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DESIGN, CONSTRUCTION, AND INSPECTION OF EMBANKMENT RETENTION SYSTEMS FOR URANIUM MILLS

A. INTRODUCTION

Each licensee who processes or refines uranium ores in a milling operation is required by §20.1 of 10 CFR Part 20, "Standards for Protection Against Radiation," to make every reasonable effort to maintain radiation exposures and releases of radioactive materials in effluents to unrestricted areas as low as is reasonably achievable, taking into account the state of technology and the economics of improvements in relation to benefits to the public health and safety. In addition, 40 CFR Part 190, "Environmental Radiation Standards for Nuclear Power Operations," requires that the maximum annual radiation dose to individual members of the public resulting from fuel cycle operations be limited to 25 millirems to the whole body and to all organs except the thyroid, which must be limited to 75 millirems. Liquid and solid wastes (tailings) generated in the uranium milling operation contain radioactive materials in excess of the discharge limits and are generally confined by an embankment retention system.

This guide describes some engineering practices and methods generally considered satisfactory for the design, construction, and inspection of earth and rockfill embankments used for retaining uranium mill tailings. They result from review and action on a number of specific cases and reflect the latest general approaches to the problem that are acceptable to the NRC staff. If new information that may be developed in the future results in alternative methods, such methods will be reviewed by the staff to determine their acceptability. Guidance on operation and abandonment of the retention system is presented in separate guides. *

B. DISCUSSION

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 non-uranium mining industry. The design and construction of tailing retention structures have in the past been based largely on mining experience, with little use of design concepts. These empirical approaches resulted in various mining dam mishaps and failures (Refs. 1 and 2). The failure of Buffalo Creek Dam in West Virginia even resulted in the U.S. Congress quickly passing a national dam safety law affecting all water-impounding structures in excess of either 25 feet in height or 50 acre-feet in impoundment capacity (Ref. 3).

Uranium mill tailings, unlike most non-uranium mine tailings, contain concentrations of radioactive materials in excess of the allowable discharge limits (Ref. 4). Furthermore, the most significant radioactive element in the tailings is radium-226, which has a half-life of about 1600 years (Ref. 5). Therefore, it is necessary to confine those tailings to prevent or control their release to the environment not only during the operating life of the mill, but also for genera-

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* Lines indicate substantive changes from previous issue.

tions after milling operation has ceased. The embankment, foundation, and abutments need to be stable under all conditions to prevent the uncontrolled release of the retained water or semifluid tailings. Seepage from the tailing pond, which contains dissolved radium and other toxic substances (Ref. 5), needs to be controlled under normal and severe operating conditions to prevent the possibility of unacceptable contamination of the groundwater or nearby streams. Wind and water erosion of the tailings needs to be prevented during and after the milling operation.

Obviously, 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 problems involved and the requirements of the milling operation.

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

1. GENERAL PLANNING AND DESIGN CONSIDERATIONS

Because the prime functions of the retention system are to store radioactive solids and to provide temporary storage of contaminated water for clarification and evaporation, it is important that the system 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 groundwaters. It must also provide effective means to prevent wind and water erosion.

Stage construction with the freeboard maintained sufficiently above the storage level may be considered. The use of coarse tailings as embankment fill materials is not desirable because the tailings contain radioactive materials that may cause unacceptable environmental impacts.

Detailed site conditions, including climate, hydrology, geology, and seismology, need to be assessed and their impact evaluated. Detailed knowledge is needed of such physical and mechanical properties of foundation and embankment materials as classification, shear strength, consolidation, permeability, sedimentation, compaction, piping and cracking susceptibility, and wind-water erosion characteristics. The chemical qualities of the tailings and slurry must be assessed to determine if a water-collecting system is needed to prevent unacceptable downstream contamination resulting from seepage or surface water runoff.

Subsurface investigations at the site of the retention system and at possible borrow areas need to be adequate to determine the suitability of the foundation and abutments, the requirements of foundation treatment, and the availability and characteristics of embankment materials. The investigations should cover classification, physical and chemical properties, location and extent of soil and rock strata, and variations in groundwater conditions.

The foundation conditions must be determined to assess the adequacy of subsurface materials to support the dam without failure and without excessive total or differential settlement. The permeability of foundation soils and rocks must be ascertained to estimate the amount of seepage, piping potential, and, if necessary, the methods of seepage control. The availability of suitable borrow material for dam construction must be assessed, taking into consideration the construction sequence and schedule.

2. DESIGN ANALYSIS

It is important that design analysis consider stability, settlement, seepage, and hydrologic analyses. Specifically, the design needs to ensure that retention dam failure would not occur. Historical records (Refs. 6–9) indicate that most failures associated with earth or tailing dams are caused by overtopping by flood waters, erosion, piping in either the dam or the foundation, collapse of the dewatering conduit, foundation failure, slope failure, or liquefaction.

2.1 Hydrologic Analyses

There will always be some catchment area contributing runoff into the tailing retention system. This may vary from the area of the system itself to a substantial area incorporating the drainage area of streams entering the valley across which a retention dam is constructed. Substantial runoff volumes and flows can result from heavy precipitation or snowmelt over relatively small catchment areas.

The maximum runoff used in the design is usually called the Spillway Design Flood (SDF), representing the largest flood that need be analyzed, regardless of whether or not a spillway is provided. The magnitude of the SDF (flood volume, peak flow, etc.) as adopted in the United States for the past 30 years is equal to that of the Probable Maximum Flood[1] at the

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[1] The Probable Maximum Flood (PMF) is defined as the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region.

site of the dam. Methodology to estimate the Probable Maximum Flood is available in Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants," and other publications (Refs. 10 and 11).

For small retention dams built on isolated streams in areas where failure would neither jeopardize human life nor create damage to property or the environment beyond the sponsor's legal liabilities and financial capabilities, less conservative flood design criteria may be used in the design. However, the selection of the design flood needs to be at least compatible with the guidelines set forth by the Corps of Engineers (Ref. 12).

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

a. Storing the whole volume of flood runoff. Sufficient freeboard should always be available to provide the necessary storage capacity without overtopping the dam.

b. Providing a spillway or diversion channels to convey runoff water safely past the dam.

Because of the toxic nature of the impounded material, a is preferred.

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 effective height of wind-generated waves. Procedures for determining the minimum freeboard are presented in Reference 10. It is important that the embankment construction schedule ensure that this 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, 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. The necessary downstream protection depends on the expected erosion of surface runoff and wind erosion. References 10 and 13 provide methods and criteria for the selection and design of slope protections.

2.2 Stability Analysis

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

2.2.1 Methods of Stability Analysis

2.2.1.1 Static Stability Analysis

There are many methods using the limiting equilibrium approach. Detailed discussion can be found in various publications (Refs. 14–16). These methods may be conveniently grouped into three categories:

a. *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. This method can only be used to evaluate failure surfaces that are circles or single straight lines. The logarithmic spiral method is a different version of this method.

b. *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 Swedish Circle Method, Modified Swedish Method, Simplified Bishop Method, and Morgenstern-Price Method.

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

The method of slices offers the best approach for obtaining a reasonably accurate solution for any shape of failure surface (Refs. 17 and 18). While the friction circle method can provide solutions in homogeneous soil, it is difficult to apply these approaches with confidence when the soil is stratified or zoned. The wedge method can provide reasonable solutions for situations where the failure surfaces are composed of straight lines.

Computer solutions to the method of slices have been developed (Ref. 18). By using computers, many more assumed conditions and failure surfaces can be tried. The effects of possible variations in material properties can also be evaluated. The computed results need to be checked with respect to their reasonableness and compatibility with the design procedures and criteria.

2.2.1.2 Seismic Stability Analysis

In areas where embankments are subjected to seismic disturbances, analyses should be made of the seismic effects on the dams. Seismic vibrations can cause liquefaction of saturated or nearly saturated loose sands and sensitive silts (Ref. 1). The dynamic shearing stresses induced during the seismic events can cause excessive deformation or distortion of the embankment—even shear failure (Refs. 19 and 20).

Seismic stability analyses of embankment dams are conventionally made using pseudostatic methods (Ref. 21). In this approach, the stability of a potential sliding mass is determined as for static loading conditions, and the effects of an earthquake are taken into account in the computation 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 dam 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 a sufficient number of times to cause permanent displacements. Procedures for estimating the magnitude of these displacements have been proposed by Newmark (Ref. 22) and by Goodman and Seed (Ref. 19). Both of these procedures presume a knowledge of the time-history of the inertia forces acting on an embankment during the earthquake. These approaches are more involved than the conventional methods and have been used successfully to predict the surface displacements of embankments of dry cohesionless soils. However, for soils in which pore pressure changes as a result of the shear strains induced by the earthquake, determination of appropriate values of the yield acceleration becomes difficult.

In dealing with saturated cohesionless soils, the dynamic analysis procedures developed by Seed (Ref. 23) 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, in the detailed steps followed to conduct the analyses, and in the evaluation of the results obtained.

A detailed discussion and applicable guidelines for seismic analysis and design of tailing dams can be found in Reference 24.

2.2.1.3 Liquefaction Potential Evaluation

It is important that the possibility of liquefaction of foundation soils be evaluated by means of "state-of-the-art" procedures involving seismological and geological investigations. The objective of such evaluations is to establish earthquake design parameters for use in the analyses and the dynamic testing of materials. Procedures currently used for evaluating liquefaction potential are based on either comparing the past experience with similar soil deposits supplemented by laboratory tests or using detailed ground response analyses combined with dynamic laboratory testing. Past experience provides the most useful guidance on the probable performance of similar soil deposits, while the ground response methods provides a means for considering the effects of the amplitude and time history of the earthquake ground motions, the in-situ soil characteristics, the overburden pressure, and the groundwater conditions.

2.2.2 Loading Conditions and Factor of Safety

A tailing dam and its foundation are subjected to shear stresses imposed by the weight of the dam and by the filling of the pool, seepage, or earthquake forces. The cases for which stability analyses are necessary are

a. *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 composed partially or entirely of impervious soils. The unconsolidated undrained (UU) shear strength should be used in the analyses for slow-draining soils, while consolidated drained (CD) shear strength should be used for free-draining soils where excess pore pressures would not develop.

b. *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 reduction in effective normal stresses where pore water pressure that developed during construction or filling are no dissipated before the subsequent partial pool condition. The lower strength from either the consolidated undrained (CU) shear test or consolidated drained (CD) shear test is used in the analyses. The minimum factor of safety should be determined as a function of pool elevations.

c. *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.

d. *Earthquake*. In areas subjected 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 design and those existing in the field and 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.

The consequence of a failure, the tolerable limit of strains, and the degree of confidence in enginee ing parameters used in the analyses all need to be considered in choosing the factor of safety. 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 be representative of actual conditions of the dam and its foundation. Otherwise, higher factors of safety would be required.

2.2.3 Settlement Analyses

If the foundations beneath an embankment consist 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 site conditions. These differential settlements may cause longitudinal or transverse cracks in the dam that could lead to subsurface erosion and dam failure by piping.

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 can also be estimated. However, the potential error in estimating the time for settlement to occur is appreciable, since settlement is influenced by soil drainage that is controlled by minute geological details that may not be detected during the foundation investigation. All predictions on the rate and magnitude of settlement and the change in pore water pressures need to be checked by field instrumentation. Predictions based on laboratory data can be modified by actual measurements to provide reasonably accurate long-term estimates.

If compressible soils are thick, it may be necessary to design the dam to absorb the anticipated differential settlements. If considerable total settlement is expected, the dam must be built higher to allow for the settlement.

2.2.4 Seepage Analyses

Seepage analyses evaluate the effects of seepage on the stability of the tailing dams and the rate of seepage through and beneath the dam and basin area. It is important that seepage pressures be controlled so that quick conditions and piping do not develop. Special design features such as impervious cores, cutoffs, impervious liners, a secondary collection system, etc., are needed to maintain the quality and quantity of seepage from the retention system within tolerable limits of water supply and pollution control requirements.

Seepage analyses—usually based on the steady flow of an incompressible fluid through a porous medium—may use the graphical method of plotting flow nets, electric analogs, model studies, or mathematical solutions by digital computer using either finite-element or finite-difference methods. The graphical method of plotting flow nets is economically and easily performed, and it gives sufficiently accurate results for many seepage problems.

3. CONSTRUCTION METHODS

Construction methods for mill tailing dams are closely related to the planning and operation of the mill. Where a tailing embankment is constructed in a single stage of natural borrow materials or overburden and waste rock, conventional procedures for earth and rock-fill dams can be used.

Where a tailing dam is constructed in stages, one of the following three methods is used: (a) upstream method, (b) downstream method, or (c) centerline method.

The upstream construction method is the oldest used by the mining industry and is a naturally developed procedure for disposing of the tailing as economically as possible. An initial starter dike is constructed at the downstream toe of the ultimate dam with borrow materials. The crest of the dam is raised by placing fill materials in successive dikes located on the upstream side of the initial starter dike. The centerline of the embankment crest is shifted toward the upstream pond area as the height of the dam increases. The downstream toe of each subsequent dike is supported on the top of the previous dike, with the upstream portion of the dike placed over finer tailings (slimes) within the impoundment. These slimes, placed hydraulically, have a relatively low shear strength and remain in a loose and saturated state for many years after deposition (Ref. 25). As the height of the dam increases, the potential failure is located at an increasingly greater distance from the downstream face and through the slimes. As a result, the outside shell contributes less to stability as the height increases. The retained slimes are sufficiently loose and saturated that they could be liquefied to cause the failure of the dam if subjected to seismic shock or blasting.

With the downstream construction method, an initial starter dike is constructed at the upstream toe of the ultimate dam. The crest of the dam is raised by placing fill materials in successive dikes located on the downstream side of the starter dike. The centerline of the dam crest is shifted downstream as the dam is raised. Each subsequent stage of dike construction is supported on the top of the downstream slope of the previous section. All of the embankment section lies ouside the boundaries of the sediment tailings. Materials incorporated in subsequent stages of the embankments may consist of the coarse mine waste or borrow materials from nearby pits. Downstream construction permits controlled placement and compaction to achieve higher shear strength. It also permits the incorporation of drainage facilities to control the piezometric pressures within the embankment. Thus the dam can be designed and subsequently constructed to whatever degree of competency may be required, including resistance to seismic and blasting shocks.

The centerline method is intermediate between the previous two construction methods. The crest of the embankment is maintained in approximately the same horizontal position as the embankment is raised to its final height. The dam is raised by spreading and compacting successive layers of materials on the crest, on the upstream shoulder, and on the downstream slope. The centerline method permits the downstream half of the tailing dam to be designed and constructed to conventionally acceptable engineering standards; however, certain portions of upstream slopes rest over the slimes and are therefore vulnerable to slope failure and seismic liquefaction.

These three construction methods lead to substantially different embankment cross sections and produce different embankment material characteristics. Consequently, the embankment stability conditions are affected. In the upstream and centerline methods of construction, the stability of the ultimate dam is dependent, to a large degree, on the shear strength characteristics of tailings deposited upstream of the dam. The shear strength is governed by the gradation and density of the solids, the consistency of the slurry, and the distribution of the pore water pressures within the deposit. When initially deposited, the tailings have very low shear strength. The strength theoretically increases with time as drainage and consolidation take place under the weight of overlying materials. However, because of the very fine gradation of the tailings and the random nature of deposition, large variations in permeability and pore water pressure exist within the tailings, and the strength may not increase adequately to ensure the stability of the final slope (Ref. 26).

Downstream construction is the only method wherein all embankment sections lie outside the tailing boundaries, thereby permitting controlled placement and compaction of fill and incorporation of drainage facilities. Thus, for a given height and a given downstream fill slope, a tailing dam constructed using the downstream method will have a higher factor of safety than a tailing dam constructed by either the upstream method or the centerline method.

Because the most important purpose of the tailing dam structure is to contain the radioactive waste materials and the performance of hydraulically constructed dams and tailing dams has been unsatisfactory (Refs. 6, 8, and 27), the downstream method appears to be the best of the stage construction methods to ensure the safety function of the tailing dams, especially in seismically active areas.

4. INSPECTION AND MAINTENANCE

Different conditions can develop throughout the whole active life of the retention system and could include unanticipated seepage conditions and changes in material characteristics. Such changes can drastically change the conditions governing the stability of a dam from those provided for in the original design. Therefore, a continuous program of inspection of the retention system is needed, beginning with the start of construction, through the tailing disposal, and continuing after abandonment of the completed system.

The main objectives of such a program are to ascertain:

a. Whether the dam and its foundation are behaving as anticipated in the design, whether there are any unusual movements, settlements, cracks, erosions, sloughs, or leakages, and whether the waste and borrow materials being placed in the dam have the characteristics assumed in the design;

b. Whether the tailing pond levels are rising as anticipated and whether the rate of dam construction is sufficiently rapid to keep the crest above rising pond; and

c. Whether embankment drainage is adequate, whether the capacity of diversion channels is adequate to pass experienced and anticipated runoffs, whether embankment soil is becoming saturated by seepage, whether piping or subsurface erosion is occurring in the tailing dam, and whether there is any unusual release of radioactive materials.

It is necessary that inspection be performed on a regular basis and that it include visual inspection of the abutments. A checklist similar to that used in water retention dams may be used to help the inspector in performing such a visual inspection.

Instrumentation needs to be installed to monitor dam and basin performances at regularly scheduled intervals. Instruments commonly used include piezometers to measure hydrostatic and pore pressure levels; weirs or flumes to measure seepage flows; wells to permit monitoring of water quality; and slope indicators, inclinometers, and settlement points to measure horizontal and vertical movements. The instrumentation should be simple, robust, rugged, reliable, and easy to read, repair, and maintain. It is important that recorded data from instrumentation and inspections be evaluated by competent personnel with delegated authority to take prompt action if remedial treatment is needed to maintain the safe operation of the retention system.

C. REGULATORY POSITION

The following criteria reflect the latest general approaches approved by NRC.[2] Information related to the investigation, engineering design, proposed construction, instrumentation, and performance of the retention system should be presented in accordance with the applicable portion of Section 2.5.6 of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants." If an applicant wishes to use new information that may be developed in the future or to use an alternative method, NRC will review the proposal and will approve its use, if it is found acceptable.

1. BASIC DESIGN CRITERIA

a. Stability of the retention system, including the tailing dam, foundation, and abutments, should be ensured under all conditions of construction and operation.

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

c. Seepage through the embankment, foundation, abutments, and basin area should be controlled to prevent excessive uplift pressures, piping, sloughing, and erosion of materials by loss into cracks, joints, and cavities. The quality and quantity of seepage should be limited to the extent that the concentration of radioactive materials and other toxic materials at the site boundary is within the limits specified in applicable Federal and State regulations.

d. Freeboard should be sufficient at all times to prevent overtopping by wind-generated waves and should include an allowance for settlement of the foundation and dam. Adequate slope protection should be provided for the embankment against wind and water erosion, weathering, and ice damage.

e. Either the surcharge capacity of the retention system should be sufficient to store runoffs over its service life or there should be an emergency discharge capacity capable of passing the probable maximum flood. The emergency discharge capacity may be obtained by constructing a spillway or by other means. The surcharge capacity should be adequate to store a probable maximum flood series[3] preceded or followed by a 100-year flood, assuming a pool elevation equivalent to the average annual runoff.

2. METHODS OF ANALYSIS

a. The probable maximum flood should be determined in accordance with applicable portions of Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants."

b. The static stability of the embankment should be analyzed using commonly accepted detailed stability methods. Appropriate static soil and rock properties established on tested representative samples over anticipated in-situ and placement conditions should be used in the analyses. Results of a manual check on computer stability analysis results should be presented to illustrate adopted design procedures and criteria.

c. 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. The extent of the required dynamic analyses will be determined in accordance with Reference 24. Appropriate dynamic material properties established on representative materials through adequate field and laboratory testing should be used in the analyses.

d. The loading conditions to be evaluated in dam stability analyses and corresponding minimum factors of safety are:

Loading Condition	Minimum Factor of Safety	Shear Strength
End of construction	1.3	UU and CD
Partial pool with steady seepage	1.5	CU or CD
Maximum pool with steady seepage	1.5	CU or CD
Earthquake (in combination with the above conditions)	1.0[4]	[5]

e. The rate and magnitude of settlement should be estimated on the basis of appropriate laboratory test results.

f. Seepage analyses may be based on a graphical method, model studies, or mathematical solutions using appropriate soil and rock parameters.

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[2] The Nuclear Regulatory Commission announced in the *Federal Register* of June 3, 1976, (41 FR 22431) its intent to prepare a generic environmental impact statement (GEIS) on uranium milling operations. Management practices for uranium mill tailings may be subject to revision in accordance with the conclusions of that statement and any related rule making.

[3] Probable maximum flood series as used herein comprises two floods: the Probable Maximum Flood and the flood equivalent to about 40% of the PMF and about 3 to 5 days prior to the occurrence of the main flood.

[4] Factor of safety is for pseudostatic stability analysis. In addition, liquefaction and excessive deformation should be assessed.

[5] Use shear strength for case analyzed without earthquake.

3. CONSTRUCTION METHODS

a. 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) should be used for mill tailing dams. Where a tailing dam is raised in stages, the downstream construction method is preferred. Provision should be made to limit the concentration of radioactive and other toxic materials released from seepage and wind-water erosion to within the limits specified in 10 CFR Part 20, 40 CFR Part 190, and applicable State regulations.

b. The upstream and centerline construction methods will be acceptable only if extensive explorations and testing reveal the extent and characteristics of deposited tailings to have adequate strength under static and dynamic loading conditions for the stability and support of the added materials.

4. INSPECTION AND MAINTENANCE

a. A detailed systematic inspection and maintenance program should be established to detect and repair damage that might tend to lessen the integrity of the retention system. Generally, visual inspections performed on a regular basis and supplemented by adequate instrumentation are acceptable. The safety inspection guidelines (Ref. 12) for earth dams set forth by the Corps of Engineers in response to the National Dam Safety Act should be used to develop a detailed checklist for performing field inspections. In addition, radiometric and water quality surveys should be included in the program.

b. Instrumentation should be installed in the dam or its foundation to monitor changes that might be critical to dam stability or seepage conditions. Generally, instruments should be installed to measure piezometric levels, seepage flows, water quality, and embankment movements. The extent to which such instrumentation should be installed will be evaluated on a case-by-case basis.

c. Results of inspection and instrumentation programs should be evaluated by competent and experienced engineers who have delegated authority to take prompt effective actions when necessary. Inspection and evaluation reports should be kept at the site and be available for staff review.

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

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