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Review of Design Approaches Applicable to Dewatering Uranium Mill Tailings Disposal Pits

Prepared by P. J. Gutknecht, T. E. Gates

Pacific Northwest Laboratory
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Division of Health, Siting and Waste Management
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U.S. Nuclear Regulatory Commission
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SUMMARY

This report is a review of design approaches in the literature that may be applicable to uranium mill tailings drainage. Tailings dewatering is required in the deep mined-out pits used for wet tailings disposal. Agricultural drainage theory is reviewed because it is seen as the most applicable technology. It is concluded that the standard drain-pipe envelope design criteria should be easily adapted. The differences in dewatering objectives and physical characteristics between agricultural and tailings drainage systems prevent direct technology transfer with respect to drain spacing calculations. Recommendations for further research are based on the drainage features unique to uranium mill tailings. It is recommended that transient solutions be applied to describe liquid movement through saturated and partially saturated tailings. Modeling should be used to evaluate the benefits of drainage design approaches after careful consideration of potential construction problems.

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1.0 INTRODUCTION

Current research is addressing the technical issues of concern with respect to uranium mill tailings operations. This includes prediction, evaluation and limitation of environmental impacts of tailings and associated gas emissions. The objective of a large part of this research is to enable earlier cover placement of long term covers on tailings pits to stop atmospheric releases of radon gas. However, techniques must be developed for efficient drainage and consolidation of a tailings pit to enable early cover placement. Drainage is necessary because the tailings contain excessive moisture required for easy transport to disposal areas.

This report is a review of design approaches that may be applicable to uranium mill tailings underdrainage. Its purpose is to review state-of-the-art drainage technology in the literature as well as to point out drainage features unique to uranium milling tailings pits. This will indicate future research needs for developing a useable methodology that will be updated with the actual experience of the future operating systems.

The report is limited to a review of design approaches and suggestions for further work toward development of tailings drainage technology. Recommendations for the design of tailings drainage systems are not made at this time.

The following section gives conclusions about the applicability of related technology and recommendations for further research based on drainage features unique to uranium mill tailings. Drainage system design is discussed in Section 3.0, including subsections on drain spacing, capacity and envelope design. Sections 4.0 and 5.0 discuss drain construction and maintenance concerns, respectively.

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2.0 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Conclusions have been made about the applicability of agricultural drainage technology to the dewatering of uranium mill tailings pits. These conclusions are discussed below.

- Criteria for gravel envelopes are well established in agricultural drainage practice as well as geotechnical engineering and should be easily adapted to tailings dewatering. The hydraulic gradients expected in tailings, however, are much higher than those seen in agricultural drainage.
- Criteria for the selection of synthetic envelope materials are still preliminary due to the short record of use for these materials. Adaptation to tailings dewatering should be easy. A choice of fabrics best suited to an uranium mill tailings environment will have to be made.
- Experience in agriculture has shown that care must be taken to prevent segregation of the graded envelope materials during placement around drains. Synthetic envelopes must be protected from sunlight and/or tearing during storage and handling. Experience is lacking in construction problems unique to tailings dewatering beyond these precautions for envelope materials.
- Drain spacing can be calculated from the tailings hydraulic conductivity, the liquid infiltration rate and desired drawdown of the saturation level. A sufficient drain-pipe diameter is required for the resulting flow. It is not considered conservative to apply the agricultural practice of increasing the drain spacing when the effective diameter of the drain is increased with an envelope. Modeling has shown that the increase, due to envelopes, allowed in agricultural drain spacing is not as great as previously reported in the literature.

- Many of the available drainage analyses for both steady state and transient conditions assume horizontal flow into the drains, which is a fair approximation for agricultural drainage. The primary flow into agricultural drains is expected to be horizontal because the permeability in that direction is believed to be much greater than the vertical permeability. This anisotropy would occur in tailings due to the sluicing of tailings into the pit which creates depositional layers of differing permeability. Therefore, horizontal flow is expected to predominate even though the vertical dimension of the pit is greater than that of the agricultural drainage system.

RECOMMENDATIONS

Drainage features unique to uranium mill tailings form the basis for research necessary in the development of underdrainage technology. In the absence of actual tailings dewatering experience, state-of-the-art technology can only offer methodologies that have proven useful in related fields of study.

This paper has reviewed agricultural drainage theory as the most applicable, although certain differences still exist in drainage objectives and the physical and chemical characteristics of the two drainage problems. These differences are summarized below along with a recommendation for future research in each area.

- The differences between objectives of tailings dewatering and those of agricultural drainage must be considered. Agricultural drainage is employed to keep the water table at a depth favorable to crop growth. Tailings drainage is aimed at reducing the moisture content as much as possible to reduce potential seepage from the pit and enable the consolidation required for earlier cover placement to reduce radon gas emissions. Transient solutions should be applied to drainage of tailings pits because the "water table" is lowering with time. The simulation of saturated and partially saturated flow to the drains is also necessary for describing the moisture content throughout the profile.

- Alternating layers of slime and sand-type materials in the tailings occur due to sluicing techniques. These layers will have differing permeabilities and saturation characteristics. Agricultural drainage theory must be carefully examined because it employs an assumption that the media being drained is homogeneous.
- The careful consideration of potential construction problems should be prerequisite to the development of uranium mill tailings drainage design. The construction of a dewatering system for a tailings pit is completely different than that of an agricultural drainage system. Agricultural drains and envelopes are placed in excavated trenches and covered with a few feet of soil. Tailings drains and sumps must be constructed before and during placement of tailings in the pit. Alternate drain layouts, such as multi-level systems, can be evaluated with modeling for benefits in drainage performance.
- The drains will logically exit to a single sump which will be pumped at defined intervals. Excess liquid required in tailings transport to the pit must be dealt with during filling and not allowed to fill the drain sump areas. Sedimentation or particles suspended in the moving liquid will settle in the sump and clog drain outlets to the sump, rendering the system inoperable. It is recommended that design, construction and operation procedures be developed to avoid this problem.
- Laboratory or field tests are recommended to establish the integrity of drainage system materials in a uranium mill tailings environment. Design of drains and envelopes should take into account the maximum allowable velocities through openings to prevent mineral deposition or other damage, the expected loadings, and the chemical differences between agricultural and tailings drainage water.
- As tailings dewatering practice begins, it is recommended that systems in operation be evaluated for drainage performance with regard to drain discharge, material stability and construction methodology. Technology development can be aided by studying drainage design approaches and the resulting system performance.

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3.0 DRAINAGE SYSTEM DESIGN

In the last 20 years, it has become apparent that there are many difficulties involved in uranium mill tailings dewatering. This is particularly true with regards to drain positioning, materials used, and the placement of tailings immediately surrounding the drains.

In the course of evaluating the most effective approach to dewatering uranium mill tailings in deep pits, saturated and partially saturated flow should be simulated. It is believed that saturated flow only occurs early in the drainage of a deep pit and, therefore, an evaluation of the partially saturated flow is very important. An analysis of saturated flow, partially saturated flow and porous media settlement during drainage would be the most desirable way to approach drainge system design. A numerical solution by Skaggs and Tang (1979) simulates two-dimensional water movement toward agricultural drains in saturated and unsaturated zones. Narasimhan (1977) presents the theory of the TRUST computer code for numerically simulating the movement of water in variably saturated porous media, including vertical consolidation of the media.

Van Zyl and Robertson (1980) discuss subsurface drainage design, construction, and management considerations for uranium mill tailings impoundments as found in state-of-the-art technology, which is primarily that of agricultural drainage theory. This technology does not, however, consider media settlement during drainage.

3.1 DRAIN SPACING AND CAPACITY

Agricultural drainage theory describes the flow of water in an idealized soil-water system (Luthin 1973). The actual field problem is simplified to enable a mathematical solution which therefore only approximates field conditions. The assumptions made in agricultural drainage theory must be compared to the uranium mill tailings dewatering problem to evaluate the theory's usefulness. It may be that the theory can only provide a first approximation to the proper design.

Steady state and transient theories exist for describing the flow of water through the soil. The actual field situation for uranium mill tailings dewatering will depend on disposal practices. During pit filling with ponded water on the surface, a constant infiltration of liquid will tend to occur, possibly holding the moisture constant, which means that the pit is kept essentially saturated in a near steady state condition. When tailings disposal is completed the saturated water level will continue to drop in a transient condition below the tailings surface. Theory for steady state and transient solutions are discussed in the following subsections.

3.1.1 Steady State Solutions

The methodology recommended by Van Zyl and Robertson (1980) for calculating drain spacing and capacity is taken from agricultural drainage theory which describes the water table in equilibrium with rainfall or irrigation water. The methodology, developed by Dr. S. B. Hooghoudt of the Netherlands, uses the Dupuit-Forchheimer assumption which states that hydraulic gradient at any point is equal to the slope of the water table above that point. This implies that water flows horizontally, which in the shallow agricultural drainage systems, is true midway between drains where the water table is nearly flat. The resulting equations satisfactorily yield values within 10% of the true values of total flow into the drains for the agricultural drainage system (Luthin 1973).

Van Zyl and Robertson (1980) considered only solutions for homogeneous, isotropic soil subjected to steady state flow. This is a simplifying assumption that will not completely represent actual tailings drainage. The drains are assumed to be directly on the impermeable layer which is the pit liner. This is a reasonable assumption since the most liquid can be drained when drains are placed at the lowest possible position. Water is assumed to infiltrate at a constant rate, W, under partially saturated conditions to the water table, Figure 1. This assumption will hold during pit filling, but the infiltration rate will not remain constant after completion of tailings disposal.

A discussion with Dirk Van Zyl, of Steffen, Robertson and Kirsten (Colorado), Inc., revealed the reasoning behind the approach described in his paper (Van Zyl and Robertson 1980). He believes that after an initial drainage period, the fully saturated condition becomes a partially saturated-saturated situation, as shown in Figure 1, because the horizontal permeability is expected to be greater than the vertical permeability in the tailings impoundment. This is due to disposal techniques and layering of tailings which may contain slimes. Therefore, partially saturated flow above the phreatic surface continues to feed the saturated flow toward the drains, which can be represented as horizontal flow. The flow rate, q, into a unit length of drain can be estimated from:

$$q = \frac{4kt^2}{s} \tag{1}$$

where k, t and s are shown in Figure 1. The coefficient of permeability, k, is a measure of the hydraulic conductivity of the material in units of length per time, t is the depth from the water table to an impermeable layer and s is the drain spacing. The required drain diameter is controlled by the hydraulic conductivity of the finest layer (smallest grains) in the drain envelope or tailings and the flow rate through the tailings, W. A simplified relationship, assuming complete drawdown at the drain, can be written as:

$$t^2 = \frac{Ws^2}{4k} \tag{2}$$

where W is less than k due to layers of slimes in the tailings. The permeability of the coarsest layer is k, while W is controlled by the layer of lowest permeability. If it is assumed that $W = 0.001k$, then $t = 0.016s$ for spacing estimates (Van Zyl and Robertson 1980).

Kirkham's formula was developed in 1958 using exact mathematical procedures. Some of Hooghoudt's assumptions were avoided, although the results are much more complicated. Solutions of the two equations were shown to differ by less than 5% (Luthin 1973). Kirkham's solution does, however, indicate that flow into a drain with water ponded on the surface is independent of spacing of

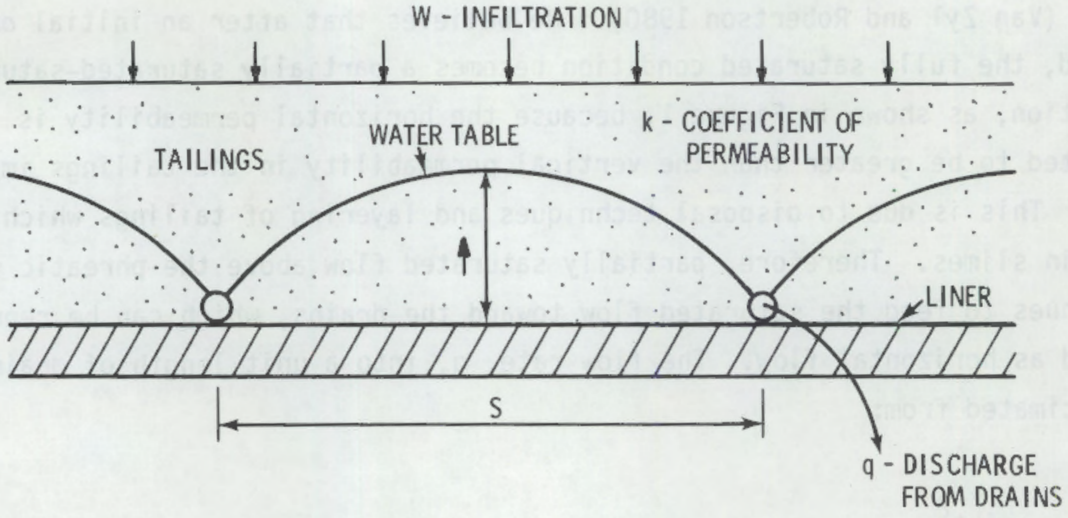


FIGURE 1. Flow Into Parallel Drains on Liner
(Van Zyl and Robertson 1980)

the drains as long as they are more than 20 ft apart. Therefore, a change in spacing does not affect the flow rate into a particular size drain in a given media provided that another drain is not located within 20 ft.

Drain-pipe capacities are estimated with Manning's formula:

$$q = \frac{1.486}{n} R^{2/3} S^{1/2} A \qquad (3)$$

where

q = flow rate in cubic feet per second

n = Mannings Roughness Coefficient

$R = A/P$, hydraulic radius of pipe in feet

A = Area of pipe in square feet

P = Wetted perimeter of pipe in feet

S = Hydraulic slope of pipe

Typical values of n for various drain pipe materials are given in Table 1. This equation should hold as well in tailings drain-pipes as in agricultural drains.

TABLE 1. Typical Values of Mannings 'n' (Van Zyl and Robertson 1980)

Material	Min.	Design	Max.
Asbestos Cement		0.009	
Cast iron, coated	0.011	0.013	0.014
Cast iron, uncoated	0.012		0.015
Clay or concrete drain tile (4-12 in.)	0.011	0.017	0.017
Concrete	0.010	0.014	0.017
Corrugated plastic	0.013	0.015	0.017
Metal, corrugated	0.021	0.025	0.0255
Steel, riveted and spiral	0.013	0.016	0.017
Vitrified sewer pipe	0.010	0.014	0.017
Wood stave	0.010	0.013	
Wrought iron, black	0.012		0.015
Wrought iron, galvanized	0.013	0.016	0.017

3.1.2 Transient Solutions

The United States Bureau of Reclamation, in particular R. D. Glover of their staff, has developed equations to describe the movement of the water table through the soil as a transient condition (Luthin 1973). This means that the hydraulic head at any point in the soil is changing with time and is not in equilibrium with rainfall or irrigation water. This would appear to be the situation in a tailings pit when disposal is completed. The drain spacing solution currently recommended is based on the assumption that the water table initially has a shape that corresponds to a fourth degree parabola, although the drain spacing obtained with the formula is little different than that based on an initially flat water table. The fourth-degree parabola is believed to better represent the true situation. The equation is:

$$H = \frac{192}{\pi^3} \sum_{n=1,3,5}^{\infty} (-1)^{(n-1)/2} \frac{n^2 - 8/\pi^2}{n^5} \exp\left(-\frac{\pi^2 n^2 \alpha t}{L^2}\right) \tag{4}$$

where

H = water-table height above drain at midpoint between drains

$\alpha = kD/s$

k = hydraulic conductivity (ft/day)

D = average depth of flow region ($d + y_o/2$, Figure 2)

s = specific yield (percent by volume) of media being drained

L = drain spacing (ft)

t = drainout time (days)

y_o and y = midpoint to water table height at beginning and end of drainout period (ft)

d = distance from drain to barrier (ft)

An approximate solution may be taken from the first term only. Curves showing the relationship between appropriate dimensionless parameters have been developed with this solution. Figure 2 shows the condition for which the curve in Figure 3 is valid, that of drains at a distance, d, above the impermeable barrier. Figure 4 shows the condition for the curve in Figure 5, that of drains on the barrier. Solutions for the condition of Figure 2 may be useful if construction of the drainage system does not allow drain placement directly on the pit liner. Inflow to an individual drain is dependent on the depth to the barrier unless the layer is more than 2 ft below the drain (Luthin 1973). Decreasing distances from 2 to 0 ft will decrease the flow rate into a drain accordingly.

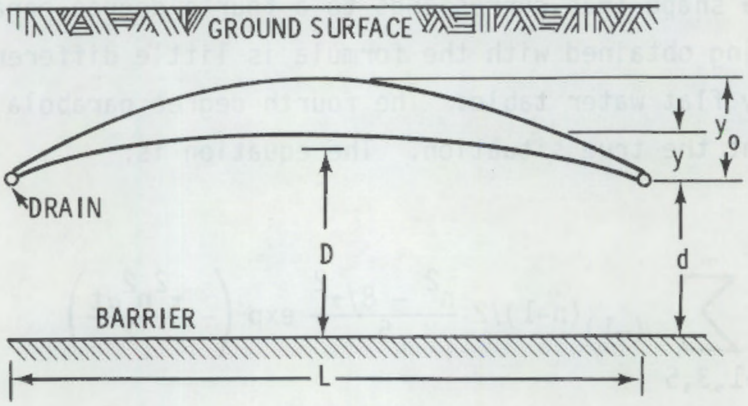


FIGURE 2. Variables for Drainage System Where Drains are not on Barrier (Luthin 1973)

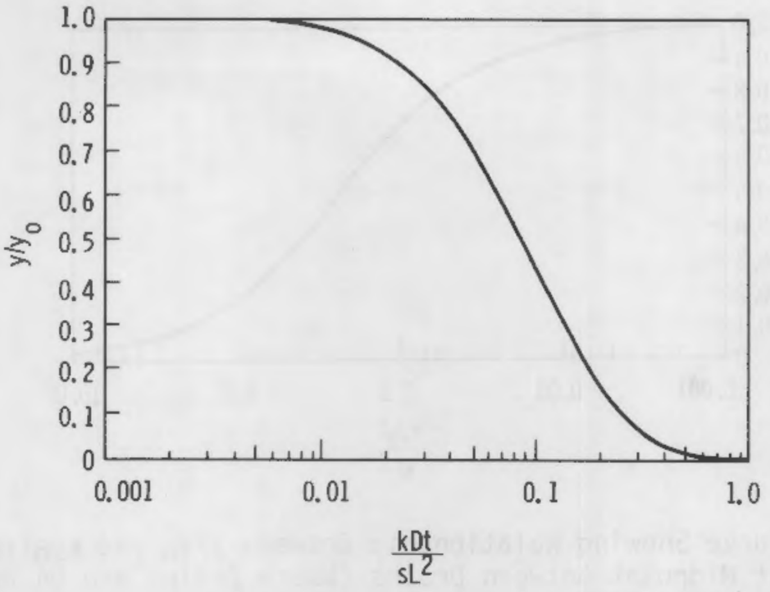


FIGURE 3. Curve Showing Relationship Between y/y_0 and kDt/sL^2 at Midpoint Between Drains (Where Drains are not on Barrier) (Luthin 1973)

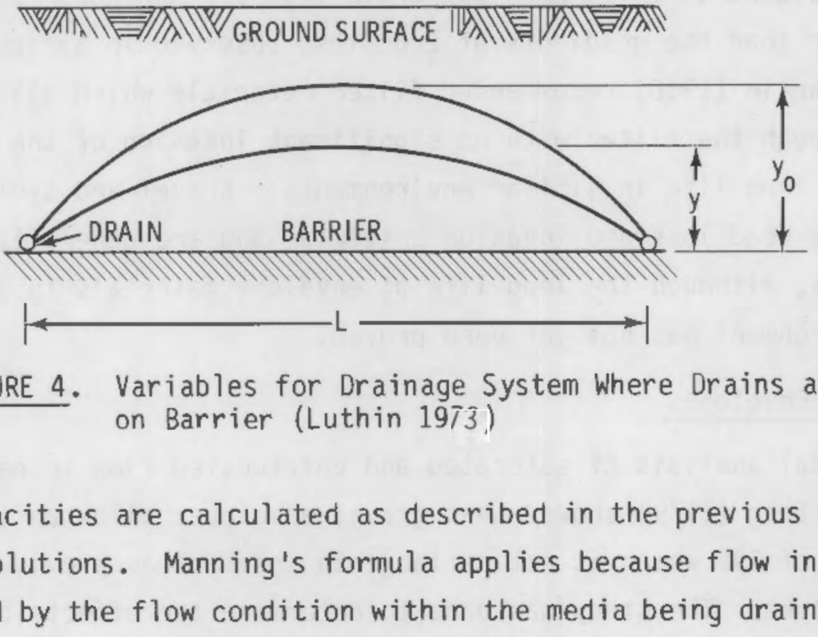


FIGURE 4. Variables for Drainage System Where Drains are on Barrier (Luthin 1973)

Drain capacities are calculated as described in the previous section on steady state solutions. Manning's formula applies because flow in the drain is not effected by the flow condition within the media being drained.

3.2 DRAIN ENVELOPES

Envelopes or "filters" are required around drains to prevent washing or piping of the tailings into the drain which would result in clogging. Tailings are more susceptible to piping than materials used in earthen dams due to their lack of initial interlocking friction or cohesion (Charlie and Martin 1980).

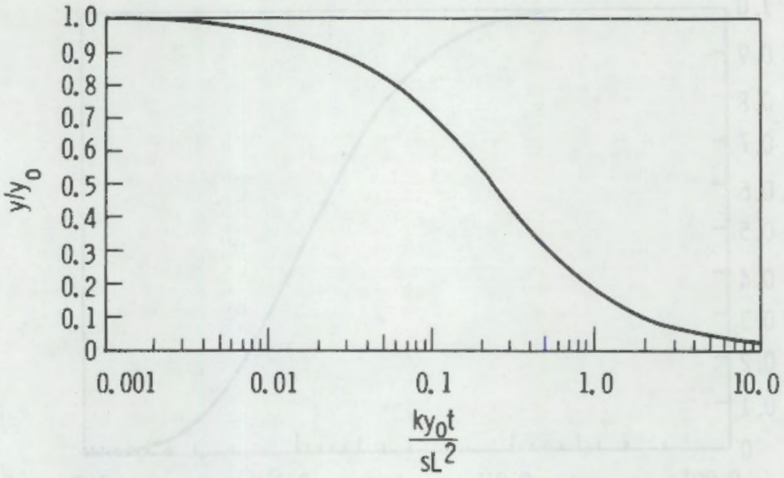


FIGURE 5. Curve Showing Relationship Between y/y_0 and ky_0t/sL^2 at Midpoint Between Drains (Where Drains are on Barrier (Luthin 1973)

The filter criteria recommended below are based on the high flow gradients of 10 to 50 assumed to exist near the drain (Van Zyl and Robertson 1980). This is much higher than the gradients of 1 or less observed in agricultural drains. Charlie and Martin (1980) recommended filter materials which allow only a small head loss through the filter with no significant invasion of the tailings and have a proven long life in similar environments. Gravel and synthetic envelopes meet the head loss and invasion criteria, and are generally employed for drainage needs, although the long life of envelope materials in a uranium mill tailings environment has not yet been proven.

3.2.1 Gravel Envelopes

A numerical analysis of saturated and unsaturated flow to parallel drains by Skaggs and Tang (1979) showed that gravel envelopes allow an increase in drain spacing of 29% which is not as large an increase as previously reported in the literature. The study was done to determine the effects of drain diameter, openings and envelopes on water table drawdown. These solutions do not require the previous simplifying assumptions regarding two-dimensional flow, convergence near the drain and unsaturated flow above the water table. The water table is assumed to be initially at the surface and the profile saturated. Two-dimensional water movement in saturated and unsaturated zones is characterized by the equation. In addition to the drain spacing conclusion, the water table drawdown rate was found to be relatively insensitive to changes of one or two sizes in drain diameter, although it is dependent on spacing, depth and hydraulic soil properties.

Van Zyl and Robertson (1980) give some general rules for gravel envelope design. First, the drainage material must be reasonably graded and free of substances which could change the permeability with time. Therefore, the coefficient of uniformity, D_{60}/D_{10}, must be at least 4 for gravel and at least 6 for sand. (D_{60}, which corresponds to the 60% finer size on a grain-size distribution curve, is the maximum diameter of grain representing 60% of the gravel by weight.) Secondly, the coefficient of curvature, $(D_{30})^2/D_{10}D_{60}$, must be between 1 and 3. A third rule states that all materials should pass the 1-1/2 in. sieve and not more than 5% should pass the No. 50 (U.S.) sieve. The maximum size for a lower envelope is 3/8 in. while the smallest size for the upper envelope is the No. 30 (U.S.) sieve. Figure 6 shows some gravel envelopes for various base materials.

The design criteria (Van Zyl and Robertson 1980) are:

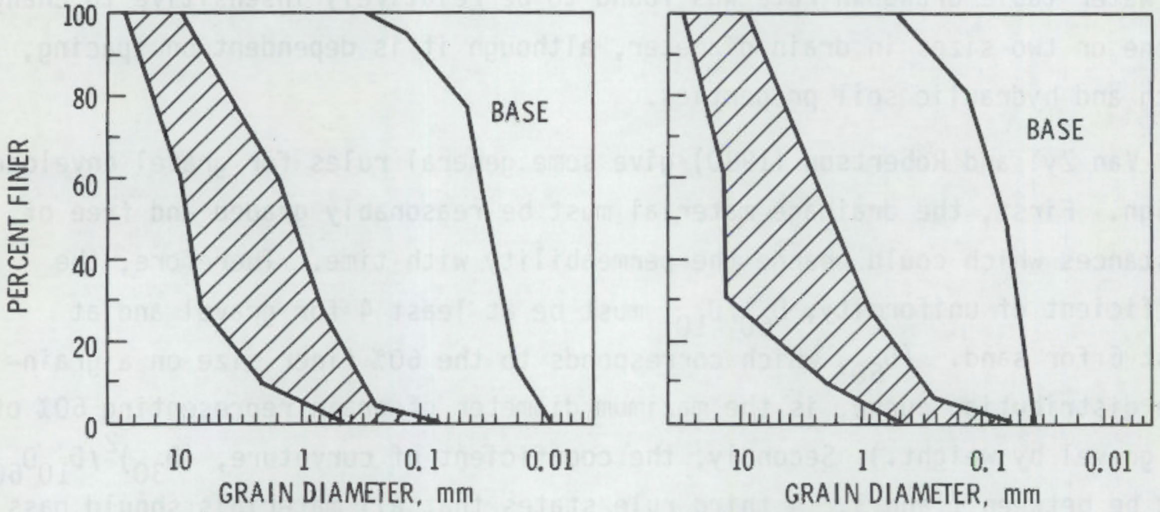
$$\frac{D_{15}\text{ filter}}{D_{85}\text{ base}} < 5 \qquad (5)$$

$$5 \leq \frac{D_{15}\text{ filter}}{D_{15}\text{ base}} \leq 20 \qquad (6)$$

$$\frac{D_{50}\text{ filter}}{D_{50}\text{ base}} < 25 \qquad (7)$$

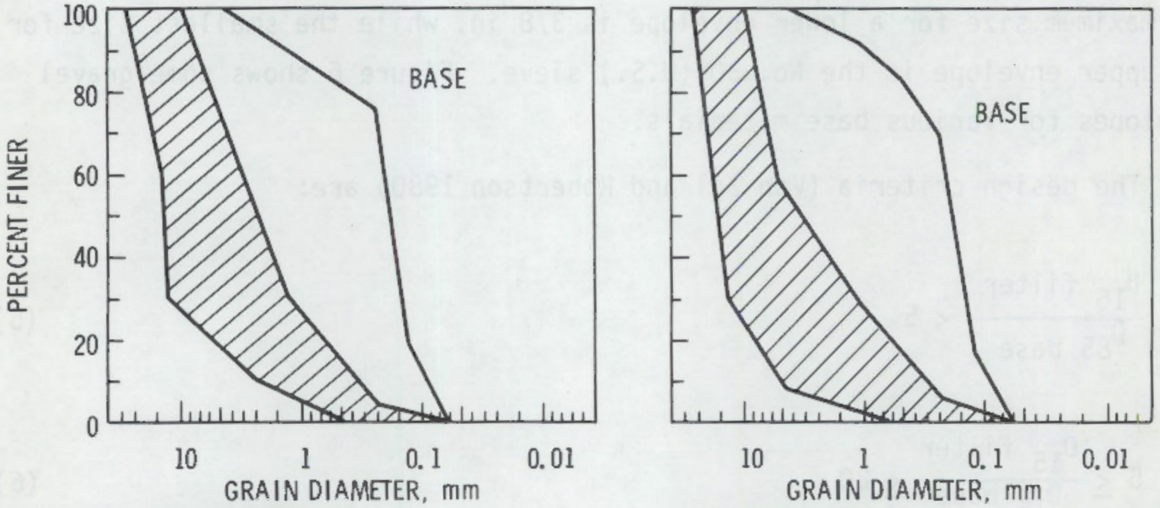
The filter should be graded smoothly and be a filter within itself (Charlie and Martin 1980):

$$\frac{D_{85}\text{ filter}}{D_{15}\text{ filter}} < 5 \qquad (8)$$



a) COARSE SILT LOAM

b) VERY FINE SAND



c) MEDIUM SAND

d) COARSE SAND

FIGURE 6. Examples of Gravel Envelopes for Various Base Materials (Winger and Ryan 1971)

Also, the grain size criterion for the filter nearest the pipe in relation to pipe slots or openings is, according to Charlie and Martin (1980):

$$\frac{D_{85}\ \text{filter}}{\text{maximum opening in pipe}} \geq 2 \qquad (9)$$

3.2.2 Synthetic Envelopes

Synthetic filters are woven or nonwoven materials called geotextiles, plastic filter, filter fabric or cloth filter. They are frequently only 1 mm thick and, therefore, must be protected from tearing during handling and storage. Different types of fabrics have different limitations and may be affected by ultraviolet light, alkalies, acidic materials or oil. Records on synthetics are not long enough to predict their performance in an uranium mill tailing environment. A tentative design criterion (Van Zyl and Robertson 1980), as stated above for filters next to pipes, is:

$$\frac{D_{85} \text{ of fine material next to pipe}}{\text{openings in woven textile}} \geq 2 \ . \tag{10}$$

Willardson and Walker (1979) discuss tests conducted to evaluate the response of synthetic drain envelope materials to problem soils needing drainage. Uniform, one-dimensional flow was provided through soil samples with the envelope material placed at the outlet end of the permeameter. No granular material was placed between the soil and geotextile. Any movement of particles with the water flowing through the envelope could be observed at the outlet. Inlet, outlet and hydraulic pressures and flows were measured and noted at equilibrium. Internal hydraulic gradients, hydraulic conductivity and head loss through the envelope were calculated. Flow rates were increased until failure, which means that continuous piping of soil or a significant reduction in system permeability occurred. The hydraulic failure gradients observed for the soils shown in Figure 7, described by the Soil Conservation Service as difficult to drain, were in the range of 2 to 8 for the synthetic envelope materials. This range is below the gradients expected in tailings drainage. A Soil Conservation Service guideline predicts that soils with greater than 40 silt sized particles (0.075 to 0.002 mm) will clog any geotextile material (USDA 1977). All five soils used in these tests are in that category.

A grading curve derived from South African gold/uranium tailings (labeled VILLAGE MAIN and BLYVOORUITZICHT in Figure 8), applicable to tailings impoundments (Robertson et al. 1978), was compared with the curves of the soils tested

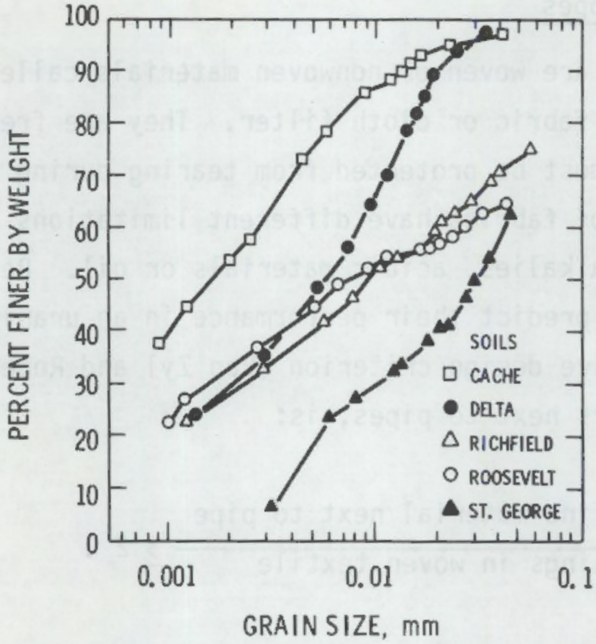


FIGURE 7. Soil Particle Size Distribution for Soils Used in Testing (Willardson and Walker 1979)

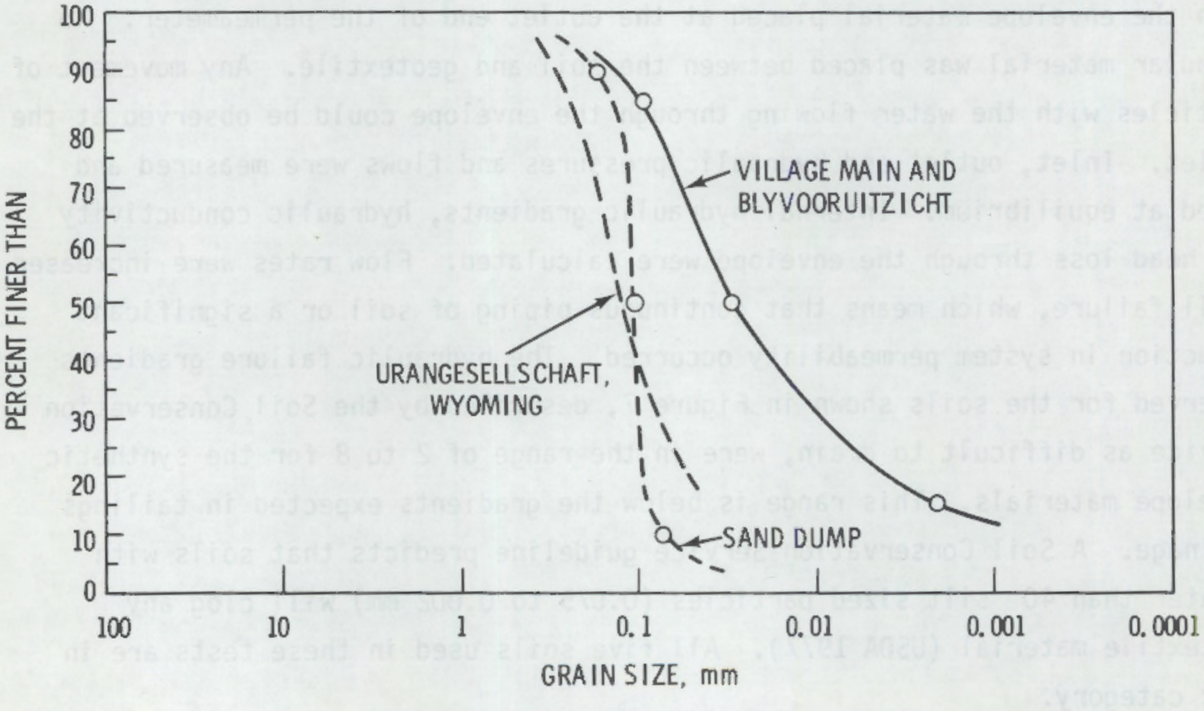


FIGURE 8. Grading Applicable to Tailings Impoundment (Robertson et al. 1978)

above. (Note that the grain size scale is reversed from that in Figure 7.) Unfortunately, the curve matched very closely with one tested soil in particular, the St. George of Utah, which had the lowest failure gradients, or worst performance, in the experiment. This would imply envelopes used in a tailings environment would not perform satisfactorily. However, the grading curve shown for tailings from a Wyoming mine does not match any of the tested soils or show 40% silt sized particles. The Wyoming tailings may be more representative of American tailings and therefore indicate a more optimistic prognosis.

Willardson and Walker (1979) also showed results of earlier analytical solutions for water flow toward drains for a ponded water case with fully saturated soil. Decreasing the drain depth or increasing the drain diameter (or envelope thickness) will both serve to reduce the gradient at the drain surface. Later work showed that a decrease in drain spacing also had this effect but that relatively high gradients can develop near drains that flow partially full. A larger envelope thickness has the same effect as a diameter increase and is recommended for unstable soils.

Tests done in Canada on synthetic filter materials used in agricultural drainage were made in such a way to simulate radial flow into drains (Broughton and English 1977). The soil used was a "troublesome" fine Bainsville sand which has only about 10% finer than silt-sized particles. Flow rates dropped significantly during the first 30 days, then leveled out at varying rates for the different filters. There were slight increases in drainage rates after short periods of no flow. The resulting flow rates through the filters seemed reasonably consistent with the field hydraulic conductivity of the fine sand. Microbial growth and air coming out of solution were eliminated as primary reasons for flow reduction which implies that fine soil particles are forming a filter cake in the soil outside the filter material. Although filter cake buildup is suspected as the cause for flow decrease, it could not be detected with a microscope. The silt and very fine sand that came through the filter materials settled in the corrugations at the bottom of the perforated plastic drain tubing used, but never filled up to the base of the corrugations during 120 inches of infiltration water.

Broughton and English (1977) report that filters of closely woven or hydrophobic material did not resist the probable flow into drains as they resisted the flow of pure water. Therefore, the primary resistance to flow in drains is due to the media being drained rather than the filter material. Recent studies indicate the percentage of fines in soil layers adjacent to geotextiles should be limited to prevent clogging. Therefore, a granular material having not more than 20% passing the No. 200 sieve should be used between the tailings and geotextile (Van Zyl and Robertson 1980). The geotextile should be sufficiently overlapped on drainage blankets or pipes. The top side of a drain using geotextile filter material should be covered with at least 4 in. of granular filter material (special filter sands or coarse tailings) to prevent direct washing of tailings across the geotextile. Figure 9 shows a typical drain of this design to be used in a parallel drain system or as an outlet drain in blanket drain design.

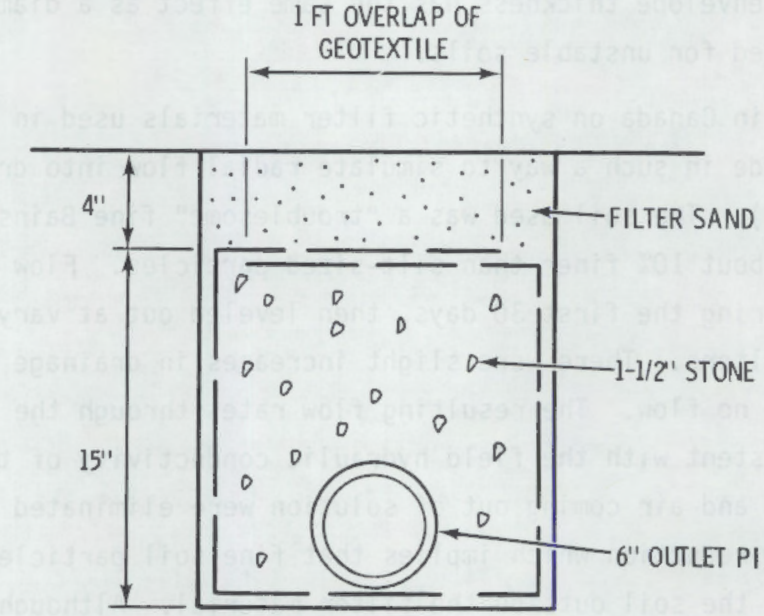


FIGURE 9. Typical Drain Detail (Van Zyl and Robertson 1980)

4.0 CONSTRUCTION OF THE DRAINAGE SYSTEM

Construction of a uranium mill tailings dewatering system is much different than that of agricultural systems where drains are placed in dug-out trenches. The integrity of the system must be protected during tailings disposal to prevent pipe breakage and geotextile envelope damage or segregation of the granular envelope material (Van Zyl and Robertson 1980). Construction of the system involves pipe and envelope layout on the liner at the pit bottom and at each level, if a multi-layered drainage system is employed. Considerations during this process are several, including the type of gravel bed or drain support to be used on the pit liner and at various levels within the tailings. Grading must be done to cause natural flow in the drains towards a sump area. Obvious construction problems will exist for a layered drainage system, suggested below, due to the need for support of the drains within a media that may shift during dewatering. Suggested layouts and construction concerns are discussed in the following subsections.

4.1 DRAIN LAYOUT

Van Zyl and Robertson (1980) recommended, for mined outpits, a blanket drain around the pit perimeter with a sump and pump system to reduce the hydraulic head on the side walls. A chimney drain or layered system, as described for embankment disposal schemes, Figure 10, could possibly be adapted to deep pits provided that its installation is related to the depositional pattern used. A drainage blanket (Figure 11) is placed on the ground surface with regularly spaced drain outlets and vertical chimneys of 18 to 24 in. boiler pipe filled with coarse drainage material. Another blanket is installed when the impoundment is filled with 12 to 15 ft of tailings at the chimneys. The chimneys act as outlets for this blanket drain. A precaution must be taken not to place an upper drainage blanket at a depth that will receive a large settlement of fines during deposition which would blind or clog the drain.

The need for a layered system should be evaluated for benefits through modeling before a considerable amount of research is done on construction problems. Settlement of fines at various depths during deposition can create

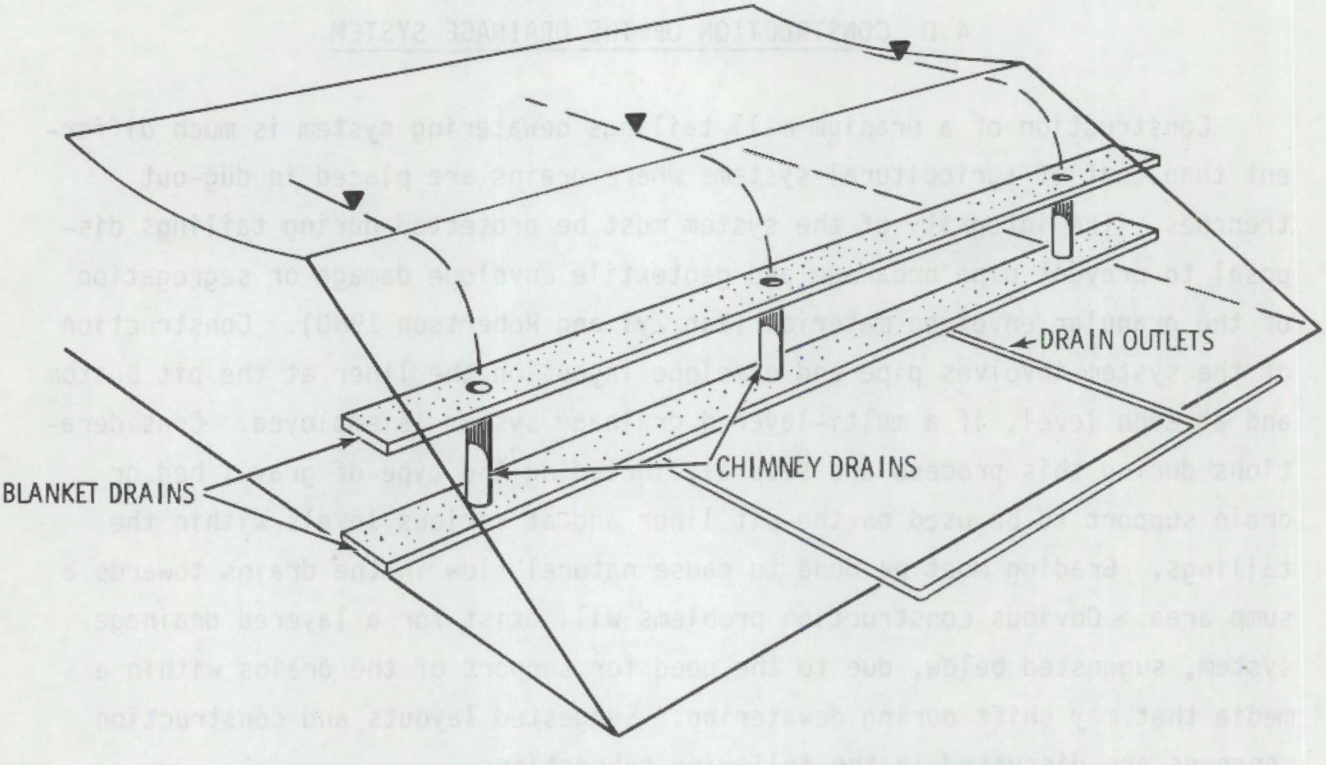


FIGURE 10. Chimney Drains for Embankment Disposal (Van Zyl and Robertson 1980)

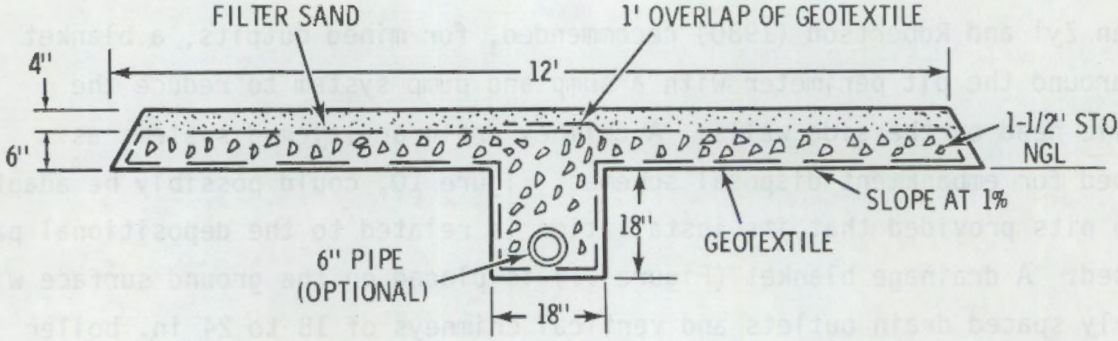


FIGURE 11. Blanket Drain Detail (Van Zyl and Robertson 1980)

comparatively impermeable layers or lenses that may prevent vertical flow. Parallel drain layouts, placed at various levels, could be constructed to drain towards the pit perimeter and then down a vertical drain to the pit bottom and sump area. This design would reduce the number of chimney drains as required in the suggested design for embankment disposal, Figure 10. The effectiveness of these alternatives could also be evaluated with models.

4.2 CONSTRUCTION CONCERNS

The sump area, or lowest drainage point in the uranium mill tailings pit, must be kept free of sediments during filling of the pit with tailings. Sedimentation from excess supernatant in the tailings can clog areas where drains enter the sump. Since there is a chance of sedimentation in the sump during long-term drainage of the pit, post-construction clean out of the sump must be allowed for during design.

Blinding of the drains with fines is very possible during the first filling with tailings. This critical time should be closely controlled to prevent such damage because the tailings would then have to be removed by hand. Discharge of tailings slurry should be done parallel to the drains instead of perpendicular in order to reduce flow velocity over the top of the drain which can destroy envelope materials.

The overburden pressures on drain-pipes in uranium mill tailings pits are expected to be much greater than that experienced in agricultural drainage systems due to greater depths. Considerations should be made for the possibility of pipe failure during construction and tailings loading. Materials should be selected to ensure stability of drains and envelopes throughout system construction and operation.

Operation of subsurface drainage should be monitored by piezometers installed in early stages of construction at a number of locations throughout the tailings impoundment to measure pore pressure. Piezometers may be located in the collection pipes, the envelope material, the drains or the tailings. This, together with drain discharge, measured by weirs, should provide an adequate analysis of drain performance and useful information for design evaluation and modification.

It is anticipated that an underdrainage system would become operational as impoundment of the tailings begins (Staub 1978). Therefore, settling may occur as soon as enough fluid has drained to lower the hydrostatic head in the tailings, even before the pit is full. The unconsolidated nature of the tailings during filling of the pit will create hazards for workers and difficulties in system construction.

The sump area of the tailings pit must have a pipe connection to the surface to allow pumping of the liquid from the pit. At pit depths of 100 to 200 ft, the construction of this column may be difficult. Pumping requirements must also be considered in design stages since several lifts may be required.

It is desirable to dispose of tailings well above the groundwater table to prevent uplift pressures on the pit liner due to the groundwater. For a tailings impoundment situation where the ground water table is at or near the surface, the less pervious pit liner should be placed on a pervious granular drainage collection system installed over the ground surface of the pit (Hanney et al. 1980). The branched lateral collector pipe system with an appropriate envelope would be designed to serve as a hydrostatic low to route local seepage and regional groundwater flow into drainage channels. Diversion of ground water would prevent uplift pressures on the liner and may provide the weight necessary to prevent uplift prior to commissioning of the tailings disposal system. Peripheral ground-water diversion drains upstream may also be necessary to minimize flows in the drains under the tailings impoundment.

5.0 DRAIN MAINTENANCE

Drains may not always function as they do at the start of operation due to clogging. Agricultural drainage experience has shown that clogging of drains due to mineral deposition is caused by a change in seepage pressure, temperature or pH. Mineral deposition due to pressure changes can be reduced by keeping the water velocity through openings drain openings below 1 cm per second (Van Zyl and Robertson 1980). Clogging due to temperature changes should not occur in tailings pits because seepage is expected to stay nearly constant in temperature except where it exits the impoundment. The use of inert filter materials will prevent clogging due to rapid changes in pH (neutralization). Although the probable causes for clogging of tailings drains are unknown at this time, it is likely that clogging will occur during the drainage period. The cleaning of drains, while a fairly easy task for agricultural drains, may be very difficult in deep tailings pits. Therefore, underdrainage design should allow for access to the drains for cleaning to remove fines and mineral deposits.

Clogging can also occur through pipe breakage and bacterial growth. Ochre is a sticky, gelatinous, yellow reddish mass of ferric hydroxide plus organic material that can clog drains and is a widespread problem in agricultural drainage. It can occur in water with a pH range of 2.5 to 8.5 due to the different types of bacteria that can influence its development. Tailings will leave the mill at a pH of 1.8-2.5 from the acid leach process, although neutralization of the tailings before disposal is inevitable due to precipitation and the addition of water for slurry transport. Tailings produced in the alkaline leach process have a pH of 10 to 10.5, although they will also be neutralized prior to disposal in the same manner. Therefore, clogging may occur in the tailings drainage system due to the initial slurry condition and neutralization of the tailings prior to disposal. Treatment of ochre clogging, which often coincides with siltation, is most effectively done with 2% SO_2 gas, or dry pelletized sulfamic acid (HSO_3NH_2) which can be neutralized with sodium carbonate, after a high pressure jet is used to remove 'loose' ochre.

Overall, it appears that much experience exists in the agricultural field with regard to the understanding and handling of drain clogging. Actual drain and envelope behavior in an uranium mill tailings environment is uncertain due to lack of experience and the chemical differences in liquids being drained.

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This report is a review of design approaches in the literature that may be applicable to uranium mill tailings drainage. Tailings dewatering is required in the deep mined-out pits used for wet tailings disposal. Agricultural drainage theory is reviewed because it is seen as the most applicable technology. It is concluded that the standard drain-pipe envelope design criteria should be easily adapted. The differences in dewatering objectives and physical characteristics between agricultural and tailings drainage systems prevent direct technology transfer with respect to drain spacing calculations. Recommendations for further research are based on the drainage features unique to uranium mill tailings. It is recommended that transient solutions be applied to describe liquid movement through saturated and partially saturated tailings. Modeling should be used to evaluate the benefits of drainage design approaches after careful consideration of potential construction problems.

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