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Revegetation/Rock Cover for Stabilization of Inactive Uranium Mill Tailings Disposal Sites A Status Report

**P. A. Beedlow
M. C. McShane
L. L. Cadwell**

July 1982

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
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REVEGETATION/ROCK COVER FOR STABILIZATION OF
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Richland, Washington 99352

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SUMMARY

Pacific Northwest Laboratory is developing design and performance guidelines for surface stabilization of inactive uranium mill tailings. In this work, vegetation and rock covers are being evaluated for maintaining long-term integrity of impoundment systems. Methods are being developed to estimate erosion rates associated with rock and/or vegetation covers, and to determine the effects of surface treatments on soil moisture. Interactions between surface treatments and barriers (radon and biological) are being studied as well. The product will be a set of guidelines to aid in designing surface covers. The following report presents the status of this program and a discussion of considerations pertinent to the application of surface covers to tailings.

Test plots located in Grand Junction, Colorado and Waterflow, New Mexico are being used to study: 1) the interactions between vegetation and radon and biological barriers, 2) the effects of surface covers on soil moisture, and 3) the effects of rock covers on vegetation. The first growing season for the Grand Junction plot was 1981; no effects on vegetation from radon barriers, overburden depth or biological barriers were detected. Noticeable treatment effects on vegetation or soil moisture were not expected the first year at Grand Junction because the plants were young and irrigation water was applied throughout the growing season. A preliminary study of plant root distribution at Grand Junction showed root penetration by annual weeds throughout the overburden and into tailings in areas without an asphalt radon barrier. No damage to the asphalt was visible. The test plot at Waterflow was completed at the end of the 1981 growing season; data collection will begin during the summer of 1982. In order to evaluate the interactions between vegetation and radon barriers fully, along with the effects of rock covers on vegetation and effects of different surface covers on soil moisture, continued monitoring of both test plots will be necessary for several years.

Data on soils, climate, and vegetation were collected from sites in close proximity to most of the tailings piles. Using these data, the western tailings sites were grouped into three distinct regions based on climate and geographical location: the Colorado Plateau, the West Slope

of the Rockies and the Northern Great Plains. The vegetation sampled throughout these three regions can be classified into six community types: perennial grassland, annual grassland, shrub steppe, woodland, forb-dominated grassland, and salt-shrubland. Grouping sites according to climate and vegetation type will facilitate characterization of the environmental factors affecting surface covers in the regions where UMTRAP sites are located.

A review of methods used for revegetating disturbed land was conducted to identify those applicable to U-tailings. The problems associated with establishing vegetation in arid and semi-arid climates were the focus of the review because most of the inactive tailings are found in these types of areas. Establishment of vegetation at sites receiving more than 25 cm (11 in.) of precipitation is feasible without irrigation. For sites receiving less than 25 cm of precipitation, irrigation will probably be necessary. Rock covers may aid in establishing plants in arid areas by reducing evaporative water loss from the soil and increasing infiltration.

An economic study was conducted to provide a general methodology for evaluating the costs of applying rock covers and/or establishing vegetation on covered U-tailings. The Grand Junction tailings site was chosen as a case study. Results of the study indicate the major expense is the cover material (topsoil or rock). Costs associated with the application of surface covers are highly site-specific because cover material must be obtained locally and no general comparison of rock and vegetative covers is possible.

Minimizing erosion of earthen covers which protect or act as radon barriers is critical to long-term stabilization of U-tailings. Moreover, estimating potential erosion rates at tailings sites is essential if surface covers that will provide adequate protection are to be designed. A review of wind and water erosion processes was conducted to ascertain the environmental and design factors that are most likely to affect erosion rates on covered tailings. Models used to estimate erosion were reviewed to determine those most applicable to the Uranium Mill Tailings Remedial Action Program (UMTRAP). A general approach to impoundment protection is suggested as is proposed work for FY 1983.

Surface covers will affect moisture dynamics within the overburden and possibly within the tailings by controlling infiltration of precipitation and evapotranspiration of water from soil. Model simulations of rock and vegetative covers over the multilayer earth radon barrier were conducted using data from the Grand Junction site. The influence of vegetation and rock covers on soil moisture in arid climates is being directly studied using weighing lysimeters. Results of the model simulations and preliminary findings of the lysimeter studies, reported here, show that rock covers increase the moisture content of soil by reducing surface runoff and evapotranspiration. If applied to covered tailings in a way that reduces plant growth, rock covers could cause water accumulation in tailings and possible drainage.

Factors that should be considered when designing site-specific surface covers are discussed. These include: erosion processes, soil moisture dynamics, integration of impoundment system components, and risk considerations. The wide range of climatic, soil and topographic conditions represented by the UMTRAP sites makes site-specific cover designs necessary.

A decision tree was constructed to serve as a basis for design planning and for determining research needs. The decision tree outlines the process of gathering necessary site information for designing surface stabilization plans and for evaluating the effects of the surface covers on impoundment systems.

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1.0 INTRODUCTION

Uranium mill tailings consist of the waste or refuse left after uranium processing. These tailings contain significant quantities of radium and radium's decay product, radon gas. In addition, tailings contain, as potential ground-water pollutants, some nonradioactive chemicals that were either introduced to or liberated from the ore in the milling process. Typical disposal for these wastes has been to slurry the tailings into large ponds that eventually dry out, leaving a tailings pile. Because exposure to radon gas has been linked to lung cancer, concern has been expressed over the health and environmental consequences of allowing bare tailings piles to remain. Of the principal radionuclides found in tailings, radium also has the most potential for ground-water contamination (Buel et al. 1981).

On November 8, 1978 the 95th Congress of the United States enacted Public Law 95-604. The intent of this law is to protect public health, safety and welfare, and to regulate interstate commerce. Under the law every reasonable effort must be made to provide for safe, environmentally sound stabilization, disposal and control of uranium mill tailings. The law's purpose is to prevent or minimize radon diffusion into the environment, and to prevent or minimize other environmental hazards from such tailings. The act specifically included remedial action on inactive mill tailings sites.

In keeping with that Act, a number of measures are being considered to prevent the escape of radon and other toxic materials from inactive uranium mill tailings piles (O'Brien 1981). Asphalt and earthen materials are being evaluated for use as barriers (or impoundments) to contain radon gas and as liners to minimize leaching of toxic compounds into ground and surface-water. To maintain long-term effectiveness, a radon barrier must be protected from wind, water, ultraviolet radiation, frost, chemical reaction, and biological degradation by a stabilizing surface cover. Because surface covers can affect the amount of water that enters the tailings from precipitation, their design must consider effects on water in the tailings and the functioning of liners when they are used.

Soil placed over an impoundment system can provide a protective mantle if the soil is not lost by erosion. Vegetation is an attractive choice for

controlling wind and water erosion since it is economical and self-renewing. In extremely arid regions, vegetation may not stabilize the surface layer adequately. In these areas rock covers may be required. However, by reducing evapotranspiration, rock covers may permit the moisture content of the tailings to increase. An advantage of maintaining elevated moisture contents in tailings/cover systems is reduced emanation of radon gas (Nelson et al. 1980, Mayer et al. 1981). Moisture accumulation, however, may result in drainage through the tailings pile and increase the potential for ground-water pollution.

Uranium mill tailings remedial action sites consist of piles that have or may be contoured to have relatively large, nearly flat surfaces and smaller embankments that adjoin the surrounding landscape. The vegetation and rock surface covers discussed here are defined as various combinations of plant types (grasses, forbs and shrubs) and/or thin layers of small to medium sized rock or aggregates. These covers can be applied to stabilize the nearly level surfaces of tailings piles from the erosive forces of wind and rainfall events. Vegetative and rock covers are distinct from more massive riprap materials, which may be required to stabilize steeper embankments that are likely to be subjected to stream channel cutting or severe runoff events.

An effective surface cover, then, is one that: 1) prevents erosion 2) minimizes the risk of bio-intrusion into the tailings and 3) maintains a level of soil moisture that maximizes radon attenuation, but does not lead to drainage of water from the tailings. Appropriate surface cover designs are dependent on the local climate, soils, vegetation, and upon the design of the impoundment system at each site. Although stabilization systems will be designed on a site-specific basis, guidelines are necessary to design and evaluate the performance of impoundment systems prior to implementation. The objective of the Revegetation/Rock Cover Program at the Pacific Northwest Laboratory (PNL)* is to establish design and

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performance evaluation guidelines for surface stabilization of inactive uranium mill tailings. The objective of this research is to provide information that will facilitate the design of effective surface treatments at minimum cost. We considered not only the use of rock and vegetation in long-term erosion control, but also the effects of rock and vegetation on soil moisture and bio-intrusion. With this information, effective surface covers suited to particular sites can be designed.

This report presents the status of the Revegetation/Rock Cover program. Our intent is to report on the status of the research to date, and to define the role of surface covers in uranium-mill tailings impoundment systems based on approximately two years of study. Technical details of the research are not included in this report in an effort to present a concise, overall view of the program's status. Detailed results of the research are reserved for topical reports. Recommendations for future research and the application of that research to uranium mill tailings problems are given.

2.0 TEST PLOTS

The objectives of the test plot studies are to: 1) evaluate the interactions between vegetation and radon and biological barriers (see O'Brien 1981); 2) determine the effects of surface covers on soil moisture; and 3) examine the effects of rock covers on vegetation. An initial test plot was constructed in conjunction with other UMTRAP projects on the inactive tailings pile at Grand Junction, Colorado. A second test plot is located on the San Juan coal mine in Waterflow, NM (approximately 11 miles west of Farmington).

GRAND JUNCTION TEST PLOT

At this test facility, studies are being conducted on: 1) the relationships between vegetation and radon barriers, 2) the interaction between vegetation and the herbicide barriers intended to limit plant root penetration, 3) the effect of soil depth on vegetation, and 4) soil moisture responses to plant cover, a rock cover and the radon barriers. These studies will provide the basis for evaluating the impacts of surface cover systems on revegetation and soil moisture.

The test plots were seeded in early November, 1980. The plant species used to seed the site were those that were adapted to the local environment, proven successful in revegetating disturbed areas, and available. The plot was irrigated throughout the 1981 growing season (approximately April through August) to insure plant establishment. No treatment effects were expected in 1981 because the plants were young and irrigation water was applied throughout the growing season. Indeed, analysis of vegetation and soil moisture data collected in 1981 showed no significant treatment effects from either multilayer earth, asphalt radon barriers or from the Treflan herbicide being tested as a root barrier.

To determine the effects of a rock cover without vegetation on soil moisture, a six inch layer of washed, two inch cobble was placed on a portion of the plot containing the multilayer earth radon barrier. Model simulation studies of the multilayer system with rock and vegetation covers indicated that rock covers would cause a significant increase in moisture

compared to vegetative covers (see Section 6.0). The field test will provide a verification of the model results.

Continued monitoring of vegetation and soil moisture in subsequent years will be necessary to determine any effects of barriers on vegetation and soil moisture under normal climatic conditions. Monitoring will also reveal the relationship between soil depth and plant community composition. No irrigation is scheduled for the plot during the summer of 1982. The plant community should begin to stabilize this year and any treatment effects should materialize within the next two to three years.

A preliminary study of plant root distribution was conducted on the asphalt portion of the test plot in late October 1981. Objectives of the study were: 1) to determine the extent of root growth after a single growing season and 2) to evaluate root excavation as a means of studying plant root distribution on covered U-tailings. Plant root intrusion into tailings is a major concern because of potential translocation of toxic materials to the surface; moreover, breaching of radon barriers by roots may increase the emanation of radon gas. Different kinds of plants have different root distributions. Grasses (monocots) tend to have shallower, more fibrous root systems than shrubs and trees. Some forb species have deep taproots (e.g. tumbleweed). Nonetheless, rooting patterns of plants are highly variable and depend on local conditions. The moisture distribution in the soil and soil physical and chemical properties can affect root distributions. Deep infiltration of water into the soil tends to stimulate deep penetration of roots. High concentrations of salts limit root growth to the topsoil covering of some mine spoils. Surface conditions can affect the types of plants that become established. Consequently, tailings cover designs must consider the distribution of plant roots and site conditions which may increase their potential for intrusion into tailings.

The effects of subsurface radon barriers and surface rock covers on plant root distributions is difficult to assess without sampling. Two general methods are available for sampling roots: direct measurement via excavation or extraction and indirect methods using tracers (Bohm 1979). Most established methods of determining root distributions were developed on agricultural plants. To aid in selecting the appropriate method of

sampling root distributions on U-tailings, a preliminary study was conducted on the asphalt portion of the Grand Junction test plot in late October 1981, approximately one year after seeding. Four trenches were dug in three to four feet of overburden (two over asphalt and two over tailings), and three trenches were dug in one to two feet of overburden (two over asphalt and one over tailings). Root distributions were estimated by sampling root frequency at 20 cm depth increments. Gravimetric soil moisture and bulk density samples were taken at the same locations.

Root distributions were not significantly affected by the radon barriers or the herbicide, Treflan, applied to prevent root intrusion. Roots were present at all depths in the overburden and had penetrated into the surface of the tailings in areas without asphalt. The roots were those of tumbleweed (Salsola kali) and summer cyprus (Kochra sp.), both invading, annual weeds. No damage to the asphalt was apparent. The frequency of roots below 60 cm depth over asphalt and asphalt with herbicide was noticeably reduced compared to frequency of root over tailings, but this reduction was not statistically significant. If this effect is not a sampling artifact, it would suggest that some factor is restricting growth in that zone when asphalt is present.

Results from sampling after one growing season indicate that plant roots are capable of growth throughout the available rooting space in a short period of time. In the absence of an asphalt barrier, the roots will grow through shallow soil covers (up to 1.2 m) and into tailings very quickly. The study has also shown that an in situ technique such as the use of radioactive tracers is necessary to evaluate the nature of root interactions with radon barriers and tailings. The cost of collecting enough data to show treatment effects and the destructive impact of excavation on the test plots limit the usefulness of this method. An in situ technique would permit more extensive sampling and sampling through time, both of which are necessary if problems associated with root distributions are to be fully evaluated.

A detailed examination of the 1981 vegetation data from the Grand Junction Test Plot is presented in the April monthly report. No further reporting of those data is planned.

Future work at the Grand Junction test plot will focus primarily on monitoring the composition and amount of above-ground vegetation and soil moisture in response to treatment variables (barrier type and depth of soil covering). Data gathered at this site will also be used to field-verify the unsaturated flow model (UNSATV) being used to predict soil moisture responses to rock and vegetation surface treatments. Computer simulations of rock and vegetative covers in Grand Junction predicted significant increases in soil moisture under rock covers (See Sec. 6.0). It is felt that field verification of the UNSATV model is necessary in light of the assumptions that were made about water extraction by plants and the effects of rock covers on water vapor diffusion during those simulations.

SAN JUAN TEST PLDT

In cooperation with the San Juan Coal Co., a second test plot was constructed on the San Juan Coal Mine in August 1981. At this site, the effects of rock covers on soil moisture and plant establishment are being studied. The test plot consists of three major surface treatments: a) topsoiled, b) topsoiled plus sorted cobble approximately two inches in diameter, c) topsoiled plus unsorted bankrun cobble. The rocks in both treatments are approximately six inches deep.

The surface treatment blocks are subdivided into the following plant treatments on plots 15' x 25': a) seeded with forb/shrub-dominant mix, b) seeded with grass-dominant mix, c) seeded with forb/shrub-dominant mix + shrub transplants, d) seeded with grass-dominant mix + shrub transplants, e) planted with shrub transplants only, and f) control - no planting/seeding.

Irrigation requirements for vegetation establishment are being studied by using a system that applies variable rates of irrigation water on each plot. The system applies a high rate of water at one end of a plot but decreases to zero at the other end, making it possible to determine the minimum amount of water necessary for plant establishment. Each increment of distance away from the line source represents a sub-plot where plant establishment and growth can be correlated with the amount of water received.

Because this plot was constructed and seeded after the 1981 growing season, 1982 will be a year of plant establishment. Based on revegetation experience at the San Juan Mine, revegetated areas must undergo a complete growing season without irrigation before the plant community begins to stabilize. Plant growth during the first year, especially under irrigation, is not representative of a stable, self-renewing plant community. Consequently, conclusions about long-term effects cannot be made from 1982 data alone. This interim period, however, will provide valuable information on the amount of irrigation necessary for plant establishment. Techniques for establishment of vegetation in rock during the first and most critical year for surface stabilization will be evaluated.

CONCLUSIONS

The test plots have been designed to answer questions critical to stabilizing the surface of inactive tailings piles. These are:

- 1) How do plants interact with radon barriers?
- 2) What are the effects of rock covers on vegetation?
- 3) How do rock covers, vegetation, and rock covers in combination with vegetation affect soil moisture?
- 4) What methods (planting and irrigation) are most successful in establishing vegetation in combination with rock covers?

We feel that the test plots will provide answers to these questions, and others that will arise during application of the remedial actions during the next seven years. Because vegetation requires several years to become established, 1982 and beyond will provide increasing amounts of data to answer the above questions. Continued monitoring will provide the field data for needed direct analysis and computer simulations designed to evaluate the consequences of rock/vegetation covers.

3.0 REGIONAL EVALUATIONS

OBJECTIVES

The Regional Evaluations Task was designed to collect data on climate, representative soils and associated native vegetation types in the vicinity of the inactive uranium tailings. The objectives are: 1) to determine the climatic and edaphic influences on plant community structure and use this information to organize tailings sites with similar characteristics into groups, and 2) to develop a data base for modeling erosion events and soil water dynamics given various soil and vegetative cover regimes. Data may also be quite useful for final selection of soil types to use on the surface of tailings piles where vegetation is desired to aid stabilization.

METHODOLOGY

Most of the inactive uranium mill tailings slated for remedial action are located in the western United States (Figure 3.1). Data on soils, climate and vegetation were collected from 40 undeveloped sites in close proximity to 21 of the 23 tailings piles shown in the figure. For each tailings pile, sampling sites were chosen on soil types representative of those suitable for use as topsoil at that pile. Soil units were selected with the help of a soil scientist and local Soil Conservation Service personnel. The criteria used in this selection process included extent (percent coverage of a county), depth, texture and absence of toxic elements. Chosen soils were usually loams, sandy loams or clay loams. The actual location of a sampling site within a particular soil unit depended upon accessibility, ownership, homogeneity of vegetative community, and level of disturbance.

At a chosen sampling location, the line intercept method (Daubenmire 1968) was used to estimate shrub cover. Ten 50 m transects were run which, at most sites, produced a coefficient of variation for the shrub cover estimate of less than 15%. At the majority of sampling sites, the 10 consecutive transects were placed in a straight line. In a few cases, there was a curve or a break in order to avoid a barrier or a change in soil type. A Daubenmire plot frame (0.2 m x 0.5 m) was used to estimate

Figure 3.7. Location of Inactive Uranium Mill Tailings Piles

grass and forb coverage at 10 m intervals along the entire 500 m line. All cover measurements were taken by species.

Raw measurements from the Daubenmire plots and line transects were converted into total and species-specific percent cover estimates for each site (Lucas and Seber 1977). In most cases, there was no significant difference in total cover estimated between the 10 sections of the total transect at a particular site. Since the structure of the vegetative community is more important than individual species in stabilizing the surface, plants were grouped into nine guilds or classes based on growth form, seasonality and tolerance to salt: perennial grasses, annual grasses, forbs, shrubs, salt-tolerant shrubs, coniferous and deciduous trees, and cacti. Percent cover for each of the groups for a particular

sampling site is simply the sum of the cover values for the included species. These values and the total cover estimates were used for data analysis.

A surface soil sample was taken every 50 m along the 500 m line for pH measurement. A bucket auger was used to take soil cores, in 20 cm depth increments to 100 cm, at the beginning, middle and end points of the transect at each site. The samples were analyzed using standard procedures for Washington State (Moodie and Kochler 1975) for texture, organic matter content, particle size, electrical conductivity and macronutrients (nitrogen, soluble sodium, exchangeable sodium, magnesium, calcium, potassium and phosphorous). Average values for the soil parameters analyzed for each site were calculated. For most soil properties at a particular site, no apparent differences were noted between three soil cores at the same depth. Values for the various depths within cores, however, were often different.

Information on the climate of the sampling sites was available from published National Oceanic and Atmospheric Administration (NOAA) reports. These are annual summaries that list average monthly temperatures, monthly precipitation, numbers of consecutive frost-free days and annual maximum and minimum temperatures at a network of stations throughout each state. Specific climatic data were not available for the individual sampling sites. However, all the inactive tailings piles are in close proximity to NOAA stations. The data from the nearest station was considered to be representative of all the sites sampled in the vicinity of a particular tailings pile. Some of the stations were well established, and it was possible to obtain average monthly temperature and precipitation values based upon years of data. For the newer stations, it was necessary to average the monthly data for the past five years to obtain an estimate of the climatological patterns for that particular area.

SITE GROUPING METHODS

The field sampling provided data on climate, soils and vegetative cover for undisturbed sites in the vicinity of 21 of the inactive tailings piles. The initial step in the site grouping procedure was variable reduction; this eliminated highly correlated variables. The product of

this procedure was a smaller set of relatively independent variables (partial listing in Table 3.1). The soils chosen for sampling in the vicinity of each tailings pile were the best available for use as topsoil, and were consequently fairly similar. Because of this similarity, soil factors accounted for very little of the variability in vegetative cover between sites and were, therefore, not included in the reduced variable set. The reduced set was subjected to the following variable multivariate analyses: cluster analysis (Morrison 1976), principal component analysis, linear discriminant function analysis, and correlation (Hartigan 1975).

GROUPS BASED ON CLIMATIC ANALYSIS

All the western tailings sites can be grouped into three general regions based on climate and geographical location: the Colorado Plateau, the West Slope of the Rocky Mountains and the Northern Great Plains.

The Colorado Plateau is a regional uplift. Because of the generally high altitude (4000-7000 ft), the climate of this area is characterized by cold winters, hot summers, and low amounts of precipitation (Bailey 1978). The inactive tailings piles located within the region include Grand Junction, CO; Green River, UT; Tuba City, AZ; Shiprock, NM; Monument Valley, AZ; Mexican Hat, UT; Slick Rock, CO; and Ambrosia Lake, NM. Annual precipitation at these sites ranges from a low of 5.8 in. at Monument Valley to a high of 11.0 in. at Slick Rock. Within the Colorado Plateau region, however, considerable variation may be found in the pattern of precipitation, and this can affect surface stabilization requirements. At the Mexican Hat and Shiprock sites, for example, less than 40% of the annual precipitation falls during the growing season (April - September), while the Grand Junction and Green River tailings receive at least half their annual precipitation during this period. The sites at Monument Valley and Ambrosia Lake, on the other hand, have frequent summer

Table 3.1. Sites Sampled in the Vicinity of Inactive Uranium Mill Tailings. Vegetative cover and soils were sampled at each site. Climatic data are mean values calculated from NOAA reports.

Tailings Piles	Site Name	Soil Type & Texture	% Total Vegetative Cover	Annual Temp °F	Precipitation in Inches				
				Jan	April	July	Oct	Annual	
Grand Junction, CO	GJ-1	Glenburg Sandy Loam	52.3	50.6	0.68	0.77	0.58	0.84	8.30
	GJ-2	Avalon Loam	59.8	"	"	"	"	"	"
	GJ-3	Fruita Loam	41.1	"	"	"	"	"	"
	GJ-4	Billings Silty Clay Loam	29.4	"	"	"	"	"	"
Naturita, CO	NA-1	Clovis-Progresso Fine Loam	48.2	45.1	0.88	1.10	1.16	1.59	12.67
Slick Rock 1&2, CO	SI-1	Minchy Fine Sandy Loam	25.0	52.0	1.05	1.07	1.57	0.64	11.14
Rifle 1&2, CO	RF-1	Potts Loam	29.9	47.2	0.92	0.93	0.85	1.24	11.24
	RF-2	Kim Loam	46.2	"	"	"	"	"	"
Maybell, CO	MB-1	Rock River Loam	78.7	42.0	1.46	1.94	0.73	1.53	18.66
Gunnison, CO	GU-1	Duffason-Copering Loam	48.6	37.7	1.00	0.78	1.41	0.89	11.24
	GU-2	Evanston Loam	49.1	"	"	"	"	"	"
Durango, CO	DU-1	Jordero Loam	76.8	46.4	1.70	1.36	1.85	1.94	18.59
	DU-2	Sili Clay Loam	75.0	"	"	"	"	"	"
	DU-3	Falfa Clay Loam	67.4	"	"	"	"	"	"
Shiprock, NM	SR-1	Los Sandy Loam	8.3	50.5	0.46	0.21	0.82	0.55	6.05
	SR-2	C-18 Sandy Loam	20.1	"	"	"	"	"	"
	RM-1	Aneth-Sheppard Loamy Fine Sand	25.2	55.9	0.57	0.44	0.86	1.05	8.41
	FA-1	Fruitland Sandy Loam	40.0	52.7	0.51	0.57	0.83	1.08	8.09
Ambrosia Lake, NM	GR-1	Penistaja Sandy Loam	36.9	49.1	0.59	0.21	1.51	0.48	9.01
	GR-2	Dioxie Loam	31.7	"	"	"	"	"	"
Tuba City, AZ	TC	Not Sampled		54.7	0.42	0.34	0.65	0.65	6.18

Table 3.1. (Contd.)

Tailings Piles	Site Name	Soil Type & Texture	Total Vegetative Cover	Annual Temp °F	Precipitation in Inches				
					Jan	April	July	Oct	Annual
Monument Valley, AZ	KA-1	Palma Colvis Sandy Loam	27.3	53.0	0.54	0.41	1.10	1.03	7.63
	KA-2	Tours-Navajo-Trial	26.3	"	"	"	"	"	"
Mexican Hat, UT	MV-1	Monue-Sheppard Loamy Fine Sand	18.0	55.2	0.96	0.24	0.71	0.53	5.80
	MV-2	Nakai Very Fine Sandy Loam	17.1	"	"	"	"	"	"
Green River, UT	MO-1	Sager Silt Loam	18.2	56.3	0.48	0.85	0.47	1.05	7.94
	MO-2	Typic Torrifluvents Silt Loam	27.9	53.0	0.65	0.81	0.61	1.11	8.92
Salt Lake City, UT	SC	Not Sampled		51.0	1.27	2.12	0.70	1.16	15.17
Baggs, WY	BG-1	Gamborhids Loam	92.5	41.4	0.87	1.23	1.06	1.27	12.46
	BG-2	Floutsch-Cushool Fine Sandy Loam	66.7	"	"	"	"	"	"
	BC-3	Ryan Park-Elk Mt. Loamy Fine Sand	71.3	"	"	"	"	"	"
Spook, WY	SP-1	Fort Collins Loam	55.5	47.4	0.5	1.57	1.05	1.02	12.91
	SP-2	Stoneham-Cushman Sandy Loam	59.3	"	"	"	"	"	"
	SP-3	Olney Sandy Loam	61.0	"	"	"	"	"	"
Riverton, WY	RI-1	Griffy Loam	46.3	43.2	0.19	1.17	0.61	0.77	8.56
	RI-2	Trook Sandy Loam	37.5	"	"	"	"	"	"
	RI-3	Apron Sandy Loam	28.1	"	"	"	"	"	"
Bowman/Belfield, ND	B0-1	Sandy Loam	71.0	42.3	0.42	1.44	2.40	0.81	16.41
	B0-2	Grassna Silt Loam	82.0	"	"	"	"	"	"
	B0-3	Chjama Silt Loam	95.7	"	"	"	"	"	"
Lowman, ID	L0-1	Coski Complex	105.3	45.0	2.78	1.51	0.85	1.01	22.26
Cannonsburg, PA	CA-1	Weikert-Muskingum Silt	120.7	49.1	2.80	3.38	4.11	2.61	36.62
Falls City, TX	FC-1	Tordia Clay	*	68.9	1.75	2.52	1.55	2.78	30.18
	FC-2	Coy Clay Loam	*	"	"	"	"	"	"
Lakeview, OR	LA	Not Sampled		46.2	2.29	1.10	0.19	1.32	16.0

*Results of sampling not compiled.

thunderstorms during late spring and summer, and these contribute 70% of the annual precipitation.

Moderate amounts of precipitation, warm summers and cold winters are the predominant climatic characteristics of the West Slope (Bailey 1978). Inactive tailings piles in this area include: Gunnison, CO; Durango, CO; Lowman, ID; Rifle, CO; Baggs, WY*; Naturita, CO; Maybell, CO; Salt Lake City, Utah; and Lakeview, OR. Annual precipitation ranges from 11.2 in. at the Gunnison and Rifle sites to 18.6 in. at Maybell and Durango and 22.3 in. at Lowman. With the exception of Lowman, all of the west slope sites receive approximately half their annual precipitation between April and September. The Lowman site is somewhat distinct. Located in Idaho on the western side of a different range of the Rockies, it is considerably further north than the rest of the West Slope sites. It receives higher annual precipitation, more of it falling as snow in the winter than do the other West Slope sites. The Gunnison site is a bit unusual as well, with an elevation of about 8000 ft. Although it has a climatic pattern similar to the other West Slope areas, Gunnison is significantly cooler and has a very short growing season.

Four of the inactive tailings piles are in an area known as the Northern Great Plains. Typically this region is characterized by cold dry winters and hot summers with most of the precipitation falling during the summer. Total precipitation is variable throughout the region, ranging from 8.8 in. at Riverton, WY to double that amount at the Bowman and Belfield sites in North Dakota. The Wyoming sites at Riverton and Spook receive approximately 70% of their annual precipitation between April and September. Over 80% of the yearly precipitation falls during this time period at the Bowman and Belfield tailings piles.

* formerly included in UMTRAP

The Canonsburg, PA and Falls City, TX sites are, of course, separate classes. Canonsburg has a distinct continental climate with a yearly average precipitation of 37 in., warm summers and cold winters. Falls City, on the Texas Coastal Plain, has hot summers and short, mild winters. It receives 30 in. of annual precipitation, with over 65% falling between April and September.

GROUPS BASED ON VEGETATION ANALYSIS

Within any geographic area, the distribution of a plant species is dependent upon its own genetic and life cycle characteristics, which dictate the plant's interactions with the physical environment and other plant species (Whittaker, 1975). Many types of vegetative communities may be found in the West. Very rarely are plant communities separate and confined to discrete locations; instead, they form a continuum. Consequently, within the climatic zones of the West, a great amount of overlap and mixing of plant communities occurs. Based upon multivariate analyses of the vegetative cover data, approximately six distinct plant community types were represented at the 40 sites sampled. The species composition of a particular community type varies between locations, but the basic structure remains unchanged.

One of the most widespread community types in the West is the perennial grassland. The vegetation of this community type primarily consists of short bunchgrasses. Scattered shrubs and small trees are also represented, along with occasional forbs and cacti. Typical grass species include Indian ricegrass (Oryzopsis hymenoides), blue gramma (Bouteloua gracilis), galleta grass (Hilaria jamesonii), threeawn (Aristida spp.), sand dropseed (Sporobolus cryptandrus), wheatgrass (Agropyron spp.) and needlegrass (Stipa spp.). All sites sampled in the vicinity of the Bowman, Belfield, Spook, Ambrosia Lake and Slick Rock tailings piles, as well as at least one of the sites sampled near Rifle, Baggs, Shiprock and Riverton piles, consist of perennial grassland vegetation.

Three of the four sites sampled in the vicinity of the Grand Junction tailings pile also had a dominant grass cover, though these were annual rather than perennial grasslands. As in the perennial grassland, there are

scattered trees and shrubs with occasional forbs, but the dominant vegetative cover consists mainly of annual grasses in the genus Bromus.

Areas predominantly covered by shrubs were also common in the West. In this community type small shrubs, mainly sagebrush (Artemisia tridentata) or blackbush (Coleogyne ramosissima) are dominant. Bunch grasses and forbs are present in the understory as well. Sampling locations having shrub-dominated communities include all those in the vicinity of Gunnison, Mexican Hat, Naturita and Maybell and one each near the Rifle, Durango, Monument Valley and Riverton tailings.

The vegetation at areas near Lowman, Canonsburg and at one location near Durango was classified as woodland. At Lowman, the tree canopy was composed mainly of ponderosa pine (Pinus ponderosa) and Douglas-fir (Pseudotsuga menziesii). In the Durango area pinyon pine (Pinus edulis), juniper (Juniperus osteosperma) and Gambel oak (Quercus gambelii) were codominant with ponderosa pine. Both of these western sites had a moderate to heavy understory of shrubs, grasses and forbs and the tree canopy was not closed. In contrast, the woodland in the vicinity of Canonsburg had a sparse understory and a closed tree canopy comprised of eastern deciduous hardwoods.

Some areas of the Colorado Plateau, particularly bottomlands, have soils with relatively high concentrations of salt. The vegetative communities in these areas are distinctive, often with saltbrush (Atriplex spp.) and greasewood (Sarcobatus vermiculatus) as the dominant shrubs. A sparse to moderate cover of forbs (often in the genus Atriplex) and salt-tolerant grasses are usually present. Sites having a salt-tolerant vegetative community include those sampled near Green River, one near Grand Junction and two in the vicinity of Shiprock.

Six of the sites sampled fall into a mixed vegetative community type that can best be described as forb-dominated. Two of the areas sampled near the Baggs tailings piles and one each in proximity to Shiprock, Durango, and Monument Valley have a forb cover greater than 30% of their total vegetative cover. Shrubs are generally sparse and grass cover is moderate to high (10-50%) in all these areas.

DISCUSSION

To summarize the results, 21 of the western inactive tailings sites can be grouped into three distinct climatic zones based on climate and geographical location. The 40 soil types sampled in the vicinity of these piles have vegetation that can be classified into six vegetative community types.

The relationship between annual precipitation and percent total vegetative cover is linear (Figure 3.2). In general, the Colorado Plateau sites, which receive less precipitation than those on the West Slope or in the Great Plains region, have lower total vegetative cover values.

However, several points should be kept in mind when using this graph:

- 1) variability between sites due to soil factors was reduced by sampling only those soils which could be used for topsoil. Thus, the relationship illustrated in the graph is not applicable to poor quality or rocky soils.
- 2) The total percent cover values used to generate the graph were obtained in summer, 1981 but are plotted against average annual precipitation values since 1981 precipitation data were not yet available from NOAA. From looking at several years of climatological data, it is obvious that total precipitation in most areas of the West fluctuates greatly from one year to the next. Using 1981 precipitation data could alter the relationship illustrated by the graph.

An additional factor is not included in the relationship illustrated in the graph, one that is rarely considered in models of vegetative covers. At a particular location, the species composition and cover of the plant community is determined not only by climate and edaphic factors, as previously mentioned, but also by the degree of disturbance to which it has been subjected. In the West, grazing deserves particular attention when analyzing any kind of vegetation data that could be used in a decision making process.

The effect of grazing on a plant community depends on the species composition of the community and the degree of disturbance by grazing animals (Daubenmire 1974). Extremely heavy grazing on a perennial grassland can reduce the cover of existing vegetation and cause marked changes in the species composition of the vegetative community. This can

Figure 3.2. Relationships Between Percent Vegetative Cover and Mean Annual Precipitation at Sites Sampled in the Vicinity of the Western Inactive Tailings Piles (See explanation in text; site codes defined in Table 3.1)

happen if the newer foliage is removed before the plants have had sufficient time to restore depleted energy reserves. The result, in some areas, is a depauperate community consisting only of unpalatable species. In other locations, this kind of disturbance to the native plants will promote the invasion of aggressive, fast growing species and will result in a completely new vegetative community. Less damaging grazing of a perennial grassland can reduce the cover of the more palatable grasses which are preferentially grazed (decreasers). Subsequently, the less palatable grasses and forbs (increasers), have more water and nutrients and

tend to increase in size and number. Thus, while the total cover and structure of the plant community may remain the same, the species composition is altered. The effect of light grazing on a perennial grassland may only be a reduction, often temporary, of total plant cover. All but the lightest grazing in the shrub steppe or woodlands areas generally causes an increase in the number and size of the shrubs by decreasing the palatable grasses and thereby making more water and nutrients available for the shrubs (Daubenmire 1974).

In the field sampling process, every attempt was made to choose sites with minimal disturbance. In some areas there were no ungrazed locations. Based upon disturbance history provided by land managers, field observations, and published information on the potential native vegetation, it is possible to note those sites where grazing may have altered the plant community composition and cover. Approximately half of the sites sampled showed signs of grazing, with effects ranging from complete community alteration to a barely noticeable reduction in vegetative cover. Three of the four sites sampled near Grand Junction had plant communities that were entirely different from the documented native communities in this area. According to the Soil Survey of the Mesa County Area, Colorado (1978), the native vegetation of these sites should consist of perennial grasses. Instead, the sites were covered with cheatgrass (Bromus tectorum L.) and were thus classed as annual grassland. Once cheatgrass, a hardy and fast-growing import from Eurasia, invades a disturbed area, it can preclude reestablishment of native species (Rickard and Sauer 1982) at least temporarily. One site sampled near Shiprock is an example of how heavy grazing can result in a depauperate plant community composed of only a few unpalatable species. Perennial grasses were almost completely eliminated from the area and the remaining vegetation consisted mainly of mat-like woody shrubs and forbs. Literature on native plant communities of the western United States (Kuchler 1964, Bailey 1978), makes no mention of a forb-dominated community type. Sites with this type of vegetation are examples of how moderate grazing may alter grassland community composition by decreasing the cover of palatable grass species and, thus, promote increased forb cover. Several grassland sites such as those near Rifle and Slick Rock are representative of areas subject to light grazing. They showed no alterations in community composition, but they had obviously been

grazed recently and had a reduced total cover. The effects of grazing were not as easily discernible in sites with shrub-steppe vegetation. According to the Soil Conservation Service (SCS 1975), "unless range condition is good or excellent, big sagebrush is dominant" in shrub-steppe communities. Therefore, those sites with a dense cover of sagebrush and little of perennial grass, such as some of those sampled near Gunnison and Durango, were considered to be disturbed by grazing.

FUTURE APPLICATIONS

Grouping similar sites by climate and vegetation type may make it possible to design surface stabilization treatments that are applicable to several sites. The general suitability of a particular cover design can be determined by using the soils, climate and vegetation data from similar sites as input parameters for soil moisture and erosion models. Subjecting these models to sensitivity analysis using representative data can reveal the effects of vegetation and soil type on erosion and soil moisture.

A detailed report on the methods and results of the Regional Evaluation Task including the full data set, will be issued in FY 1983.

4.0 METHODS EVALUATION

The Methods Evaluation Task is intended to provide information on revegetation methods and surface stabilization costs for uranium mill tailings. Research on vegetation establishment has evolved from the need to reclaim surface mined lands, primarily those mined for coal. We reviewed the literature on plant species selection and planting methods for revegetation in the western U.S. and evaluated those methods with respect to mill tailings stabilization. A review of rock and riprap application methods was not done under this program since a project currently underway at PNL (under NRC sponsorship) is studying application methods for rock covers (See PNL-4105-2, NUREG/CR-2564). A general costing methodology was developed and applied to the Grand Junction site.

A topical report on methods and cost estimation is being prepared and is scheduled for release in FY 1983. A summary is reported here.

REVEGETATION

A review of reclamation literature identifies principles and problems involved in species selection and revegetation methods suitable for uranium mill tailings sites located primarily in arid and semi-arid western states.

Selection of species adapted to dry environments is critical to revegetating most of the tailings. Establishment of a vegetal cover on the western sites involves such general problems as limited and erratic precipitation, temperature extremes, shallow and saline soils, and grazing.

Generally, the species chosen for use on tailings should:

- have demonstrated survival ability in the environs of a particular site
- have the ability to become established and survive on areas that have been disturbed
- be able to tolerate grazing
- be capable of reducing erosion and
- require no maintenance after the establishment period.

Methods for vegetation establishment must be specific for the conditions that exist on each tailings site to insure plant survival. Long-term stability (tens to hundreds of years) is considered to be achievable if long-lived trees, shrubs and grasses can be established. Short-term maintenance (1-3 yr) will likely be necessary to insure vegetation establishment. Establishment in areas with more than 25 cm (11 in.) of precipitation poses no particular problems; for sites receiving less than 25 cm of precipitation, irrigation will probably be necessary. Site-specific evaluation of soils, climate and available plant species is essential prior to producing a revegetation/ cover plan.

Much has been published on revegetation methodology for arid and semi-arid lands; these technologies will be generally applicable to the UMRAP sites. A problem specific to the tailings piles, however, is the penetration of radon barriers by roots, whether vegetation is used for surface stabilization or whether it invades gradually. Some radon barriers rely on retaining moisture to reduce radon emanation. Root contact may lead to drying and subsequent loss of containment. Also, the effects of rock covers on vegetation and the tailings themselves are largely unknown. Rock covers may aid in establishing vegetation in arid areas by reducing evaporative water loss and increasing infiltration.

ECONOMIC EVALUATIONS

This analysis is intended to provide a general methodology for evaluating the economics of applying rock covers and/or establishing vegetation on covered U-tailings. Although the literature does not always evaluate remedial action activities, specific operations were identified which could be used in the stabilization of uranium mill tailings.

To obtain a cost estimate for specific surface treatments, the applicable cost components must be identified. After calculating the quantities of materials necessary for a specific action, the expected costs of the operations can be determined. The total cost configuration can be obtained by combining these costs like building blocks. The methodology for determining costs consist of:

- 1) establishing the quantity and cost of cover material (topsoil or rock),
- 2) determining the cost of actions which must be performed with that material, (i.e. mining, hauling, spreading, seeding, etc.), and
- 3) calculating operating costs for the remediation alternative.

To develop the methodology, cost data were reviewed and updated from literature. Data sources include:

- 1) environmental impact statements for uranium mills,
- 2) reports on reclamation from the U.S. Bureau of Mines, and
- 3) construction costs information from various state departments of highways.

Costs should reflect regional price differences and provide allowances for the remoteness of the site.

The Grand Junction tailings site was chosen as a case study for determining the relative costs of surface covers. The surface covers we compared were:

- 1) rock cover of bankrun gravel
- 2) vegetation
- 3) vegetation plus a 2 in. layer of gravel.

The tailings occupy approximately 60 acres. A source of rock material is located within five miles. Topsoil can be obtained at a haul distance of about 10 miles. The quantity of rock and topsoil required to cover the tailings to a depth of 18 in. was used. For calculating costs associated with a cover of rock and vegetation 18 in. of topsoil and 2 in. of rock were used. The cost of large riprap used for flood protection was not calculated.

The results, shown in Table 4.1, indicate that rock covers of bankrun stone are the least expensive form of surface treatment. However, technical design specifications for rock cover have not been determined. If larger sizes, greater quantities, or specific types of rock are required, purchase costs and haul distances (transportation costs)

Table 4.1. Costs for Surface Covers at the Grand Junction Site

<u>Treatment</u>	<u>Approximate Total Cost</u>	<u>Cost/Acre/Inch of Depth</u>
Topsoil plus seeding plus irrigation	\$1,400,000	\$1,296
Rock cover	833,000	771
Topsoil plus seeding plus 2 in. of rock plus irrigation	1,500,000	1,389

could increase dramatically. Consequently, rock covers would become much more expensive. Results of this study indicate that the cover material (topsoil or rock) is the major expense. Any design which reduces the amount of cover material could reduce costs significantly.

The methods for determining costs of surface treatments at any site would be identical to those used in this study; however, specific costs associated with surface treatments cannot be extrapolated to other sites. The availability of topsoil and rock at any given site will be the major determinant of costs. Additionally, because design specifications for vegetation and rock covers have not been determined, the quantities of material required cannot be stated with confidence. The amount of topsoil required will depend on the characteristics of the overburden material; overburden favorable to plant growth will require little or no covering of topsoil. The amount of rock required will depend on the erosion potential and vegetation at a particular site.

5.0 EROSION OF TAILINGS COVERS

Minimizing erosion of earthen covers that protect engineered radon barriers or act as radon barriers themselves is the key to long-term stabilization of U-tailings. Because the impoundment system will contain wastes only as long as the cover remains intact, cover selection is critical. Vegetation and rock are commonly used to reduce or prevent erosion; selection of a specific cover design for surface stabilization depends largely on climate, soils, vegetation and geomorphology of the site. Deep rock covers may be more reliable in the short-term at preventing erosion, but they can be more costly if a local source is not available and their effects on soil moisture could promote water percolation through the tailings and contribute to leaching of contaminants into groundwater (Section 6.0). Vegetation, over the long-term, may be subject to change (increases and decreases) in response to perturbations such as changing climate, fire and pests. Though both rock covers and vegetation have been used successfully to stabilize soils, vegetation is likely to occur on all remedial action tailings sites and does have the feature of being self-renewing. Under certain circumstances a combination of rock and vegetation may be cost effective, and provide the greatest likelihood of long-term stability.

The objectives of this task are to review wind and water erosional processes relative to mill tailings stabilization and to survey erosion models for potential use in the UMTRAP program. One water erosion model, the Universal Soil Loss Equation (USLE), was applied to the Grand Junction tailings pile; site variables having the most influence on rainfall-runoff erosion were determined.

Wind Erosion

The rate of wind erosion is most dependent surface wind velocity, the soil particle size distribution, surface conditions and field length. These factors are all interrelated so that when one changes, the effects of the others change.

To cause erosion, wind speed must be great enough to cause turbulent flow at the surface. The turbulent wind velocity has been modeled by von

Karman (1934). Bagnold (1943) experimentally determined a modified version of von Karmen's equation. The wind creates a lift and drag force which acts on the particles at the surface and causes suspension when of sufficient magnitude. Of course, the magnitude of the lift and drag force required to suspend soil particles depends on the particle size and shape. Therefore, another important factor in wind erosion is the particle size distribution of the soil. Soil is capable of three types of motion, all of which depend on particle size: surface creep, saltation and suspension. General limits of soil particle diameter for the three transport modes are (Travis 1974):

surface creep	>1000 μm
saltation	50-1000 μm
suspension	<50 μm

Surface creep describes the rolling or sliding motion of a particle on the surface when the lift and drag forces are less than the gravitational force and adhesive force between particles. Saltation is the motion of a dislodged particle when it is injected into the air stream and then, due to its relatively large mass, returns to the surface with a rather flat trajectory. Particles moving in saltation do not generally travel more than 10 m in a single flight. Airborne suspension describes the movement of a dislodged particle with relatively small mass, i.e., its settling velocity is less than the average vertical fluctuation of the surface wind.

The effects of wind turbulence on soil particles of any size can be modified by the surface conditions. Since many erosion models were designed to describe agricultural field erosion, ridge roughness is usually a parameter in the models. Roughness also depends on the amount and type of vegetation growing. Another factor, used in some models but not very well defined, is soil condition. Soil condition includes such considerations as soil moisture, organic residue, and soil cloddishness. In some models all these parameters have been combined into a soil erodibility index. Finally, the configuration of the tailings pile is important. The length and width (as seen by the prevailing wind direction) and the height above the surrounding terrain influence the flow of the wind and the development of turbulence.

The wind erosion equation was developed by W.S. Chepil (Skidmore 1974) and is based on wind tunnel and agricultural field measurements. It is the

result of nearly 30 years of research on the primary variables or factors that influence erosion of soil by wind. The equation has the following general form:

$$E = f(I, K, C, L, V)$$

where

E = soil loss by wind in tons/acre/year

I = soil erodibility factor

K = soil surface roughness factor

C = local climatic factor

L = equivalent field length

V = vegetative cover factor

The soil erodibility factor (I) was developed from wind tunnel and field measures of erodibility. Clods larger than 0.84 mm in diameter were nonerodible in the tests. Thus, the nonerodible soil fractions greater than 0.84 mm, as determined by dry sieving, have been used to indicate erodibility of soil by wind. The soil surface roughness factor (K) is a function of the effects of ridges or small undulations on the surface. The local climatic factor (C) was developed from the relationship between soil flow and wind speed, where the rate of soil flow varies directly as the cube of the wind speed, and inversely as the square of the effective moisture. Effective moisture of the surface soil particles was assumed to vary according to the Thornthwaite P-E index (Thornthwaite 1931), an estimate of precipitation effectiveness. The equivalent field length (L) is the unsheltered distance across the field along the prevailing wind direction. The rate of soil movement is zero on the windward side of a field and increases with distance downwind. If the field is large enough, the maximum soil flow at a given wind velocity will be attained. Equivalent field length graphs adjust for this variation in soil flow over the length of the field. The preponderance of wind erosion forces in the prevailing wind direction is incorporated into the equivalent field length term. The vegetative cover factor V is determined from the quantity, kind and orientation of vegetative cover. Graphs have been developed for various types of crops and at different stages of development.

Charts and graphs for obtaining values of the various factors have appeared in several reports (Woodruff and Siddoway 1965; Nelson and Sheperd 1978). Relationships among variables are complex; a single

equation that expresses E as a function of the dependent variables has not been devised. The equation can be solved in a stepwise procedure involving graphical solutions. To allow more effective predictions of soil loss, the wind erosion equation has been computerized in the program WEROS (Fisher and Skidmore 1970). Besides solving the equation quickly and accurately, the computer program has made it easier to visualize the problem in reverse. That is, the tolerable limits of soil erosion can be specified, and the program can then determine conditions for controlling soil loss within those limits.

Water Erosion

Only a summary of the work on water erosion is presented here. A complete discussion of water-related erosional processes and the results of the application of the USLE to the Grand Junction tailings pile are being prepared for publication as a PNL topical report. The report is tentatively scheduled for release early in FY 1983.

Earth scientists draw an important distinction between geological and accelerated erosion. These two categories actually imply different rates of erosion. Geological erosion is the rate at which the land would normally be eroded without disturbance. Accelerated erosion is the increased rate of erosion that arises when natural land surface conditions are altered. This accelerated erosion within watersheds is due predominantly to the removal of the natural vegetation cover. The removal could be a result of man's activities such as farming, overgrazing and construction, or of natural causes such as fire and drought. Direct exposure to the rainfall-runoff process following the removal of vegetation causes the rate of erosion to increase significantly. Uranium mill tailings impoundments would fall under the "accelerated" category because they lack natural cover, and because easily erodible fine sedimentary material is typically used to decrease radon emanation.

Both geologic and accelerated erosion are caused by the same two principal agents: raindrops and flowing water. Raindrop erosion involves the detachment of particles from soil by impact and their movement by splashing. Runoff erosion is the transportation of loose material by the overland flow of water in sheets, rills, or gullies. Much of the loose

material originates with raindrop erosion, although some detachment of particles can occur with runoff.

The factors contributing to erosion and sediment production from a particular land surface area are numerous and vary in their importance depending upon climatic conditions, soil types and vegetation cover. The dominant climatic variable affecting erosion is precipitation because it directly influences vegetation and runoff. The soil characteristics of texture, structure, depth, porosity, and the percolation rate of subsurface horizons collectively determine the infiltration rate of the topmost soil mantle; infiltration in turn affects the amount of overland flow and sediment yield. Vegetation cover has a significant role in promoting soil stability because it binds the soil, promotes infiltration, dissipates raindrop energy, and creates greater porosity. Erosion will always be present as a geologic process but the rate of erosion will decrease as vegetative cover is increased. The presence or absence of vegetation disrupts the soil stability balance and promotes accelerated erosion.

Mathematical models used to simulate overland erosion that were found to be applicable to uranium mill tailings impoundments are:

- 1) the Universal Soil Loss Equation (USLE),
- 2) the Agricultural Runoff Model (ARM), and
- 3) the Watersheds Model developed at Colorado State University.

The last two are complex physical process simulation models requiring comprehensive data packages for the modeling effort, but they permit the evaluation of individual storm events. In arid and semi-arid regions of the Rocky Mountain Region and throughout the Colorado Plateau, intense, short duration storms are frequent during the growing season and can result in severe erosion.

The Agricultural Runoff Model (ARM) is mathematical. It simulates the hydrologic processes which convert precipitation to overland, subsurface, and groundwater flow and the erosion of soil materials due to rainfall impact and runoff (Donigian and Crawford 1976). The major components of the model, LANDS and QUAL, simulate the hydrologic response of the watershed, and sediment production and transport, respectively.

Basically, LANDS is an accounting procedure for surface and subsurface moisture. It simulates all flow components (overland, subsurface, and groundwater flow) and moisture storages by representing the processes of interception, infiltration, percolation, evapotranspiration, and snow accumulation and melt. QUAL simulates accumulation and removal of sediment, erosion of soil particles by rainfall detachment, and transport by overland flow. By continuously simulating the rain/runoff and soil erosion process, ARM provides a means of analyzing the erosional effects of sequential rain/runoff events. ARM requires considerable amounts of detailed hydrologic and meteorologic data and information on watershed characteristics and land use. The major limitation of the model is that it uses empirically developed equations which require a considerable amount of calibration.

The Colorado State University Watersheds model is a high resolution model of overland flow and sediment routing (See Li 1979). The model is divided into an overland flow portion and a channel system component. These two functions account for: interception, infiltration, overland surface water, and overland flow sediment routing. The model is termed high resolution because it uses a finite difference solution technique to solve the water continuity and soil erosion equations. Such a scheme provides the capability for describing in detail the surface slope and shape and eliminates possible errors due to the assumption of uniform slope made by ARM. The model can be used to analyze in detail the consequences of extreme events, both observed and hypothetical. Also, since the model is more deterministic in nature than ARM, it is less reliant on calibration. It too requires a significant amount of information for its operation, however.

Of the available methods for estimating erosion, regression models are the simplest to use. The most widely used regression model is the USLE. The USLE was designed to estimate long-term soil loss for a specific site quantitatively and to estimate reductions in soil loss resulting from specific erosion control measures.

The development of the USLE was based on continuous measurements of precipitation, runoff, and soil loss from 42 stations in 23 states for

periods of five to 30 years. Measurements were taken from field plots on areas with a nine percent slope in bare soil tilled to break surface crusts. Using these data six factors were incorporated into the USLE: rainfall (R), soil erodibility (K), slope-length (L), slope gradient (S), erosion control practices (P) and cropping and management (C). The USLE is written as follows:

$$\underline{E} = R K L S C P$$

where L, S, C, and P are all dimensionless. The computed soil loss $\underline{E}$ has the time period of R and soil loss dimensions of K. Smith and Wischmeier (1957), Meyer (1971), and Wischmeier (1973) provide detailed descriptions of this equation and its terms.

The USLE has certain limitations. The model was designed to predict average annual soil losses by sheet and rill erosion on upslope areas such as construction sites. Its predictions do not include sediment contributions from gully erosion or landslides. The equation is most accurate for silt, silt loam, and loam soils, for uniform slopes from 5 to 12 percent, and lengths less than 400 feet. Beyond these limits model accuracy decreases, but the model is believed to be adequate for most applications over a much wider range of conditions.

The USLE is appropriate for providing reasonable estimates of soil erosion when little or no site specific streamflow or sediment data are available. Thus, when applied to uranium mine and mill tailings piles, the USLE provides a fairly simple means for estimating long-term erosion potential of the earthen cap for the given site conditions. The USLE was applied to the Grand Junction tailings impoundment by estimating each of the terms in the equation using the best available information. The terms were estimated graphically using Agricultural Handbook Number 537, Predicting Erosion Losses (Wischmeier and Smith 1978).

Soil loss rates for the Grand Junction tailings pile varied from 1.5 to 54.0 in./1000 yr, depending on rainfall, slope and soil type. Slope appears to be the most critical variable followed by soil type and rainfall. Both slope and soil type can be varied at each site to enhance erosion control as much as possible. It may be desirable to transport the

necessary soils from distant borrow areas if only poor quality soils are available at the sites.

Both types of models described in this report should be used to evaluate vegetation protection schemes for uranium mill tailings impoundments. The USLE method provides quick answers for annual or long-term time periods. The more complex models are applicable to high intensity, single event storms that would need evaluation on a site-by-site basis. The complex models could also simulate typical area rainfall-runoff-erosion processes up to about 10 to 15 years without excessive costs.

Any approach to surface stabilization design should involve an evaluation of erosion and vegetative potential. Areas of the tailings subject to flooding are likely to require rock riprap. For areas not subject to flooding, less rigorous covers such as rock and vegetation can be used. On portions not requiring riprap, erosion rates for long time periods and for expected high intensity storms can be determined based on vegetative potential, soil characteristics, and climate. Estimated erosion rates should be used to calculate the minimum thickness of overburden needed to protect the radon barrier. Expected erosion rates could then be used to determine the need for rock covers alone or in conjunction with vegetation. Modeling results should be used to perform sensitivity analyses to optimize the soil type, land surface slopes and to determine cover types required for long-term stability.

Future Work

Erosion control must be adequate for long-term protection of radon barriers and not compromise the containment of toxic materials by the impoundment system. The modeling effort in this project is intended to provide a method to estimate erosion potential and effects on soil moisture (Sec. 6.0). Surface covers can then be adequately designed for the expected environmental conditions occurring at tailings sites.

Once the capability to model the types of erosional processes expected at the UMTRAP sites is acquired, environmental and design factors most likely to influence erosion on the tailings can be determined. The effectiveness of general surface cover types such as vegetation, rock and

combinations of rock and vegetation will then be a basis for specifying the type surface cover needed at individual tailings sites.

Surface stabilization designs will affect the moisture status within the overburden and the tailings, which in turn may affect leaching of contaminants to ground water. To facilitate interaction with soil water models, the model(s) used for erosion prediction should incorporate the range of hydraulic processes affecting cover performance. Specifically, these include: runoff, infiltration, percolation, evapotranspiration, soil moisture, and erosion. Because these processes are interrelated, a water balance must be maintained in the model in response to continuously changing climatic variables. A simulation model with these capabilities will be a powerful tool for ensuring that cover designs are adequate for long-term erosion control and minimize the potential for containment leaching.

In response to these needs, we have acquired a model capable of performing the required calculations. The model, entitled CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, was developed by the U.S. Department of Agriculture to evaluate nonpoint source pollution from agricultural lands. A group of 50 scientists participated in developing this field scale model, which includes portions of the ARM and USLE models discussed above. CREAMS has recently been applied to management problems associated with shallow land burial of low-level radioactive material by researchers at Alamos National Laboratory (Nyhan and Lane 1982). FY 1983 work is proposed to evaluate this model fully. If the CREAMS model is acceptable, the appropriate modifications will be made and the model will be used to simulate erosional processes and soil moisture using data collected from the UMTRAP sites.

6.0 EFFECTS OF SURFACE COVERS ON SOIL MOISTURE

Rock covers placed on the surface of tailings piles will affect moisture within the overburden and the tailings. In arid and semi-arid regions, evaporation from the soil surface and transpiration by plants remove most of the water entering the soil by precipitation. Only water that infiltrates below the root zone escapes. Rock covers placed on the surface to a depth that excludes plant growth (at least for a period of time) would drastically reduce soil moisture lost via evapotranspiration. The result would be that increased moisture in the overburden and tailings. Our preliminary research results indicate that thin rock covers permit plant growth while reducing water loss from evaporation. This suggests that increased water is available for plant growth, thus producing a more stable cover than would be available from either rock cover or revegetation alone.

The Revegetation/Rock Cover program is evaluating the effects of surface treatments on soil moisture by using mathematical simulations of unsaturated moisture flow and field tests. An unsaturated flow model (UNSATV) has been used to simulate soil moisture dynamics of a multilayer earth cover system as affected by vegetation and rock surface treatments. Field studies are being conducted as part of the test plot work in Grand Junction, CO and near Farmington, NM to evaluate how rock, vegetation, and rock-vegetation combinations affect soil moisture (See Sec. 2.0). A lysimeter study is being conducted at PNL to determine the effects of rock size, rock cover thickness, vegetation type, and vegetation density on soil moisture loss. The lysimeter study will enable us to examine the processes of water loss in greater detail than in the field studies and will require less time. The field studies will allow large scale testing of mathematical simulations and will provide realistic comparisons with the lysimeter studies. No results are yet available from the field studies because the test plot vegetation is too young.

Model Simulations

A modeling study was designed to determine the effect of vegetation and rock covers on moisture movement through the tailings and cover layers

(Mayer, Beedlow and Cadwell 1981). The cover system was simulated under climatic conditions occurring at Grand Junction, CO and consisted of a layer of wet clay/gravel mix followed by a capillary barrier of washed rock and surface layer of fill soil. Vegetation and rock were used as the surface layer. The simulations yielded moisture content and moisture storage values for the tailings and cover system, along with information about moisture losses due to evaporation, transpiration, and drainage.

The model results indicate that different surface stabilization treatments lead to different degrees of water retention in, and percolating through covered tailings. Evapotranspiration from vegetation resulted in a relatively stable moisture content. A 0.5 m rock cover, however, induced drainage because of reduced moisture loss to the atmosphere (evapotranspiration). It is important to consider these effects when designing a surface stabilization treatment. Drainage may contribute to leaching of contaminants and subsequent ground-water pollution. On the other hand, a surface treatment that allows the cover system to dry out can increase the permeability of the cover to radon diffusion.

Lysimeter Studies

This ongoing study is evaluating the effects of vegetation and rock covers on soil moisture loss. The use of lysimeters permits much more detailed study of the processes of water loss in a shorter time and with less expense than do field tests. The effects of size and depth of rock covers, as well as the effects of plants with thin rock covers, are being studied. This work is scheduled for completion during the summer of 1982 with the results to be reported in FY 1983.

Vegetation and rock covers are being studied in weighing lysimeters to determine their influence on soil water dynamics in arid climates. The lysimeters consist of 10 gallon cans positioned in sleeves sunk into the ground. The lysimeters are weighed to determine moisture loss.

A range of particle sizes for aggregate that could be used to stabilize surface soils were explored. Even a thin covering (1.9 cm) of coarse sand, pea gravel and coarse crushed gravel reduced evaporative loss from soil by approximately 70, 40 and 30 percent respectively relative to bare soil.

The results of experiments in which a range of coarse gravel thickness were used showed that rock cover treatments decreased the rate of evaporation dramatically during the first seven days after a simulated rainfall event. The thicker rock covers showed the greatest reduction in rates of evaporative moisture loss. After seven days, however, a decline in the rate of evaporation from bare soil relative to the rates of evaporation from rock cover treatments occurred. Beyond 14 days, little difference in cumulative water losses from bare soil compared with rock cover treatments could be discerned.

Anticipated increases in soil moisture resulting from large scale applications of rock covers to tailings piles suggest increased potential for leaching of contaminants to ground water (see Model Simulations, Sec. 6.0). Thus, additional lysimeter studies were designed to examine the influence of vegetation and rock cover combinations. The rationale was that plants, through transpiration, can contribute to the functional integrity of the stabilization system by removing excess soil moisture from the soil cover before it has an opportunity to percolate through the tailings and leach contaminants.

The rock/vegetation combination studies are now in progress and one trial has been completed comparing bare soil, vegetation alone, vegetation combined with rock, and rock alone. A winter annual grass was readily established through a 90 kg/m^2 (about three inches) coarse gravel cover. Results from measurements made in spring, 1982 show a sizable reduction in evaporative moisture loss with the rock cover. The combined evapotranspirative moisture loss from the vegetation only treatment exceeded moisture loss by evaporation from bare soil. The moisture loss from the combined rock/vegetation treatment was nearly as great as from the treatment with vegetation alone. This finding supports the thesis that combined rock/vegetation covers may be useful to minimize potential leaching of contaminants, while providing the combined benefits of erosion resistance afforded by both rock and vegetation.

Although the above generalized observations and conclusions are now available from the lysimeter study, much of the value of this work will be realized when the data are analyzed and applied to the modeling effort. This study will provide model parameters for rates of moisture loss with

many rock and vegetation cover treatments. Model simulations can then be used to estimate consequences (movement of water volumes through tailings) fully and thus guide the decision process for selecting final surface stabilization designs.

Test plots will be monitored to evaluate effects of rock and vegetation covers on soil moisture. Model simulations will be compared to the test plot and lysimeter data to fine tune model predictions relative to real situations. Simulations of the multilayer earth system at Grand Junction have identified some weak points in the UNSATV model with respect to vegetation and rock cover effects on water loss. The simulations indicate a need for future studies to refine the description of the surface boundary condition and, therefore, to provide a more accurate moisture sink term. This work should focus on better descriptions of plant growth and moisture extraction behavior as a function of climatological conditions. Additional work to describe the diffusion of water vapor through rock covers more accurately, and to quantify the effects of wind would also be highly desirable.

The overall goal of the soil moisture studies is to develop the capability to evaluate fully the effects of various surface covers on the functioning of impoundment systems. Until this capability is developed in such a way as to permit the evaluation of various cover schemes in a range of climates, guidelines cannot be written with assurance that rock cover designs will not increase the potential for contaminant leaching.

7.0 CONCLUSIONS AND DISCUSSION

A single design for surface covers on all sites is not possible. However, a basic design that allows for differences in climate, soils and impoundment techniques may be useful for preliminary planning of site designs. To proceed from such a basic design to a site-specific design would require detailed site information combined with the proper techniques to evaluate the information. This section contains a discussion of basic surface cover design, an approach to designing site specific surface covers, and factors that should be taken into account while evaluating site designs.

Basic Surface Cover Designs

The typical disposal method for uranium mill tailings has been to slurry the tailings into large ponds. As the tailings dry, dikes are formed by bulldozers from the the coarse tailings material to produce subsequent tailings ponds. This results in tailings piles with generally flat tops and sloped sides or embankments (Figure 7.1a). Some piles become terraced (Figure 1b), especially in areas where the original soil surface is on hillsides or valley floors (Figure 7.1c). On most tailings, sloped areas will require different surface cover designs than the flatter surfaces.

Amounts of rock and vegetation used in constructing surface covers for inactive tailings will vary, depending on individual site conditions. The type of surface cover used on a pile or portions of a pile should be based on the expected type and severity of erosion. Excess protection will lead to unnecessary expense, while too little protection could result in impoundment failure. However, surface covers should not be expected to correct or compensate for inadequate geometrical configurations (such as steep slopes) or other physical/structural features that contribute to tailings pile erosion. For each site an initial evaluation must identify the types of erosion likely to occur and the portion of the tailings impoundment to be impacted. Stabilization designs should be adequate to resist erosion from channeling, wind and rainfall runoff processes as necessary. Where channel cutting is likely to occur, relatively massive

Figure 7.1. General Shapes of Inactive Uranium Mill Tailings; a) untterraced, usually on flat terrain; b) terraced, occurring on flat to moderately sloped terrain; c) terraced, occurring on steep slopes.

riprap may be required for long-term stability. Portions of the tailings above projected flood stage, will require stabilization from wind and rainfall events. The uppermost surfaces of tailings piles should be leveled to minimize erosion potential. For those sites where soil and climatic conditions are favorable, vegetation alone may be adequate to stabilize the surface. Sloped areas above flood stage may require a

surface covering of rock or a combined rock/vegetation cover to resist water erosion.

Erosion Considerations

Dominant erosive processes will differ from one area of the pile to the next. Level surfaces will not be subjected to the same erosive milieu as sloped surfaces. Windward surfaces will differ from lee surfaces. On some piles, slope aspect will have a strong influence on erosion; especially in valley areas. Portions of tailings exposed to flood waters will require substantially more protection than upland portions.

Superimposed on the variation in erosional processes caused by topography are those caused by climate and soils used to cover the tailings. Climate varies on a regional scale, while considerable variation in soil characteristics can be found locally. UMTRAP sites are located throughout a broad range of physiographic regions (See Sec. 3.0). Not only do the dominant erosion processes vary from region to region, but so does the availability of materials to use as surface covers. Rock with suitable properties for use as cover material may not be available at all sites. Sufficient vegetative cover to control erosion on tailings covers cannot be expected in extremely dry areas or in areas without a source of sufficient topsoil.

Given the extent of regional and local variation in erosive forces found among tailings sites, no single surface cover strategy can be considered both effective and economical for all UMTRAP sites. At some sites composite covers consisting of several types of surface treatments may provide the most cost/effective means for controlling erosion.

Soil Moisture Considerations

Except in cases where the ground-water level lies within the tailings, soil moisture dynamics are driven by input from precipitation and regulated by surface conditions. The expected range of surface conditions on tailings ranges from a cover where vegetation is predominant, to a cover of total rock, with various combinations of rock and vegetation in between.

At all UMTRAP sites except Canonsburg, potential evapotranspiration equals or exceeds precipitation. Under these conditions no net accumulation of moisture in the soil-tailings profile is expected;

normally, evaporation from the soil surface and transpiration by plants effectively remove the water that enters the soil as precipitation. Rock covers will cause increased infiltration and decreased evaporation (Sec. 6.0). Areas covered with rock will effectively capture more precipitation than adjacent areas without rocks. Thick rock covers exclude plant growth for a number of years and contribute further to water accumulation in and percolation through the tailings cover system. Thin rock covers (rock mulches) that permit plant growth may make additional moisture (from increased infiltration and decreased evaporation) available to plants and thereby provide a more vigorous vegetative cover than would otherwise be available. Thus, the combined rock/vegetation cover offers more surface stability than either a thin rock or vegetative cover alone, and for maintaining a favorable moisture balance as well.

Although site-specific model evaluations have not been completed, it appears that to limit percolation of water through tailings, the surface area requiring riprap or thick rock cover should be minimized. Areas with vegetation or rock and vegetation combinations should be maximized for the same reason.

Integration of System Components

Soil moisture is the common link between the components of the impoundment system. The amount of soil moisture affects radon attenuation by earthen materials because radon emanation is inversely related to soil moisture content (Mayer et al. 1981). The design of effective liners depends on knowing the amount and rate of water passing through the tailings. At sites where tailings will not be moved, calculations of leachate movement will require information on water input via precipitation. Increases in the amount of soil moisture will encourage deeper penetrations by plant roots. Consequently, soil moisture dynamics may influence the need for biointrusion barriers. Hence, understanding the factors affecting soil moisture is critical to designing effective impoundment systems. The optimal amount of soil moisture retained in the overburden will vary depending on the impoundment design. Radon barriers of earthen materials will operate most effectively if adequate soil moisture is present to reduce radon emanation. Designs using radon barriers of asphalt do not require soil moisture to reduce radon emanation

and would benefit from minimizing soil moisture. Accumulation of moisture at the asphalt surface, if subject to freezing, could damage the integrity of the asphalt seal. Because soil moisture affects the types of plants and animals inhabiting a site, the design of biointrusion barriers will require knowledge of expected soil moisture in the overburden. Generally, because the occurrence of living organisms is dependent on water, minimizing water in the overburden will minimize the occurrence of plant and animal life.

It is obvious that impoundment designs will involve a number of trade-offs. Increase the amount of soil moisture to reduce radon flux and increase the chance of biotic intrusion. Reduce the erosion potential by thickening rock covers and increase the amount of water in the system --- and so on. Optimization of system components will be a vital part of impoundment design. Because soil moisture is a factor in the functioning of all components, the ability to regulate the amount of moisture in the system would allow a greater range of design options. With sufficient knowledge of how surface covers affect soil moisture dynamics, it will be possible to engineer surface covers that would maintain a desired amount of soil moisture. Control of soil moisture is conceivable by properly mixing the amounts of rock and vegetation in the surface cover and by controlling the depth to which roots penetrate through proper placement of a root barrier. Maximum soil moisture may be achieved by placing thick rock covers on the surface to reduce evapotranspiration and by placing a root barrier close to the surface. In this way, precipitation quickly infiltrates beyond the rooting zone and can only be lost by drainage. Minimal soil moisture could be achieved by maximizing vegetation to extract the water and by keeping the surface free of rocks to encourage surface evaporation. Combinations of rock, vegetation, and biobarriers could result in the desired amounts of soil moisture maintained in the system.

An Approach to Designing Surface Covers

The wide range of site conditions and availability of cover materials makes designing appropriate surface covers difficult. Climate, soil, and topographic conditions must be considered in conjunction with the revegetation potential and the availability of rock material at a given site. As a basis for design planning and for determining research needs,

we have constructed a decision tree (Figure 7.2). The decision tree outlines the process of gathering site information necessary for designing

Figure 7.2. Decision Tree for Designing Inactive Mill Tailings Surface Covers

a surface stabilization plan and for evaluating the effects of the surface cover on the impoundment system. The Revegetation/Rock Cover program is attempting to develop the methods to make the decision tree a viable process for designing surface covers.

The decision tree shows the process of designing surface covers as having three phases: The first, or assessment phase, involves collecting the appropriate site information in order to construct a preliminary surface cover design (phase two). The preliminary surface design will describe the general type of cover necessary to prevent erosion damage to the impoundment system. The general surface cover design can be combined with preliminary designs of the other components of the impoundment system to produce a conceptual site design. After a conceptual design has been formulated, phase three begins. During phase three, an optimization procedure results in a final site-specific surface cover design. A brief discussion of the steps involved will illustrate the procedure.

Phase one consists of evaluating site conditions. For a given site, data on climate, soils, topography and vegetation are collected. Some of this information can be regional for sites with similar environmental characteristics (See Sec. 3.0). The vegetative potential of the site may then be determined by evaluating existing vegetative cover on soils that are available and desirable for topsoiling at the site. Over the long-term, vegetation on the impoundment can be expected to resemble that on the surrounding land with similar soils and topography. The site data on vegetation, climate, soils and topography are then used in conjunction with an appropriate erosion model to predict erosion potential with vegetative cover. Based on the calculated erosion and criteria for stability, the adequacy of vegetation for surface protection can be determined. If vegetation is considered adequate, a preliminary revegetation plan is produced. If vegetation is judged to be inadequate for long-term erosion control on all or parts of the pile, other means must be used to prevent erosion damage. The recommended next step is to determine the need and cost of suitable rock for covering the entire pile or portions of pile exposed to high erosion rates. Some types of rock can be very effective in reducing erosion, but it may not be available locally.

The cost of using rock covers is heavily dependent on the distance the rock must be hauled. At some distance rock may no longer be affordable.

If rock cover is feasible, a preliminary design using rock or a combination of rock and vegetative covers can be produced. If suitable rock is not available, the use of additional overburden, greater amounts or better quality topsoil, or recontouring the pile may reduce erosion rates; once these options are determined, erosion potential is recalculated and again the adequacies of vegetation as a surface cover are evaluated. This process may require several iterations before a preliminary plan is produced.

The preliminary surface stabilization plan is intended to provide information and alternative surface covers to those planning radon barriers, biobarriers and liners (if piles are moved). Once the overall impoundment system has been conceptually designed, a final design for surface covers can be produced.

The third phase of the design process begins by determining the options for surface stabilization available for the site. The cost and effectiveness of the alternatives are optimized in conjunction with other impoundment system components. Before the final design can be chosen, impacts of surface stabilization design on the functioning of impoundment system must be evaluated in detail. Erosion rates are determined using site specifications. Effects of surface covers on soil moisture are determined, taking radon and biological barrier designs (and liners when appropriate) into account. Biointrusion resulting from the proposed surface cover must be evaluated at this time. If the consequences of surface cover design do not jeopardize the functioning of the impoundment system based on the above evaluations, the design can be finalized. If the surface cover does jeopardize the functioning of the system, then alternative designs must be considered. Again, several iterations of this process may be necessary.

The Revegetation/Rock Cover program is developing the methodology to make this decision tree a working tool for designing surface covers. All parts of the decision tree are not being addressed in this program, however. The tree is intended to make use of information and methodologies

being developed in other programs dealing with surface stabilization problems as well as those programs developing barriers and liners.

Methodologies for site assessment and design evaluations are being developed in this program. Techniques for evaluating regional and site data are being developed under the Region Evaluations task (Section 3.0). Selection of a mathematical model(s) to determine erosion potentials is scheduled for FY 1983. When a model(s) is on-line, evaluations of vegetation adequacy and other site variables can be made. The information can then be used to produce preliminary surface stabilization designs. Methodologies for designing vegetative covers are being developed. Methods for selection and application of rock covers are being developed under a NRC funded program at PNL (Schwendiman et al. 1982); the Revegetation/Rock Cover program is coordinating with that program.

The need for methods to determine the effects of surface covers on soil moisture and biological intrusion has prompted this program to conduct research in the areas of unsaturated moisture flow and vegetation response to rock covers and barriers. Field scale test plots have been established to identify the effects of radon barriers on vegetation at the Grand Junction Test Site. Rock cover effects on on soil moisture and vegetation are being studied at Grand Junction and at a second test plot (San Juan) near Farmington, NM. Methods for establishing vegetation in conjunction with rock covers are also under investigation at the San Juan Test Plot. The mathematical methodology for simulating soil moisture responses to surface covers is being developed under this program.

Risk Considerations

Assessments of risk related to particular methods of tailings stabilization will play an important role in designing stabilization schemes. The appropriate level of risk will vary from site to site as will the elements of that risk. Stabilization designs must reflect real concerns of specific sites. The costs associated with maximum assurance of long-term stability may be prohibitive. The risk associated with surface stabilization involves failure of the protective cover, which allows radon to escape and contaminants to leach into groundwater. Vegetative and rock covers are both subject to failure for a variety of reasons.

Vegetation can be removed by grazing, fire or climatic change. Of these, grazing poses the most serious threat, but the use of plant species that are resistant to grazing or unpalatable may minimize the problem. Fire can burn off the vegetation, but if fire-tolerant plant species are used the effect on the cover will be minimal. Fire-tolerant plants typically resume normal growth within a year of the fire, and even though the above-ground parts are lost until the next growing season, the root systems remain intact and stabilize the soil surface. Long-term climatic change is the most difficult risk to assess. For vegetative covers long-term drying could affect the cover integrity, whereas a change toward a wetter climate would increase the vegetation cover. Combined rock and vegetative covers offer some redundancy of cover type and tend to increase the effective moisture content of the system, and this may reduce the detrimental effects of drier climates in the future. Reasonable estimates of the extent of drying in a particular region may be obtained from tree ring dating and pollen records.

Rock covers present a different set of risks. These are associated with increasing moisture in the soil-tailings system, human disturbance, fire, salt accumulation and climate effects. By placing rocks on the surface to prevent erosion, evaporation and run-off are reduced. If enough rocks are placed on the surface, plant cover and, hence, transpiration will also be reduced. The net result will be increased soil moisture throughout the tailings system. Whether or not the increase in moisture poses a greater risk than increased erosion if the rocks are not used remains a site-specific question. Aside from flood damage, most washing probably poses the most serious threat to impoundment stability (Young et al. 1982, Zellmer 1981). The effects of the added weight of rock covers and increased moisture in the overburden may contribute to mass wasting (sloughing) on steeper slopes. Another major risk involved with rock covers is removal by humans. Archeologists are familiar with the subsequent use of building materials by later generations unfamiliar with the purpose of a structure. Many Roman ruins have had stones removed for use as building materials by later generations. Some burial mounds constructed by the North American Indians originally had rock covers. Europeans who later dominated the land removed the stones to build fences and buildings. Tailings sites with elaborately engineered rock covers in

areas where little rock is available would be prime targets for disturbance once institutional control is lost. The removal of rock covers by future generations of man would certainly be a significant and permanent risk to the functional integrity of impoundment systems. Burning of vegetation growing on rock covers can seriously reduce rock survivability if the rocks are strongly heated (Winkler 1975). The disintegration of rock by salt action is one of the most potent and rapid weathering processes (Winkler 1975). If rock covers are placed on overburden containing salt or if salts from tailings rise to the surface, rock covers could be adversely affected. Extensive chemical weathering of rock is related to high moisture availability and high temperatures and may be accelerated by high levels of organic acids produced by vegetation (Trudgill 1976). If rock covers are used in humid areas such as Canonsburg, PA or Falls City TX, or if future climates are wetter, survivability of rock cover will be reduced.

To summarize, mill tailings stabilization designs must be considered in a realistic way. The major factors to be considered are

- Damage due to erosion
- Ground and surfacewater contamination
- Radon emanation
- Natural disturbance
- Human disturbance
- Costs

These factors will vary from site to site. The decision making process involved with stabilization designs must be flexible enough to incorporate (i.e. optimize) these factors.

8.0 FUTURE PROJECT OBJECTIVES

The overall objective of the Revegetation/Rock Cover program for FY 83 and beyond is to develop the methodology to assess site conditions and evaluate surface stabilization designs. To achieve this goal a number of intermediate steps must be taken. These are:

1. Obtain and apply a mathematical model(s) to determine the site and regional factors affecting erosion.
2. Determine methods for establishing combined rock/vegetation covers in landscapes.
3. Develop the capability to evaluate the effects of surface covers on soil moisture. This will involve analysis of test plot data and field verification of model predictions.
4. Evaluate the effects of rock covers and barriers on vegetation. This will involve analysis of test plot data.
5. Establish guidelines for designing surface covers that are applicable to all UMTRAP sites.

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