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REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 3.11.1

OPERATIONAL INSPECTION AND SURVEILLANCE OF EMBANKMENT RETENTION SYSTEMS FOR URANIUM MILL TAILINGS

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.

Regulatory Guide 3.11, "Design, Construction, and Inspection of Embankment Retention Systems for Uranium Mills," describes a general basis for inspection of an embankment retention system. This guide, a supplement to Regulatory Guide 3.11, describes in greater detail a basis acceptable to the NRC staff for developing an appropriate inservice inspection and surveillance program for earth and rock fill embankments used to retain uranium mill tailings. It results from review and action on a number of specific cases and reflects the latest general approaches to the problem. The NRC staff will review any alternative methods to determine their acceptability.

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 man-made retaining structures, following the practice of the non-uranium mining industry. Unlike most non-uranium mine tailings, uranium mill tailings contain concentrations of radioactive materials in excess of the allowable discharge limits (Ref. 1). Furthermore, the most significant radioactive element in the tailings is radium-226, which has a half-life of about 1600 years (Ref. 2). 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 generations after milling operation has ceased. The embankment, foundation, and abutments need to be stable 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. 2), 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.

Therefore, the design and construction of these facilities require a high degree of professional engineering performance. The foundation of the dam should be stable and should be capable of carrying the weight of the structure. The dam should be safe under the application of external forces such as those resulting from earthquakes. The reservoir area should be water retentive and free of the possibilities of dangerous slides. Dams and associated facilities should be maintained in good working condition throughout their operating lives. Operation and surveillance through the years should be conducted in such a manner that any changes in their structural, hydraulic, and foundation conditions can be detected promptly and corrections made.

Statistics of water retention dam failures, based on the sum of operation years of a regional group of dams (Ref. 3), show a frequency of one failure every 1500 to 1800 dam-years. Statistics of uranium mill tailing retention dam failures show a frequency of one failure every 40 dam-years (Ref. 4).

*Lines indicate substantive changes from previous issue.

Causes of latent danger inherent in such works arise from site conditions, hydrologic and hydraulic features, types and qualities of the structures, operation and maintenance, and influence of the environment (Refs. 3, 5, 6, and 7). Of these causes, the majority lie within the boundaries of modern technology and can be avoided. Most failures have resulted from gradually worsening defects (due to design, construction, operation, or lack of maintenance) that were either undiscovered or misjudged. Table 1 lists the reported tailing accidents from 1959 through 1979.

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 have resulted in various mining dam mishaps and failures (Refs. 8 and 9). 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 tailing retention dams. However, the retention systems may not always perform as expected, construction may be defective, and foundations may need further treatment after a period of operation. To detect such behavior deviations, regular surveillance is essential.

The weakening of a dam or its foundation may become apparent only after many years of safe operation. Painstaking monitoring and analysis of performance data are necessary to ensure detection of adverse conditions. Each structure, as well as each site, has its own characteristics and its own susceptibilities to problems, and the surveillance program should be tailored to account for these.

Thorough physical examination is an essential part of the surveillance 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 life and inflicting property damage.

Before the start of tailing disposal, it is important that records of piezometer levels (including seasonal fluctuations, groundwater quality, ground elevations, and background radioactivities at the site) be compiled so that comparison can be made with the effects of the impoundment. Data gathered in accordance with Regulatory Guide 4.14, "Radiological Effluent and Environmental Monitoring at Uranium Mills," will provide useful information for determining the integrity of tailings dams. As soon as the tailing disposal begins, the inspection and maintenance program for structures and operating equipment needs to be initiated. This program includes regular patrol of the dam and its abutments, observations and estimates of seepage flows, piezometric levels related to pond levels, structural and foundation movements, sampling of groundwater, and examination of slurry transport and decant pipelines. Attention also needs to be focused on inspection and data collection during relatively rapid changes in reservoir water surface elevations. The emergency discharge facility (for disposing of floodwater runoff in excess of designed pond capacity) may consist of diversion channels, spillways, culverts, or other designs. To ensure proper operation, it needs to be examined for any conditions that may impose constraints on its operation.

The operation of the slurry transport pipelines seems to be relatively simple, but the frequent ruptures of the pipelines (Ref. 10) indicate that close monitoring needs to be performed during operation. A certain degree of segregation occurs, with the coarse sand fraction of the tailings tending to settle at the bottom portion of the pipe. On relatively steep downslopes, the coarse sand fraction cascades down and, in the process, abrades the pipe wall. When air is entrained in the pipeline, the pulp velocity increases as a result of the reduced cross-sectional area of the pulp flow and results in relatively fast wear on the pipe wall. Regular pipe-wall-thickness determinations will enable various remedial measures to be adopted to alleviate the situation. To help protect against the consequences of slurry ruptures at critical locations, the flow can be caught and safely directed by an adequate trough-like device (e.g., a launder). Safety can be further ensured by detecting ruptures immediately so measures can be taken quickly. Currently, it is practice to use alarm-triggering flowrate sensors installed at nozzle outlets to detect ruptures, cloggings, or other slurry flow irregularities.

Inspection personnel need to be carefully selected. It is important that they be practical, dedicated diagnosticians who examine thoroughly every clue during their scrutiny of the behavior of these facilities. They need to be trained to be able to recognize and assess signs of possible distress or abnormality and to recommend appropriate mitigating measures.

C. REGULATORY POSITION

This guide applies to those systems or portions of systems whose failure could cause releases of radioactive effluents in excess of the limits given in 10 CFR Part 20. Inservice inspection and surveillance 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 and surveillance program should consist of, but not necessarily be limited to, the following:

1. Engineering Data Compilation

Engineering data[1] related to the design, construction, and operation of the tailing retention systems should be collected and, to the extent practicable, included in the initial inspection report. These data should include the following items, where available and appropriate:

a. General Project Data

(1) Regional vicinity map showing the project location and the upstream and downstream drainage areas.

[1] Most engineering data (as presented in accordance with Regulatory Guide 3.11 and Section 2.5.6 of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants") are readily available in documents filed for a mill license application. A detailed reference or the original documents kept at the project site should be adequate.

(2) As-built drawings and photographs of important project features, including details of decant systems and typical installation of instrumentation (e.g., sectional views and material zoning and foundation stratification, final top and bottom elevation, gradation and properties of materials placed in installation).

b. Hydrologic and Hydraulic Data

(1) Drainage area and basin characteristics.

(2) Storage for tailings and surcharge capacities for floods and rate of slurry inflow.

(3) Elevation of the maximum design pool and freeboard height.

(4) Outlet facility characteristics (location, type, dimensions, and elevation).

c. Foundation data and geological features, including boring logs, geological maps, profiles, and cross sections.

d. Properties of embankment and foundation materials, including results of laboratory tests and field tests, and assumed design material properties.

e. Pertinent construction photographs and records, including construction control tests, dewatering method and construction problems, alterations, modifications, and maintenance repairs.

f. Contingency plan, including a plan for the regulation of pond water elevation under normal conditions and during flood events or other emergency conditions.

g. Principal design assumptions and analyses, including hydrologic and hydraulic analyses, stability and stress analyses, and seepage and settlement analyses.

h. Special license conditions and discussion on how these conditions have been met.

2. Onsite Inspection Program

The onsite inspection program of the retention system should be established and conducted in a systematic manner to minimize the possibility of overlooking any significant features. A detailed checklist should be developed and followed to document the observations of each significant geotechnical, structural, and hydraulic feature, including electrical and mechanical control equipment.

The use of photographs for comparison of previous and present conditions should be included as a part of the inspection program.

The inspection should include appropriate features and items, including, but not limited to, the following:

a. Daily Inspection

(1) Decant systems should be examined for any evidence of clogging of the intake; corrosion, cracking, or crushing of decant pipes; and erosion at the discharge point. The character and quantity of water flowing into the inlet and flowing out of the discharge should be compared for evidence of cracks or open joints.

(2) Effluent from underdrain pipes should be examined for evidence of clogging, cracking, and erosion.

(3) Pond water elevations should be examined and recorded to correlate them with piezometer levels and to ensure that minimum freeboard is maintained.

(4) The slurry transport system should be examined for any evidence of obstruction of the pipes or pumps due to sand clogging or ice accumulation. The pipe couplings should be examined for leakage of slurry, any flowrate sensor should be tested, and any launder examined to ensure proper operation.

(5) The retention dam should be visually inspected for signs of cracking, slumping, movement, or concentration of seepage.

b. Monthly Inspection

(1) 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 embankment.

(2) Diversion 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.

c. Quarterly Inspection

(1) *Embankment Settlement*. The top of the embankment and downstream toe areas should be examined and surveyed for any evidence of unusual localized or overall settlement or depressions.

(2) *Embankment Slope Conditions*. Embankment slopes should be examined and surveyed 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, erosions, and surface cracks that indicate movement.

(3) *Seepage*. The downstream face of abutments, embankment slopes and toes, embankment-structure contacts, and the downstream valley areas should be examined for evidence of existing or past seepage, springs, and wet or boggy areas.

(4) *Slope Protection*. 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.

(5) *Emergency Discharge Facility*. The emergency discharge facility examination should cover the structures and features, including spillway bulkheads, culverts, retaining walls, and wing walls of diversion channels, for any condition that may impose operational constraints on their functioning.

(6) *Safety and Performance Instrumentation.*[2] All installed instrumentation such as flow-monitoring weirs, survey monuments, settlement plates or gages, and 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.

(7) *Operation and Maintenance Features*. 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 dam and facilities in safe operating condition.

(8) *Postconstruction Changes*. Data should be collected on changes such as land development or large-scale tree cutting in the watershed area above the facility that have occurred since project construction and that might influence the safety of the project.

d. Special Inspection

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

[2]Immediately following installation or the discovery of an unusual condition, all instrumentation needs more frequent readings than quarterly (e.g., daily or weekly) until the patterns of the structural behaviors are stabilized.

3. Technical Evaluation

An evaluation of the existing conditions of the retention system should be made annually unless changing conditions dictate a shorter period. This evaluation should include an assessment of the hydraulic and hydrologic capacities,[3] water quality, and structural stability and should take into account both existing conditions and any changing conditions. In addition, surface water and groundwater 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. Inspection Report

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, should be available for inspection by regulatory authorities, and should be retired only on termination of the project. Any abnormal hazardous conditions observed during the inspection should be reported immediately to the NRC staff.

5. Inspection Personnel

Inspections and evaluations should be planned and conducted under the direction of an experienced professional who is thoroughly familiar with the investigation, design, construction, and operation of these types of facilities. At each facility, this individual should ensure that all field inspectors are trained to be able to recognize and assess signs of possible distress or abnormality.

[3]If additional storage capacity is needed, NRC should be notified a year in advance.

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TABLE 1

URANIUM MILL TAILINGS RELEASES
1959-1979

DATE	MILL AND LOCATION	TYPE OF INCIDENT	REMARKS
8/19/59	Union Carbide Green River, UT	Tailing Dike Failure	Tailings dam washed out; ∿ 15,000 T sands lost to Browns Wash and Green River in flash flood; no increase in dissolved Ra was noted in river.
8/22/60	Kerr-McGee Shiprock, NM	Raffinate Pond Dike Failure	240,000 gal of raffinate released into San Juan River; ∿ 50×10^{-8} μCi/ml Ra-226; river samples collected several days after release showed no increase in Ra-226 background; river at Medicine Hat (100 mi downstream of plant) showed 0.36×10^{-9} μCi/ml Ra-226 on 8/30/60.
12/6/61	Union Carbide Maybell, CO	Tailing Dike Failure	∿ 500 T solids released from tailings area; 200 T reached unrestricted area; no liquid reached any flowing stream. These tailings (offsite) did not constitute a hazard as no persons lived in the area and no drinking water was taken from surface or groundwater in the near vicinity.
6/11/62	Mines Development, Inc. Edgemont, SD	Tailing Dike Failure	200 T solids washed into Cottonwood Creek and some carried 25 mi into Angostura Reservoir.
8/17/62	Atlas-Zinc Minerals Mexican Hat, UT	Slurry Pipeline Rupture	Est. 280 T solids + 240 T liquids released from broken tailings discharge line into draw 1.5 mi from San Juan River. Calculated concentration of river water would have been below 10 CFR Part 20 maximum permissible concentration.
6/16/63	Utah Construction Riverton, WY	Tailing Dike Precautionary Release	Material released by 2-ft drainage cut made to prevent cresting due to heavy rains; material released below 10 CFR Part 20 values.
11/17/66	VCA Shiprock, NM	Raffinate Line Failure	Est. 16,000 gal of liquid lost because of break in raffinate line; material spread over 1/4 acre; break occurred 1 mi from San Juan River with some small amount reaching river.
2/6/67	Atlas Corp. Moab, UT	Auxiliary Decant Line Failure	Overflow from main tailings pond overflowed aux. decant system; 440,000 gal lost; average Ra-226 concentration was 5.5×10^{-8} μCi/ml.
7/2/67	Climax Uranium Grand Junction, CO	Tailing Dike Failure	Dike failure of unapproved retention system released 1-10 acre-ft of waste liquid into Colorado River; no indication that Ra conc. in river exceeded 10 CFR Part 20 limits.

TABLE 1 (Continued)

URANIUM MILL TAILINGS RELEASES
1959-1979

DATE	MILL AND LOCATION	TYPE OF INCIDENT	REMARKS
11/23/68	Atlas Corp. Moab, UT	Slurry Pipeline Rupture	35,000 gal of tailings slurry lost; effluent flowed down drywash and then 1/2 mile to Colorado River; riverflow sufficient to give 10,000:1 dilution; most solids settled out in drywash; measurement of river downstream of plant immediately after release and at 4-hr intervals in 24 hr following release showed U, Ra-226, Th-230 below 10 CFR Part 20 limits.
2/16/71	Petrotomics Shirley Basin, WY	Secondary Tailing Dike Failure	2,000 gal of liquid lost to unrestricted area; break in dike of effluent sump; spill frozen in place.
3/23/71	Western Nuclear Jeffrey City, WY	Tailing Line–Dike Failure	Break in sand tails slurry line caused a dike failure allowing sand tails to flow for 2 hr into natural basin adjacent to tailings site on licensee's property; fence extended to make this area restricted.
2/5/77	United Nuclear- Homestake Partners Grants, NM	Slurry Pipeline Rupture	Tailings slurry pipeline ruptured by high pressure buildup in a frozen line. The slurry released eroded a "V" cut in the dam face, which led to the escape of approximately 50,000 tons of solids and slimes and somewhere between 2 million and 8 million gal of liquid. All material released was confined to company property.
4/77	Western Nuclear, Inc. Jeffrey City, WY	Failure of Tailing Pond Embankment	Tailings slurry overtopped the embankment because of insufficient freeboard space, considerably less slope than the requisite 3 horizontal to 1 vertical, and a loss in structural integrity caused by the melting of snow interspersed with the fill used to construct the embankment. $\sim$ 2 million gal of liquid tailings (55 yd^3 of solids) were released. The grind mill and mill yard were completely covered, but no material was released to unrestricted areas.
9/26/77 9/27/77	United Nuclear Church Rock, NM	Release from Tailings Slurry Line	In the process of flushing tailings lines, it was discovered that a 2-inch water line had insufficient pressure to flush out plug. The line was uncoupled and roughly 1/4 ton of tails ran out of the line. With the line still uncoupled, flushing was inadvertently initiated again, resulting in the release of 4,000 gal of flush water and an additional ton of tailings. Approximately 1 ton of solids and slurries and 900 gal of liquid entered the watercourse. The liquid flowing to the watercourse was almost entirely mine water, a portion of which had not been treated (i.e., high in uranium and radium values).

TABLE 1 (Continued)

URANIUM MILL TAILINGS RELEASES
1959-1979

DATE	MILL AND LOCATION	TYPE OF INCIDENT	REMARKS
7/16/79	United Nuclear Church Rock, NM	Tailing Dike Failure	The tailings embankment failure was a result of internal erosion of the embankment caused by a combination of two factors. Differential settlement occurred in the foundation materials underlying the embankment and resulted in cracking of the embankment. In addition, tailings liquid was allowed to come into direct contact with the embankment near the area eventually breached. The flow of liquid through the cracks resulted in the internal erosion of the embankment and the eventual breach. The breach resulted in the release of approximately 100,000,000 gallons of tailings solution and 1,100 tons of tailings solids. Though most of the solids were deposited near the impoundment, much of the solution reached the Rio Puerco. Cleanup actions were undertaken and use of the river water for livestock watering was restricted pending reduction of contaminant levels. The river water is not used for human consumption.