Chapter 26

COVER DESIGN FOR URANIUM MILL TAILINGS PILES: A STANDARD FOR THE FUTURE

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Abstract This paper describes the covers used to stabilize inactive uranium mill tailings piles and the recent geotechnical advances incorporated into the design of such covers. Although generally too conservative and expensive for use in conventional mine reclamation projects, the covers designed and constructed to remediate inactive uranium mill tailings piles incorporate most or all of the components required to provide long-term erosion resistance and groundwater protection in reclaiming a mine waste disposal facility. This paper evaluates the applicability of established and new technical approaches for uranium mill tailings stabilization to the broader field of general mine reclamation.

INTRODUCTION

The Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604) grants the Secretary of Energy the authority and responsibility to perform such actions as are necessary to minimize radiation health hazards and other environmental hazards caused by inactive uranium mill sites. The U.S. Department of Energy is meeting this responsibility through the Uranium Mill Tailings Remedial Action (UMTRA) Project. The program involves the cleanup and stabilization of 24 inactive uranium mill tailings piles in ten states. Remedial work is complete at eight of the sites, nearing completion at an additional four, and the detailed design or early construction work is in progress at the remainder.

The U.S. Environmental Protection Agency (EPA) issued the standards which govern the remedial work (40 CFR 192). These translate into the following design criteria:

- Stabilization control for up to 1000 years to the extent reasonably achievable, and in any case for at least 200 years.
- Minimum maintenance.
- Prevention of inadvertent human intrusion.
- Reduction of radon flux from the pile to an average release rate of 20 pC/m2s.
- Protection of surface water and groundwater. (Groundwater protection standards parallel those in the Resource Conservation and Recovery Act (RCRA)).

Remedial work at UMTRA Project sites generally involves stabilizing the uranium mill tailings in place, or relocating them to another disposal area for stabilization. The final remediated pile is called the tailings disposal cell. The contaminated materials are consolidated into gently sloping piles and then covered with earthen and rock layers that control radon emanation, resist erosion, and prevent the infiltration of water that might transport contaminants to the groundwater.

If the tailings are relocated, a basal layer may be placed to control seepage or geochemically alter the quality of water seeping from the cell. Liners, in the conventional sense (i.e., layers of very low permeability that inhibit seepage), are not used in the basal layer. All infiltration control, hence control of the quantity of seepage, is achieved by the cover placed over the stabilized pile.

In order to meet the three simultaneous demands of erosion control, infiltration control, and radon flux reduction, the art and science of the design and construction of covers has been significantly advanced on the UMTRA Project. This paper describes the current status of knowledge, as well as some of the more significant advances. In addition, the paper explores the extent to which the UMTRA Project cover design technical approach may be applicable to the long-term stabilization of other mine waste disposal facilities.

COVER DESIGN

Following is a list of the main performance criteria that govern the design and construction of covers for UMTRA Project, and a brief description of how those criteria are achieved:

- Remain stable for 1,000 years: use only natural materials that have proven long-term durability and integrity. Design for extreme events such as the probable maximum precipitation. Provide multiple redundant layers.

- Limit infiltration (to achieve groundwater protection standards): provide for evapotranspiration; shed water that falls on the pile. Incorporate low permeability soils (silts, clays, and bentonite mixes)

- Minimize long-term maintenance: reduce the potential for the establishment of vegetation, or provide for the establishment of climax vegetation.

- Control the dispersal of the tailings: provide erosion protection features.

- Prevent intrusion to the pile by animals and plants: provide biointrusion barriers.

- Limit radon gas flux from the pile: provide radon barrier of natural soil.

The Checklist Cover and Variants

The UMTRA Project Technical Approach Document (DOE, 1989) describes the design procedures and details for uranium mill tailings disposal cells and the cell covers. A checklist approach to cell and cover design is used. A disposal cell consists essentially of two distinct parts: the perimeter dike and the top cover. The cover design details may differ on the top and sideslope of the disposal cell, depending on the details of the perimeter dike design. Figure 1 shows the so-called Checklist Cover. It incorporates a number of components that alone, or in concert with other components, provide a means of achieving all of the above-listed design and performance criteria. Table 1 lists for each component the main purpose or function of the component. Depending on site-specific factors, one or more of the components of the checklist cover may be omitted. In practice, the following cover variants are being used on the UMTRA Project:

- The simple rock cover: the three components are the radon/infiltration barrier of compacted soil, the bedding layer of fine sand or gravel, and the erosion protection riprap rock. This cover may be used on both the sides and topslopes of a disposal cell. This cover is suitable for use at sites in arid climates where vegetation growth is sparse. To control the germination of stray seeds, the bedding should be as permeable as possible. In that way water is shed rapidly from the pile and an environment conducive to plant growth is avoided.

- The double drain cover: the components are the radon/infiltration barrier; a drain; a zone of random soil, the purpose of which is to increase the depth of the cover and protect the infiltration barrier against freezing and thawing; a bedding layer; and the erosion resistant rock. Advantages of this cover include protection of the radon/infiltration barrier from frost damage in cold climates and the existence of a controlled zone - the random soil - for vegetation that might establish through the riprap.

- The full component cover: this cover incorporates all the elements of the Checklist Cover. Because of the difficulty of providing for slope stability (due to the low-strength bentonite elements) and the need to prevent long-term erosion, this cover is used only on the topslopes of the cell. The most significant benefits of this cover are its ability to deal effectively with vegetation and to reduce infiltration to the cell because of effective evapotranspiration.

Sideslope Design Approaches

Figure 1 shows a cross section of an UMTRA Project disposal cell for relocated tailings. Preparation of the site involves excavation below grade. This is done to reduce the overall height of the cell, and hence reduce sideslope lengths and the cost of rock for erosion protection. Excavation produces excess fill that may be used to form the so-called clean fill dikes that ring the cell itself. Two significant advantages of a clean fill dike sideslope detail, as compared to a shaped tailings pile covered by the simple or double drain cover, are the following:

- Infiltration through the sideslope does not contribute to groundwater contamination. Because we cannot rely on a full vegetation stand or low permeability bentonite elements to control infiltration on the sideslopes (i.e., we cannot use the full component cover), the infiltration through the sideslopes is usually considerably greater than through a full component topslope cover. Clean fill dikes avoid excess contaminant transport to the groundwater that may preclude compliance with relevant groundwater protection standards.

- In the event that vegetation does establish on the sideslopes, the clean fill dikes are not likely to be significantly affected by the roots of even deep root-penetrating species.

RECENT TECHNICAL ADVANCES

The U.S. Department of Energy (DOE) and its contractors on the UMTRA Project have undertaken a number of special studies to evaluate alternative approaches to improving the performance of cell covers, to effect all possible cost savings, and to comply efficiently with the relevant EPA standards. The following is a brief description of some of these advances.

High Percentage Bentonite Mixes

Figure 1 shows that the primary infiltration barrier is a commercial product (Claymax^{R}) that

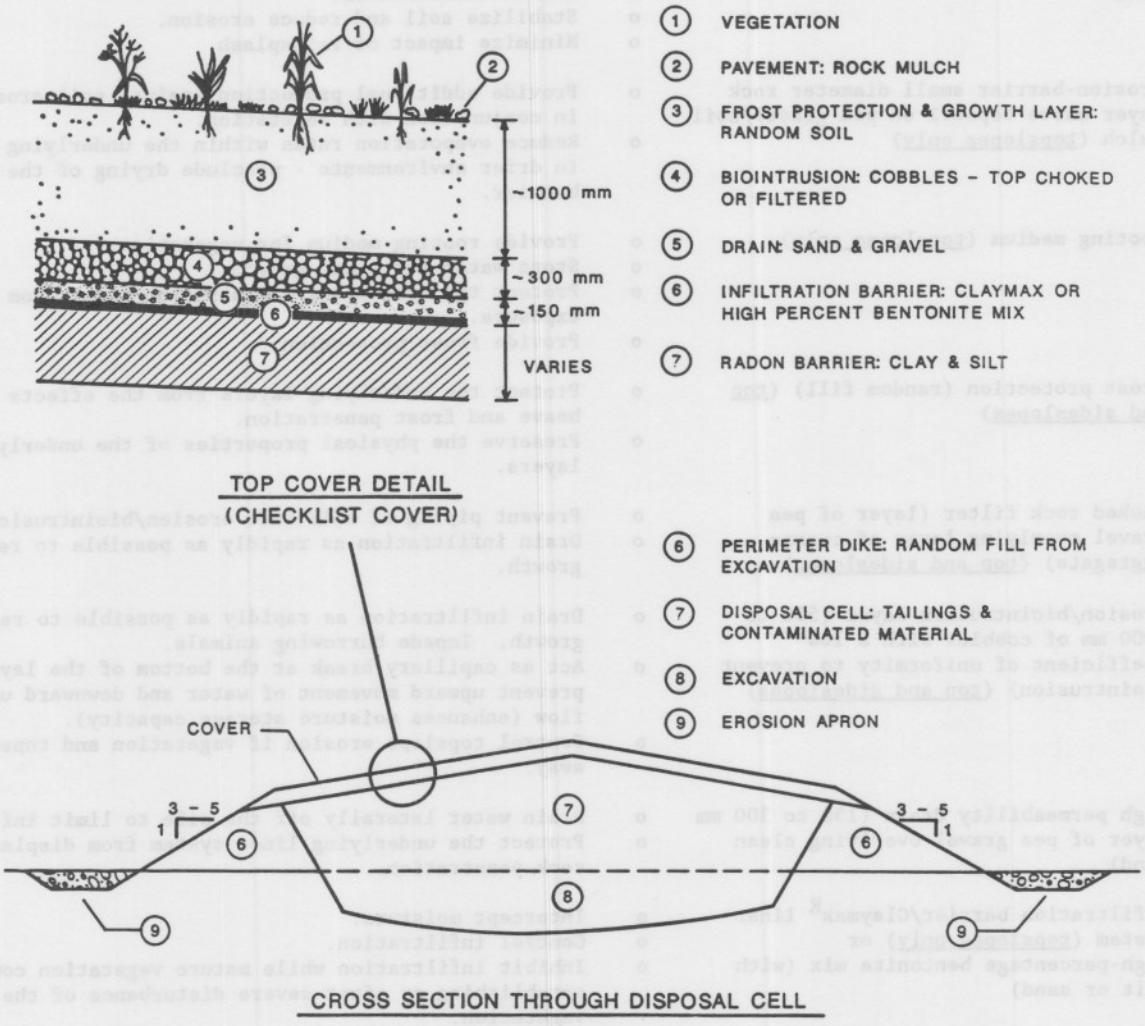

FIGURE 1 A CONSERVATIVE DESIGN FOR AN UMTRA DISPOSAL CELL

Table 1 Checklist Cover Component Functions

Cover component	Purpose and function
1. Erosion-barrier vegetation (topslopes only)	o Transpire moisture that enters the soil. o Reduce infiltration. o Stabilize soil and reduce erosion. o Minimize impact of rainsplash.
2. Erosion-barrier small diameter rock layer above topsoil on pea gravel/soil mulch (topslopes only)	o Provide additional protection against soil erosion used in conjunction with vegetation. o Reduce evaporation rates within the underlying soil layer in drier environments - preclude drying of the radon barrier.
3. Rooting medium (topslopes only)	o Provide rooting medium for vegetation. o Store water for plant growth. o Protect the underlying biointrusion layer from surface exposure. o Provide frost protection.
4. Frost protection (random fill) (top and sideslopes)	o Protect the underlying layers from the effects of frost heave and frost penetration. o Preserve the physical properties of the underlying layers.
5. Choked rock filter (layer of pea gravel overlying layer of coarse aggregate) (top and sideslopes)	o Prevent piping of soil into erosion/biointrusion barrier. o Drain infiltration as rapidly as possible to retard root growth.
6. Erosion/biointrusion layer (500 to 1000 mm of cobbles with a low coefficient of uniformity to prevent biointrusion) (top and sideslopes)	o Drain infiltration as rapidly as possible to retard root growth. Impede burrowing animals. o Act as capillary break at the bottom of the layer to prevent upward movement of water and downward unsaturated flow (enhances moisture storage capacity). o Control topslope erosion if vegetation and topsoil eroded away.
7. High permeability drain (150 to 300 mm layer of pea gravel overlying clean sand)	o Drain water laterally off the pile to limit infiltration. o Protect the underlying liner system from displacement and rock penetration.
8. Infiltration barrier/Claymax^{R} liner system (topslopes only) or high-percentage bentonite mix (with silt or sand)	o Intercept moisture. o Control infiltration. o Inhibit infiltration while mature vegetation community is establishing or after severe disturbance of the vegetation.
9. Radon barrier (clay/silt) (top and sideslopes)	o Inhibit radon emanation. o Limit infiltration.

is essentially a layer of bentonite sandwiched between two geotextiles. As an alternative, we evaluated the use of sandy soils amended with high percentages (up to 25 percent) of bentonite. Conventionally, silts and clays have been amended with up to ten percent of bentonite to reduce their hydraulic conductivity. Bentonite-amended silts and clays are, however, often subject to significant volume changes with changing moisture content. The use of sand as the matrix reduces volume changes and increases the overall strength of the material, thus facilitating its use on sideslopes.

In our test program we showed that the addition of up to 25 percent bentonite to sands produces a material that has laboratory hydraulic conductivities as low as 1E-9 cm/s and drained angles of friction as great as 28 degrees. Site-specific testing of high percentage bentonite-amended soils is currently in progress on the UMTRA Project.

Radon Barrier Erosion

Water flowing in the bedding layer and on top of the radon barrier could erode the upper surface of the radon barrier. If this were to occur, it could lead to surface deformation of the cover, concentrated flow, and potential cover instability. For the first UMTRA Project piles to be stabilized, the technical approach to preventing erosion of the radon barrier was to adopt the conservative criterion that the bedding layer gradation should comply with conventional filter criteria. At the Shiprock, New Mexico, site, the resulting fine-grained bedding reduced the rate at which water is shed from the pile, and hence increased the potential for germination of seeds and potential infiltration to the cell.

Abt et al. (1989) describe the study that provided the basis for the recommendation that the median bedding layer grain size be approximately 8 mm. On the basis of extensive full-scale flume testing, Abt concludes that this larger bedding size enhances drainage, minimizes retention of residual water, and adequately protects the radon barrier from excessive erosion.

Soil Erosion

The U.S. Nuclear Regulatory Commission (NRC) (1989) has now established procedures for evaluating the resistance to erosion of a soil cover for the long-term performance standards applicable to the UMTRA Project and the reclamation of the remaining active uranium mill tailings piles. In brief, the procedure involves the calculation of the tractive force caused by the water flowing down the slope, and selection of a soil that is resistant to the calculated tractive force. The significant advances are the new technical procedures for calculating the shear stress on the soil caused by the flowing water and the identification of the resistance of various soils to flow-induced tractive forces. In practice, on UMTRA covers where soil covers are proposed, use of the NRC procedure leads to placement of a veneer of rock mulch on the soil surface of the topslope. The resultant surface is similar to the desert pavements that characterize stable surfaces in many desert ecosystems. The rock may be applied as a monolayer or a sand/gravel admixture. This veneer may reduce evaporation from the soil surface; however, the additional moisture will probably support a more vigorous plant community that will in turn increase evapotranspiration.

Cover Performance Evaluation

Standard practice on the UMTRA Project is to calculate the potential water flux through the cover with standard computer codes such as HELP or UNSAT-H. Numerous studies (e.g., Gee and Hillel, 1988) have established the sensitivity of the calculated flux to assumptions about material properties and climatic conditions. In order to reflect the reality that infiltration will vary over the 1,000 years of pile performance, we approach the specification of pile water fluxes as shown in Figure 2. In essence, we recognize that there is some site- and cover-specific variation of cover flux that must be compared to the ability of the foundation subsoils, including the groundwater, to accept the full flux range (i.e., to comply with groundwater protection standards).

Other Studies

Other special studies of cover performance undertaken on the UMTRA Project include:

- In situ measurement of the actual moisture content of the radon barrier at the Shiprock, New Mexico pile.
- Development of computer programs for the site-specific prediction of the depth and effect of freezing and thawing on cover materials.
- Comparative evaluations of alternate cover designs and cover materials (including geomembranes).
- Geochemical attenuation or alteration of the tailings pile and its leachate as a way to enhance groundwater protection.

TITLE II PROCEDURES

Approaches to the long-term stabilization of uranium mill tailings piles that are not part of the UMTRA Project are different from those discussed above. Range (1989) describes the cover for the Exxon Wyoming uranium mill tailings pile. The tailings at that site were covered with 1 m of sandy clay compacted to 95 percent of standard Procter and 150 mm of topsoil. The thickness of the soil layer was established by the need to control radon flux from the pile. Groundwater protection was not addressed in the paper and was not a controlling factor in cover design.

At Ray Point in Texas, the Title II uranium mill tailings pile has been covered with 1.2 m of soil and vegetation (Miller and Davis, 1986). Runoff control is achieved with a gentle, half-percent topslope that directs water to a broad swale down the central part of the pile.

OTHER APPROACHES TO TAILINGS PILE STABILIZATION

Consider a large, inactive tailings pile in an arid part of the west. Wind and water are eroding the tailings sands and silts. Dust is blowing from the pile across a neighboring community and onto the flat lands downwind of the facility. Water has eroded the sides of the pile and deposited tailings across large parts of the area surrounding the pile. Wind picks up the eroded, redeposited tailings and increases the dust from the site.

Table 2 lists potential measures to suppress the dust from such a facility. The ideas tabulated range from the simple and obvious one

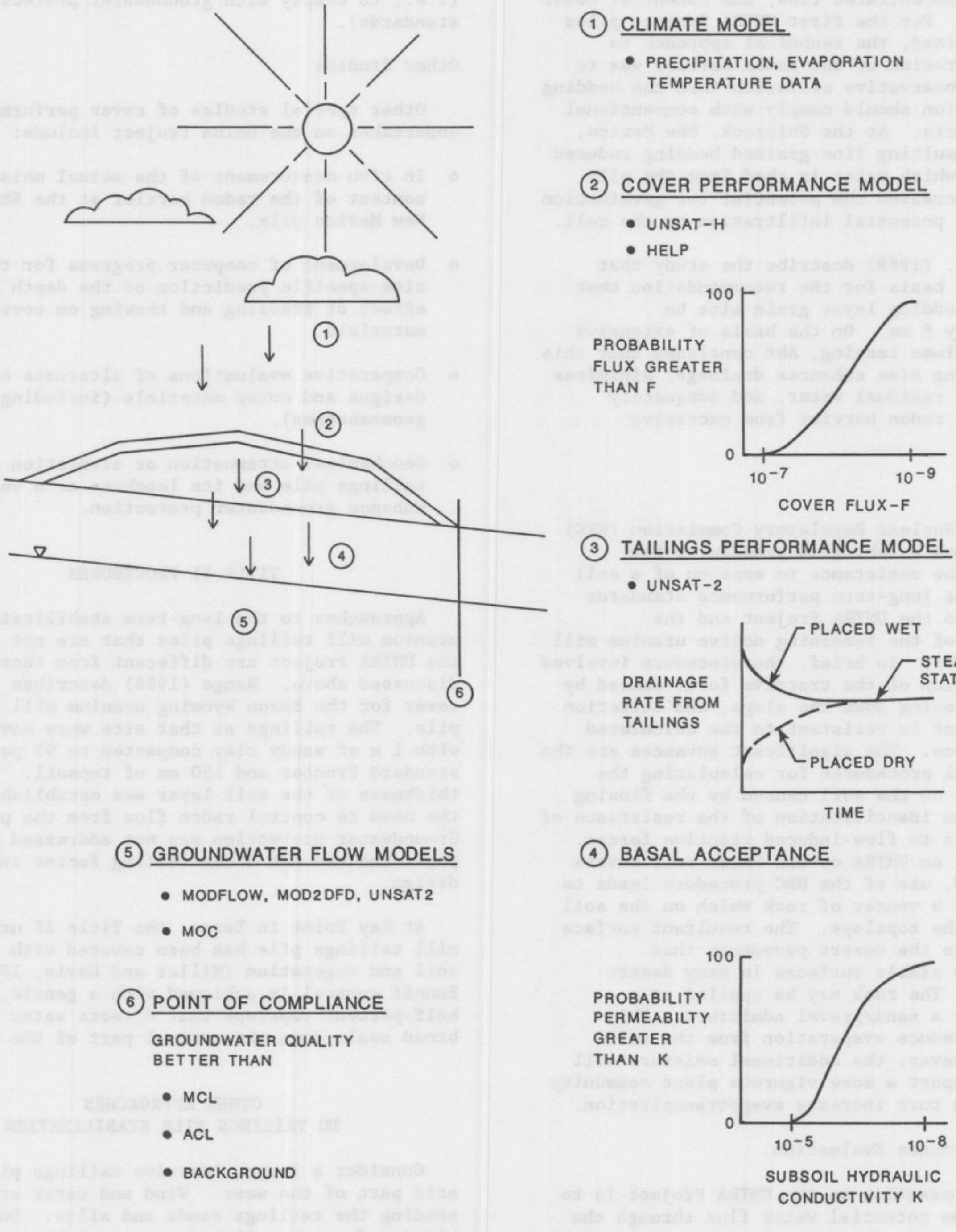

FIGURE 2
DISPOSAL CELL HYDRAULIC PERFORMANCE ASSESSMENTS

TABLE 2 Potential Dust-Suppression Measures

Action	Mechanism	Advantages	Disadvantages	Remarks
Relocate Materials	Reduces surface area to be eroded	Permanent	Expensive; requires much heavy equipment	Even carefully performed, this activity will generate dust, but will be perceived by local community as a major effort toward a permanent solution. Maintenance: Low.
Install Vegetated Windbreaks	Plants reduce wind velocities and intercept airborne particulates	Relatively permanent; aesthetically pleasing	Vegetation takes time to grow and perform as intended. Some maintenance may be required	A revegetation program builds on existing reclamation and takes advantage of previous research. Maintenance: Moderate.
Pave with Soil Cement	Creates an erosion-resistant surface	Fairly simple to implement; will yield immediate results	Somewhat impermanent; will eventually succumb to sandblasting and other weathering	This can be combined with other measures to address short- and long-term goals. For instance, cement aprons could "harvest" water into planting areas. Maintenance: Moderate.
Treat with Blinding Agent (e.g., Coherex)	Creates an erosion-resistant surface	Simple to implement; will yield immediate results	Impermanent; repetitive applications will be needed	Possibly could be used for water harvesting as described above. Water repellency needs to be investigated. Maintenance: High.
Place Geomembranes or Geonet	Isolates particles from wind or binds particles	Immediate, positive effect	Difficult to install, permanence in this application is uncertain; unsightly	Geomembrane could be used for water harvesting surface, geonet could stabilize surface long enough to facilitate plant establishment. Maintenance: Moderate.
Place Rock Cover or Rock Mulch	Protects particles from wind	Immediate, positive & permanent effect; can be applied to topslopes and sideslopes	Significant transportation expense in moving rock to tailings surface	Rock mulch can favorably influence plant growth by reducing moisture loss to evaporation, thereby increasing moisture availability. Maintenance: Low.
Install Snow Fences or Wind Berms	Reduces wind velocities and encourage particle deposition	Inexpensive and simple to install; immediate (though partial) effect	Positive effect is short-lived, as fences are quickly knocked over or buried	Snow fences should probably be used only in conjunction with other measures; for instance, to provide temporary protection to small plants. Berms could be used to divert surface water to plants. Maintenance: High.
Place Widely Scattered Rocks	Increases surface roughness, reducing wind velocities	Less expensive than placement of a continuous layer of rock mulch	Less effective than a continuous layer of rock mulch	Using wind velocities and tailings texture, calculations could be performed to determine size and placement of rocks necessary to achieve desired dust suppression. Maintenance: Low.

of reducing the pile size to reduce the source area, to the complex idea of developing the site for alternative uses that can afford to pay for final surface stabilization with a non-eroding cover.

Of the numerous possible surface stabilization approaches listed in Table 2, only placement of a rock layer or rock mulch has the potential to provide a long-term, stable cover that will control dust and minimize water erosion. If the rock mulch is properly placed, vegetation may establish or be established on the reclaimed pile. To our knowledge, this approach has not yet been implemented at any specific site. In theory, it is an attractive option: rock is usually commonly available at mines whereas topsoil is usually not readily available.

POTENTIAL IMPACT OF UMTRA PROJECT PRACTICES ON CONVENTIONAL STABILIZATION APPROACHES

There is no doubt that the technical approaches and the design details adopted on the UMTRA Project to stabilize inactive uranium mine and mill tailings piles are conservative. The driving forces behind such conservative practices are the EPA regulations that govern the program. The need to provide remedial schemes that have long-term stability and that comply with groundwater protection standards has led to cover details and construction costs exceeding those in any other arena of the reclamation of mining facilities (Caldwell, Rager, and Coons, 1988).

We do not believe that the non-uranium mining industry should, or will ever find it necessary to, remediate to the standards that govern the UMTRA Project. Accordingly, we recognize that the design approaches described in this paper will not be used tomorrow on gold or copper mine tailings impoundment stabilization projects. Nevertheless, we believe that many of the individual ideas, technical approaches, analytical procedures, and design details formulated on the UMTRA Project, when suitably adapted to non-uranium mine reclamation schemes, will provide guidance and insight to those charged with the responsibility of reclaiming old mines and their associated tailings piles in such a way that they protect human health and the environment.

For example, in an arid environment the placement of a veneer or mulch of mine waste rock may be the only certain way to control long-term wind and water erosion. If acid drainage from a pile could detrimentally affect groundwater, a cover of natural material with very low permeability might be the appropriate solution. If soil covers are established on a reclaimed pile, an evaluation of the cover stability according to the NRC approach will provide the designer with valuable insight into the probable performance of the reclamation scheme.

CONCLUSIONS

Public concern, federal laws, EPA regulations, NRC review, and the ever-changing public attitude to providing long-term cleanup of contaminated sites have resulted, on the UMTRA Project, in the development of conservative designs for tailings reclamation. The pressure to meet groundwater protection standards and to provide stability for 1000 years has lead to the formulation of technical approaches that extend the state of practice in mine reclamation. Special studies have advanced geotechnical technology for the design of waste disposal covers. Some of the more recent advances have been described here.

The work done on the UMTRA Project holds lessons for the entire mining industry. Each mine will no doubt interpret the lessons differently, according to the particulars of its own situation. On the basis that the UMTRA Project approach represents the most conservative possible approach, the remainder of the mining industry may regard the UMTRA Project's as a yardstick for establishing its own goals and measuring its own performance in the stabilization of mine waste disposal facilities.

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