12-inch thick layer of compacted, low permeability soils was constructed over the alluvium throughout the basin and upstream slope of the initial stage to provide a hydraulic barrier to reduce seepage losses from the tailings basin. This layer is overlain by a 12-inch-thick sand and gravel drain layer, base drain, containing a series of corrugated, slotted, HDPE drain pipes to remove seepage and reduce the hydraulic head on the liner. Collected seepage is conveyed to the underdrain seepage collection pond by double contained HDPE pipes. An HDPE liner has been included in the liner system beneath the areas of the supernatant pond.

2.3 *Foundation Preparation for Upstream Shell Construction on Tailings*

Foundation preparation and placement of the initial and subsequent lifts of rockfill beneath the upstream portion of the embankment raises extending over the tailing surface has been ongoing since the late 1980’s. Approximately 20 miles of foundation surface has been prepared successfully. The drier denser tailing resulting from the depositional procedure provides a stable base for the raises. The procedure used is as follows:

- Once the tailing surface has reached the desired foundation elevation, it is allowed to drain and air dry, to the extent practical, to gain strength prior to placement of the initial lift of rock fill.
- The first lift of rockfill is placed in about a 4 to 6-foot thickness. In wetter areas it displaces several feet of tailing. The lift is allowed to rest and stabilize, as needed, prior to the placement of subsequent fill. The lift thickness may need to be varied based on observation of performance during the actual construction.
- Thicker lifts are not desirable as they create additional load to the tailings surface.
- Some experimentation may be needed in the selection of the dozer model used to push the initial lift of rockfill over the tailing. If the available dozers cause excessive deformation, it may be necessary to use smaller equipment with wider tracks.
- The lift is placed by dozing the rockfill dumped on previously prepared foundation onto the tailing surface. On the advance, the dozer should push a full load and not push the entire load over the working face. The amount of material left should be small enough that it can be moved on the subsequent push out. It should also serve as a safety berm. Care needs to be taken to operate the dozer normal to the working face. Likewise, haul truck traffic should avoid travel adjacent and parallel to the working face and always maintain a safe distance from the working face. The trucks should turn and back toward the working face, dumping the load so that the toe of the dumped pile is about 20 feet from the working face.
- Subsequent lifts should be placed in the same manner for any working face adjacent to a slope.
- For rock being placed in a single lift over a previously placed lift of rockfill, a safety berm should be constructed at the crest of the advancing face and the haul truck backed toward the safety berm for dumping normal to the advancing face.
- Safety berms are maintained along each working or advancing face in keeping with mine safety protocol.

Also, as with any project, the construction is continuously observed to identify any abnormal soft areas, cracking, deformations at the toe of the slope, on the slope or at the crest or “waves” made as the haul trucks or other equipment travel on the fill surface.

3 ROTATOINAL, THIN-LAYER, AIR-DRIED TAILING DEPOSITION

The tailing is being placed by rotational, air-dried, thin-layer deposition to produce a denser, drier tailings deposit that increases the amount of tailing that can be contained within a given volume and increases the strength of the tailings deposit. The tailings distribution system is designed to accommodate up to 15,500 tpd at a 40 percent solids content. The tailing distribution system includes a tailing delivery pipeline around the perimeter of the facility with valves and drop bars at 125-foot centers. The drop bars extend from the discharge valves to the tailing surface. The drop bars are 6-inch-diameter pipes with a series of 4-inch-diameter holes drilled in the top of the pipe, through which the tailings slurry is deposited on the surface of the facility. This distribution system produces laminar flow of tailings over the surface of the facility. The tailing is deposited by sequentially rotating the point of deposition around the facility so that as the depth of deposited tailing reaches 4- to 6-inches in thickness, the point of deposition is moved or rotated to the next area of deposition. Usually about 8 to 10 of the drop bars are in use at any one time.

The surface area of the facility and tailing production rate are such that the most recently-deposited lift of tailing, preferably, will have a month or more to air dry and consolidate prior to placement of the next tailing layer. As the tailing dries, drying cracks form on the tailing surface, which indicate that the tailing is consolidating and increasing in density. The net result is a denser, drier, more stable tailing deposit, as demonstrated by indications that the pore pressures in the tailing facility, outside the limits of the water pool, are less than hydrostatic. This condition reduces the potential for loss of strength in the event of earthquake loading, as supported by the measured in-situ densities. The current tailing density near the point of deposition that has the most opportunity to dry averages 76 pcf, whereas near the supernatant pond, the density averages 69 pcf.

It should also be noted that the benefits of rotational, air-dried, thin-layer deposition are enhanced by the crew operating the tailing facility. Based on our observations made during the annual inspections, the crew clearly understands the deposition procedures and accordingly implements them. This develops the beneficial attributes in the deposited tailing described above. The facility is generally operated by a one operator, occasionally supported by one or two others.

4 TAILING PROPERTIES

4.0 *Tailings Gradation and Density History*

When the facility was commissioned, tailings from oxide ore pulp processed through the Juniper Mill were deposited in Cells A and B at a density of 90 pcf compared to the predicted drained and air dried density of 85 pcf. For comparison the predicted undrained density was 60 pcf. In November 1996, tailings from sulfide ore pulp processed in the new Sage Mill and autoclaves were first produced and added to the existing oxide millstream and deposited in Cell 1. The predicted undrained density was 45 pcf and the predicted drained and air-dried density was 80 pcf.

Based on the above it can be seen that the predicted densities compared fairly well with the in-situ densities and that there was a significant variance in the densities that was basically a function of the amount of fines and nature of the fines.

4.1 *Recently Deposited Tailing Classification and Density*

Based on index test results of the recently deposited tailing, there was no discernable difference in the tailings gradation based on samples from the beach near the point of deposition or near the supernatant pond or with depth. However, as would be expected, variations in average moisture contents and average dry density were noted between materials from near the supernatant pond with an average moisture content of about 51 percent and average dry density of about 69 pcf and materials in the tailings beach areas with an average moisture content of about 36 percent and average dry density of about 76 pcf.

4.2 *Permeability*

The consolidation test data was used to develop a hydraulic conductivity vs. effective stress profile, which estimated an average hydraulic conductivity of 2.5×10^{-7} centimeters per second (cm/s) (1×10^{-7} inches per second [in/s]). This value was used as input for the seepage analyses. Additionally, this testing indicates that at the end of consolidation the tailings are anticipated to reduce in hydraulic conductivity with increasing effective confining stress (i.e., increased depth of burial); however, the average was used for analyses presented herein to represent the vertical hydraulic conductivity of the tailings.

5 STABILITY ANALYSES

Slope stability for both the static and earthquake loading conditions were considered. The minimum static, drained, factor of safety considering steady-state conditions found for the downstream slope was 2.0 and upstream slope, prior to any tailing placement, was 1.9 for the raises evaluated versus the minimum of 1.4 required by Nevada Dam Safety. It should be noted that most other agencies, international design guidelines for tailings dams, and practitioners use 1.5 as the minimum factor of safety for these cases. The level of conservatism indicated by the factors of safety is reasonable. It is recommended that factors of safety in the range of 1.8 to 2.0 be used in the initial design as there are often changes in the materials or construction or operations that tend to reduce the factor of safety. If one has designed for the minimum value and there is a change, as there often is, the resulting factor of safety will be below the minimum. In this case additional raises are being considered so the factors of safety being above the minimums are supportive of the potential for significant raises. If the factor of safety used for the initial design was near the minimum value a new facility would likely have been needed that would have greatly increased the cost of tailing disposal.

Analyses of the upstream slope stability for selected embankment raises, prior to any tailing being deposited against the slope, under post-earthquake conditions was considered for both the Operating Based Earthquake (OBE), representing the 475-year probabilistic event, and Maximum Design Earthquake (MDE), representing the 2,475-year probabilistic event. Generally, the OBE is selected with input from the operator to estimate a level of damage and cost to repair the damage that is acceptable to the operator. The MDE is the earthquake that the structure can tolerate without the release of tailing or supernatant fluid.

The CPT data indicated that the tailings in the area on which the upstream raise is to be constructed should not liquefy under either the OBE or MDE. The other three sets of CPT data evaluated were adjacent to or near the supernatant pond. The analyses indicate that liquefaction would be unlikely under the OBE and that the top 5 to 15 feet of tailings might liquefy under the MDE. These results are reasonable as the tailing deposited around the perimeter gets the full benefit of densification created by the rotational, thin layer, air dried deposition and the drainage provided by the proximity to permeable rock fill embankment. The tailing near the supernatant pool is continually wet so does not gain the advantage. The average densities measured in the test work support this: the average density of the tailing near the crest was 76 pounds per cubic foot and near the water pond was 69 pounds per cubic foot.

For the downstream slope, assuming the tailing liquefied, the minimum factor of safety found was 1.9, which is well above the minimum commonly accepted value of 1.1. This high factor of safety is attributed to the massive compacted rockfill perimeter embankment and very dense alluvial foundation. The deformation analyses indicated there would be negligible deformation for both the OBE and MDE. This is also consistent with the massive compacted rockfill perimeter embankment and very dense alluvial foundation.

Consequently, the risk of significant damage to the upstream slope of the facility from the earthquakes evaluated appears to be low or nil given the following considerations:

- The OBE can be thought of as occurring on average about once every 475 years (i.e., a 10% probability of occurrence in a 50-year period) and the MDE about once every 2,475 years (i.e., a 2% probability of occurrence in a 50-year period).
- The level of damage to the upstream slope would be nil on the evaluation of the CPT data described above.

6 WATER MANAGEMENT

General

This section discusses the three areas of interest related to water management including (1) surface water diversion, (2) the supernatant pond and (3) under seepage. Hydrologic analyses for design of storm water management facilities were based on the regulatory criteria that indicate the primary fluid management system must be designed to be able to remain fully functional and fully contain all process fluids including accumulations resulting from a 24-hour storm event with a 25-year recurrence interval and to withstand the runoff from a 24-hour storm event with a 100-year recurrence interval. For this site, the 25-year storm has a rainfall of 2.1 inches and the 100-year storm 2.6 inches (Knight Piésold, 1996). Given that the difference in the storm events is small the 100 year 24 hour storm event was used as the design storm.

Surface Water Diversion.

The primary drainage crossing the site is Rabbit Creek. As part of the Cell 2 construction Rabbit Creek was diverted around the northeast side of the facility in a channel designed to pass the 24-hour 100-year storm event. The area around the northeast corner is such that if the 24-hour 100-year channel overflowed the natural topography is such that it can safely pass storms much larger than the design storm. The drainage areas on the other sides of the facility are small and the runoff diversion is provided by constructed channels.

Supernatant Pond

Water falling directly on the surface of the tailing will in part infiltrate into the tailing or runoff to the supernatant pond. The limits of the supernatant pond are set to provide a minimum of 3 feet of freeboard while containing the 24-hour 100-year storm.

Under Seepage

In 1999 as part of the evaluation of the Cell 3 expansion, a seepage analysis was performed to predict estimated seepage from each of the cells. Collected seepage reports to the underdrain seepage collection pond at the downstream side of the facility where underflow quantities are monitored.

It was estimated that flows from Cell 1/2 would be on the order of 430 gpm and from Cell 3 510 gpm. The average flows from Cell 1/2 from 2004 to 2013 were 231 gpm and the average for 2012 and 2013 was 128 gpm. For Cell 3 from 2004 to 2013 the average flow was 379 gpm and for 2012 and 2013 198 gpm. During the 2017 annual inspection the flow from Cell 1/2 was 137 gpm and Cell 3 131 gpm. This information is summarized in the following table.

Table 1. Estimated versus Measured Underseepage

Period	Cell 1/2 Seepage (gpm)	Cell 3 Seepage (gpm)
1999 Estimated Seepage Rates	430	510
2004 to 2013 Average	231	379
2012 and 2013 Average	128	198
September 25, 2017	137	131

The estimated seepage values compare well with the measured values. The measured seepage is reducing with time as would be expected as the vertical load on the lower tailing is increasing thus reducing the permeability and flow.

7 INSPECTIONS AND PERFORMANCE

7.1 *General*

The inspections and monitoring systems include:

- Daily observations by the operations personnel
- Periodic inspections by the site geotechnical group
- Annual inspections by the designers
- Groundwater monitoring wells
- Basin underdrain pore water pressure piezometers
- Flow-measuring flumes at the underdrainage pond
- Overflow alarm at the underdrainage pond
- Tailings distribution delivery pipeline pressure sensor

7.2 *Performance*

Juniper tailings storage facility is performing very well and in conformance with the design intent. A few key observations from the inspections related to seepage and stability are worthy of note. There is little, if any, indication of significant settlement of the embankment. There have been no indications of slope or foundation instability. For a structure of this size, there was remarkably little cracking in the crest associated with settlement of the tailing beneath the upstream portion of the embankment constructed over the tailings beach.

This is consistent with the expected performance of a well-compacted rockfill embankment founded on a dense alluvial deposit and an indication that the tailing itself had gained density and strength from the deposition method used and the procedures used to prepare the tailing surface for construction of the upstream portion of the embankment extending onto the tailing surface.

Additionally, the estimated seepage from the facility compares very closely with the seepage monitored and collected at the underdrain seepage collection pond indicating the underdrain system is performing as designed. There has been no indication of seepage in the area of the downstream slopes or the natural ground adjacent to the downstream slopes.

8 RECLAMATION

For ease of reclamation, the drained and air dried tailing deposition scheme has distinct benefits in comparison to other methods. It is the only slurry deposition method that the authors are currently aware of that is currently in use that leaves a consolidated tailing deposit for ease of reclamation. Usually, construction equipment can be operated on the tailing surface a few months after deposition has stopped up to near the limits of the supernatant pond. With subaqueous deposition the resulting deposits are generally saturated and low density subject to considerable long term consolidation after deposition ceases. The long term consolidation presents considerable challenges to design of a reclamation system.

For example, reclamation of the surface of the Big Springs subaerial tailings facility was accomplished with scrapers and low ground pressure dozers to grade the surface of the facility for drainage and placement of the cover system. Scrapers were able to operate directly on the graded surface to place the cover materials.

9 CLOSING - PERFORMANCE AND BENEFIT SUMMARY

There are a number of notable benefits associated with the design and construction of this facility that have made this a safe and secure structure, as well as, a well performing and cost-effective structure including the following:

- As is often the case, the initial facility was expanded to provide storage for additional tailing. In the initial design consideration should be given to opportunities to expand the facility.
- The facility location and design have been compatible with two major horizontal expansions and numerous vertical raises. This has provided a facility that has been able to be safely, and cost effectively expanded to provide additional tailing storage well beyond the storage need that was initially envisioned.
- Use of higher than minimum factors of safety for slope stability has proven beneficial for providing safe and secure facility expansions.
- Use of mine waste rock for embankment construction provided a low cost yet robust embankment.
- Modified centerline construction minimized the amount of material in the embankment and thus cost. Also, as additional stages were constructed the outer limits of tailing were moved inside the facility and over the basin and liner system constructed throughout the basin and on the upstream face of the initial stage negating the need for lining raises. This simplified construction and reduced costs.
- The rotational deposition system yielded cost savings with the increased storage created by air drying and hence compaction of the newly deposited tailing.
- Rotational deposition provided a stable foundation for the upstream slopes of the embankment raise.
- Under normal operating conditions only one operator is needed to operate the facility.
- The operators understand the general engineering concepts related to the TSF construction and tailing deposition leading to a well-managed and monitored facility.
- The facility design and size provided flexibility or ability to retain varying types of fine grained tailings ranging from silts to clayey silts.
- Comparison of the estimated seepage rate to measured seepage rates indicates that the underdrain system and liner are performing as designed.

Reclamation costs should be considerably lower with the use of air dried deposition in comparison to subaqueous or thicker layer deposition.

10 REFERENCES

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