DESIGN, PERMITTING, AND CONSTRUCTION ISSUES ASSOCIATED WITH CLOSURE OF THE PANNA MARIA URANIUM TAILINGS IMPOUNDMENT[1]

by

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Abstract. In 1992, Panna Maria Uranium Operations (PMUO) initiated licensing and engineering activities for closure of the Panna Maria mill and 150-acre tailings impoundment located in southeast Texas. Closure of the tailings impoundment is permitted by license amendment through the Texas Natural Resources Conservation Commission (TNRCC), and based on closure criteria outlined in Texas regulations. The closure plan for the Panna Maria tailings impoundment was submitted for Texas regulatory agency review in April 1993, with details of the closure plan modified in 1994, 1995, and 1996. The closure plan included a multi-layered cover over the regraded tailings surface which was designed for long-term isolation of tailings, reduction of radon emanation to regulated levels, and reduction of infiltration to TNRCC-accepted levels. The cover and embankment slope surfaces and surrounding areas were designed to provide acceptable erosional stability as compared to runoff velocities from the Probable Maximum Precipitation event. Cover materials were selected from on-site materials and evaluated for suitability based on permeability, radon attenuation, and soil dispersivity characteristics. Off-site materials were used when necessary. The cover over the tailings has a maximum slope of 0.5 percent, and the regraded embankment slopes outside the perimeter of the impoundment have a maximum slope of 20 percent. All reclaimed slopes are covered with topsoil and revegetated. A riprap-lined channel is to be used to convey runoff from within the perimeter of the reclaimed impoundment to the north of the impoundment.

Additional Key Words: reclamation, soil cover construction, mill tailings

Introduction

The Panna Maria mill was operated by Panna Maria Uranium Operations (PMUO) from 1979 to May 1992. The Panna Maria site is approximately 60 miles (96 km) southeast of San Antonio in Karnes County, Texas. The site is in a region of uranium mining and milling dating from the 1950's.

The site is in the south Texas Plains vegetation region, characterized by gently rolling hills covered with grasses and brushwood. Annual precipitation averages approximately 30 inches (760 mm) and annual pan evaporation averages approximately 80 inches (2032 mm). The site is within the San Antonio River watershed, one of the primary river systems in the region draining to the southeast into the Gulf of Mexico.

[1]Paper presented at the 1997 Annual Meeting of the American Society of Surface Mining and Reclamation, Austin, Texas, May 1997.

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The site is underlain by southeast-dipping Tertiary sediments, consisting primarily of poorly-consolidated siltstones, claystones, and fine-grained sandstones. In the site area, these sediments include the lower sequence of the Catahoula Formation, underlain by the Fashing and Tordilla Members of the Whitsett Formation of the Jackson Group. The Tordilla Member (consisting primarily of sands) contains the uranium mineralization that was mined at Panna Maria. The Catahoula and Fashing Members are the units immediately beneath the site and comprise the overburden materials removed during mining. Stockpiled overburden materials provided the primary borrow materials for reclamation.

This paper outlines the regulatory criteria for closure of the tailings pond, and discusses how site conditions, milling, tailings pond operation, and available construction materials influenced development of the plan. These factors are presented in the following sections.

Mining And Mill Description

The Panna Maria mines (named for the nearby historic Polish settlement of Panna Maria) are within the South Texas Uranium Region, an area of uranium occurrences in Miocene and younger sediments in the Gulf Coast basin. In this area, uranium mineralization occurred as a

Proceedings America Society of Mining and Reclamation, 1997 pp 601-610
DOI: 10.21000/JASMR97010601

https://doi.org/10.21000/JASMR980109601

roll-front deposit in marginal marine sediments. Five mine sites, totaling approximately 1,800 acres (728 ha), were developed by PMUO starting in 1977. The mines were operated until 1985 as open-pit structures, with ore and mine overburden hauled with trucks and scrapers. Mine sites were reclaimed on an ongoing basis by backfilling with overburden and revegetating the reclaimed surface. Reclamation of the final mine site (which was left open in anticipation of improved uranium market conditions) was completed in 1994.

The Panna Maria mill and associated facilities were constructed near the planned mine sites within a selected 560-acre (227 ha) area underlain by a clayey unit within the Catahoula Formation. This area is shown in Figure 1. PMUO operated the Panna Maria mill starting in 1979 for recovery of uranium as U_3O_8. The mill produced approximately 6.8 million tons (6.2 million tonnes) of tailings as a by-product of ore processing by an acid leach and solvent extraction process. The milling process included single- and double-stage sulfuric acid leach, liquid-solid separation, solvent extraction, ammonia precipitation, drying, and packaging.

Tailings Impoundment Description

The Panna Maria tailings pond site was selected based on proximity to the mill, as well as site hydrology and underlying geology (specifically the clayey unit within the Catahoula Formation). The impoundment was designed as a ring-dike structure, with tailings contained within a zoned earth embankment and on top of natural silts and clays. The tailings impoundment within the embankment centerline covered approximately 150 acres (61 ha) and was designed for an ultimate capacity for 10 million tons (9.1 million tonnes) of tailings. The tailings impoundment layout is shown in Figure 2.

The zoned earth embankment was constructed in one stage to a crest elevation of 375 feet (114 m). The embankment contained a central core that was keyed into underlying silts and clays. The embankment was constructed with 2:1 inside slopes and 3:1 outside slopes, with embankment heights varying with underlying topography and ranging from 30 to 60 feet (9 to 18 m).

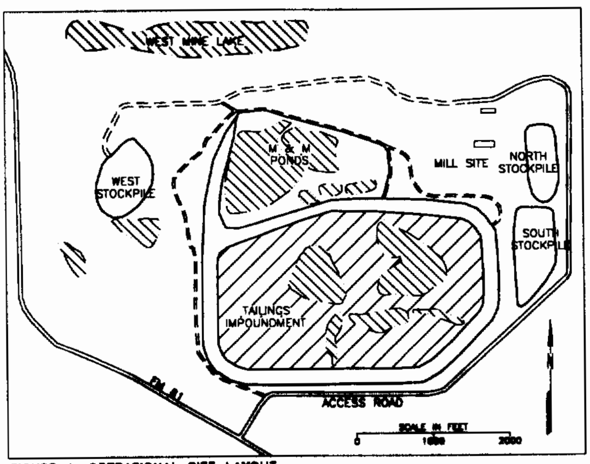

FIGURE 1. OPERATIONAL SITE LAYOUT

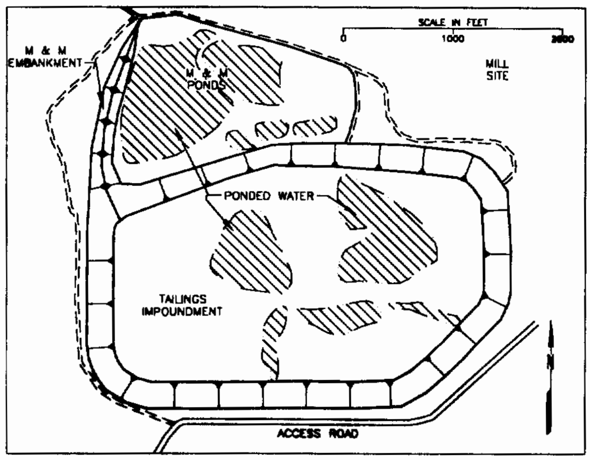

FIGURE 2. OPERATIONAL TAILINGS IMPOUNDMENT LAYOUT

The mill was initially shut down in 1985 with the completion of Panna Maria mine production. The mill was converted to an acid neutralization process to treat tailings pond water and make it usable for dust control during mine reclamation. The mill was modified for renewed start-up in 1986 to process ore from the Mount Taylor underground uranium mine in New Mexico. Milling of Mount Taylor ore was stopped for economic reasons in 1988, when the mill was modified to process ore from the Rhode Ranch open-pit uranium mine in Texas. Rhode Ranch uranium ore was processed until final mill shutdown in 1992.

Final tailings thicknesses within the impoundment ranged from approximately 10 to 50 feet (3 to 15 m). Of these tailings, approximately 77 percent of the total tonnage is from Panna Maria mine ore processing, which was discharged in the impoundment prior to 1986. The Panna Maria mine tailings form the bottom portion of the tailings stratigraphy. The next major tailings component is from Rhode Ranch ore processing (approximately 15 percent of the total), which was discharged into the impoundment from 1988 to 1992. The Rhode Ranch tailings form the top portion of the tailings stratigraphy and were the coarsest of the tailings discharged in the impoundment, containing approximately 20 percent fines (material passing the No. 200 sieve or 0.074-millimeter opening size). The tailings from Mount Taylor ore (less than 8 percent of the total) are generally between the Panna Maria mine and Rhode Ranch mine tailings in stratigraphy.

Closure Criteria And Plan Approval

The mill and tailings impoundment were permitted and operated under regulations administered by Texas regulatory agencies (TNRCC, 1990). Closure plan permitting and reclamation for the tailings impoundment was permitted as a Radioactive Materials License amendment administered by Texas Natural Resources Conservation Commission (TNRCC).

Closure criteria for the tailings impoundment are based on U.S. Environmental Protection Agency (EPA) reclamation standards (40 CFR 192) that are administered by the U.S. Nuclear Regulatory Commission (NRC) as technical criteria for reclamation (10 CFR 40, Appendix A). The technical criteria pertain to isolation and stabilization of the tailings. The release of radon gas (radon-222) from the cover over the tailings (generated by radioactive decay of radium-226 in the tailings) is limited to an average of 20 picocuries per square meter per second. Closure must be effective for a design period of 1,000 years, or at least 200 years. Furthermore, the reclaimed impoundment is to be designed without reliance on active maintenance. These criteria are met by design for extreme storm events, with conservative evaluation of erosional stability.

In addition, agreement on ground water protection issues with TNRCC resulted in limiting infiltration through the reclaimed tailings impoundment to an equivalent saturated hydraulic conductivity of $5x10^{-8}$ centimeters per second (cm/sec) or 0.05 feet per year (ft/yr).

In order to meet these criteria, the closure plan for the tailings impoundment included the following components:

1. Consolidating and covering the tailings with random fill.

2. Constructing a multi-layered cover system over the tailings, which is designed to reduce the rate of radon emanation and the rate of precipitation infiltration.

3. Regrading the original tailings embankment slopes to a maximum slope of 5:1.

4. Managing surface runoff from the reclaimed tailings impoundment with designed slopes, channels, and selected vegetation and rock protection for non-erosive conveyance of storm runoff.

5. Regrading and excavating (where necessary) soils in the mill site, ore storage, and pond areas with radium-226 concentrations above specified limits.

Pre-Closure Planning

In 1990 (two years prior to mill shutdown), PMUO started reclamation planning. This work included comparison of potential slope alternatives for the reclamation surface for the tailings impoundment and evaluation of reclamation cover systems. The planning provided guidance for water management for the final stages of tailings impoundment operation. This planning also resulted in discharge of tailings during the final years of operation in areas that were consistent with the planned reclamation surface, thereby reducing the amount of tailings regrading after mill shutdown.

Prior to mill shutdown, the water stored in the tailings impoundment was processed for recovery of uranium in the solvent extraction circuit in the mill, then neutralized with calcium carbonate from local sources of caliche. The neutralized water was stored in the solution storage ponds on site until the neutralization process was completed. These ponds, referred by PMUO as the M&M ponds, are shown in Figure 2. This processing and neutralization treatment was conducted in 1985 and also prior to mill shutdown in 1992. The latter stage of treatment neutralized approximately 100 million gallons (380,000 cubic meters) of water, which were discharged into the M&M ponds and then transferred back into the tailings impoundment.

The residual, neutralized tailings fluids were evaporated within the tailings impoundment. Due to the volume of water to be evaporated and the planned schedule for tailings pond closure, the rate of evaporation was optimized by spray systems and by construction of shallow evaporation ponds within the tailings impoundment. The shallow evaporation ponds were constructed at elevations consistent with the planned cover system, thereby reducing subsequent earthwork quantities.

Tailings Regrading And Covering

A key component of tailings pond closure was the method for initial covering of the tailings, providing a surface for earthmoving equipment and a foundation for subsequent cover system construction. As the first stage, causeways were constructed across the tailings impoundment with random fill. These causeways divided the impoundment into four cells and served as access roads for subsequent tailings regrading and covering. These areas are shown in Figure 3.

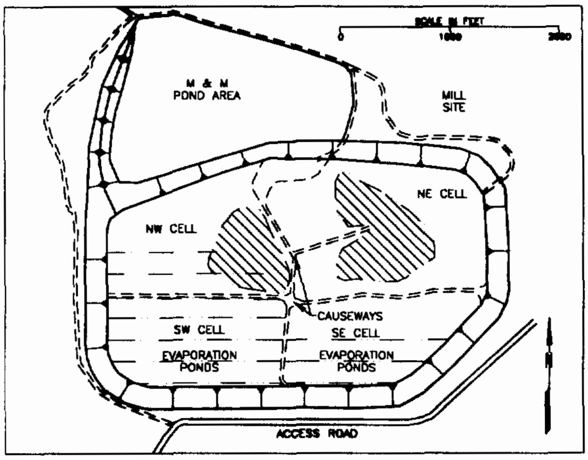

FIGURE 3. TAILINGS IMPOUNDMENT COVERING LAYOUT

From these causeways, a random fill or interim cover zone was constructed over the tailings using random fill soils from adjacent area cleanup and stockpiled soils not suitable for cover material. The random fill zone was an important component of the reclamation work, providing a firm base for cover system construction, a zone of separation between tailings and uncontaminated cover materials, and a fill zone to meet desired closure plan grades and elevations. The random fill zone was constructed with conventional earth moving equipment in tailings areas that had experienced sufficient consolidation to allow equipment travel.

In limited areas between the causeways, tailings were regraded to match the planned subgrade surface. Regrading was accomplished with low ground pressure equipment in tailings areas that were above the tailings water surface and had experienced sufficient consolidation to allow equipment travel.

From prediction of tailings settlement during closure plan design, the most significant component of tailings settlement was expected to be from initial settlement of the tailings slurry. The next most significant component of settlement was expected to be during tailings water evaporation and tailings regrading and covering, when the tailings experience the largest increase in effective stress since tailings discharge.

Actual tailings settlement was evaluated during the tailings regrading and covering stage. Additional random fill was added to compensate for this settlement, and settlement was correlated with the volume of additional random fill that was required. This evaluation showed that actual settlement was similar to predicted settlement. Actual settlement was not significantly large due to: discharge of the majority of tailings prior to 1985 (allowing sufficient time for consolidation of these tailings), the relatively coarse grind of the tailings, and the managed disposal of tailings in the later stages of operation.

Cover System

The tailings cover system is shown in Figure 4. The portion of the cover system above the random fill zone consisted of the components summarized below. The sources of cover materials were primarily the stockpiled mine overburden and the M&M pond embankment shown in Figure 1. These materials were evaluated for compaction, hydraulic conductivity, radon attenuation, and dispersivity prior to use in construction. Topsoil was obtained from existing stockpiles on site and had previously been evaluated (along with vegetation species) as part of the mine site reclamation work completed by PMUO.

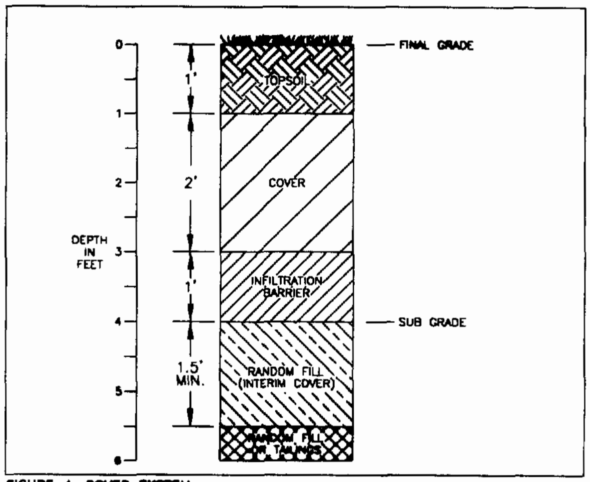

FIGURE 4. COVER SYSTEM

The total cover system thickness is a minimum of four feet, meeting design criteria for tailings isolation, radon attenuation, and reduction of infiltration. The four-foot cover thickness is also required to meet applicable Railroad Commission of Texas reclamation regulations. The cover system was keyed into the existing perimeter embankment, as shown in Figure 5.

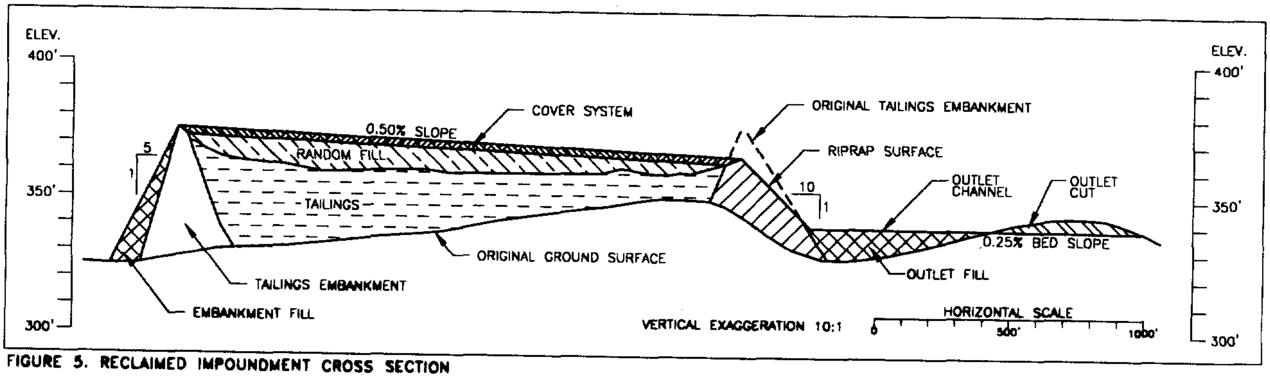

FIGURE 5. RECLAIMED IMPOUNDMENT CROSS SECTION

The lower layer of the cover system is the infiltration barrier, a one-foot thick zone of compacted soils consisting of selected materials designed to achieve an equivalent saturated hydraulic conductivity of 5×10^{-8} cm/sec (0.05 ft/yr). On-site clayey soils were evaluated and did not have sufficient clay content to consistently achieve the desired hydraulic conductivity. Two off-site clays were selected as additives to the on-site stockpiled overburden. The additives consisted of a sodium bentonite from western Texas (added at two percent by weight) and a silty clay from a sand washing operation near San Antonio (added at a minimum of five percent by weight).

The barrier was placed, mixed, and compacted with standard earthmoving equipment to standard compaction specifications (95 percent of Standard Proctor density and one percent below to three percent above optimum moisture content). Material specifications for the infiltration barrier included plasticity index and fines fraction requirements for the stockpile material, as well as for the two clay additives. Material specifications for the clay-amended mixture consisted of a percentage of fines of at least 45 percent and a plasticity index of at least 15. The minimum clay percentage by weight was converted to an equivalent volume per specified area for construction control. During construction, PMUO collected samples of completed infiltration barrier for permeability testing to confirm that the design value of less than 5×10^{-8} cm/sec was met.

The middle layer of the cover system is a two-foot thick zone of compacted, on-site materials to provide additional radon attenuation and protection of the infiltration barrier. This layer was placed and compacted with standard earthmoving equipment to standard compaction specifications (95 percent of Standard Proctor density and one percent below to three percent above optimum moisture content). Material specifications for this layer consisted of a percentage of fines of at least 30 to ensure desired radon attenuation characteristics.

The top layer of the cover system is a one-foot thick zone of topsoil for establishment of vegetation. The topsoil had been salvaged and stockpiled from initial mill site construction and overburden excavation. The topsoil was placed and prepared for revegetation.

Closure Drainage Plan

The drainage plan for the tailings impoundment area is shown in Figure 6. The cover surface over the reclaimed tailings impoundment slopes to the north at a maximum grade of 0.50 percent. Runoff from the north-sloping cover surface discharges in a controlled manner through a channel down to the natural ground surface and into the reclaimed West Mine Lake. Where the channel bed slope has a 10 percent slope and requires erosion protection, riprap was designed for the channel surface. Other reaches of the channel surface with less steep slopes were topsoiled and vegetated.

Drainage was evaluated for erosional stability according to guidelines documented in NRC (1990). This includes calculation of runoff velocities due to peak flow from the Probable Maximum Precipitation (PMP) event. This peak runoff velocity is compared with permissible non-erosive velocities and acceptable tractive forces on the reclaimed surface under varying conditions of vegetation quality.

The surrounding area was reclaimed in a manner that removed contaminated soils and established drainage for runoff away from and around the reclaimed tailings impoundment. The mill site area was regraded for runoff to drain to the north and into the reclaimed West Mine Lake (shown in Figure 6). Contaminated soils and other materials excavated from the surrounding reclaimed area were placed in the tailings impoundment as random fill (as discussed above). Contaminated soils were determined by radium-226 activity, at levels established by TNRCC. Unsalvageable materials from mill decommissioning were taken apart and buried in the tailings impoundment.

The initial tailings embankment outside slopes (constructed at slopes of 3:1) were regraded by cut-and-fill earthwork to a maximum slope of 5:1. The top surface of the reclaimed embankment was designed to be several feet higher than the top of the cover system surface to ensure that runoff will not overtop the reclaimed embankment crest. Embankment fill was placed in lifts of 12-inch maximum thickness and compacted to standard compaction specifications (90 percent of Standard Proctor density and two percent below to two percent above optimum moisture content). The final embankment slopes were covered with a one-foot thick layer of topsoil for establishment of vegetation.

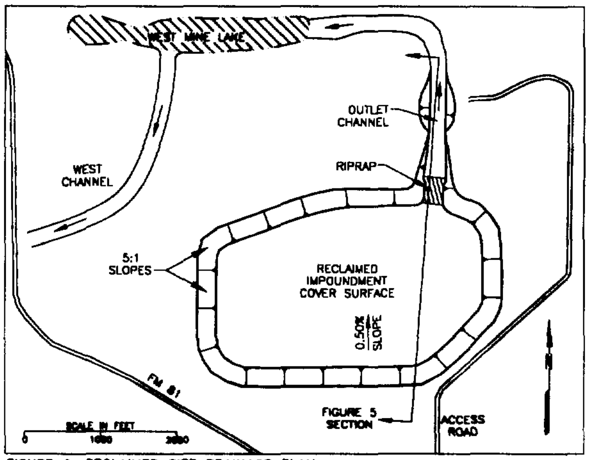

FIGURE 6. RECLAIMED SITE DRAINAGE PLAN

The reclaimed impoundment cover surface, reclaimed embankment slopes, and surrounding areas were covered with topsoil for establishment of vegetation. For all of the vegetated areas on site, species were selected for eventual establishment of a full, self-sustaining vegetative cover. These species consisted of King Ranch bluestem (*Bothriochloa ischaemum Var. songarica*), buffalograss (*Buchloe dactyloides*), sideoats grama (*Bouteloua curtipendula*), and kleingrass (*Panicum coloratum*) on gently sloping areas; and kleingrass and medio bluestem (*Dichanthium aristatum*) on embankment slopes and channel surfaces. Maintenance of these species and discouragement of woody or brushy species will be conducted by fertilizing and mowing.

Reclamation Schedule

After mill shutdown in 1992, PMUO started site closure with mill decommissioning and surrounding site regrading and cleanup. The closure plan was submitted by PMUO to TNRCC in 1993. Based on TNRCC comments, additional issues were evaluated and documented in an updated closure plan that was submitted to TNRCC in late 1994 (WWL, 1994). Many of the closure plan elements had been previously discussed with TNRCC prior to closure plan submittal. This allowed mill site decommissioning and reclamation to take place in late 1992 and 1993, and for M&M pond reclamation to start in 1993. Fill placement and regrading within the tailings impoundment was started in 1993 and was conducted concurrently with evaporation of remaining tailings water. Tailings impoundment reclamation work started in 1994 with regrading on the outside slopes of the tailings embankment. Cover system construction started along the southern side of the impoundment in late 1995.

Based on finalizing the clay-amended mixture design for the infiltration barrier, updated construction specifications were submitted by PMUO to TNRCC in 1995 (SMI, 1995). Adjustments to the outlet channel design on the north side of the impoundment were submitted by PMUO to TNRCC in 1996 (SMI, 1996).

Through 1996, tailings pond closure work has been conducted in a manner consistent with the closure plan and included embankment slope regrading, impoundment surface regrading, and cover construction. Outlet channel construction was started at the end of 1996. Completion of the cover system, outlet channel, and remaining closure plan components is scheduled for the end of 1997, with vegetation to be established by the end of 1998. Performance monitoring of the site will continue for a period of time after 1998, as established by TNRCC. Monitoring will include cover settlement, cover radon emanation, erosion, and ground water levels and quality.

Summary and Conclusions

The closure plan described in this paper is in the final stages of construction. The plan has met the design criteria administered by TNRCC and incorporated existing site conditions and on-site materials as much as possible to minimize construction costs. Final closure plan success will be assessed by post-closure performance monitoring. Following a prescribed post-closure monitoring period, the tailings impoundment site is to be transferred to the State of Texas.

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