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LONG-TERM STABILIZATION OF URANIUM MILL TAILINGS

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LONG-TERM STABILIZATION OF URANIUM MILL TAILINGS*

Abstract

The primary hazard associated with uranium mill tailings is exposure to a radioactive gas, radon-222, the concentration of which has been correlated with the occurrence of lung cancer. Previous studies on radon attenuation conclude that the placement of earthen cover materials over the tailings is the most effective technique for reducing radioactive emissions and dispersal of tailings. The success of such a plan, however, is dependent on ensuring the long-term integrity of these cover materials. Soil erosion from water and wind is the major natural cause of destabilizing earthen cover materials.

Field data related to the control of soil loss are limited and only indirectly apply to the problem of isolation of uranium mill tailings over very long time periods (up to 80,000 a). However, sufficient information is available to determine benefits that will result from changes in specific design variables and to evaluate the need for different design strategies among potential disposal sites. The three major options available for stabilization of uranium mill tailings are (1) rock cover, (2) soil and revegetation, or (3) a combination of both on different portions of the tailings cover. The optimal choice among these alternatives depends on site-specific characteristics such as climate and local geomorphology and soils, and on design variables such as embankment heights and slopes, modification of upstream drainage, and revegetation practices.

Generally, geomorphic evidence suggests that use of soil and vegetation alone will not be adequate to reduce erosion on slopes greater than about 5 to 9%. For these steeper slopes, the use of rock talus or riprap will be necessary to maximize the probability of long-term stability. The use of vegetation to control erosion on the flatter portions of the site may be practicable in regions of the United States with sufficient rainfall and suitable soil types, but revegetation practices must be carefully evaluated to ensure that long-term performance objectives are achieved.

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1. INTRODUCTION

Uranium milling consists of crushing, grinding, and leaching uranium ore. One of the greatest potential problems associated with uranium milling is disposal and long-term stabilization of wastes or mill tailings. The tailings emit a radioactive gas, radon-222, the concentration of which has been correlated with the occurrence of lung cancer [1]. Although the concentration of radon-222 can be limited with existing waste disposal technology to small increments above background levels, the tailings remain hazardous for an extremely long period of time. Thorium which decays to radon-222 has a half-life of approximately 80,000 a.

Previous studies on radon attenuation conclude that the placement of earthen cover materials over the tailings is the most effective technique for reducing radioactive emissions and dispersal of tailings [2]. The success of this technique, however, is dependent on long-term protection of the cover materials from erosion. In this paper we present an analysis of the design of earthen cover materials based on past experience, on recent research and development, and on policy considerations. Specifically, we discuss the means for minimizing erosion, disturbance, and dispersion of uranium mill tailings by natural forces over the long term.

2. APPROACH

2.1. Conceptual design

The U.S. Nuclear Regulatory Commission (NRC) established performance objectives to be used in developing plans for disposal of uranium mill tailings [3]. Use of performance objectives rather than rigid technical requirements allows operators to design the most practical and efficient disposal plans on a site-specific basis. The NRC performance objectives related to this paper are:

1. Locate the tailings isolation area such that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable; and

2. Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation.

These concepts for management of uranium mill tailings are similar to those of a number of other countries including Canada [4] and Australia [5].

Uranium milling operations in the United States to date have been concentrated in the relatively dry environments of the western states. Approximately 83% of existing mill sites receive between 20 and 40 cm of precipitation annually. This low precipitation is important in terms of the potential to establish a self-sustaining plant community. Also, such areas have the highest erosion rates in the United States [6]. The geographic distribution of uranium mills can be shown to have a dominant influence on how the tailings should be stabilized. Because the environmental characteristics and engineered designs for each uranium mill are unique, we do not specifically address how each site should be stabilized. Instead, we identify the information needed to design an optimal plan for long-term tailings disposal with respect to site-specific conditions.

In general, the required information can be divided into the following categories (FIG. 1): (1) performance objectives, (2) site-specific environmental characteristics, (3) disposal design variables, and (4) economic considerations. Factors such as performance objectives and site-specific environmental characteristics dictate how the disposal design variables should be manipulated to optimize the plan (FIG. 1). Because the NRC has recognized the need to avoid being overly restrictive, economic considerations also influence the final selection of the disposal design variables.

Although many uncertainties are involved with long-term planning, it is a desirable goal to design disposal areas to be effective for thousands of years. Planning over the length of time in which geologic processes operate, however, is extremely speculative. Nevertheless, scientific and engineering principles can and should be used to optimize the design variables to promote stabilization of the tailings.

2.2. Variables affecting stabilization

Stabilization of covers for uranium mill tailings is a function of both site-specific environmental factors and design variables. Although there are yearly variations in precipitation and temperature, such environmental factors can be thought of as being fixed because they cannot be altered easily by man. The environmental conditions at each mill site, therefore, form a set of constraints that limit the success of the cover design and define the destabilizing forces to which the site will be subjected. Design variables, however, can be manipulated to improve the chances of achieving the performance objectives. Design variables include specific location of the disposal site, embankment height, embankment slope, upstream drainage area, types and characteristics of cover material (e.g., rock, soil and vegetation), foundation materials for rock cover, and soil and nutrient (chemical and water) requirements for a self-sustaining vegetation cover. These variables should be considered with respect to effectiveness, availability and reliability/durability of materials, resistance to and recoverability from potentially damaging natural phenomena (e.g., earthquakes, floods, fire, insect infestation, drought), and general practicability and cost.

3. PROCESSES AFFECTING STABILIZATION

3.1. Physical processes

The primary physical processes affecting surface stabilization are denudation and mass wasting. Denudation consists of the sequential process of weathering and erosion and results in lowering the ground surface and exposing subsurface materials. Mass wasting refers to the movement of large masses of earth material by gravitational forces; slope failure is one example.

Short-term processes (up to a few hundred years) of denudation and mass wasting for which there may be engineering solutions include wind and water erosion, floods, differential compaction and settlement, and landslides. Surface erosion is probably the most important destabilizing force during the initial stages of stabilization of the tailings. The dominant erosive agent in most areas, including many arid and semiarid regions, is flowing water [7]. Despite the obvious severity of gully erosion in most arid and semiarid regions, sheet erosion is the more common denudation mechanism in most drainages [8,9].

Various predictive equations have been developed to estimate effects of sheet erosion given certain site-specific information [10]. The most common of these is the Universal Soil Loss Equation[1] (USLE) which was developed to predict erosion in agricultural areas [11]:

$$A = R * K * L * S * VM \quad ,$$

in which,

A = soil loss (tonnes ha^{-1} a^{-1}),
R = rainfall factor,
K = erodibility factor,
L = slope length factor,
S = slope gradient factor, and
VM = erosion control factor including mechanical and vegetative practices (proportion of erosion compared to that of unprotected soils).

Potential wind erosion can be estimated by using an equation that is analogous in many respects to the USLE [12,13].

The values of the parameters in the USLE are all based on readily available information: R is calculated from local rainfall intensity and total kinetic energy of storm events; K is calculated from particle-size distribution (% sand, silt, and clay), organic-matter content, soil structure, and

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[1]Original equation uses english units.

permeability; and VM is determined by characteristics of the vegetation on the site and management practices to control erosion. The L and S parameters can be combined into a single topographic factor and calculated from slope length and steepness. First approximations of the USLE factors (R, K, VM, LS) for all present and proposed uranium mill sites in the United States can be obtained from several existing tables, graphs, and maps [10,13,14,15]. To optimize the design of a tailings disposal plan, however, site-specific information obtained by experts familiar with a specific area and sampling techniques will be necessary.

Although the USLE can be used to make relative comparisons between design alternatives, it is essentially unproven as a predictive tool for the very long time periods associated with tailings disposal. To design a tailings disposal system that will be naturally stable for thousands of years, examples of stable landforms found in nature should be studied. Geomorphic studies have indicated that soil covers in arid and semiarid regions are unlikely to persist over the long term on slopes greater than about 5 to 9% because soil loss exceeds soil formation [16,17]. For such slopes, rock placed over the soil is necessary to ensure long-term stability.

3.2. Biological processes

Erosion reduction by vegetation is related directly to the amount of plant material, living and dead, both above and below the soil surface [18]. Many early, semiquantitative studies indicate that undisturbed native vegetation with less than 30% canopy cover is unlikely to provide much erosion protection [19,20]. Furthermore, a diverse community including many fibrous-rooted and perennial species provides greater erosion control than a simple community with a high percentage of annuals and/or tap-rooted species [20,21,22].

Estimates of erosion control factors (VM) for the USLE (Sect. 3.1) have been made from the literature and from practical experience dealing with native vegetation and erosion [14,23]. Although the USLE was originally developed for use with crops, preliminary erosion control factors have been published for woodland, permanent pasture, and rangeland vegetation. These factors reflect differences in ground and canopy cover, amount of litter, and proportion of herbaceous and grass cover [14,23]. Erosion control factors for predominantly grass rangeland are shown in FIG. 2. The ordinate value is the proportion of erosion that would occur under the specified condition of vegetative ground and canopy cover when compared to a fallow, clean-tilled area. Thus, erosion of an area with 45% ground cover and 75% canopy cover would be about 5% of the erosion on a similar fallow, clean-tilled area. The actual amount of vegetation cover required for adequate erosion protection, of course, depends upon several factors, including the amount and intensity of rainfall, length and angle of slope to be stabilized, and erodibility of the site-specific soils (Sect. 3.1).

Although revegetation may be useful for short-term stabilization, a number of uncertainties lessen its attractiveness as a long-term strategy. First, disturbance of soil may cause release of nutrients that may initially enhance productivity [24]. Unless these nutrients are retained and cycled within the system, however, the long-term result will be a nutrient-poor medium supporting reduced cover. Secondly, successful establishment of a "crop" of grasses does not automatically ensure that a diverse, self-sustaining plant community will develop. Newly established communities are often invaded by a few aggressive early successional plants, such as the imported Russian thistle (Salsola kali) or the annual cheatgrass (Bromus tectorum), which have limited value in stabilization because of their root systems. Even stable, successfully revegetated tailings can be affected by long-term climatic trends (e.g., increase in CO_2 and change in global climate) and infrequent but catastrophic events (e.g., massive floods, windstorms, earthquakes, volcanic eruptions, fires, and insect or disease outbreaks). A final problem that might occur with revegetation is penetration of tailings by plant roots, causing breaching of the cap with possible release of radon-222 and uptake of contaminants by plants. Although roots of many species commonly used in revegetation (e.g., the clovers) as well as invader species such as mesquite (Prosopis spp.) and the acacias (Acacia spp.) are capable of attaining lengths which would allow them to reach the tailings, it is not known if they would penetrate the material (e.g., compacted clay) used for radon attenuation.

4. EVALUATION OF DISPOSAL PLANS

Because the environmental conditions of a site are essentially fixed and limit the success of cover strategies, determination of these site-specific constraints should be the first step in the evaluation process (FIG. 3). Topographic location, including watershed area and local geomorphology, and any planned alteration in the original drainage patterns should be evaluated next. Finally, cover design variables should be evaluated for each surface type. If a proposed design is inadequate in terms of one or more long-term performance criteria, then a modified design should be examined (indicated by the feedback loop on the left side of FIG. 3). The evaluation of cover designs should be repeated for all surface types (combinations of slope and cover material) within the tailings disposal site (feedback loop on the right side of FIG. 3).

Observations of existing sites that have been covered and revegetated [25] indicate that within less than a decade, many earthen covers have been damaged by water and wind erosion, and revegetation has failed to achieve cover densities sufficient to provide erosion protection. Therefore, even though one of the performance objectives is to minimize continuing maintenance of the disposal site, near-term monitoring plans should accompany plans for covering tailings with vegetation (FIG. 3). This monitoring can be limited to the detection of major destabilization of cover materials early enough to allow for corrective action. Remote sensing technology provides an excellent, efficient means for detecting erosion-related land disturbances [26,27].

Although all design variables must be carefully evaluated, space limitations prevent discussions of each here. Major design variables are discussed in Voorhees et al. [28]. Because the most important destabilizing force during the initial stages of stabilization is sheet erosion, however, we examine the usefulness of the Universal Soil Loss Equation below.

Potential erosion rates (A_p) are those that would occur from unprotected soils in the absence of erosion control practices; they can be calculated by using the first four terms of the USLE (Sect. 3.1):

$$A_p = R * K * L * S \quad .$$

This calculation can be made for each mill site by using site-specific values for the erodibility (K) and rainfall (R) parameters [13] and length/slope factors typical of tailings cover designs. Two representative slope types were evaluated: (1) a typical embankment with a slope length of 100 m and slope of 20% (LS = 7.4) and (2) a typical surface cap design with a slope length of 500 m and slope of 1% (LS = 0.3).

Assuming a soil density of 1.8 g/cm^3, potential erosion on the model embankment would result in soil losses ranging from a minimum of 0.18 cm/a in western Washington to a maximum of 5.9 cm/a at sites along the Texas Coastal Plain. Soil losses from the cap portion of tailings cover would be more than an order of magnitude less (0.007 to 0.24 cm/a at the same two sites). These rates would be representative only for the first few years after placement of the cover material, because the erosion control factor (VM; Sect. 3.2) can be expected to increase with time due to natural processes [13]. The expected erosion rates, however, demonstrate the need for different erosion control measures both among sites and between the different slope types. For instance, to reduce the embankment erosion rates at Texas mill sites to a value approaching 10 cm/1000 a (approximately 1.8 tonnes ha^{-1} a^{-1}), the USLE analysis indicates that the VM factor would have to be about 0.002. Similarly, the VM factor for the cap portion of tailings covers in Texas would have to be approximately 0.04. While reclamation could achieve the necessary vegetation cover to protect the cap, it is unlikely that sufficient cover could be established to satisfy the VM factor required for the embankments at the Texas sites (FIG. 2).

5. CONCLUSIONS

Disposal plans should be evaluated in terms of (1) site-specific environmental characteristics, (2) proposed design configurations, and (3) ability to satisfy long-term performance requirements. Despite the uncertainties associated with long-term disposal of wastes, sufficient information is available to eliminate inadequate designs; to distinguish relative, incremental benefits resulting from changes in specific design variables; and to compare the needs for different design strategies among sites. A minimal amount of monitoring is necessary to ensure the adequacy of the disposal plan and to increase our understanding of methods for long-term stabilizaiton. Until more experience is acquired, evaluation of tailings disposal plans can be justifiably based on these types of analyses.

REFERENCES

[1] JOINT COMMITTEE ON ATOMIC ENERGY, Radiation exposure to uranium miners (hearings before the Joint Committee, 90th Congress, Part 2): U.S. Govt. Print. Off., Washington, D.C. (1967) pp. 1262-1277.

[2] U.S. NUCLEAR REGULATORY COMMISSION (NRC), Final Generic Environmental Impact Statement on Uranium Milling, Project M-25, Vols. I, II, and III, NUREG-0706, Office of Nuclear Material Safety and Safeguards, NRC, Washington, D.C. (1980).

[3] SCARANO, R.A., LINEHAN, J.J., Current U.S. Nuclear Regulatory Commission licensing review process: Uranium mill tailings management. Proc., Nuclear Energy Agency Seminar: Management, Stabilization and Environmental Impact of Uranium Mill Tailings (Albuquerque, New Mexico) OECD, Paris (1978) pp. 407-425.

[4] ATOMIC ENERGY CONTROL BOARD, CANADA, Long Term Aspects of Uranium Tailings Management, Proposed Regulatory Guide, Consultative Document C-1, AECB, Ottawa, Ontario, Canada (1981).

[5] DEPARTMENT OF HOME AFFAIRS AND ENVIRONMENT, Proposed Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores (1981), Commonwealth of Australia, Canberra (1981).

[6] LANGBEIN, W.B., SCHUMM, S. A., Yield of sediment in relation to mean annual precipitation, Trans. Am. Geophys. Union 39 (1958) 1076-1084.

[7] COOKE, R.U., WARREN, A., Geomorphology in Deserts, University of California Press, Berkeley (1973) 374 pp.

[8] LEOPOLD, L.B., EMMETT, W.W., MYRICK, R.M., Channel and hillslope processes in a semi-arid area, New Mexico, U.S. Geol. Surv. Prof. Pap. 352G (1966) 193-253.

[9] EMMETT, W.W., The hydraulics of overland flow on hillslopes, U.S. Geol. Surv. Prof. Pap. 662-A (1970).

[10] VANONI, V.A. (ed.), Sedimentation Engineering, American Society of Civil Engineers, New York (1975) 745 pp.
[11] PETERSON, A.E., SWAN, J.B. (eds.), Universal Soil Loss Equation: Past, present, and future, SSSA Special Publication No. 8, Soil Science Society of America, Madison, Wisconsin (1979) 53 pp.
[12] CHEPIL, W.S., WOODRUFF, N.P., The physics of wind erosion and its control. Adv. Agron. 15 (1963) 211-302.
[13] ISRAELSEN, C.E., CLYDE, C.G., FLETCHER, J.E., ISRAELSEN, E.K., HAWS, F.W., PACKER, P.E., FARMER, E.E., Erosion control during highway construction: manual on principles and practices, National Cooperative Highway Research Program Report 221, Transportation Research Board, National Research Council, Washington, D.C. (1980).
[14] WISCHMEIER, W.H., SMITH, D.D., Predicting rainfall erosion losses: a guide to conservation planning, U.S.D.A. Handbook. 537 (1978) 58 pp.
[15] LUTTON, R.J., REGAN, G.L., JONES, L.W., Design and construction of covers for solid waste landfills, EPA-600/2-79-165, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio (1979) 249 pp.
[16] CHOW, V.T. (ed.), Handbook of Applied Hydrology, McGraw-Hill, New York (1964).
[17] EARDLEY, A.J., VIAVANT, W., Rates of denudation as measured by bristlecone pines, Cedar Breaks, Utah, Special Studies 21, Utah Geological and Mineralogical Survey, University of Utah, Salt Lake City, Utah (1967).
[18] WEAVER, J.E., CLEMENTS, F.E., Plant Ecology, McGraw-Hill Book Co., New York (1938) 601 pp.
[19] MEGINNIS, H.G., Effect of cover on surface run-off and erosion in the loessial uplands of Mississippi. U.S.D.A. Circ. No. 347 (June 1935) 15 pp.
[20] RENNER, F.G., Conditions influencing erosion on the Boise River watershed, U.S.D.A. Tech. Bull. No. 528 (October 1936) 32 pp.
[21] SPENCE, L.E., Root studies of important range plants of the Boise River watershed. J. For. 35 (1937) 747-754.
[22] CRADDOCK, G.W., PEARSE, C.K., Surface runoff and erosion on granitic mountain soils of Idaho as influenced by range cover, soil disturbance, slope and precipitation intensity, U.S.D.A. Circ. No. 482 (August 1938) 24 pp.
[23] U.S. ENVIRONMENTAL PROTECTION AGENCY, Preliminary guidance for estimating erosion on areas disturbed by surface mining activities in the interior western United States, Interim Final Report, EPA-908/4-77-005, Prepared for the U.S. Environmental Protection Agency, Region VIII, Denver, Colorado, by the U.S. Soil Conservation Service (July 1977).
[24] CURRY, R.R., Reviewer comments, pp. 165-171 in Rehabilitation Potential of Western Coal Lands, National Academy of Sciences, Ballinger Publishing Co., Cambridge, Massachusetts (1974) 197 pp.

[25] U.S. DEPARTMENT OF ENERGY, Background report for the Uranium Mill Tailings Sites Remedial Action Program, DOE/EP-0011, U.S. DOE, Environmental and Safety Engineering Division, Washington, D.C. (1981).

[26] KLEIN, S.B., Soil erosion and sediment control laws, Natural Resource Information Systems Project, National Conference of State Legislatures, Denver, Colorado (1980) 110 pp.

[27] THOMPSON, D.L., HAAS, R.H., MILFORD, M.H., Evaluation of LANDSAT multispectral scanner data for mapping vegetated soil landscapes, Soil Sci. Soc. Am. J. 45 1 (1981) 91-95.

[28] VOORHEES, L.D., SALE, M.J., WEBB, J.W., MULHOLLAND, P.J., Guidance for disposal of uranium mill tailings: Long-term stabilization of earthen cover materials, ORNL/TM-8685, NUREG/CR-3199, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, D.C. (in press).

LIST OF FIGURES

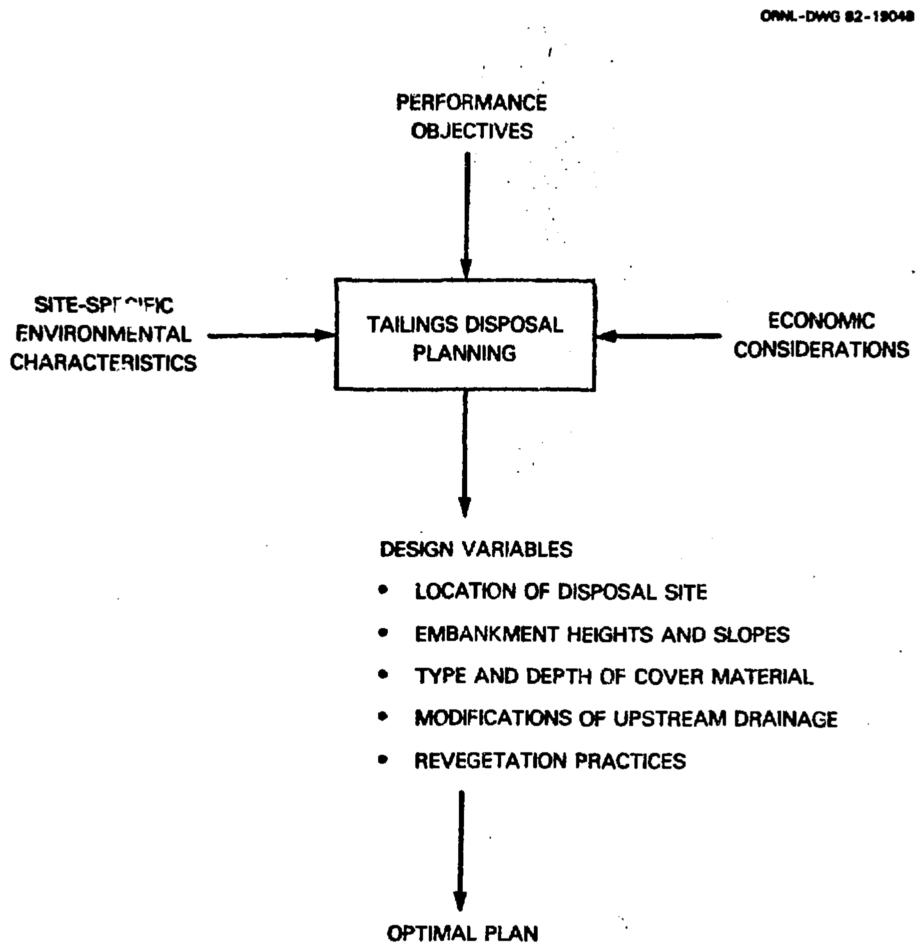

FIG. 1. Conceptual process for developing a tailings disposal plan.

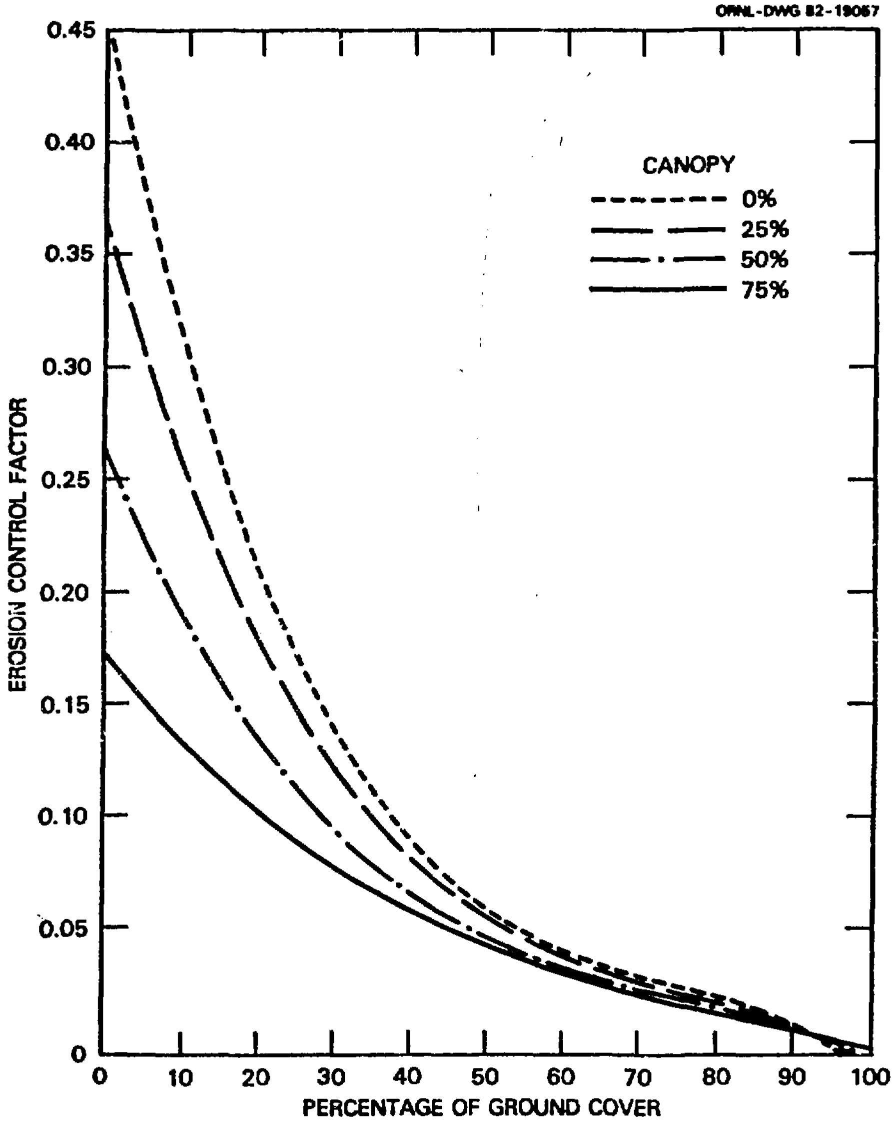

FIG. 2. Influence of ground and canopy cover on the erosion control factor (VM) used in the USLE. [Source: Ref. 14].

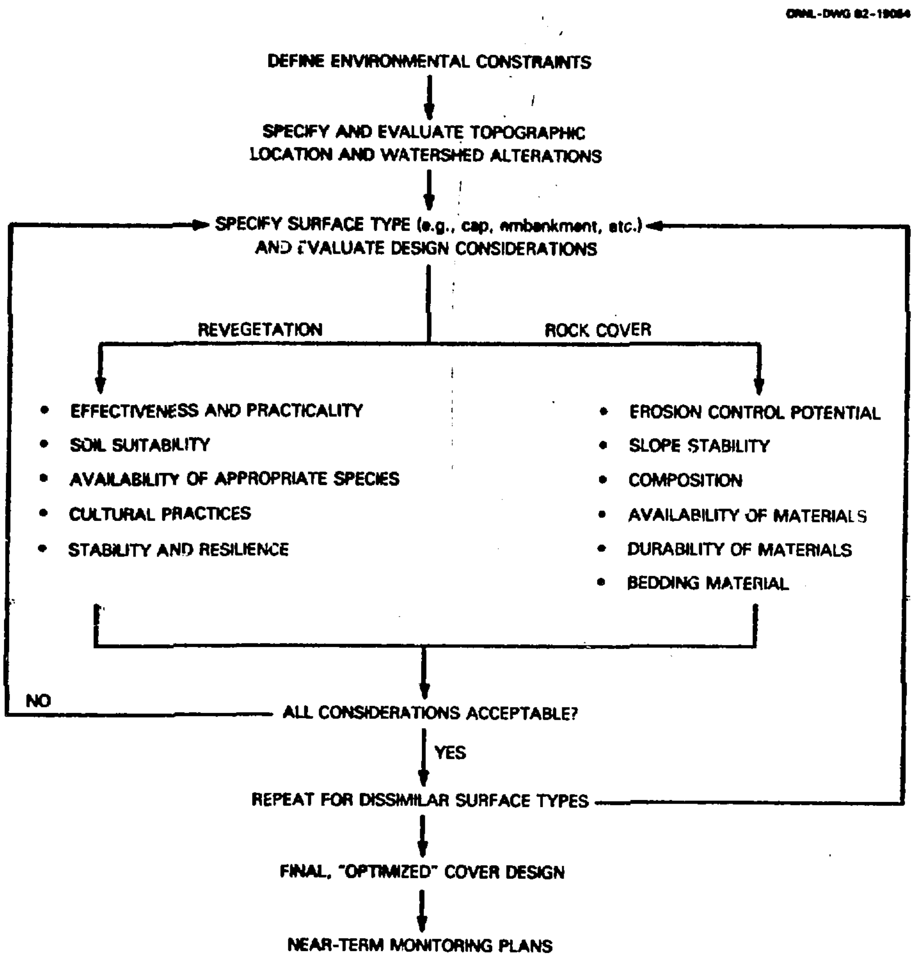

FIG. 3. Evaluation of cover materials for long-term stabilization of uranium mill tailings.