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Alternative Cover Design

Final Report

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Uranium Mill Tailings Remedial Action Project UMTRAP

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1.0 INTRODUCTION

The special study on Alternative Cover Designs is one of several studies initiated by the U.S. Department of Energy (DOE) in response to the proposed U.S. Environmental Protection Agency (EPA) groundwater standards. The objective of this study is to investigate the possibility of minimizing the infiltration of precipitation through stabilized tailings piles by altering the standard design of covers currently used on the Uranium Mill Tailings Remedial Action (UMTRA) Project.

Prior to the issuance of the proposed standards, UMTRA Project piles had common design elements to meet the required criteria, the most important of which were for radon diffusion, long-term stability, erosion protection, and groundwater protection. The standard pile covers consisted of three distinct layers. From top to bottom they were: rock for erosion protection; a sand bedding layer; and the radon barrier, usually consisting of a clayey sand material, which also functioned to limit infiltration into the tailings. The piles generally had topslopes from 2 to 4 percent and sideslopes of 20 percent.

2.0 SCOPE OF WORK

The scope of work for this special study consisted of the following tasks:

1) Selection of design alternatives.
2) Literature review.
3) Identification of evaluation methods.
4) Evaluation of alternative designs.

A discussion of each of these tasks is provided in the following sections.

2.1 SELECTION OF DESIGN ALTERNATIVES

The selection of design alternatives for evaluation was based on the need for limiting infiltration to the tailings while using current cover materials. The design alternatives evaluated consisted of changes in pile slope lengths or angles, material properties, surface geometry, or layer components from previous UMTRA Project piles and covers. Because no new cover materials were considered, most of these design alternatives would have a minimal effect on project costs and schedules and could therefore be incorporated into current designs relatively easily. Two other special studies have focused on the use of geomembranes or alternative cover materials in minimizing infiltration into the tailings.

2.2 LITERATURE REVIEW

A literature review was performed to help in the selection of potential designs and to locate applicable references dealing with the various designs analyzed. These references were studied in detail to obtain relevant information for use in the evaluations.

2.3 IDENTIFICATION OF EVALUATION METHODS

Evaluations in this study used both analytical and numerical models. The primary numerical model used in the investigations was SOILMOIST. A limitation of this model is that evaporation at the surface of the cover cannot be accurately modeled and there is no theory available that relates material properties of the erosion protection layer to transport coefficients for use in calculating evaporation. SOILMOIST underestimates evaporation, but the relative suitability of the various design alternatives can still be determined with this model. Other numerical models considered for use in the study were UNSAT2 (NRC, 1983), TRUST (USGS, 1984), FEMWATER (Yeh, 1987), and SUTRA (Milly and Eagleson, 1980). The evaporation algorithm in each of these models has the same limitations as SOILMOIST or requires a value for evaporation as an input parameter, and each is generally more complex; therefore, SOILMOIST was judged to be the most suitable. For design purposes the evaporation algorithm of SOILMOIST is considered to be conservative.

2.4 ANALYSIS AND EVALUATION

The alternative designs identified in task 2.1 were evaluated using the methods described in tasks 2.2 and 2.3. Final recommendations were based on the following criteria: 1) effect on the moisture flux rate through the radon barrier; 2) constructibility; and 3) application to UMTRA Project sites, including cost and quality control/quality assurance considerations.

3.0 EVALUATION OF ALTERNATIVE DESIGNS

Each cover design was evaluated for its ability to meet the existing design criteria. Designs and design parameters evaluated in this study were:

1) Rock-soil matrix.
2) Pile cover slope angles and lengths.
3) Corrugated cover.
4) Increasing the bedding layer permeability.
5) Capillary break.

These conceptual designs were developed to limit infiltration into the tailings by one of the following three mechanisms: 1) maximizing flow of precipitation off the pile; 2) decreasing residence time of infiltrating water on the radon barrier; or 3) intercepting infiltrating water. The first three design concepts listed were analyzed for their ability to increase surface runoff of precipitation so that less would be available for infiltration into the tailings. The fourth design incorporates a higher-permeability bedding material to provide drainage of near-surface water, thereby reducing residence time and infiltration into the radon barrier. The fifth design listed uses a capillary break to prevent downward migration of water. This design would be used in conjunction with the corrugated cover concept to channel infiltrating water to troughs that would carry the water off the pile.

3.1 ROCK-SOIL MATRIX

The rock-soil matrix design consists of four layers (Figure 3.1. From the top down they are: 1) rock-soil matrix; 2) frost protection; 3) biointrusion layer; and 4) radon/infiltration barrier. The rock-soil matrix layer is a mixture of gravel and cobble sized rock with soil filling the voids. The frost protection layer is fine to coarse-grained random fill material. A biointrusion layer, below the frost protection layer, is gravel and cobble sized rock but the voids would not be filled. The radon/infiltration barrier is similar in design to radon barriers at other UMTRA Project sites.

As can be seen, this design differs substantially from previous UMTRA Project covers (see section 1.0) but is similar to vegetative cover designs. The rock-soil matrix layer has the same function as the rock erosion protection layer in the standard design. The radon/infiltration layer and the frost protection layer (where needed) fulfill the same functions for both types of designs. That is true also for the biointrusion layer on current vegetative cover designs.

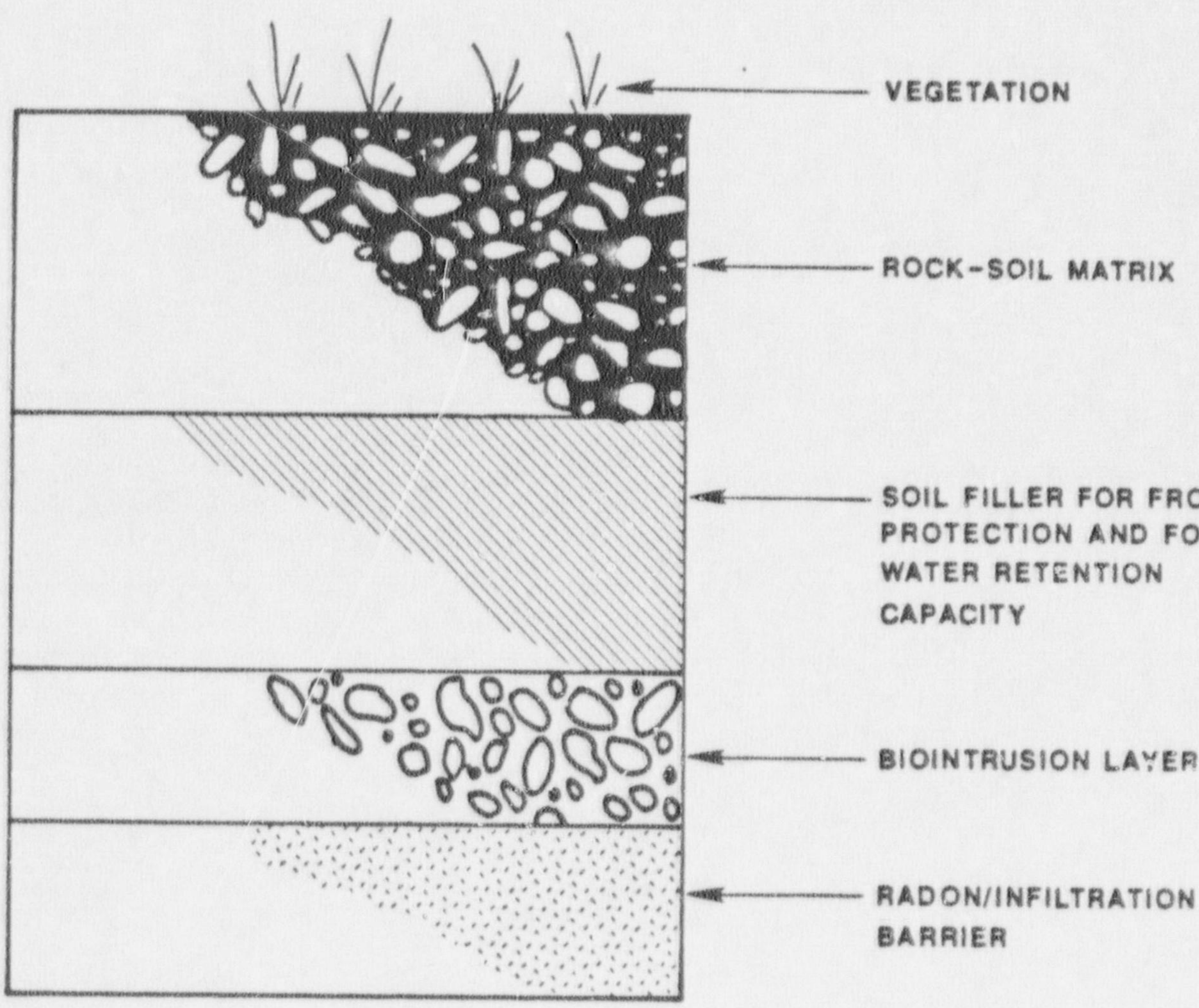

FIGURE 3.1
ROCK-SOIL MATRIX

3.1.1 Analysis and Evaluation

The rock-soil matrix was conceived as a method of providing rock erosion protection for stabilized UMTRA Project piles while at the same time allowing bare soil evaporation to occur through the rock layer. Bare soil evaporates water at a higher rate than does a rock mulch, and a matrix of soil fines would also increase the amount of surface runoff. In order to meet the design criteria of limiting radon emanation, limiting infiltration, and providing long-term stability, the design layers would fulfill the following functions:

Rock-soil matrix:

a) Provides primary erosion protection to the stabilized pile during high-intensity storm events.
b) Provides a water storage volume in the interparticle void space between precipitation events. Water is stored until evaporated or transpired.

Frost protection layer:

a) Protects underlying layers from full-depth frost penetration.
b) Provides additional water storage capacity.

Biointrusion layer:

a) Prevents roots and animals from penetrating the tailings.
b) Impedes deep drying of the radon barrier.

Radon/infiltration barrier:

a) Limits radon emanation.
b) Limits infiltration when the moisture retention capacity of the soil matrix is exceeded.

This design was evaluated on the basis of the functional requirements and interactions of each layer. For the rock-soil matrix cover system to function adequately, each component must perform without inhibiting or negatively affecting other components or the overall objective of the cover design.

In order to eliminate the potential for extreme storms to cause erosion of the tailings piles, the rock of the rock-soil matrix should exhibit sufficient particle-to-particle contact (HRB, 1970). This would require a void ratio of approximately 0.3 (Bell, 1983). Assuming that the voids are filled with the soil matrix, the composition of a rock-soil matrix would be 30 percent soil and 70 percent rock.

The near-surface soil in the rock-soil matrix will be subject to frequent wetting and drying, shrinking and swelling, freezing and thawing, rain splash impact, and other destabilizing forces that act on unconfined soil. These forces could be sufficient to cause surficial erosion of the soil matrix (Beedlow, 1984a,b). While this erosion will be limited in depth by the rock particles, it is conceivable that the soil will erode to a shallow depth over the 1,000-year design life of the pile, thus leaving only rock at the surface. This phenomenon is supported by the geomorphic process in the arid southwest known as "desert pavement" (McFadden et al., 1987). Desert pavement is a layer of gravel-sized particles concentrated on an unvegetated surface due to gradual deflation of the sand, silt, and clay-sized soil particles.

Once the soil is eroded, even to a shallow depth, the bare soil effect of the rock-soil matrix is lost and infiltration will increase to that of a rock mulch (Lopez et al., 1988). Therefore, the soil would require stabilization, which could be afforded only by vegetation.

At UMTRA Project sites a vigorous vegetative community cannot effectively be supported by the rock-soil matrix described above. A 30 percent volume of soil fines will have insufficient moisture capacity to support a stable vegetation community having adequate transpiration capacity. In all but the most humid climates, the rock-soil matrix would have to contain at least 70 percent soil to support the vegetation. Thus, the rock-soil matrix concept (30 percent soil--70 percent rock) would not be compatible with the needs of a vegetation community (at least 70 percent soil).

3.1.2 Conclusions

The rock-soil matrix design has a functional incompatibility in that the minimum amount of soil matrix needed to sustain vegetation is 70 percent of the total volume but there is also the need for 70 percent rock to provide the particle-to-particle contact necessary for erosion protection. Without the vegetation to prevent the fines from eroding, the long-term configuration of the cover would be similar to that of the current design--rock over soil. The benefit of bare soil evaporation and increased runoff would be negated.

3.1.3 Recommendations

Because this alternative is not viable as conceived, it cannot be directly incorporated into UMTRA Project cover designs. However, since vegetation is necessary for soil surface stabilization, the rock-soil matrix concept can be used in support of the special study on vegetative covers. Large rock would not be required in the upper layer for erosion protection, but a surface mulch composed of small rocks could be used to decrease surface evaporation and the effects of rain splash.

3.2 PILE SLOPE ANGLES AND LENGTHS

The pile design parameters of slope angle and slope length were analyzed concurrently (Figure 3.2). Pile slope angles from five percent to 20 percent and slope lengths from 20 feet to 500 feet were evaluated for their effects on moisture flux rates though the radon barrier. There were no other changes in design from the standard three-component UMTRA Project cover (i.e., the thicknesses and properties of the radon barrier bedding) and erosion protection layers were not changed. Design changes to the stabilized pile that would incorporate either the constant slope angles or the shorter lengths analyzed in this study could be made by varying the geometry of the pile.

3.2.1 Analysis and Evaluation

For the SOILMOIST model runs, the radon barrier was assigned a vertical saturated hydraulic conductivity of 1x10E-7 centimeters per second (cm/s) and the bedding layer 1x10E-2 (0.01) cm/s. Climatological data from Durango, Colorado, and Green River, Utah, were used in the various model runs to evaluate the effect of climate in the analyses.

Three variables were analyzed for their effect on the net infiltration into the radon barrier; these variables were slope angle, slope length, and saturated hydraulic conductivity (Ksat) of the bedding layer. Only the variables of slope angle and slope length will be discussed in this section. Table 3.1 shows the results of the modeling runs. Using the Durango data, net infiltration ranged from 4.4 to 0.68 centimeters per year (cm/yr) and the number of ponding days decreased from 365 to 99 days per year. A ponding day is a day in which at least a portion of the bedding layer remains saturated and there is available moisture for the next day. The infiltration results using the Green River data ranged from 3.5 to 0.22 cm/yr with ponding from 354 to 62 days. Acting under a unit gradient, a material with a saturated hydraulic conductivity of 1x10E-7 cm/s would have a moisture flux of 3.15 cm/yr. Saturated conditions would exist in the radon barrier until the flux is less than this amount. Maintaining the same hydraulic conductivity for the bedding layer of 0.01 cm/s, a pile with constant slopes of five or 15 percent would have to be shorter than 40 and 120 feet, respectively, for unsaturated conditions to be predicted to occur at Durango. These lengths are too short to be practicable for an efficient pile design.

It should be noted that with a saturated hydraulic conductivity in the range of 0.01 cm/s, soil types are such (fine sand) that capillary tension is a factor that must be considered. Capillary tension will prevent drainage of the bedding layer from occurring as quickly as calculated by SOILMOIST. Lateral flow of precipitation in the bedding layer is calculated by the following equation for seepage velocity (Kashef, 1986):

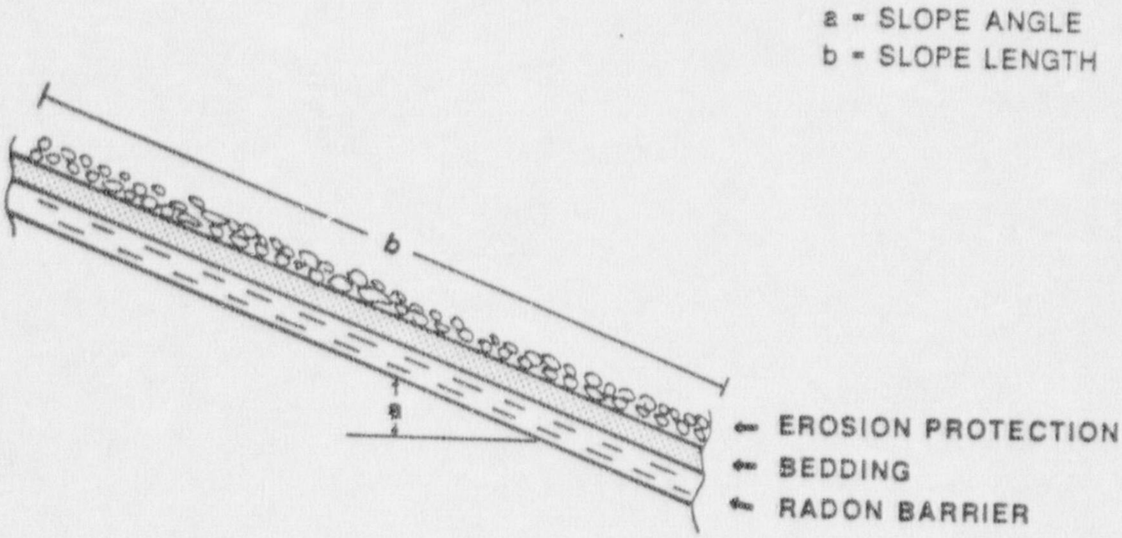

FIGURE 3.2
COVER SLOPE ANGLES AND LENGTHS

Table 3.1 SOILMOIST model runs

SLOPE (%)	LENGTH (ft)	Ksat[1] (cm/s)	VELOCITY (cm/s)	RUNOFF (hrs)	PONDING (days)	INFIL. (cm)	EVAP. (cm)
			DURANGO DATA				
2	20	0.01	0.0007	254.0	332	3.2	0.01
2	100	0.01	0.0007	1270.0	365	4.4	<.01
2	20	0.1	0.0067	25.4	131	1.4	0.05
2	100	0.1	0.0067	127.0	274	2.7	0.02
2	500	1	0.0667	63.5	204	2.1	0.05
5	20	0.01	0.0017	101.6	253	2.5	0.02
5	20	0.1	0.0167	10.2	99	0.95	0.06
5	100	0.1	0.0167	50.8	183	1.9	0.05
5	500	1	0.1667	25.4	131	1.4	0.07
10	20	0.01	0.0033	50.8	183	1.9	0.04
10	100	0.01	0.0033	254.0	332	3.2	<.01
10	100	0.1	0.0333	25.4	131	1.4	0.07
10	250	1	0.3333	6.4	99	0.78	0.1
15	20	0.01	0.0050	33.9	154	1.6	0.05
15	100	0.1	0.0500	16.9	99	1.2	0.08
			GREEN RIVER DATA				
5	90	0.05	0.0076	100.6	150	1.6	0.07
5	313	0.05	0.0076	349.8	273	2.6	0.05
5	895	0.05	0.0076	1000.3	354	3.5	0.01
5	20	0.1	0.0167	10.2	62	0.7	0.18
5	100	1	0.1667	5.1	62	0.55	0.18
10	20	0.1	0.0333	5.1	62	0.55	0.18
10	100	0.1	0.0333	25.4	75	0.92	0.15
15	100	0.1	0.0500	16.9	62	0.8	0.16
20	100	0.5	0.3333	2.5	62	0.39	0.17

[1]of the drainage layer (filter)

$$v = \frac{K\,i}{n}$$

where v = velocity.
K = hydraulic conductivity.
i = gradient (slope angle).
n = porosity.

This equation assumes saturated conditions with no capillary pressures. Actual drainage would occur under unsaturated conditions and capillary pressures would affect the time to drain. The saturated flow assumption is nonconservative, i.e., it underestimates the runoff time, especially for relatively low-hydraulic-conductivity materials such as fine to medium sands under nonsaturated (draining) conditions. Therefore, the slope angles and lengths stated above would be maximum values (conservative in this case) because the calculated runoff times would minimize slope lengths. The degree of capillary tension acting on the soil moisture is a function of the type of materials: the finer the material the greater the suction pressure.

3.2.2 Conclusions

Conditions evaluated using SOILMOIST for a pile design of constant 15 percent slopes and slope lengths of 300 feet and a saturated hydraulic conductivity of 0.01 cm/s for the bedding layer would create a predicted moisture flux of approximately 3.7 cm/yr for Durango and 2.9 cm/s for Green River. Both of these values are close to, or greater than, the moisture flux through the radon barrier (3.15 cm/yr) under saturated conditions. Because of the nonconservative calculation of the runoff by SOILMOIST, the radon barrier can be considered to be saturated, which is the same as currently predicted. Therefore, by themselves, changes in slope angles or slope lengths would not be beneficial design modifications. The runoff and residence times of water in the bedding layer are too long if the hydraulic conductivity of the bedding layer is 0.01 cm/s or less. These conclusions go along with the findings of Wright et al., 1987 and Miller and Wright, 1988. Both of these modeling studies concluded that of the parameters analyzed, net infiltration of moisture into landfills or tailings materials was least sensitive to the slope angle of the cover.

Capillary tension is a factor in increasing the drainage time in the types of soils (fine to medium sands) that have hydraulic conductivities of approximately 0.01 cm/s. One of the conclusions of the special study on vegetative covers is that the bedding layer needs to be freely draining in order to reduce the possibility of voluntary growth of vegetation on the cover. Fine to medium sands would not be classed as freely draining.

3.2.3 Recommendations

On a site-specific basis, unless another pile configuration is required, current pile geometries with two to four percent topslopes and 20 percent sideslopes are adequate if other design parameters are changed (see recommendations in section 3.4). Also, fine to medium sands should not be used in significant percentages in the bedding layer.

3.3 CORRUGATED COVER

A corrugated cover design for large pile topslopes was evaluated because of its proposed ability to increase surface runoff in comparison to planar topslopes. In this design, a series of troughs and ridges would be built parallel to the slope of the pile. Surface flow off the ridges would concentrate in the troughs and then be carried off the pile. Figure 3.3 shows a cross section of one of these corrugations with 20 percent sideslopes on the ridges and a five percent slope of the troughs down the pile. The design evaluated using SOILMOIST assumed that the troughs covered 25 percent of the pile topslopes and the ridges 75 percent of the topslopes.

3.3.1 Analysis and Evaluation

The corrugated cover design was analyzed using both analytical means and numerical methods. The seepage velocity equation was used to estimate flow times in the bedding layer and SOILMOIST was used to calculate the flux into the radon barrier at various locations down the troughs. The flux rates calculated by previous model runs (section 3.2) were used for locations perpendicular to the ridges with the same slope angles and lengths. To perform an accurate simulation of this design, the travel times of flows down the ridges had to be less than 10 percent of the travel times down the troughs. The hydraulic conductivities of the materials were the same as in the previous analyses.

Drainage times were approximately 12 hours for the ridges and 1500 hours for the troughs with slope lengths of 300 feet. Because the runoff times were so long for the bedding layer in the troughs, ponding on the radon barrier was predicted to occur 365 days per year. Therefore, the troughs would provide a constant source of water for infiltration into the radon barrier.

The thickness of the bedding layer in the trough limits the horizontal extent of saturation; ponding will not build up to a greater depth than the thickness of the bedding layer - it will generate surface runoff in the riprap layer. To calculate the area of the radon barrier that would be saturated, the thickness and slope of the bedding layer (perpendicular to the ridge) are used. For example, a ten percent slope and a thickness of 0.5 foot will result in ponding extending five feet from the center

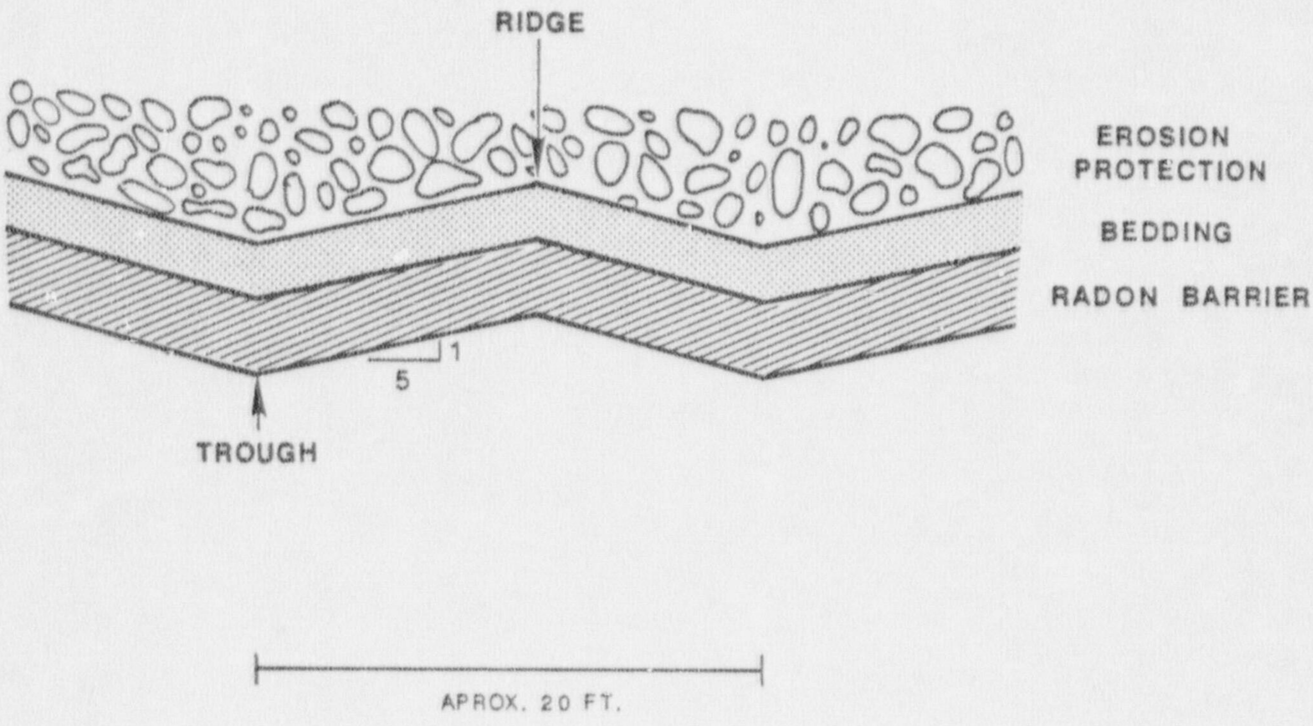

FIGURE 3.3
CORRUGATED COVER

of the trough. If the distance from the trough to the ridge is ten feet, half of the surface of the pile would have the potential for ponding. The relative percentage of ponding area can be reduced either by increasing the slope angle or by increasing the distance to the ridge from the trough (a 0.5 foot bedding layer thickness is a minimum for constructibility). By maintaining a 10% slope, the percent of pile saturation could be reduced to 25% by increasing the slope length to 20 feet, the five feet of ponding would remain the same. Because runoff times increase with an increase in distance, increasing the slope angle is the best alternative for decreasing the ponding area. The maximum easily constructible slope was judged to be 20 percent. Therefore, with the same bedding layer thickness, the ponding area would extend only 2.5 feet from the center of the trough.

It cannot be assumed, because of capillary tension in both the bedding layer and radon barrier, that saturation of the radon barrier will occur only over the 25 percent of the pile along the bottom of the trough. Capillary rise in silts and clays can easily exceed three feet (Fetter, 1980), so a conservative estimate of the distance that saturation would occur in the radon barrier is 1.5 feet horizontally from the edge of the ponding zone in the trough. This distance would be added to the 2.5 feet; it can be expected that the moisture flux through the radon barrier would be under saturated conditions up to four feet from the center of the trough. This would be 40 percent of the pile area.

3.3.2 Conclusions

This modeling showed that travel time down the ridges was fast enough (due to the short lengths) so that unsaturated conditions would be predicted in the radon barrier under the ridges (75 percent of the pile). The trough lengths were such that the results were similar to the previous analyses; travel and residence times were 365 days per year so that saturated conditions (and moisture flux rate) were predicted for the radon barrier in the troughs. These saturated conditions were expected to extend over 40 percent of the pile.

The same concerns as were stated in section 3.2 for bedding layer materials with saturated hydraulic conductivities of 0.01 cm/s (fine sand) would apply to the corrugated cover design. Other design parameters analyzed (see section 3.4) had greater impact on limiting infiltration into the radon barrier than did this design.

3.3.3 Recommendations

The corrugated cover design can reduce infiltration by approximately 60 percent from that on planar slopes. However, this design is not recommended unless the bedding layer material grain size is increased in accordance with the recommendations of section 3.4.

3.4 HIGHLY PERMEABLE BEDDING LAYER

SOILMOIST was also used to analyze the effect of a highly permeable bedding layer on the moisture flux rate though the radon barrier (Figure 3.2). This parameter was varied along with slope lengths and angles; input values for soil characteristics and climate were the same as in previous analyses. The primary benefit of increasing the hydraulic conductivity of the bedding layer would be to decrease the residence time of the near-surface runoff on top of the radon barrier, thereby decreasing the flux.

Current design parameters for the bedding layer are based on criteria used for filters in dam design. Due to the high hydraulic gradients in these designs, strict criteria have to be followed. Because there are no high gradients near the surface of UMTRA Project piles, higher flow velocities in the bedding layer can be allowed. Evaluation of the upper limit of the flow velocity will be the focus of the Hydraulic Flume Studies. Design of the grain-size distribution of materials for the bedding layers on previous piles did not consider the rapid shedding of precipitation; only compliance with the filter criteria was considered.

3.4.1 Analysis and Evaluation

For the site disposal cell geometry and climate at Durango and Green River, the effect of various pile design details on the infiltration into the cell was examined. The parameters varied for each site in this evaluation were: slope length, slope inclination, and hydraulic conductivity of the bedding layer. Because two different sites were evaluated, it was possible to include the influence of different climates on the infiltration.

The evaluation consisted of calculating the infiltration for a range of slope lengths, slope angles, and bedding permeabilities at each site. For a given infiltration barrier hydraulic conductivity, predicted infiltration into the cell is primarily dependent on the number of days that water is available on the top of the infiltration barrier. Days in which water is available is termed a ponding day; the number of ponding days is a function of the slope geometry, bedding permeability, and site climate.

In order to present the results of the numerous model runs, the effect of various slope geometries and bedding permeability were combined into a single parameter--runoff time. Runoff time is independent of the site climate; it represents the length of time for water from a single precipitation event to flow off the pile. Runoff time was plotted versus net infiltration per year (Figure 3.4). In order to obtain a specific value of runoff time, the basic parameters-slope length and inclination, and bedding hydraulic conductivity were defined. Then using SOILMOIST for the specified set of parameters, the runoff time and the net annual infiltration was calculated.

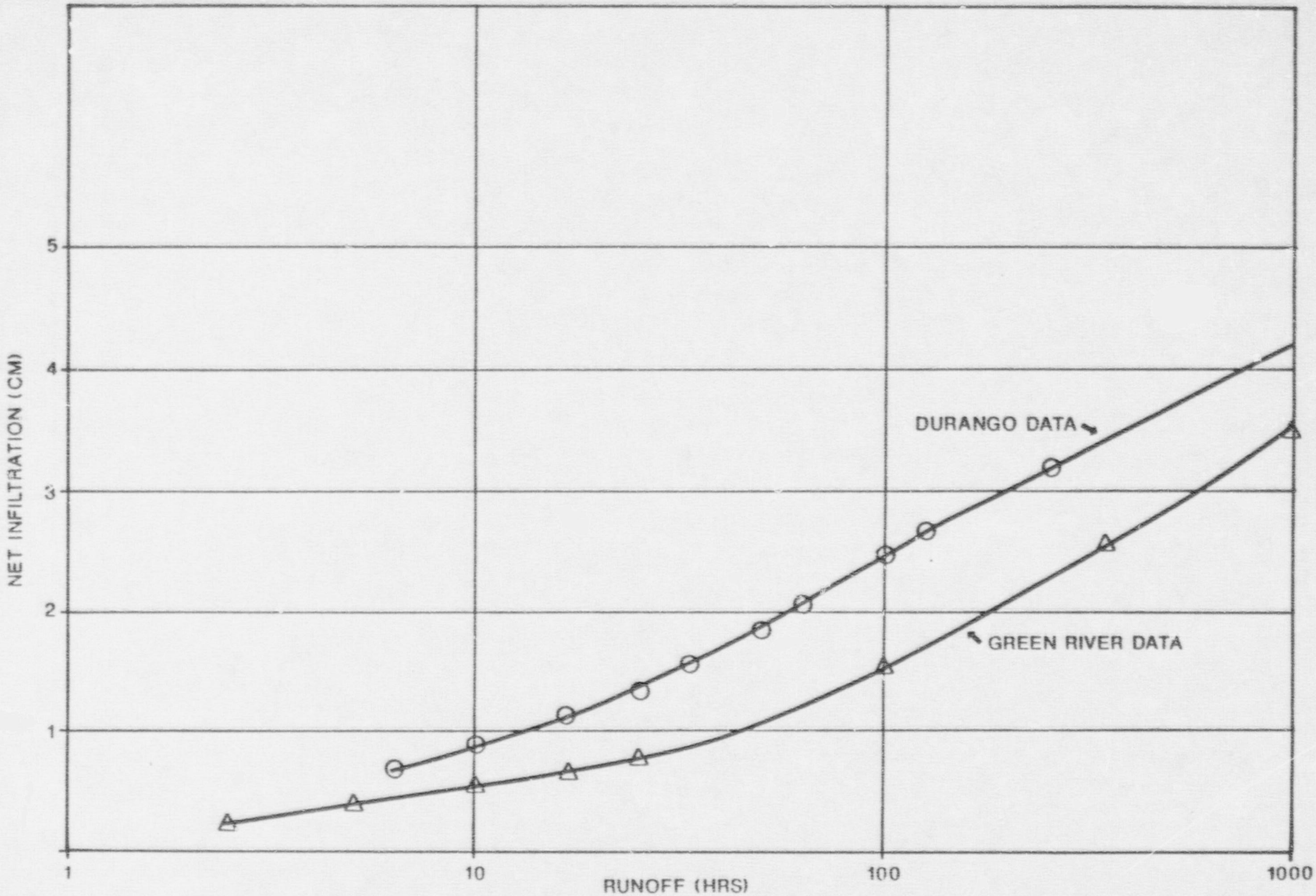

FIGURE 3.4
INFILTRATION vs RUNOFF TIME

As shown in Figure 3.4 the net annual infiltration is significantly affected by the runoff time. For both sites the infiltration barrier hydraulic conductivity was set at 1x10E-7 cm/s. If saturated flow conditions prevailed the entire year and the seepage gradient were unity, the resultant infiltration would be 3.15 cm. For long runoff periods, e.g., for Durango greater than 200 hours, water is predicted to build up in the bedding layer over the infiltration barrier, hence increasing the gradient and the annual infiltration above 3.15 cm.

The following are relevant climatic parameters for the two sites considered:

	Average Precipitation (inches)	Potential Evaporation (inches)	Days of Precipitation
Durango	19	40	112
Green River	6	42	67

As shown on Figure 3.4, the greater precipitation and number of precipitation days causes a higher net infiltration at Durango than at Green River for the same runoff period, or combination of slope length, slope angle, and bedding permeability.

The predicted runoff times and net infiltration of the two site covers as presented in Figure 3.4 are to be viewed as a comparative assessment only. Because of certain constraints in the SOILMOIST code actual runoff times and infiltration may vary from that shown.

SOILMOIST is nonconservative when calculating lateral flow in the bedding layer; the code assumes Darcian flow and saturated conditions. These assumptions are not met in practice, i.e., draining conditions and variable hydraulic pressures prevail in the bedding layer during draining. The actual conditions of lateral flow would cause the runoff times to be longer than predicted.

Conversely, SOILMOST is conservative in estimating evaporation of water in the bedding layer and from the infiltration barrier (refer to discussion in section 2.3). The extent to which these two opposite inaccuracies balance each other is not known.

3.4.2 Conclusions

From Figure 3.4 it is apparent that the shorter the runoff time the better. There is a limit to the practical range of slope lengths, slope angles, and bedding permeabilities that can be constructed. Table 3.2 shows different combinations of hydraulic conductivity values of the bedding layer, pile slope angles, and slope lengths that would yield runoff times in the bedding layer of approximately 25 hours.

Materials that have saturated hydraulic conductivities in the range listed in Table 3.2 are medium sands to fine gravels. Bedding layer materials with a hydraulic conductivity of 0.1 to 0.5 cm/s would have a grain size distribution where 15 percent (D_{15}) of the materials are smaller than 0.5 to 1.2 mm. Materials of this size are medium sands which are subject to significant capillary pressures and would not be considered freely draining. To ensure that the bedding layer is freely draining and the runoff times as short as possible, the D_{15} of the materials should be 2.0 mm or larger.

Table 3.2 Conditions for predicted unsaturated flux

Ksat (cm/s)	SLOPE (%)	LENGTH (ft)
2.5	2	500
1.0	5	500
0.1	10	100
0.5	10	500
0.1	20	200

3.4.3 Recommendations

Incorporate high hydraulic conductivity materials when designing the bedding layer; use a minimum D_{15} (on a grain-size distribution) of 2.0 mm for the materials on both the topslopes and sideslopes. This recommendation will add to the cost of the bedding layer because of the need to eliminate the finer grain-sizes of the borrow materials, which previously could have been left in. In most cases these cost increases should not be significant.

The Hydraulic Flume Studies, an outgrowth of this study scheduled for completion in 1989, should test the coarsest materials (erosion protection rock and gravels) that could be used in place of the bedding layer. This may result in having more latitude when designing the bedding layers and the potential elimination of the bedding layer on the topslopes. The flume studies will also define the erodibility of the radon barrier materials and identify suitable soils for use.

3.5 CAPILLARY BREAK

Infiltrating water will not enter very coarse materials that are at atmospheric pressure (zero) if the overlying materials are fine-grained and exert negative (suction) pressures so that the water is held in tension. This system will fail when the overlying materials become saturated and the water pressure becomes positive. The key parameters for this design are a conductive layer of silty sand overlying a capillary break layer of coarse gravel (Figure 3.5). The capillary break layer also serve as a biointrusion layer if the top surface is vegetated.

3.5.1 Analysis and Evaluation

Field tests have shown that lateral flow in the conductive layer will occur up to distances of 25 feet at 10 percent slopes (Caldwell, 1988) before breakthrough occurs and the infiltrating water enters the capillary break layer. If water enters this layer it will continue downward into the radon barrier and tailings. Because of this length limitation, the corrugated cover concept was incorporated to make this design feasible for large piles. The bottom of the troughs would be lined with a low-permeability material, i.e., clay or bentonite-amended soil, to channel the water from the conductive layer off the pile. In Figure 3.5, the top surface is shown to be vegetated, but it could have a rock and bedding layer cover without changing the performance of the design.

The trough bottoms would comprise 10 percent of the pile area and would remain saturated. To estimate the total flux through the pile, 90 percent of the pile would have zero flux and the 10 percent trough area would have a flux equal to or slightly greater than the saturated hydraulic conductivity of the low-permeability material (1x10E-8 cm/s). Because the hydraulic conductivity of the trough liner would be less than the hydraulic conductivity of the underlying radon barrier material, the moisture flux would act only vertically and not laterally as in the corrugated cover design. Using the weighted average of the two flux rates, the overall rate through the cover would be 1x10E-9 cm/s.

The main drawback of this design centers on its constructibility. Good quality control/quality assurance would be necessary to ensure that the interstices of the capillary break layer would remain open. This concern is also applicable to the construction of the biointrusion layer in a vegetated cover. Having the corrugations in the surface of the pile along with the low-permeability layer on the bottom of the trench also adds to the complexity of construction. Comparison of construction costs between this design and the current cover design for Grand Junction shows an increase of approximately 40 percent.

3.5.2 Conclusions

The capillary break design is feasible but will be more complex to construct and therefore more costly. No numerical modeling is necessary to quantify the flux rate and the demonstration that an average flux through the radon barrier of 1x10E-9 cm/s can be attained is based on empirical data of zero breakthrough for 25 feet laterally.

3.5.3 Recommendations

The capillary break design would be useful if a flux of 1x10E-9 cm/s through the radon barrier is necessary for groundwater compliance and other, more cost-effective designs cannot be applied at a particular site.

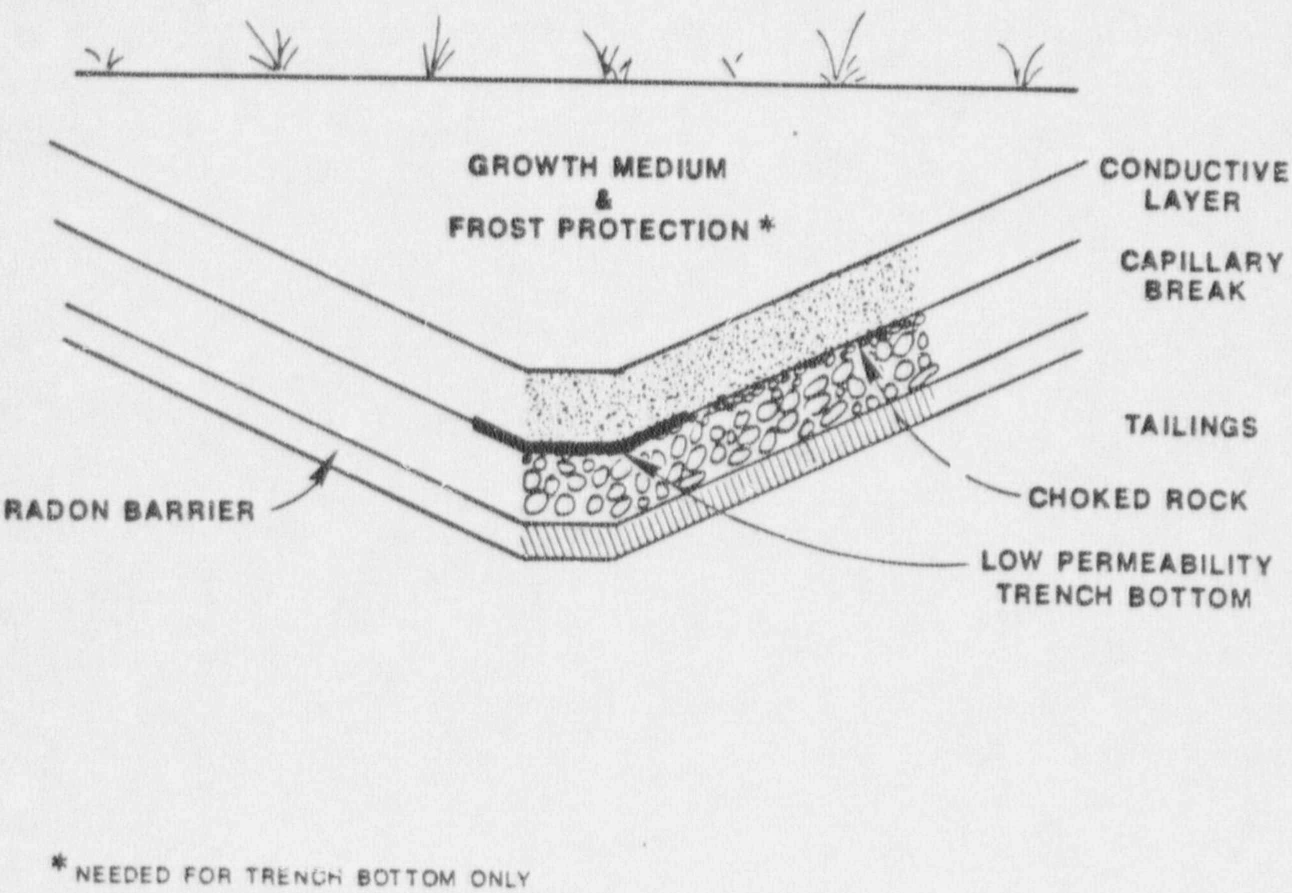

FIGURE 3.5
CAPILLARY BREAK DESIGN

BIBLIOGRAPHY

Beedlow, P.A., 1984a. "Designing Vegetation Covers for Long-Term Stabilization of Uranium Mill Tailings," prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-3674/PNL-4986, Washington, D.C.

Beedlow, P.A., 1984b. "Revegetation and Rock Cover for Stabilization of Inactive Uranium Mill Tailings Disposal Sites: Final Report," prepared for the U.S. Department of Energy, DOE/UMT-0217/PNL-5105, Albuquerque Operations Office, Albuquerque, NM.

Bell, F. G., 1983. Engineering Properties of Soils and Rock, Butterworths, London, England.

Caldwell, J.A., 1988. "Unpublished Notes of DOE Conference on Disposal Cell Design, Washington D.C., July 1988," available from Project Document Control Center, PDC #0.21.2, U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

DOE (U.S. Department of Energy), 1988. Technical Approach Document, UMTRA-DOE/050425.0001, DOE, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, NM.

Donaghe, R. T. and V. H. Torrey, III, 1979. "Scalping and Replacement Effects on Strength Parameters of Earth-Rock Mixtures," U.S. Army Engineers Waterways Experiment Stations, Vicksburg, MS.

Fetter, C.W., 1980. Applied Hydrogeology, Charles E. Merrill Publishing Co., Columbus, Ohio.

HRB (Highway Research Board), 1970. "Tentative Design Procedure for Riprap-Lined Channels," Highway Research Board Program Report 108, Washington, D.C.

Hussain, B. and R.K. Katti, 1980. "Behavior of Soil Rock Mixtures in Shear and Compression,": in Proceedings, International Symposium on Landslides, Vol. I, New Delhi, India.

Kashef, A.I., 1986. Groundwater Engineering, McGraw-Hill Book Company, New York, New York.

Lopez et al. (E.A. Lopez, F. J. Barnes, and E. J. Antonio), 1988. "Effects of Vegetation and Soil-Surface Cover Treatments on the Hydrologic Behavior of Low-Level Waste Trench Caps," in Proceedings of Waste Management 88, University of Arizona, Tucson, AZ.

McFadden, L. D., et al. (L. D. McFadden, S. G. Wells, and M. J. Jercinovich), 1987. "Influences of Eolian and Pedogenic Processes on the Origin and Evolution of Desert Pavements," in Geology, Vol. 15, Davis, CA.

Miller, C.J. and S.J. Wright, 1988. "Application of Variably Saturated Flow Theory to Clay Cover Liners," in Journal of Hydraulic Engineering, Vol. 114, No. 10, pp.1283-1300.

Milly, P.C.D. and P.S. Eagleson, 1980. "The Coupled Transport of Water and Heat in a Vertical Soil Column Under Atmospheric Exitation," Department of Civil Engineering, Report No. 258, Massachusetts Institute of Technology, Boston, Massachusetts.

Mitchell, J. K., 1976. Fundamentals of Soil Behavior, John Wiley & Sons Inc., New York, NY

NRC (U.S. Nuclear Regulatory Commission), 1983. "Documentation and User's Guide: UNSAT2- Variably Saturated Flow Model," NUREG/CR-3390, prepared by L.A. Davis and S.P.Neuman, for the U.S. Nuclear Regulatory Commission, Washington, D.C.

Potter, L. D. and C. C. Reith, 1986. "Preliminary Assessments of Reclamation Potential," in Principles and Methods of Reclamation Science, ppp. 41-64, University of New Mexico Press, Albuquerque, NM.

Sherard et al. (J.L. Sherard, L.P. Dunnigan, and J.R. Talbot), 1984. "Basic Properties of Sand and Gravel Filters," in Journal of Geotechnical Engineering, Vol.110, No. 6, pp. 684-699.

Simmons, C. S. and G. W. Gee, 1981. "Simulation of Water Flow and Retention in Earthen Cover Materials Overlying Uranium Mill Tailings," prepared for the U.S. Department of Energy, DOE/UMT-0203/PNL-3877, Albuquerque Operations Office, Albuquerque, NM.

USGS (U.S. Geological Survey), 1984. "A Finite Element Simulation Model for Saturated-Unsaturated Fluid Density Dependent Groundwater Flow with Energy Transport or Chemically Reactive Single Species Solute Transport," USGS WRI 84-4369, prepared by C.I. Voss.

Wright et al. (W. Wright, C.E. Kooper, and A.K. Turner), 1987. "Use of the HELP Model in Evaluating the Cover Design for a Uranium Mill Tailings Disposal Site," in Proceedings: HMCRI 4th National Conference and Exhibition on Hazardous Materials and Hazardous Wastes, Hazardous Materials Control Research Institute, Washington D.C.

Yen, G.T., 1987. "FEMWATER: A Finite Element Model of Water Flow through Saturated-Unsaturated Prous Media--First Revision", Oak Ridge National Laboratories, Environmental Sciences Division, Oak Ridge, Tennessee, Pub. No. 2943.