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DESIGN, CONSTRUCTION, AND INSPECTION OF EMBANKMENT RETENTION SYSTEMS AT URANIUM RECOVERY FACILITIES

A. INTRODUCTION

This guide describes some engineering practices and methods generally considered by the U.S. Nuclear Regulatory Commission (NRC) to be satisfactory for the design, construction, and inspection of embankment retention systems used for retaining liquid and solid wastes from uranium recovery operations. These practices and methods are the result of NRC review and action on a number of specific cases, and they reflect the latest general engineering approaches that are acceptable to the NRC staff. If future information results in alternative methods, the NRC staff will review such methods to determine their acceptability. Separate guidance (Refs. 1–3) addresses the closure of retention systems.

Licensees who process or refine uranium ores in a milling operation are required by Title 10, Section 20.1101, "Radiation Protection Programs," of the *Code of Federal Regulations* (10 CFR 20.1101) to use, to the extent practical, procedures and engineering controls based on sound radiation protection principles, to maintain occupational radiation exposure and radiation exposure to members of the public that are as low as is reasonably achievable (ALARA). In addition, Subpart B, "Environmental Standards for the Uranium Fuel Cycle," of 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations," requires that the annual dose equivalent not exceed 25×10^{-5} sieverts (Sv) (25 millirem (mrem)) to the whole body, 75×10^{-5} Sv (75 mrem) to the thyroid, and 25×10^{-5} Sv (25 mrem) to any other organ of any member of the public as the result of exposures to radiation (radon and its daughters excepted) from uranium fuel cycle operations, including planned discharges of radioactive

materials to the general environment. Liquid and solid wastes generated in uranium recovery operations typically contain radioactive materials in excess of the discharge limits and are generally confined by an embankment retention system.

This regulatory guide contains information collection requirements covered by 10 CFR Part 20 and 10 CFR Part 40 and that the Office of Management and Budget (OMB) approved under OMB control numbers 3150-0014 and 3150-0020, respectively. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number.

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B. DISCUSSION

Background

The milling of uranium ores results in the production of large volumes of liquid and solid wastes (tailings). These tailings are usually stored behind manmade retaining structures, following the practice of the nonuranium mining industry. In addition, other liquid wastes from operations and ground-water corrective action activities at uranium recovery facilities are often retained behind evaporation pond embankments. The design and construction of early tailings retention structures were based largely on mining experience, with little use of design concepts. These empirical approaches resulted in various mining dam mishaps and failures (Refs. 4 and 5). The 1972 failure of Buffalo Creek Dam in West Virginia resulted in the U.S. Congress passing a national dam safety law affecting all water-impounding structures in excess of either 7.62 meters (25 feet) in height or 61,674 cubic meters (50 acre-feet) in impoundment capacity (Ref. 6).

Wastes from uranium recovery operations, unlike most nonuranium mine wastes, contain concentrations of radioactive materials in excess of allowable discharge limits (Ref. 7). Furthermore, the most significant radioactive element in the wastes is radium-226, which has a half-life of about 1600 years (Ref. 8). Therefore, it is necessary to confine such wastes to prevent or control their release to the environment, not only during the operation of the uranium recovery facility, but also for generations after operations have ceased. The embankments, foundation, and any abutments need to be stable under all conditions to prevent the uncontrolled release of the retained liquid or semifluid wastes. Seepage from the tailings cell or evaporation pond, which contains dissolved radium and other toxic substances (Ref. 8), needs to be controlled under normal and severe operating conditions to prevent the possibility of unacceptable contamination of the ground water or nearby streams. The impoundment and embankments need to be designed to prevent wind and water erosion during operation, and after facility closure in the case of reclaimed tailings impoundments.

Factors pertaining to safety, contamination, and environmental damage determine the basic requirements in planning and constructing retention systems. To achieve the basic requirements, the design must be based on a thorough understanding of both the geotechnical and hydrological problems involved and the requirements of the uranium recovery operation.

The latest advances in geotechnical engineering, together with engineering experience and knowledge in the field of water storage dams and retention structures, can be used in the design and construction of uranium recovery retention systems. The basic concepts of conventional water storage impoundments can be suitably modified to produce economical designs that will ensure the stability of the retention system and minimal contamination.

1. General Planning, Siting, and Design Considerations

Because the prime functions of the retention system are to store radioactive solids and/or to provide temporary storage of contaminated water for clarification and evaporation, the system must be designed and constructed to remain stable for its intended life. It must provide the required storage at any given time, and it must provide sufficient control of seepage to prevent unacceptable contamination of adjacent land, waterways, and ground waters. It must also be designed to be resistant to wind and water erosion during and after facility operations.

The planning, siting, and design of uranium recovery retention systems need to ensure that such systems meet any other regulatory and permitting requirements for a proposed impoundment that exist outside NRC's regulations (10 CFR Part 40, Appendix A) and regulatory process.

The siting and design should consider the requirements of the U.S. Environmental Protection Agency's (EPA) national emission regulations at Subpart W, "National Emissions Standards for Radon Emissions from Operating Mill Tailings," of 40 CFR Part 61, "National Emission Standards for Hazardous Air Pollutants." Subpart W requires that "… no new tailings impoundment can be built unless it is designed, constructed, and operated to meet one of the two following work practices: (1) Phased disposal in lined tailings impoundments that are no more than 40 acres in area and meet the requirements of 40 CFR 192.32(a) as determined by the Nuclear Regulatory Commission. The owner or operator shall have no more than two impoundments, including existing impoundments, in operation at any one time. (2) Continuous disposal of tailings such that tailings are dewatered and immediately disposed with no more than 10 acres uncovered at any time and operated in accordance with 40 CFR 192.32(a) as determined by the Nuclear Regulatory Commission." Furthermore, the design should consider the requirements of 40 CFR 264.221 addressing surface impoundment design and operation. An applicant or licensee should consider these EPA regulations during the preliminary design and planning stages of the tailings retention system.

1.1 Site Evaluation

The goal in the siting and design of uranium recovery retention systems is to achieve permanent isolation of tailings and associated contaminants by minimizing disturbance and dispersion by natural forces and to do so without ongoing maintenance. In the selection of alternative tailings disposal sites or in the evaluation of the adequacy of existing tailings sites, all site features that will contribute to this goal should be considered, including (1) remoteness from populated areas, (2) hydrologic and other natural conditions as they contribute to continued immobilization and isolation of contaminants from ground-water sources, and (3) potential for minimizing erosion, disturbance, and dispersion by natural forces over the long term. In the selection of disposal sites, primary emphasis must be given to the isolation of tailings or wastes, a matter having long-term impacts, as opposed to the consideration of only short-term convenience or benefits, such as minimization of transportation or land acquisition costs. While isolation of tailings will be a function of both site conditions and engineering design, siting features are the primary consideration for ensuring permanent isolation of wastes given the long-term nature of the tailings hazards.

To the extent possible, sites should be selected that are at or near the top of local drainage divides and/or are not located in floodplains or flood-prone areas. Such site selection will avoid the need for diversion channels or extensive riprap protection to prevent erosion of the toes and slopes of the embankments.

The "prime option" for the disposal of tailings is placement below grade. Where full below-grade burial is not feasible, the size of retention structures, as well as the size and steepness of slopes associated with exposed embankments, must be minimized by excavation to the maximum extent reasonably achievable given the geologic and hydrologic conditions at a site. In these cases, it must be demonstrated that an above-grade disposal program will provide equivalent isolation of the tailings from natural erosion forces.

In selecting any site for uranium recovery waste retention, detailed local conditions, including climate, ground-water and surface-water hydrology, geology, and seismology, need to be assessed and their impacts evaluated.

1.2 Field Exploration

Subsurface investigations at the site of the retention system and at possible borrow areas need to be of adequate scope to determine the suitability of the foundation and the availability and characteristics of embankment materials. Borings should be drilled along the axis of the retention structure and at critical locations perpendicular to the axis to establish geologic sections and ground-water conditions. Generally, borings should extend to a depth in the natural soils at least equal to the height of the planned embankment section. A minimum of 4.57 meters (15 feet) into natural soils is required for small retention structures. The investigations should cover classification, physical and chemical properties, location, and extent of soil and rock strata, and variations in ground-water conditions. Evaluation of ground water should be focused on the uppermost aquifer. The field exploration should identify this aquifer, its flow direction, and the distance from the impoundment to potential down-gradient users. In addition, the background ground-water quality of the uppermost aquifer should be obtained in accordance with the preoperational guidance in Regulatory Guide 4.14, Revision 1, "Radiological Effluent and Environmental Monitoring at Uranium Mills," issued April 1980. Observation of ground-water conditions should be recorded over a sufficient period to permit the ground-water depths and range of seasonal fluctuations to be established.

The foundation conditions must be determined to assess the ability of subsurface materials to support the embankments without failure and without excessive total or differential settlement. The permeability of foundation soils and rocks must be ascertained to estimate the seepage potential. The availability of suitable borrow material for retention system construction must be assessed with consideration of the construction sequence and schedule.

Information is needed on the characteristics of the underlying soil and geologic formations, particularly as they will control transport of contaminants and solutions. This includes detailed information concerning extent, thickness, uniformity, shape, and orientation of underlying strata. Hydraulic gradients and conductivities of the various formations must be determined. This information must be gathered from borings and field survey methods taken within the proposed impoundment area and in surrounding areas where contaminants might migrate to ground water. Hydrologic parameters such as permeability may not be determined on the basis of laboratory analysis of samples alone; a sufficient amount of field testing (e.g., pump tests) must be conducted to ensure an adequate understanding of actual field properties.

1.3 Laboratory Tests

Testing soil samples of foundation and embankment materials from the field investigation should result in detailed knowledge of such physical and mechanical properties as classification, gradation, shear strength, consolidation, permeability, sedimentation, compaction, piping and cracking susceptibility, and wind-water erosion characteristics.

2. Design Analysis

Design analysis should consider stability, settlement, seepage, hydrologic analyses, liner stability, and liner compatibility. Specifically, the design must ensure that retention system failure will not occur. Historical records (Refs. 9–12) indicate that most failures associated with tailings retention systems have been caused by overtopping by flood waters, erosion, piping in the retention embankment or the foundation, foundation failure, slope failure, or liquefaction.

2.1 Stability and Failure Analyses

2.1.1 Slope Stability

Slope failure occurs when an outer portion of an embankment slides downward and outward with respect to the remaining part of the embankment. The slide generally occurs along a fairly well-defined slip surface.

2.1.1.1 Methods of Analyses

Stability analyses involve comparing the shearing stresses along potential failure surfaces with the available shearing resistance along those surfaces. The factor of safety is the ratio of the available shear strength to the developed maximum shear stress.

A number of computer programs can be used to perform slope stability analyses. Computer programs provide an easier means to (1) consider complex slope geometries and subsurface soil layering, (2) use a number of different types of soil in the analysis, (3) search for circular, wedge, and noncircular failure surfaces, (4) consider different models to represent soil strength, and (5) consider different loading conditions. When used properly, these programs can allow a designer to consider a significant number of potential slip surfaces. Commercially available programs also may allow calculation of the factor of safety using several of the methods identified below. Despite these advantages, the output from a computer program needs to be checked carefully to verify that the critical surface with the lowest factor of safety has been identified, the critical surface represents a possible or realistic scenario, and computational problems resulting from the parameters used are minimized. For complicated situations, it may be prudent to verify the analysis with a second computer program or a hand calculation.

2.1.1.2 Static Stability Analysis

Limit Equilibrium

Conventional limit equilibrium methods of slope stability analysis evaluate the equilibrium of a soil mass tending to move down slope under the influence of gravity. Many methods use the limit equilibrium approach. Various publications (Refs. 13–15) offer detailed discussions. The following provides a brief overview of several of these methods:

- *Friction Circle Method*—This method considers the entire sliding block as a rigid free body and makes assumptions regarding the distribution of normal stresses along the failure surface. It can be used only to evaluate failure surfaces that are circles or single straight lines and is most suited to homogeneous soil conditions. The Logarithmic Spiral Method is a different version of this method.

- *Method of Slices*—This method divides the free body into many vertical slices, and the equilibrium of each slice is considered. The best known and most widely used versions of this method are the Ordinary Method of Slices, the Swedish Circle Method, Modified Swedish Method, Simplified Bishop Method, Spencer's Method, and Morgenstern-Price Method. Although this method can be used to analyze wedge and noncircular slip surfaces, certain methods, such as the Ordinary Method of Slices and Simplified Bishop Method, require a circular slip surface. The analyses should consider both shallow slip surfaces that run through the embankment as well as deep slip surfaces that run beneath the embankment (Refs. 16 and 17).

- *Wedge Method*—This method is used whenever the failure surface can be satisfactorily approximated by a series of straight lines (usually two or three).

- *Special Cases*

  - Infinite Slope—This analysis is suited to cases in which a slip surface may form parallel to the face of the slope. This type of failure can be approximated using a circular surface with a large radius. However, a simple approach has been developed based on equilibrium of forces. Several publications (Refs. 15–18) discuss this situation in detail.

  - Geomembranes—If a geomembrane is to be used as a component of a retention system, a stability analysis of a layer of cover soil on top of the geomembrane may be needed. This type of analysis can be sensitive to the slope angle and the interface friction between the cover soil and the geomembrane (Refs. 19 and 20).

Deterministic versus Probabilistic Analyses

In traditional deterministic approaches to slope stability analysis, the foundation soil properties, pore pressure, geometry, and loading conditions are held constant, and one of the analysis techniques identified above is used to calculate the factor of safety. In this approach, the numerical values used in the analysis do not account for the inherent variability of material properties, pore pressures, and loading conditions that can exist within a given slope. Probabilistic methods make it possible for a slope stability analysis to consider the variability of these parameters. While the use of probabilistic methods is not required when designing an embankment or retention system, it can aid in the interpretation of an analysis. Reference 21 further discusses probabilistic methods in slope stability analysis.

Finite Element Method

The finite element method (FEM) is most useful when calculating the stresses, pore pressures, and deformation of a slope. FEM can be used to calculate a factor of safety in a slope stability analysis, but this requires additional steps beyond the typical FEM output. FEM usually requires information about the stress-strain behavior of soil to provide a reasonable answer. This can require complex laboratory testing. Because of the considerable time and effort required to develop an accurate and representative understanding of the soil conditions, FEM is best suited to aiding the interpretation of difficult slope stability problems. Examples of situations in which FEM may be applicable include (1) pore pressure dissipation and corresponding strength gain in tailings slimes, (2) settlement of an embankment as it is raised, (3) consolidation of soft soils beneath an embankment, and (4) identifying areas of displacement near critical structures. References 15 and 22 further discuss FEM.

2.1.1.3 Dynamic (Seismic) Stability Analysis

In areas where embankments are subjected to seismic disturbances, seismic stability analyses should be performed. Seismic vibrations can cause liquefaction of saturated or nearly saturated loose sands and sensitive silts (Ref. 4). The dynamic shearing stresses induced during the seismic events can cause excessive deformation, distortion, or even shear failure of the embankment (Refs. 23 and 24).

Seismic stability analyses of embankments are conventionally made using pseudostatic methods (Ref. 25). In this approach, the stability of a potential sliding mass is determined assuming static loading conditions, and the computation accounts for the effects of an earthquake by including an equivalent horizontal force acting on the potential sliding mass. The horizontal force representing earthquake effects is expressed as the product of the weight of the sliding mass and a seismic coefficient. The value of the

seismic coefficient is normally selected on the basis of the seismicity of the region in which the embankment is to be constructed.

During earthquakes, large cyclic inertia forces are induced in embankments. In certain zones of an embankment, the inertia forces may be sufficiently large and may occur often enough to cause permanent displacements. Newmark (Ref. 26), Goodman and Seed (Ref. 23), and Makdisi and Seed (Refs. 27 and 28) have proposed procedures for estimating the magnitude of these displacements. These approaches are more involved than conventional methods and have been used successfully to predict the surface displacements of embankments. Other approaches may be used; however, good engineering judgment should be exercised in the selection of soil characteristics, the application of the approach to the soil type and saturation conditions, and the evaluation of the results obtained.

In dealing with saturated, cohesionless soils, the dynamic analysis procedures developed by Seed et al. (Ref. 29) provide a basis for assessing the stability and deformation of the embankment during earthquakes. This type of analysis may be used to predict the development of the liquefaction zone and the anticipated movements, deformation, and stability of the embankment and its foundation. However, good engineering judgment based on adequate data must be exercised in the selection of soil characteristics for use in the analyses, the detailed steps followed to conduct the analyses, and the evaluation of the results obtained.

Reference 30 contains a detailed discussion and applicable guidelines for seismic analysis and design of tailings embankments.

2.1.1.4 Loading Conditions and Factors of Safety

A tailings embankment and its foundation are subjected to shear stresses imposed by the weight of the embankment, the filling of the impoundment, seepage, or earthquake forces. The cases for which stability analyses are necessary include the following:

- *End of construction*—Analyses of the upstream and downstream slopes are needed for the end-of-construction conditions if the embankment and its foundation are partially or entirely composed of impervious soils. The unconsolidated undrained shear strength should be used in the analyses for slow-draining soils, while consolidated drained shear strength should be used for free-draining soils in which excess pore pressures would not develop.

- *Partial pool with steady seepage*—Analyses of the upstream slope are needed for several intermediate pool stages with corresponding steady seepage conditions. The analyses account for a reduction in effective normal stresses when pore water pressure that developed during construction or filling did not dissipate before the subsequent partial pool condition. The lower strength from either the consolidated undrained shear test or consolidated drained shear test is used in the analyses. The minimum factor of safety should be determined as a function of pool elevations.

- *Maximum storage pool with steady seepage*—This condition may develop and may be critical to downstream slope stability. A flow net would be helpful in determining the phreatic line and seepage forces. Shear strength selection should be the same as for the partial pool with steady seepage condition.

- *Earthquake*—In areas subject to seismic shocks, appropriate earthquake forces need to be added onto the previous loading conditions in the stability analyses.

The use of a factor of safety in stability analyses should allow sufficient margin for variations between the parameters used in the design and those existing in the field, as well as consideration of the limits of strains. Many soils undergo relatively large plastic strains as the applied shear stresses approach the shear strength of the soil.

When choosing the factor of safety, the analyst needs to consider the consequence of a failure, the tolerable limits of strains, and the degree of confidence in engineering parameters used in the analyses. The minimum factor of safety suggested in the regulatory position of this guide presumes that the stability analysis has been sufficient to locate the critical failure surface and that parameters used in the analysis are known, with reasonable certainty, to represent actual conditions of the dam and its foundation. Otherwise, higher factors of safety would be required.

2.1.2 *Liquefaction*

Liquefaction impacts on stability need to be considered, if potentially liquefiable soils exist below the site of a retention system. Evaluation of liquefaction potential should include laboratory testing, in situ testing, and comparisons to similar soil deposits. The following five screening criteria should be used to determine whether there are potentially liquefiable soils at a site (Ref. 31):

(1) *Geologic age and origin*—If a soil layer is a fluvial, lacustrine, or aeolian deposit of Holocene age, a greater potential for liquefaction exists than for till, residual deposits, or older deposits.

(2) *Fines content and plasticity index*—Liquefaction potential in a soil layer increases with decreasing fines content and plasticity of the soil. Cohesionless soils having less than 15 percent (by weight) of particles smaller than 0.005 millimeters, a liquid limit less than 35 percent, and an in situ water content greater than 0.9 times the liquid limit may be susceptible to liquefaction (Ref. 32).

(3) *Saturation*—Although soils with low water content have been reported to liquefy, at least 80- to 85-percent saturation is generally deemed to be a necessary condition for soil liquefaction. The highest anticipated temporal phreatic surface elevations should be considered when evaluating saturation.

(4) *Depth below ground surface*—If a soil layer is within 15.24 meters (50 feet) of the ground surface, it is more likely to liquefy than deeper layers.

(5) *Soil penetration resistance*—Seed et al. (Ref. 33) state that soil layers with a normalized standard penetration test (SPT) blowcount [(N1)60] less than 22 have been known to liquefy. Marcuson et al. (Ref. 34) suggest an SPT value of [(N1)60] less than 30 as the threshold to use for suspecting liquefaction potential. Liquefaction also has been shown to occur if the normalized cone penetration test cone resistance is less than 1.59 megapascals (157 tons per square foot) (Ref. 35).

If three or more of the above criteria indicate that liquefaction is not likely, the potential for liquefaction can be dismissed. Otherwise, a more rigorous analysis of the liquefaction potential at a facility is required. However, even if three or more of the liquefaction evaluation criteria indicate that liquefaction is unlikely, historical evidence of past liquefaction or sample testing data collected during the subsurface investigation may raise enough of a concern that a full liquefaction analysis still should be done.

If liquefaction potential exists at a retention system site, additional subsurface investigation may be necessary. Once all testing is complete, a factor of safety against liquefaction should be calculated for

each critical layer that may liquefy. Seed and Idriss (Ref. 36) outline one procedure for evaluating liquefaction potential. A liquefaction analysis should, at a minimum, include the following:

- development of a detailed understanding of site conditions, the soil stratigraphy, material properties and their variability, and the areal extent of potential critical layers
- development of simplified cross-sections amenable to analysis
- calculation of the force required to liquefy the critical zones (resisting force), based on the characteristics of the critical zone(s) (e.g., fines content, normalized standardized blow count, overburden stresses, level of saturation)
- calculation of the design earthquake effect (driving force) on each potentially liquefiable layer using the site-specific, in situ soil data and an understanding of the earthquake magnitude potential for the facility
- computation of the factor of safety against liquefaction (resisting force divided by driving force) for each liquefaction susceptible critical layer

2.1.3 *Settlement*

If the foundation beneath an embankment retention system consists of layers of compressible soils or weathered rock, or if the bedrock profile is very irregular, differential settlements could result from uneven loading or variable thicknesses in the compressible soils. Total settlement and differential settlements may cause cracking and/or excessive strain in the embankments or other retention system components that could lead to system failure.

The magnitude of the anticipated settlement can be estimated from the results of laboratory consolidation tests on samples recovered from the compressible foundation strata and remolded embankment materials. The rate of settlement also can be estimated. However, the potential error in estimating the time for settlement to occur is significant, since settlement is influenced by soil drainage, which is controlled by minute geological details that may not be detected during the geotechnical investigation. Predictions based on laboratory data can be modified by actual measurements to provide reasonably accurate long-term estimates. Settlement should be calculated along as many cross-sections as are necessary to ensure that the expected amounts of overall and differential settlement that the engineered components of the facility will experience have been adequately estimated.

After total and differential settlement analyses have been performed, the engineered components of the waste retention system, such as geotextiles, geomembranes, clay liners, drainage layers, leachate collection piping, and waste piping, should be analyzed for tensile strain. The analysis should verify that the components can maintain their integrity when subjected to the induced strain associated with the settlement determined in the total and differential settlement analyses. If analysis indicates that total and differential settlement along any cross-section is likely to damage an engineered component, or to cause the engineered component to be unable to meet the minimum design criteria, then the retention system must be redesigned to eliminate the adverse effects of total and differential settlement. Methods such as overbuilding, surcharging, removal of the material causing the problem, or engineered reinforcement can be used to mitigate the effects of settlement.

2.2 Water Control and Management

2.2.1 *Impoundment Storage Capacity*

Some catchment area will always contribute runoff into the tailings retention system. This generally will be the area of the system itself, given requirements for below-grade impoundments, but might, in some cases, be a larger area incorporating the drainage area of streams entering a valley in which a retention embankment is constructed. Substantial runoff volumes and flows can result from heavy precipitation or snowmelt over relatively small catchment areas.

Because the probability of occurrence of large floods on small drainage basins in arid regions is very small and onsite personnel should be available to repair any minor damage that could occur, the staff may accept less conservative options for determining the design-basis flood. For small retention systems built in isolated areas where failure would neither jeopardize human life nor create damage to property or the environment beyond the licensee's legal liabilities and financial capabilities, the design need not use extremely conservative flood design criteria. However, the selection of the design flood needs to be at least compatible with the hazard category guidelines set forth by the U.S. Army Corps of Engineers (Ref. 37). If impoundments are designed to contain only direct precipitation that falls into the reservoir area, a single occurrence of the 6 hour probable maximum precipitation (PMP) may be used to determine storage capacity and freeboard requirements. If the tailings retention system has some external drainage area, and hydraulic structures (such as diversion channels) are needed to safely divert the probable maximum flood (PMF), the peak PMF inflows and runoff used to design such structures should be determined in accordance with the suggested flood design criteria in NUREG-1623, "Design of Erosion Protection for Long-Term Stabilization," (Ref. 2).

If decant or other reclaim systems have not been designed specifically to handle the design flood, other measures need to be taken. Those other measures may be one or a combination of the following:

- The whole volume of flood runoff is stored. Sufficient freeboard should always be available to provide the necessary storage capacity without overtopping the embankment, as well as adequate protection against wave runup.

- Diversion channels are provided to convey runoff water safely past the retention system.

Determination of the freeboard necessary at any time to store flood runoff will require information on pond storage versus elevation, anticipated embankment settlement versus time, and the expected runup of wind-generated waves. Reference 38 presents procedures for determining wave runup. It is important that the embankment construction schedule ensure that the required freeboard is always available.

Adequate slope protection is needed to guard the embankment against wind and water erosion, weathering, and ice damage. Methods for protecting slopes include dumped riprap, precast and cast-in-place concrete pavements, bituminous pavement, soil cement, tailings beaches, sodding, and planting. The necessary upstream slope protection depends on the expected wind velocity and duration and the size and configuration of the reservoir at the water-surface elevation. Reference 38 provides methods and criteria for the selection and design of slope protections. If the toe of the embankment is subject to flooding or erosion from nearby streams or arroyos, it may be necessary to provide erosion protection for the toes and exterior side slopes. NUREG-1623 (Ref. 2) provides guidance for determining design floods and erosion protection.

2.2.2 *Diversion Channel Design*

Any channels that are needed to protect against flooding and erosion of embankments or tailings should be designed to safely pass a PMF with minimal, if any, damage to the channel. The essential criterion is that no release of tailings or contaminated materials should occur during a PMF, with the recognition that onsite personnel can repair minor damage within a short period of time. For example, a channel could be designed to pass only a 100-year flood, so long as the PMF does not result in the release of contaminated material.

2.2.3 *Seepage and Hydrostatic Uplift Analyses*

Since regulations require retention systems to be lined, seepage analysis for embankment stability purposes is unnecessary. However, special design features, such as impervious liners and collection systems, are needed to maintain the quality and quantity of seepage from the retention system within tolerable limits of water supply and pollution control requirements. Section 2.2.4 of this regulatory guide details seepage control considerations.

Hydrostatic uplift may affect the subbase or engineered components of a waste containment facility anytime ground water exists at a facility. When an excavation or a portion of a waste containment facility is to be constructed at a depth at which a phreatic surface of ground water or piezometric pressures are present, the potential adverse effects on the waste containment facility need to be taken into account. An unstable condition caused by hydrostatic uplift may develop when the hydrostatic uplift force overcomes the downward force created by the weight of the overlying soil. If the area acted on by the hydrostatic force is sufficiently great, excess water pressure may cause overlying soil to rise, creating a failure known as "heave." Although heave can take place in any soil, it will most likely occur at an interface between a relatively impervious layer (such as a clay liner) and a saturated, relatively pervious base.

2.2.4 *Seepage Control*

The potential for seepage at an embankment retention system can be controlled through two means. The first is to employ a system to provide a method to dewater tailings after they are placed in the retention system. The other means is to install a liner system.

Regulations focus on using synthetic liners for the retention systems. However, a design should consider that, with an impervious bottom, process liquids and/or infiltration into the impoundment can result in excessive buildup of liquids after closure. The minimization of this potential for "bathtubbing" should be addressed through discussion of mitigative design aspects, including plans for operational dewatering (see 2.2.4.1 below) and future construction of an infiltration barrier in the closure cover.

2.2.4.1 <u>Dewatering</u>

Regulations require that new tailings impoundment retention systems be dewatered by a drainage system installed at the bottom of the impoundment. The goal of the drainage system is to lower the phreatic surface within the waste materials to reduce the head acting on the liner system. This can be accomplished by several methods. One method is to include a highly permeable layer immediately above the liner system and slope the liner system to a low point. A pump or gravity drain system can then be used to remove the collected liquids from this low point. An alternative method would be to pump liquids out of vertical wells within the tailings. In either case, the potential clogging of the drainage materials should be addressed. The U.S. Department of Agriculture (USDA) Engineering Handbook (Ref. 39)

offers examples of design methods for soil filters. References 40 and 41 outline methods for designing synthetic filters.

2.2.4.2 Liners

An embankment retention system for uranium recovery wastes is required to have a liner to prevent the migration of wastes to surrounding soil, ground water, or surface water during its operation and closure period. The design of a liner system should consider subgrade material, type of liner system, liner system protection, and leak detection. A complete liner system design also should address anticipated installation techniques and operating practices. Sections 3 and 4 of this regulatory guide present specific items related to construction and operation respectively.

Subgrade

Proper design and understanding of the subgrade soils is very important to the success of a liner system. Design of the subgrade should consider the available soils, focusing on their gradation and moisture/density relationships. The subgrade surface needs to be competent and able to withstand the anticipated construction traffic. As previously mentioned in Section 2.1.3, a settlement analysis should be performed on the subgrade soils. The purpose of this analysis is to demonstrate that the anticipated settlement of the subgrade will not damage the liner system. The amount of settlement will depend on several factors, including the soil type, subgrade drainage condition, the depth and weight of the material that will be placed on the liner, and the rate of placement of the material on the liner system.

As discussed in Section 2.2.3, the subgrade design should consider the location and potential changes in the ground-water table. If a retention system is located in an area where the water table could rise above the bottom of the liner system, an underdrain may be required to prevent the development of upward water pressure on the liner.

Liner System Selection

The choice of the liner system should consider several factors. A key factor is the liner material's physical and chemical inertness when exposed to the waste materials within the retention system. The chemical qualities of the tailings, slurry, and/or liquid wastes must be assessed to determine the impacts on liners and/or the environment, if contamination resulting from seepage or surface water runoff occurs.

One issue specific to earthen liner layers is the potential for the hydraulic conductivity to increase with time (Ref. 42). Excessive settlement or desiccation can lead to the development of cracks within an earthen layer. This increases the hydraulic conductivity which in turn decreases the effectiveness of the liner system. The subgrade design should address settlement, and desiccation should be handled through an understanding of the subgrade soil conditions and an identification of the proper moisture content range during design.

The advantages of a synthetic liner system include a significantly reduced thickness, a greater resistance to cracking, and a much lower hydraulic conductivity (typically several orders of magnitude lower than an earthen liner system). The design of a synthetic liner system should consider the method of placement, the seaming techniques, and the puncture resistance. Lupo and Morrison (Refs. 43 and 44) outline current design approaches using synthetic materials for mining applications. Theory and design methods to evaluate puncture resistance have been developed and can be used to evaluate the puncture resistance of synthetics for different conditions (Refs. 45–47).

Protection of the Liner System

Ultraviolet radiation, wave action, surface runoff, foot traffic, animals, ice, wind, and construction equipment may damage a liner system. Therefore, a liner system design should consider various protective measures to prevent damage. Protective measures may be particularly important when a synthetic liner is used. Possible protection methods include soil covers, sand bags, game-proof fences, and access restrictions.

Soil covers can protect against ultraviolet radiation, wave action, animals, wind, and construction equipment. The design should address certain aspects of soil covers, including sloughing during heavy precipitation or during rapid drawdown of the liquid within the retention system and erosion during high-precipitation events. The stability of soil covers placed over synthetic liners may need to be analyzed. A series of properly arranged sandbags can be an effective method of protecting a synthetic liner from wind damage. The sandbags need to have an appropriate weight, spacing, and anchoring system to provide the required resistance to wind forces. Use of sandbags as protection has the added benefit of preserving access to the liner for visual inspection and repair. A game-proof fence may need to be installed around the perimeter of the embankment system. The fence should be designed to prevent entry of sharp-hoofed animals such as antelope, deer, and cattle. The fence should be of sufficient height and strength to preclude entry of species known to be in the area.

Leak Detection

A leak detection system is required with a synthetic liner. The leak detection system should be designed to identify the approximate locations of leaks so repairs can be made and to isolate leaks so that they can be controlled. The leak detection system generally consists of either a highly permeable soil or synthetic material such as a geonet located immediately beneath the synthetic liner. This highly permeable layer should be designed to drain to sumps where the leakage can be monitored. Consideration should be given to developing a contoured grading plan that has a series of peaks and valleys for the liner and leak detection system to identify the approximate location of any leak. The design of a leak detection system also should establish an allowable leakage rate (ALR). The ALR should take into account anticipated defect rates in the synthetic layer, hydraulic head conditions on the liner system, and flow rates within the detection layer. If leakage is found in the detection system at a rate greater than the ALR, remedial action is necessary.

3. Construction Considerations

Construction approaches for impoundments are closely related to the specific site and operational conditions. As discussed in Section 1.1 of this guidance, the prime option identified in Criterion 3 of Appendix A, "Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for Their Source Material Content," to 10 CFR Part 40, "Domestic Licensing of Source Material," is to locate an impoundment below grade. However, certain geologic or hydrogeologic features at a site may make it impractical to locate an impoundment entirely below grade. Given the flexibility provided by Criterion 3, three possible construction scenarios exist:

(1) *Full excavation*—In this scenario, the impoundment would be constructed by excavation to a depth sufficient to accommodate the tailings volume. Depending on the topography of the site, a small perimeter embankment may be required to prevent storm-water runoff from entering the impoundment. This scenario would result in excess soil that would have to be disposed of or used elsewhere.

(2) *Partial excavation*—Under this scenario, the site conditions prevent full excavation of the impoundment. A portion of the retention system would be excavated and an embankment would be built around the excavated cell to create the required disposal capacity. In this scenario, the depth of excavation and height of the perimeter embankment will dictate whether there will be a balanced soil cut and fill, some excess soil to use elsewhere, or a need for some additional borrow material.

(3) *No excavation*—This scenario should be considered only when adverse site conditions exist, such as a high ground-water table or bedrock near the ground surface. The impoundment would be created by constructing an embankment around its perimeter. This scenario would require that a borrow source for embankment material be located in the general vicinity of the impoundment.

The construction of embankment retention systems generally involves both excavation and filling in some specified order. For any of the construction scenarios identified above, successful embankment retention system construction requires understanding the moisture/density relationships of the soils, providing adequate compaction, and preventing poor-quality soils from being incorporated into the embankment retention system fill materials. Much additional information on the characteristics of foundations is obtained during clearing and stripping operations, which may confirm or contradict design assumptions based on earlier geotechnical investigations. Weather and ground-water conditions during construction may significantly alter water contents of proposed fill material or create seepage and/or hydraulic conditions, necessitating modifications in design. Projects must be evaluated and "reengineered" continuously during construction to ensure that the final design is compatible with conditions encountered during construction. Construction supervision, management, and monitoring of the embankment and associated structures are a critical part of the overall project management plan. Once the facility is placed into operation, observations, surveillance, inspections, and continuing evaluation are required to ensure the satisfactory performance of the retention system (see Section 4 of this regulatory guide).

Installation of a synthetic liner system should focus on minimizing liner damage. Damage can occur in the form of wrinkles, improper seaming techniques, poor synthetic panel orientation, and punctures caused by construction equipment. The potential for wrinkle development can be minimized by orienting panels properly, seaming within the allowable range of temperatures, and compacting the subgrade properly. Synthetic liner manufacturers often provide specific guidance on proper techniques for minimizing wrinkles. Seams typically constitute the weakest portion of a synthetic liner system. Therefore, the layout of the synthetic panels should minimize the location of seams in high-stress areas. Punctures can be minimized by following manufacturer recommendations for allowable ground pressures and minimum protective cover requirements for construction equipment working on a synthetic liner. Quality assurance practices during synthetic liner installation need to be rigorous, and a leak location survey after synthetic liner installation may be beneficial.

The construction plans should include construction specifications for excavation, embankment construction, subgrade preparation, liner placement, and the like. The general construction considerations for earthwork listed below should be considered as minimum guidelines, with the understanding that additional or more stringent specifications may be required depending on individual site conditions:

- A geotechnical or construction inspector should be on site during embankment construction.

- Fill material should be taken from an approved, designated borrow area. It should be free of roots, stumps, wood, rubbish, stones greater than 6 inches, and frozen or other objectionable materials.

- Areas on which fill is to be placed should be scarified before its placement.

- The compaction requirements for the fill material should include the percent of maximum dry density for the specified density standard, allowable range of moisture content, and maximum loose lift thickness.

- Fill material should be compacted with appropriate compaction equipment such as a sheepsfoot, rubber-tired, or vibratory roller. The number of required passes by the compaction equipment over the fill material may vary with soil conditions.

- Fill material should contain sufficient moisture to allow the required degree of compaction to be obtained with the equipment used.

- Field density tests should be performed regularly throughout the embankment construction. Many factors influence the frequency and location of control tests. Typically, a routine control test should be performed for every 764.5 to 2293.6 cubic meters (1000 to 3000 cubic yards) of compacted material or as directed by the geotechnical engineer.

- Proper subgrade preparation during construction is necessary for the installation of a liner system. The site of the retention system should be cleared of all debris, vegetation, and potential root systems. The surface should be graded so that it is smooth and free of protruding rock particles. The soil may need to be moisture conditioned to prevent it from drying out before the liner is put into use.

- To the extent possible, synthetic liner seams should run up and down and not across a slope. They should not be located near the crest of a slope. Seams should be tested for integrity along their entire length using methods recommended by the manufacturer. Seaming should be performed only under the supervision of experienced personnel.

In general, widely accepted construction standards and specifications for embankments, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed (Refs. 48 and 49).

4. Inspection and Maintenance

Different conditions can develop throughout the active life of the retention system. Such changes can significantly affect the conditions governing the stability of a retention system. Therefore, a continuous program of inspection of the retention system is needed, beginning with the start of construction, through the waste disposal, and, in the case of tailings disposal areas, continuing after reclamation. Each site and structure has its own characteristics and its own susceptibilities to problems, and the inspection program should be tailored to consider these. Thorough physical examination is an essential part of the inspection program. The optimal frequency of inspections depends on the size and condition of the facilities, the character of the foundation, the regional geological setting, and the consequences of failure in jeopardizing human health and safety and inflicting property and environmental damage. Monitoring and analysis of performance data are necessary to ensure detection of adverse conditions.

Before the start of waste disposal, records of ground-water levels (including seasonal fluctuations), ground-water quality, ground elevations, and background radioactivities at the site should be compiled and compared with the operational conditions of the impoundment. Data gathered in accordance with Regulatory Guide 4.14 will be useful in these comparisons. As soon as waste disposal

begins, inspection should be performed at regular intervals to check the condition of the retention systems and associated facilities and to evaluate their structural safety and operational adequacy. A detailed, systematic inspection program should consist of, but not necessarily be limited to, the elements described in the sections below.

4.1 Engineering Data Compilation

Engineering data related to the design, construction, and operation of the retention systems should be compiled and, to the extent practicable, included in the initial inspection report. Most engineering data are readily available in documents filed for the license application. A detailed reference to the original documents kept at the project site should be adequate. These data should include the following items, as available and applicable:

- general project data, including regional vicinity maps showing the project location and the upstream and downstream drainage areas, and as-built drawings and photographs of the retention system
- hydrologic and hydraulic data, including drainage area and basin characteristics, waste storage volume, surcharge capacity for floods, rate of waste inflow, elevation of the maximum design pool, and freeboard height
- foundation data and geological features, including boring logs, geological maps, profiles, and cross-sections
- properties of embankment and foundation materials, including results of laboratory and field tests, and assumed design material properties
- principal design assumptions and analyses, including hydrologic and hydraulic analyses, stability and stress analyses, and seepage and settlement analyses
- pertinent construction photographs and records, including construction control tests, construction problems and modifications, and maintenance repairs

4.2 Inspection Programs

The retention system inspection program should be established and conducted systematically to minimize the possibility of overlooking any significant features. A detailed checklist should be developed and followed to document the observations of each significant feature. Photographs for comparison of previous and present conditions should be used as a part of the inspection program. The inspection program should include, but not be limited to, the following as appropriate:

- Daily Inspection
  - Pond water elevations should be examined and recorded to ensure that minimum freeboard is maintained.
  - The slurry transport system should be examined for any evidence of obstruction of the pipes or pumps caused by waste clogging or ice accumulation. The pipe couplings should be examined for leakage of waste, and any flow rate sensor should be tested.

- The retention embankments should be visually inspected for signs of erosion, cracking, slumping, movement, or concentration of seepage.

- The liner system should be inspected to identify any damage to the liner and any operating practices that may contribute to liner damage. The inspection should include a visual check of the presence of animals and the accumulation of water in the leak detection system.

- Monthly Inspection

  - Slurry transport pipes should be examined using an ultrasonic device at locations where pipes cross streams or other natural water courses or where a rupture of the pipe could be expected to affect the stability of the retention system.

  - Channels should be examined for channel bank erosion, bed aggradation or degradation and siltation, obstruction to flow, undesirable vegetation, or any unusual or inadequate operational behavior.

- Quarterly Inspection

  - The top of the embankment and downstream toe areas should be examined and surveyed, if necessary, for any evidence of unusual localized or overall settlement or depressions.

  - Embankment slopes should be examined for irregularities in alignment and variance from originally constructed slopes, unusual changes from original crest alignment and elevation, evidence of movement at or beyond the toe, erosion, and surface cracks that indicate movement.

  - The downstream embankment slopes and toes, and other downstream areas, should be examined for evidence of existing or past seepage, springs, and wet or boggy areas.

  - The slope protection should be examined for erosion-formed gullies and wave-formed notches and benches. The adequacy of slope protection against waves and surface runoff that may occur at the site should be evaluated. The condition of vegetation or any other types of protective covers should be evaluated, when pertinent.

  - Any installed instrumentation, such as survey monuments, settlement plates or gauges, and/or piezometers, should be examined and tested for proper functioning. The available records and readings of these instruments should be reviewed to detect any unusual performance or distress of the structure. Immediately following installation or the discovery of an unusual condition, all instrumentation readings should be taken more frequently than once a quarter (e.g., daily or weekly) until the patterns of the structural behaviors are stabilized.

  - The maintenance of operating facilities and features (such as pumps and valves) that pertain to the safety of the retention system should be examined to determine the adequacy and quality of the maintenance procedures followed in maintaining the retention system in a safe operating condition.

  - The general long-term performance of the liner, such as its resistance to degradation, should be examined.

- Special Inspections

  - Unscheduled inspections should be performed after the occurrence of significant earthquakes, tornadoes, floods, intense local rainfalls, or other unusual events.

  - The NRC's implementation of the National Dam Safety Program and its associated guidelines may require special inspections of any uranium recovery site embankments that fall within the scope of the program. The Federal Emergency Management Agency guidelines for dam safety (Ref. 50) specifically include tailings dams in its program and define a dam in the following manner:

    > Any artificial barrier, including appurtenant works, which impounds or diverts water, and which (1) is twenty-five feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier or from the lowest elevation of the outside limit of the barrier if it is not across a stream channel or watercourse, to the maximum water storage elevation or (2) has an impounding capacity at maximum water storage elevation of fifty acre-feet or more.

4.3 Technical Evaluation

The existing conditions of the retention system should be evaluated annually unless changing conditions dictate a shorter period. This evaluation should include an assessment of the hydraulic and hydrologic capacities, water quality, and structural stability and should take into account both existing conditions and any changing conditions. In addition, surface-water and ground-water sampling data collected in accordance with Regulatory Guide 4.14 should be examined at the time of the technical evaluation to detect any patterns that could be a sign of failure of seepage control measures or foundation distress.

4.4 Inspection Reporting

A report should be prepared to present the results of each technical evaluation and the inspection data accumulated since the last report. These documents should be kept at the project site for reference purposes, available for inspection by regulatory authorities, and retired only upon termination of the project. Any abnormal hazardous conditions observed during the inspection should be reported immediately to the NRC staff.

4.5 Inspection Personnel

An experienced professional who is thoroughly familiar with the investigation, design, construction, and operation of these types of facilities should direct the planning and conduct of the inspections and evaluations. At each facility, this individual should ensure that all field inspectors are trained to recognize and assess signs of possible distress or abnormality.

C. REGULATORY POSITION

Basic design criteria generally are drawn from 10 CFR Part 40, Appendix A, and describe the latest approaches approved by the NRC for compliance with the applicable regulations. Information related to the investigation, engineering design, proposed construction, inspection, and performance of a uranium recovery waste retention system should address all applicable areas discussed in Section B of this regulatory guide. If an applicant proposes the use of an alternative method or new information that may be developed in the future, the NRC will review the proposal and, if acceptable, approve its use.

1. Basic Design Criteria

a. The "prime option" for disposal of tailings is placement below grade. Where full below-grade burial is not practicable, the size of retention structures and the size and steepness of slopes associated with exposed embankments must be minimized by excavation to the maximum extent reasonably achievable or appropriate, given the geologic and hydrologic conditions at a site (10 CFR Part 40, Appendix A, Criterion 3).

b. Stability of the retention system should be ensured under all conditions of construction and operation. In ensuring structural integrity, it must not be presumed that the liner system will function without leakage during the active life of the impoundment (10 CFR Part 40, Appendix A, Criterion 5A(5)).

c. The magnitude of total and differential settlement should be within tolerable limits that will not result in harmful cracking and embankment instability.

d. Unless exempted under the regulations in Criterion 5A(3) of Appendix A to 10 CFR Part 40, liners and leak detection systems need to be included in the design of retention systems per 10 CFR Part 40, Appendix A, Criteria 5A(1), 5A(2), and 5E(1), and considering EPA requirements in 40 CFR 264.221.

e. Freeboard must be sufficient at all times to prevent overtopping by flood inflows and wind-generated waves and should include an allowance for settlement of the foundation and embankments (10 CFR Part 40, Appendix A, Criterion 5A(4)). Adequate slope protection should be provided for the embankment against wind and water erosion, weathering, and ice damage.

f. Upstream rainfall catchment areas must be minimized to decrease erosion potential and the size of the floods that could erode or wash out sections of the tailings retention system (10 CFR Part 40, Appendix A, Criterion 4(a)). The surcharge capacity of the retention system must be adequate to store a PMF, calculated using the 6-hour PMP.

2. Methods of Analysis

a. The PMF should be based on the 6-hour PMP and should be developed in accordance with procedures provided in NUREG-1623 (Ref. 2).

b. Wave runup may be determined using procedures discussed in the U.S. Army Corps of Engineers "Coastal Engineering Manual," issued April 2002 (Ref. 38).

c. The static stability of the embankment should be analyzed using commonly accepted detailed stability methods. The analysis should use appropriate static soil and rock properties established

on tested representative samples over anticipated in situ and placement conditions. Results of a manual check of the computer stability analysis outcome should be presented to illustrate adopted design procedures and criteria.

d. Conventional pseudostatic analysis may be considered acceptable if the seismic coefficient appropriately reflects the geologic and seismologic conditions of the site and if the materials are not subject to significant loss of strength under dynamic loads. Liquefaction potential and the dynamic stability of the tailing dam and foundation should be assessed using appropriate state-of-the-art methods. Reference 30 will be used to determine the extent of the required dynamic analyses. The analyses should employ appropriate dynamic material properties established on representative materials through adequate field and laboratory testing.

e. The loading conditions to be evaluated in embankment stability analyses and corresponding minimum factors of safety are as follows:

Loading Condition	Minimum Factor of Safety
End of construction	1.3
Partial pool with steady seepage	1.5
Maximum pool with steady seepage	1.5
Earthquake (in combination with the above conditions)	1.0

f. Evaluation of liquefaction potential should include laboratory testing, in situ testing, and comparisons to similar soil deposits. Screening criteria should be used to determine whether there are potentially liquefiable soils at a site. The factor of safety for liquefaction potential should be greater than 1.0.

g. Appropriate laboratory test results should be used to estimate the rate and magnitude of settlement.

3. Construction Methods

a. Mill tailings embankment retention systems should use conventional acceptable engineering practices of construction control for water retention dams (e.g., controls on foundation preparation, suitability of materials, proper placement, field moisture, and density).

b. Installation of a synthetic liner system should focus on minimizing liner damage. Damage can occur in the form of wrinkles, improper seaming techniques, poor synthetic panel orientation, and punctures caused by construction equipment.

4. Inspection and Maintenance

a. A detailed, systematic inspection and maintenance program should be established to detect and repair damage that might lessen the integrity of the retention system. Generally, visual inspections performed on a regular basis and supplemented by adequate instrumentation are acceptable. A detailed checklist should be developed and followed to document the observations of each significant feature. The inspection program should use photographs to compare previous and present conditions. In addition, the program should include radiometric and water quality surveys.

b. Daily inspections of tailings or waste retention systems should be planned, conducted, evaluated, and documented under the direction of an experienced professional who is thoroughly familiar with the investigation, design, construction, and operation of these types of facilities. The licensee should retain documentation (i.e., a record) of each daily inspection for 3 years after the documentation is made. The NRC must be immediately notified of any failure in a tailings or waste retention system that results in a release of tailings or waste into unrestricted areas or of any unusual conditions (conditions not contemplated in the design of the retention system) that, if not corrected, could indicate the potential for, or lead to, failure of the system and result in a release of tailings or waste into unrestricted areas.

c. Unscheduled inspections should be performed after the occurrence of significant earthquakes, tornadoes, floods, intense local rainfalls, or other unusual events. The NRC's implementation of the National Dam Safety Program and its associated guidelines may require special inspections of any uranium recovery site embankments that fall within the scope of the program.

d. The inspection and maintenance program should start at the beginning of construction and continue at least through the operation of the facility.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC's plans for using this regulatory guide. The NRC does not intend or approve any imposition or backfit in connection with its issuance.

In some cases, applicants or licensees may propose or use a previously established acceptable alternative method for complying with specified portions of the NRC's regulations. Otherwise, the methods described in this guide will be used in evaluating compliance with the applicable regulations for license applications, license amendment applications, and amendment requests.

REFERENCES

1. NUREG-1620, "Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act of 1978," U.S. Nuclear Regulatory Commission, Washington, DC, June 2003.

2. NUREG-1623, "Design of Erosion Protection for Long-Term Stabilization," U.S. Nuclear Regulatory Commission, Washington, DC, September 2002.

3. Regulatory Guide 3.64, "Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers," U.S. Nuclear Regulatory Commission, Washington, DC, June 1989.

4. R. Dobrey and L. Alvarez, "Seismic Failures of Chilean Tailings Dams," *Journal of the Soil Mechanics and Foundations Division*, American Society of Civil Engineers, November 1967.

5. W.A. Wahler and D.P. Schlick, "Mine Refuse Impoundments in the U.S.," *Proceedings of the International Congress on Large Dams*, Mexico City, Mexico, 1976.

6. Public Law No. 92-367, National Dam Safety Act, August 8, 1972.

7. S.R. Borrowman and P.T. Brooks, "Radium Removal from Uranium Ores and Mill Tailings," U.S. Bureau of Mines, U.S. Department of the Interior, Washington, DC, 1975.

8. "Use of Uranium Mill Tailings for Construction Purposes," Hearings before the Subcommittee on Raw Materials of the Joint Committee on Atomic Energy of the U.S. Congress, Washington, DC, October 28 and 29, 1971.

9. E.S. Smith, "Tailing Disposal—Failures and Lessons," *Proceedings of the First International Tailing Symposium*, Tucson, Arizona, November 1972.

10. E. Gruner, "Classification of Risk," *Proceedings of the International Congress on Large Dams*, Vol. 1, Madrid, Spain, 1973.

11. A.O. Babb and T.W. Mermel, "Catalog of Dam Disasters, Failures and Accidents," Bureau of Reclamation, U.S. Department of the Interior, Washington, DC, 1968.

12. A. Casagrande, "Notes on the Design of Earth Dams," *Journal of the Boston Society of Civil Engineers*, October 1950.

13. J.L. Sherard, R.J. Woodward, and S.F. Gizienski, *Earth and Earth-Rock Dams*, John Wiley & Sons, Inc., New York, 1963.

14. T.W. Lambe and R.V. Whitman, *Soil Mechanics*, John Wiley & Sons, Inc., New York, 1969.

15. EM 1110-2-1902, "Engineering and Design Slope Stability," U.S. Army Corps of Engineers, Washington, DC, October 2003.

16. L.W. Abramson, T.S. Lee, S. Sharma, and G.M. Boyce, *Slope Stability and Stabilization Methods*, First Edition, Wiley Interscience, New York, 1996.

17. J.M. Duncan and S.G. Wright, *Soil Strength and Slope Stability*, John Wiley & Sons, Inc., New York, 2005.

18. J.N. Cernica, *Geotechnical Engineering Soil Mechanics*, John Wiley & Sons, Inc., New York, 1995.

19. R.M. Koerner and T.-Y. Soong, "Analysis and Design of Veneer Cover Soils," *Proceedings of 6th IGS Conference*, Industrial Fabrics Association International, St. Paul, Minnesota, 1998.

20. R.M. Koerner, *Designing with Geosynthetics*, Fourth Edition, Prentice Hall, Upper Saddle River, New Jersey, 1998.

21. J.M. Duncan, "Factors of Safety and Reliability in Geotechnical Engineering," *Journal of Geotechnical and Geoenvironmental Engineering*, American Society of Civil Engineers, 126(4):307–316, 2000.

22. D.V. Griffiths and G.A. Fenton, "Probabilistic Slope Stability Analysis by Finite Elements," *Journal of Geotechnical and Geoenvironmental Engineering*, American Society of Civil Engineers, 130(1), Issue 5:507–518, May 2004.

23. R.E. Goodman and H.B. Seed, "Earthquake Induced Displacement in Sand Embankments," *Journal of the Soil Mechanics and Foundations Division*, American Society of Civil Engineers, March 1965.

24. H.B. Seed, K. Mori, I.M. Idriss, and F. Makdisi, "The Slides in the San Fernando Dam During the Earthquake of February 9, 1971," *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, July 1975.

25. H.B. Seed, "Slope Stability During Earthquakes," *Journal of the Soil Mechanics and Foundations Division*, American Society of Civil Engineers, July 1967.

26. N.M. Newmark, "Effects of Earthquakes on Dams and Embankments," *Geotechnique*, June 1965.

27. F.I. Makdisi and H.B. Seed, "Simplified Procedure for Estimating Dam and Embankment Earthquake Induced Deformations," *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, 104(GT-7):849–867, 1978.

28. F.I. Makdisi and H.B. Seed, "Simplified Procedure for Evaluating Embankment Response," *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, 105(GT-12):1427–1434, 1979.

29. H.B. Seed, H.B. Lee, I.M. Idriss, and F. Makdisi, "Dynamic Analysis of the Slide in the Lower San Fernando Dam During the Earthquake of February 9, 1971," *Journal of the Geotechnical Engineering Division*, American Society of Civil Engineers, September 1975.

30. Engineer Regulation 1110-2-1806, "Earthquake Design and Evaluation for Civil Works Projects," U.S. Army Corps of Engineers, Washington, DC, 1995.

31. EPA/600/R-95/051, "RCRA Subtitle D (258): Seismic Design Guidance for Municipal Solid Waste Landfill Facilities," U.S. Environmental Protection Agency, Washington, DC, April 1995.

32. H.B. Seed and I.M. Idriss, "Ground Motions and Soil Liquefaction During Earthquakes," Monograph No. 5, page 134, Earthquake Engineering Research Institute, Berkeley, California, 1982.

33. H.B. Seed, K. Tokimatsu, L.F. Harder, and R.M. Chung, "Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations," *Journal of Geotechnical Engineering*, American Society of Civil Engineers, 111(12):1425–1445, 1985.

34. W.F. Marcuson, III, M.E. Hynes, and A.G. Franklin, "Evaluation and Use of Residual Strength in Seismic Safety Analysis of Embankments," *Earthquake Spectra*, 6(3):529–572, 1990.

35. T. Shibata and W. Taparaska, "Evaluation of Liquefaction Potentials of Soils Using Cone Penetration Tests," *Soils and Foundations*, 28(2):49–60, 1988.

36. H.B. Seed and I.M. Idriss, "Simplified Procedure for Evaluating Soil Liquefaction Potential," *Journal of the Soil Mechanics and Foundation Division*, American Society of Civil Engineers, 97(SM9):1249–1273, 1971.

37. "Recommended Guidelines for Safety Inspection of Dams," Table 3, U.S. Army Corps of Engineers, ER1110-2-106, Washington, DC, September 1979.

38. EM 1110-2-1100, "Coastal Engineering Manual," U.S. Army Corps of Engineers, Washington, DC, April 2002.

39. "Gradation Design of Sand and Gravel Filters," Part 633, *National Engineering Handbook*, Chapter 26, 210-vi-NEH, U.S. Department of Agriculture, Washington, DC, October 1994.

40. J.P. Giroud, "Granular Filters and Geotextile Filters," *Proceedings of Geofilters '96*, edited by J. LaFleur and A. Rollin, Ecole Polytechnique, Montreal, Canada, 1996.

41. S.M. Luettich, J.P. Giroud, and R.C. Bachus, "Geotextile Filter Design Guide," *Journal of Geotextiles and Geomembranes*, 11(4–6), 1992.

42. "Assessment of the Performance of Engineered Waste Containment Barriers," Committee to Assess the Performance of Engineered Barriers, National Research Council, May 2007.

43. J.F. Lupo and K.F. Morrison, "Geosynthetic Design and Construction Approaches in the Mining Industry," *Journal of Geotextiles and Geomembranes*, Special Issue on Geosynthetics in Harsh Environments, 25(2), April 2007.

44. J.F. Lupo and K.F. Morrison, "Innovative Geosynthetic Liner Design Approaches and Construction in the Mining Industry," *Proceedings of ASCE Geo-Frontiers Conference*, Austin, Texas, January 2005.

45. R.F. Wilson-Fahmy, D.B. Narejo, and R.M. Koerner, "Puncture Protection of Geomembranes, Part I—Theory," *Geosynthetics International*, 3(5), 1996.

46. D.B. Narejo, R.M. Koerner, and R.F. Wilson-Fahmy, "Puncture Protection of Geomembranes, Part II—Experimental," *Geosynthetics International*, 3(5), 1996.

47. R.M. Koerner, R.F. Wilson-Fahmy, and D.B. Narejo, "Puncture Protection of Geomembranes, Part III—Examples," *Geosynthetics International*, 3(5), 1996.

48. Construction Specification 23, "Earthfill," U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC, May 2001.

49. Unified Facilities Guide Specification UFGS-31, "Division 31—Earthwork," U.S. Army Corps of Engineers, Washington, DC, July 2006.

50. "Federal Guidelines for Dam Safety, FEMA 93," U.S. Department of Homeland Security, Federal Emergency Management Agency, Washington, DC, April 2004.