VEGETATIVE COVERS FOR URANIUM MILL TAILINGS

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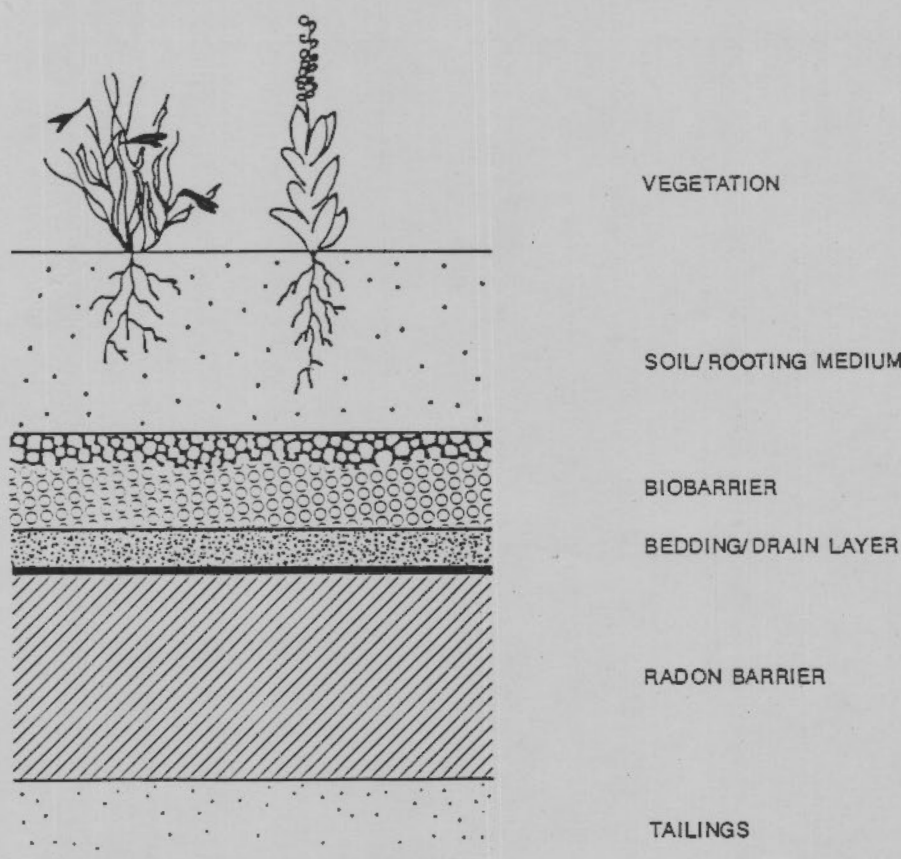

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VEGETATIVE COVERS FOR UMTRA PROJECT DISPOSAL CELLS

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ABSTRACT

The goal of the Uranium Mill Tailings Remedial Action (UMTRA) Project is to clean up and permanently stabilize uranium mill tailings and other contaminated materials at 24 inactive mill sites in the United States. The basic approach is to consolidate the contaminated materials into gently sloped piles and then to cover the contaminated materials with earthen layers that will control radon emanation, resist erosion, and prevent the infiltration of excess moisture that might dissolve and transport hazardous constituents.

The most widely used cover design, called a rock cover, consists of a compacted clay radon barrier overlain by a filter layer overlain by erosion-resistant rock. Completed covers for disposal cells at Shiprock, New Mexico, and Clive, Utah, are examples of covers that conform to this basic configuration, which continues to be used for sideslopes at most sites and for both topslopes and sideslopes in highly arid environments.

Vegetative covers are now proposed for use on topslopes of disposal cells at UMTRA Project sites in less arid environments. Vegetative covers generally consist of the components described above, but with an overlying layer of carefully selected soil, upon which a locally adapted plant community is established. The three principal advantages of vegetative covers are (1) control of water balance, (2) enhanced protection against root penetration of the radon barrier, relative to rock covers, and (3) consistency of the "climax vegetation" concept with the 1000 year (200-year minimum) design life for disposal cells on the UMTRA Project.

The major liabilities of vegetative covers are their reduced resistance to erosion, relative to rock covers, and their vulnerability to disturbances such as fire, drought, or heavy grazing, any of which could impair the vegetation's ability to stabilize against erosion and maintain water balance. However, a properly established vegetative cover will be self-healing, reestablishing protective biomass and restoring water balance after periods of disturbance and reduced performance.

This paper chronicles the developments that have led to the increased use of vegetative covers on the UMTRA Project, and it identifies the factors that are considered in selecting a cover system. Our progress in this arena represents an integration and application of research findings from experimental programs throughout the waste management community, and our experiences may be of value to other programs requiring a choice of cover systems among several alternatives.

INTRODUCTION

The Uranium Mill Tailings Remedial Action (UMTRA) Project is a major Department of Energy (DOE) initiative to clean up radioactive and hazardous chemical contamination at 24 inactive uranium processing sites in the United States. The approach is to consolidate uranium mill tailings and contaminated soils into gently sloped mounds and to place enduring covers over the materials that will control radon emanation, resist erosion, and prevent the infiltration of water that might dissolve and transport contaminants. The design criteria for the stabilized piles are as follows (1):

- Effective isolation (and control of radon emanation) for up to 1000 years, to the extent reasonably achievable and, in any case, for at least 200 years
- Minimum requirement for maintenance
- Prevention of inadvertent human intrusion, and minimization of plant and animal intrusion
- Protection of surface water and groundwater.

Our basic cover design incorporates, from the tailings up, the following layers: (1) a radon barrier of compacted clay or silt, (2) a filter layer of coarse sand or gravel to encourage drainage and discourage erosion of the radon barrier, and (3) a rock layer of particles sized to resist erosion during conditions up to and including the probable maximum precipitation. Figure 1 is schematic of this design, which has been used to cap a number of UMTRA Project disposal cells.

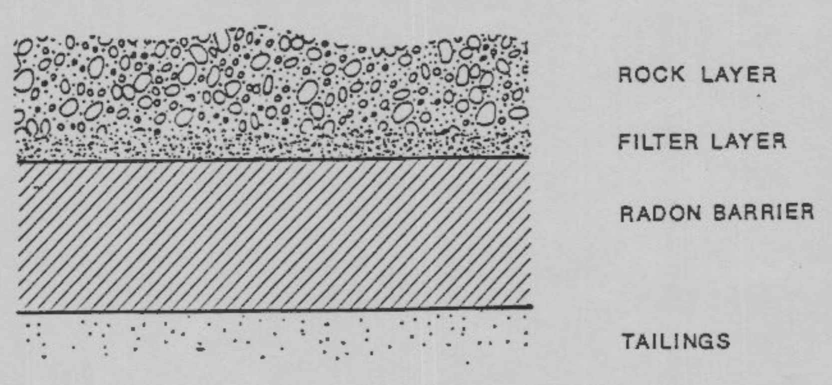


FIGURE 1
BASIC COMPONENTS OF A ROCK COVER AS USED ON UMTRA PROJECT DISPOSAL CELLS

In 1987, the basic UMTRA Project cover design came under review as part of a series of special studies performed in anticipation of revised groundwater standards. One of the special studies evaluated the applicability of vegetative covers for use in stabilizing disposal cells. The objectives of the study were to examine the feasibility of using vegetative covers, to define their advantages and disadvantages, and to develop general guidelines for their use, if feasible.

The study included a survey of the relevant literature, as well as a compilation of recent findings from cover research programs at Los Alamos National Laboratory, Pacific Northwest Laboratories, and the Nuclear Regulatory Commission. We also visited already constructed UMTRA Project disposal cells in order to determine whether rock covers were preventing the unwanted invasion of volunteer plants.

The principal finding of the study was that "vegetative covers are appropriate for use on topslopes of stabilized UMTRA Project piles." (2) Figure 2 illustrates the basic elements of a vegetative cover. From the tailings up, the layers are as follows: The radon barrier, which consists of compacted clay and silt, serves to limit radon emanation and, as a backup to overlying layers, retard moisture infiltration. The bedding or drain layer consists of coarse sand or gravel; its purpose is to prevent erosion of the radon barrier and to allow the rapid shedding of moisture that drips from the overlying layers. (This assumes, of course, that the surface is adequately tilted to allow lateral drainage.)

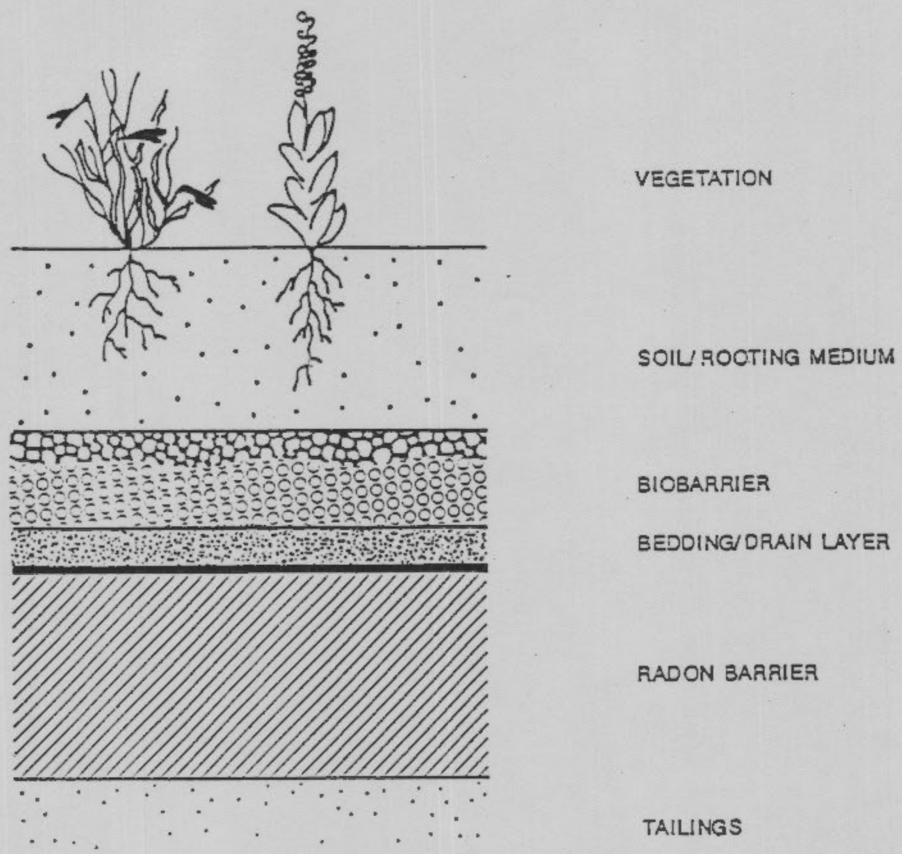


FIGURE 2
BASIC COMPONENTS OF A VEGETATIVE COVER

The biobarrier consists of clean rock and serves to limit the advancement of roots and burrowing animals from the overlying layer, thereby reducing biointrusion damage to the underlying layers. The upper part of the biobarrier is choked to prevent overlying soil from filtering downward. The soil provides a favorable rooting medium for plants, and it retains moisture for transpiration, rather than allowing the moisture to percolate down to the underlying layers of the cover. The uppermost layer is the vegetation, which transpires moisture and protects against erosion.

Each component of the vegetative cover is subject to refinement depending upon the circumstances at a given site. An important characteristic of vegetative covers, relative to the simple "soil covers" that have been used to stabilize mill tailings in the past, is that each component contributes to the overall performance of the disposal cell in a way that is measured, to the extent possible, and optimized. Moreover, the components provide desirable redundancy with respect to critical performance objectives such as limiting moisture infiltration.

PERFORMANCE CHARACTERISTICS

In the Vegetative Cover Special Study, we focussed on four primary performance objectives for the UMTRA Project. Each is discussed below.

Prevention of Biointrusion

The rock cover design in Figure 1 was intended, among other things, to "satisfy requirements for the control of animal burrowing and root penetration." (3) Observations at several recently completed disposal cells indicated that plants had invaded the rock covers and were growing with unexpected vigor and abundance. We excavated roots from beneath the rock layer and discovered that the taproots and major feeders were mostly in the upper foot of the radon barrier; however, some deeper root penetration was evident. Our conclusion is that rock covers do not necessarily prevent volunteer plants from colonizing the surfaces of disposal cells and extending their roots into the underlying layers. While the surficial rock layer may somewhat inhibit plant colonization by making it difficult for seeds to contact the underlying soil, the conditions in the soil beneath the rock seem to be quite favorable with respect to moisture availability. Thus, the plants that germinate and extend their crowns through the rock layer may grow rapidly. The favorable moisture conditions in the soil beneath the rock cover are discussed in the next section.

A study is underway on the UMTRA Project to develop effective methods for removing, with minimum damage to the cover, volunteer plants from rock covers that have already been constructed. Design improvements have also been made to reduce plant colonization onto recently designed rock covers for sites where vegetative covers are not appropriate. For instance, we have designed the drain layer to be more permeable, which enables water to move more quickly off the pile and reduces the time during which seeds can germinate and extend their roots into the underlying clay.

However, one of the important arguments in favor of a vegetative cover, such as illustrated in Figure 2, is the ability to install a buried biobarrier that probably represents the best possible long-term protection against root penetration and animal damage to the radon barrier. The intactness of the radon barrier is important to prevent unacceptably high fluxes of radon and moisture. Morris and Fraley (4) have shown that plants rooted in clay above uranium mill tailings can transport large amounts of radon to the surface, a phenomenon that could defeat the purpose of the radon barrier. Radon emanation would be even greater were the roots to fully penetrate the radon barrier and contact the underlying tailings.

A buried layer of loose cobbles (Figure 3) may deter biointrusion by plants and animals. In the original study by Cline et al. (5), roots and ants advanced into the rock only where soil fines had filtered into the interstices. One explanation for this is the lack of capillary surfaces for moisture storage in the biobarrier (except where fines are present), resulting in a unacceptably dry environment for organisms. The theory is that water which drains into the cobble layer will move quickly down to the underlying drain layer because of the lack of capillary surfaces for moisture storage.

The mechanism and, for that matter, the effectiveness of a buried loose cobble biobarrier is disputed in the research community. One point of consensus, however, is that roots will probably not move into the cobble layer if the cover is designed so that moisture never enters the layer. Thus, an important part of our approach to the prevention of biointrusion is the provision of adequate soil above the barrier to store moisture during periods of vegetational dormancy. Simply speaking, roots are kept out by keeping out water. The retention of water in the overlying soil may be somewhat enhanced by the soil/rock transition if that transition functions as a capillary barrier to unsaturated flow, although the performance of a capillary barrier is questionable on such a large scale as an UMTRA Project disposal cell.

In any case, the performance of the biobarrier depends in large part upon the absence of soil fines, hence capillary surfaces, among the cobbles. Accordingly, we design our biobarriers on UMTRA with choked rock along the top to prevent soil fines from filtering into interstitial spaces (see Fig. 2).

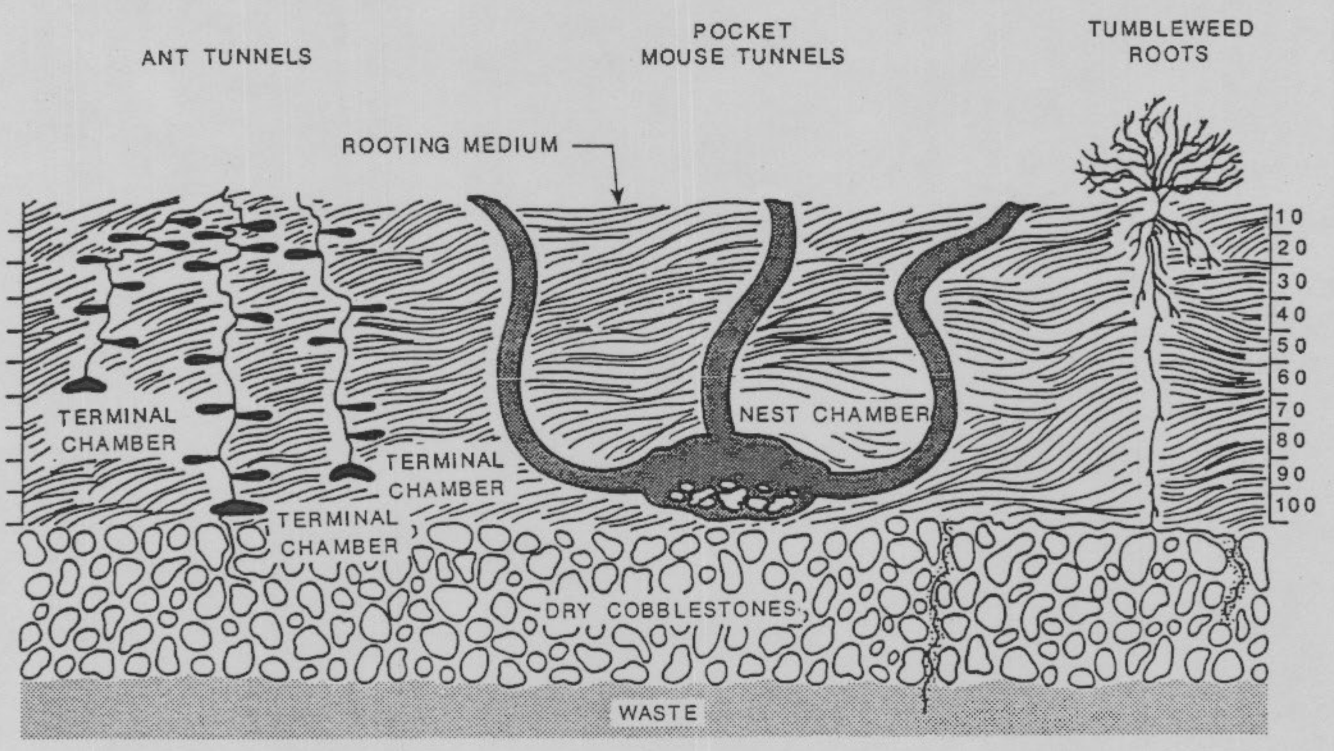


FIGURE 3

BURIED LOOSE-COBBLE BIOBARRIER AND OBSERVED EFFECT ON ORGANISMS (FROM REFERENCE 5)

Control of Water Balance

Besides preventing biointrusion, the covers for UMTRA Project disposal cells must limit the amount of precipitation that infiltrates to the tailings. This water can liberate contaminants and transport them to groundwater. Rock covers such as depicted in Figure 1 are designed to shed precipitation off the slopes of the disposal cell through the filter layer. The moisture input to the lower layers may be quite high because the rocks may be serving as a one-way valve, allowing infiltration while retarding evaporation.

Our observations of volunteer plant growth on rock covers suggest that highly favorable moisture conditions are created by the combination of rock overlying clay-rich soil. The best evidence for this is the vigorous growth of those plants which have managed to extend their roots into the radon barrier. Water-balance models have suggested that the deeper portion of the radon barrier is generally quite moist, though not saturated. Plants rooted at this depth encounter ideal conditions for growth.

Vegetative covers offer an alternative approach to the management of water balance. Precipitation falling on a vegetative cover is stored in the soil until it can be removed by evapotranspiration. Rainwater that infiltrates during the growing season is quite promptly evaporated or transpired back to the atmosphere. Rain or snowmelt that infiltrates during cool weather or during periods of plant dormancy must be stored until warm weather returns or the plants renew their transpirational activity.

We use water balance models on UMTRA such as CREAMS and HELP to determine how thick the soil must be to store moisture during periods of no evapotranspiration. These models are programmed with actual or expected climatic conditions, as well as the anticipated cover characteristics, to mathematically simulate long-term performance. We determine the type, thickness, and placement density of soil that will optimize evapotranspiration relative to percolation.

It is important to mention that our efforts to design covers that will maintain the desired water balance serve two purposes. First, the covers minimize the downward movement of moisture that could mobilize contaminants. Second, the exclusion of moisture from the underlying layers will decrease the likelihood that roots will move into those layers and degrade their performance.

Resistance to Erosion

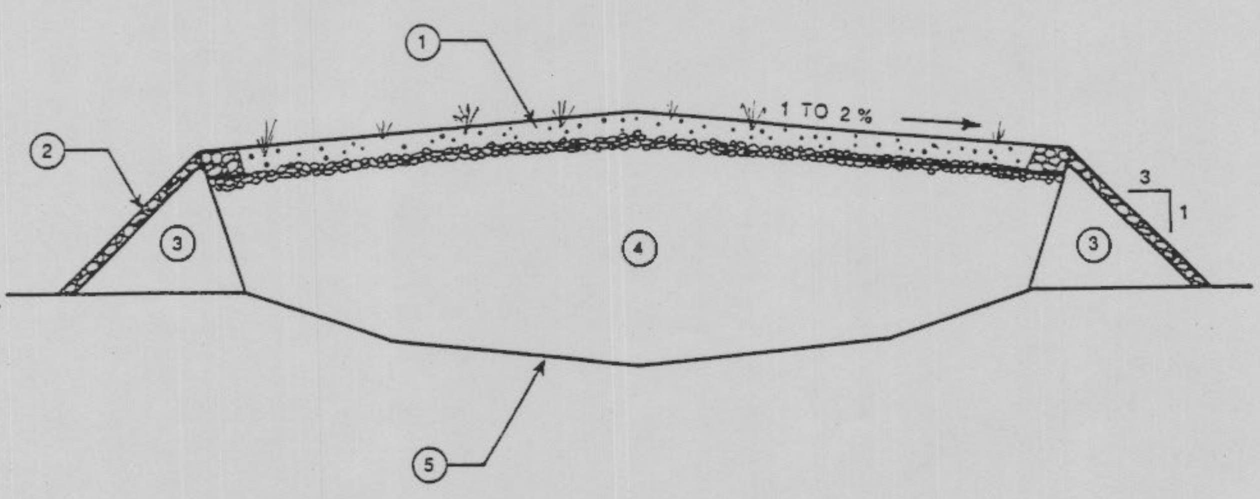
A vegetative cover is much less resistant to erosion than a rock cover and much more resistant than a cover of bare soil. Vegetation resists erosion by:

- Intercepting rainfall, absorbing energy and resisting compaction
- Binding soil particles and filtering mobilized sediments
- Retarding overland water flow, encouraging sedimentation
- Enhancing surface roughness, which enhances moisture infiltration and reduces runoff
- Depleting soil moisture, which also enhances moisture infiltration.

The effectiveness of vegetation in resisting erosion is difficult to quantify. The Universal Soil Loss Equation (USLE) and its variations are available for predicting sheetwash erosion; Beedlow (6) was among the first to apply the USLE to the design and performance assessment of vegetative covers for uranium mill tailings impoundments. Beedlow's calculations suggested that properly designed vegetative covers could resist breaching by sheetwash erosion for the required 1000 years.

The greater challenge on the UMTRA Project has been to understand gully formation and its potential impact on cover performance. We found no widely accepted models to use for predicting what conditions on a stabilized pile would preclude gully formation. One idea of value to UMTRA designers has been that of Walters et al. (7), who suggested that riprap parapets be used to surround vegetated topslopes on stabilized piles. The parapet would resist erosion and establish a base level that is sufficiently high as to discourage gully formation on the vegetated soil of the topslope. Figure 4 illustrates a pile configuration based upon this approach.

An additional benefit of the design in Figure 4 is that volunteer plant growth on the rocky sideslopes will not be a serious biointrusion problem because the roots will be primarily in clean fill rather than in the radon barrier or underlying tailings. The steep rocky sideslopes will also serve as a partial barrier to the movement of fire or large herds of grazers onto the pile, both of which could deplete the vegetation on the topslope.



(1) TOP VEGETATIVE COVER: SEE DETAIL IN FIGURE 2

(2) SIDE ROCK COVER: SEE DETAIL IN FIGURE 1

(3) PERIMETER DIKE: COMPACTED SOIL & ROCK

(4) TAILINGS & CONTAMINATED MATERIAL

(5) BASE: EXCAVATED SOIL

FIGURE 4

DISPOSAL CELL WITH VEGETATED TOPSLOPES AND ROCK SIDESLOPES

The approach in Figure 4 has yet to receive the full endorsement of the Nuclear Regulatory Commission (NRC) for its ability to prevent catastrophic gullying of the topslope, particularly in arid areas where vegetation cannot be expected to grow profusely. Accordingly, we have implemented a number of other measures on a site-specific basis. For instance, the rock of the biobarrier may be sized to preclude its mobilization by a gully that has breached the overlying soil. Another approach with multiple benefits is to apply a veneer of rock mulch on the soil surface of the topslope. The resultant surface is similar to the desert pavement that characterizes stable surfaces in many desert ecosystems. The rock, which may be applied as a monolayer or a sand/gravel admix, not only resists erosion, but also reduces evaporation. This reduction in evaporation is desirable in arid climates, even though the cover is intended to return as much moisture as possible to the atmosphere. By reducing the amount of moisture lost to evaporation, the cover provides more moisture for transpiration and therefore supports a more vigorous plant community and, more importantly, keeps that community alive during droughts. Transpiration is generally considered more desirable than evaporation as a mode of water removal because plant roots can reach deeper into the soil profile than can the forces of evaporation.

Longevity

The authorizing legislation for the UMTRA Project requires that disposal cells be designed to contain wastes for 1000 years or, in any case, for 200 years. Completed cells are to require minimum maintenance. Performance assessment models are available, and are widely used on the UMTRA Project, to demonstrate a planned cell's longevity with respect to erosion and hydrologic isolation. However, it is difficult to predict the extent of colonization of a rock cover by unwanted vegetation, and the degradation in performance than might result from root growth in the radon barrier and tailings. For the moment, surveillance and maintenance (specifically, plant removal) is the best means to ensure that vegetation does not damage rock covers that have already been built.

Under certain circumstances, vegetative covers may provide greater confidence than rock covers in the longevity of a disposal cell, and may promise greater freedom from maintenance. The buried loose-cobble biobarrier reduces, and possibly prevents altogether, root damage to the underlying layers. If the proper soil is used for the growth medium, the designer may be absolutely confident that vegetation will be present over the long term to transpire moisture and resist erosion. It must be said that vegetative covers are susceptible to episodic disturbance by factors such as drought or fire, and that performance will be reduced whenever plants are absent. However, vegetative covers will, except under extreme circumstances, repair themselves as part of the natural colonization and stabilization of denuded surfaces. Rock mulches, as mentioned above, can reduce erosion when plants are absent.

We carefully determine which natural vegetation community is appropriate for establishment on each pile. Our goal is to develop a community that is consistent with one of the numerous "climax" vegetation types in the region. Having identified a local vegetation type (often a grassland community) as a target for our vegetative cover, we analyze the ecological factors responsible for that natural community and emulate those factors in our vegetative cover. The use of productive local soils and native plant species provides confidence that our vegetative cover will support an enduring and resilient plant community.

SUMMARY AND CONCLUSIONS

Cover design is very much a site-specific process. The decision on whether to use a rock cover versus a vegetative cover depends upon numerous factors such as climate, native vegetation, availability of materials, economics, and the nature of the waste. The combination of vegetative and rock covers such as shown in Figure 4 may provide the best overall performance.

On the UMTRA Project, we plan to establish vegetative covers on topslopes at a number of sites in Colorado and Texas. Final designs have been prepared for several of these covers, although last-minute refinements are always a possibility. In any case, the construction and performance of these covers will be closely monitored. Designers of disposal cells will always face decisions on whether to use rock covers versus vegetative covers, and we intend that our experiences on the UMTRA Project be made available so as to facilitate those decisions.

ACKNOWLEDGEMENTS

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