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DRAFT REGULATORY GUIDE

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INSPECTION OF WATER-CONTROL STRUCTURES ASSOCIATED WITH NUCLEAR POWER PLANTS

A. INTRODUCTION

This guide describes a method the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for developing an appropriate inservice inspection (ISI) and surveillance program for dams, slopes, canals, and other water-control structures associated with emergency cooling water systems or flood protection of nuclear power plants.

General Design Criterion 45, "Inspection of Cooling Water System," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," (Ref. 1) requires that the cooling water system be designed to permit the appropriate periodic inspection of important components, such as heat exchangers and piping, to ensure the integrity and capability of the system.

The regulations in 10 CFR 50.34(a)(4) and 50.34(b)(4) require each applicant for a nuclear power plant construction permit or operating license to provide an analysis and evaluation of the design and performance of structures, systems, and components of the facility for the purpose of assessing the risk to public health and safety resulting from the operation of the facility. The regulation at 10 CFR 50.36(c)(3) defines surveillance requirements as those relating to test, calibration, or inspection to ensure that the necessary quality of systems and components is maintained, that facility operation will be within safe limits, and that the limiting conditions of operation will be met.

Multiple sections of 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 2) including sections 52.47(a)(2), 52.79(a)(4), and 52.137(a)(3) state that the General Design Criteria in Appendix A to 10 CFR Part 50 establish the minimum requirements for the principal design criteria for water-cooled nuclear power plants. The regulations at 10 CFR 52.79(a)(29) state that an application for a combined license must contain a final safety analysis report that includes plans for the conduct of normal operations, including maintenance, surveillance, and periodic testing of structures, systems, and components.

Other regulatory guides contain guidance for the design and construction of these structures. The NRC and other governmental organizations have published documents containing additional guidance on the NRC analysis and evaluation of these structures. A few references of particular interest to Regulatory Guide 1.127 are provided in the following paragraphs and in the reference section.

The current revision of Regulatory Guide 3.11, "Design, Construction, and Inspection of Embankment Retention Systems at Uranium Recovery Facilities," (Ref. 2) provides guidelines related to the design, analysis, construction, and inspection of embankment retention systems. Although this guide deals with embankments at uranium recovery facilities, it provides details of the stability analysis of embankment slopes existing at nuclear power plant sites and a long list of useful references pertaining to earth embankments.

NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," (Ref. 3) Section 2.5.4, "Stability of Subsurface Materials and Foundations," provides general information concerning the stability of the subsurface of materials and foundations. Section 2.5.5, "Stability of Slopes," of NUREG-0800 discusses the analysis procedures to evaluate the stability of slopes.

Federal Guidelines for Dam Safety (FEMA publication 93) from the Federal Emergency Management Agency (FEMA) Guides provide detailed guidelines related to dam safety (Ref. 4).

The NRC issues regulatory guides to describe methods the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required.

This regulatory guide contains information collection requirements covered by 10 CFR Part 50 that the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. 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. The NRC has determined that this Regulatory Guide is not a major rule as designated by the Congressional Review Act and has verified this determination with the OMB.

B. DISCUSSION

Background

The 1972 failure of Buffalo Creek Dam in West Virginia and several other dam failures in the United States and abroad acted as a catalyst for the U.S. Congress to pass the National Dam Inspection Act (Public Law (P.L.) 92-367) on August 8, 1972, 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.

The National Dam Inspection Act of 1972 requires, in part, that the Secretary of the Army, acting through the Chief of the U.S. Army Corps of Engineers, carry out a national program of inspection of dams[1] for the purpose of protecting human life and property. To determine whether a dam (including the

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[1] Section 2 of the National Dam Inspection Act specifically excludes from the inspection program (1) dams under the jurisdiction of the Bureau of Reclamation, the Tennessee Valley Authority, or the International Boundary and Water Commission, (2) dams that have been constructed in accordance with licenses issued under the authority of the Federal Power Act, (3) dams that a State agency had inspected within the 12-month period immediately before the enactment of the act and that the Governor of such State requests be excluded from inspection, and (4) dams that the Secretary

waters impounded by the dam) constitutes a danger to human life or property, the Secretary is required to take into consideration the possibility that the dam might be endangered by overtopping, seepage, settlement, erosion, sediment, cracking, earth movement, earthquakes, failure of bulkheads, flashboards, gates on conduits, or other conditions that exist or that might occur in any area in the vicinity of the dam. As soon as practicable after inspection of a dam, the Secretary is to notify the Governor of the State the results of the investigation. If any hazardous conditions are found during the inspection, the Secretary is required to notify the Governor immediately and, on request, advise the Governor of timely remedial measures necessary to mitigate or obviate identified hazardous conditions.

The legislation was developed as an expression of public and congressional concern over the safety of dams in the United States. On August 28, 1974, the U.S. Army Corps of Engineers published "Proposed Guidelines for Safety Inspection of Dams" in the *Federal Register* (39 FR 31334). These guidelines proposed procedures for the inspection and evaluation of dams to determine if they constitute hazards to human life and property. In April 1977, President Carter appointed an ad hoc panel of experts to review the then existing Federal safety activities. In June 1979, the ad hoc Interagency Committee on Dam Safety issued its report, which contained safety guidelines for dam owners. The NRC is a member of this committee. The proposed inspection procedures contained in the guidelines are similar to the procedures discussed in this guide.

In 1996, the National Dam Safety Program Act (P.L. 104-303) was passed. Congress later amended this act into the National Dam Safety and Security Act of 2002 (P.L. 107-310), which created the National Dam Safety Review Board. On December 22, 2006, Congress enacted the Dam Safety Act (P.L. 109-460) to amend the National Dam Safety Program Act (33 U.S.C. 467d) and to reauthorize the national dam safety program to maintain and update the inventory of dams in the United States. The Dam Safety Act mandated that the updated inventory of dams include any available information assessing each dam based on inspections completed by either a Federal agency or a State dam safety agency.

Nuclear power plants use dams, slopes, canals, and other water-control structures, and their associated facilities, to impound, retain, and divert water sources for the reliable operation of emergency cooling systems for an extended period of time – specifically, until the reactor is in a cold shutdown condition. Failure of the water-control structures to perform their functions could trigger the failure of the emergency cooling systems, thus endangering the plant and possibly allowing the release of radioactive material to the environment. Therefore, the continued operation of these facilities dictates a high degree of reliable performance. Dams and the associated facilities should be maintained in good working condition throughout their lives. The foundation should be stable under all conditions and should be capable of carrying the weight of the structure. The dam should impound its reservoir water without undue strain and should be safe under the application of external forces such as those resulting from earthquakes. The reservoir area should retain water and be free of the possibility of dangerous slides. Operation and surveillance activities through the years should be conducted in such a manner that any change in structural, hydraulic, and foundation conditions of the dam can be detected promptly and corrections made.

Statistics of dam failures, based on the sum of operation years of a regional group of dams (Ref. 5), show a frequency of one failure every 1,500 to 1,800 operating years. These failures are usually caused by: (1) site conditions such as geotechnical, hydrologic, and hydraulic features; (2) types and quality of the structures; (3) operation and maintenance; and (4) environmental influences. Most failures are caused by gradually worsening defects due to errors in design, construction, operation, or lack of

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determines do not pose any threat to human life or property. The Secretary may inspect dams that have been licensed under the Federal Power Act on request of the Federal Power Commission and dams under the jurisdiction of the International Boundary and Water Commission on request of that commission.

maintenance that were either undiscovered or misjudged. Most of these causes could have been detected by modern detection and monitoring equipment and, if the technology is used correctly, the problems can be mitigated or avoided.

Better inspection may have prevented several dam failures from occurring. These include failure of the Nashville Masonry Dam in Tennessee, which failed because of saturation of concealed clay seams (Ref. 5). South Fork Dam in Pennsylvania failed because of the overgrown vegetation at the spillway (Ref. 5). The Waco Dam slide in Texas, which occurred during construction, is attributed to the low residual strength, high pore pressure buildup (Ref. 6), and highly anisotropic behavior of the shale (Ref. 7). Dams and the associated facilities have not always performed as expected, as exemplified by the excessively high pressure buildup discovered in the foundation soil at West Branch Dam in Ohio (Ref. 8) and by the unusually high uplift pressure noted at Hoover Dam (Ref. 9). Construction defects also have been found, such as soft materials left in the abutments of a gravity dam, inadequate provisions for heat dissipation of mass concrete structures, or impervious fill misplaced in the shell of a zoned earthfill dam (Ref. 10). Foundations may need further treatment after a period of operation (e.g., the foundation at Hoover Dam was treated by providing additional drainage and grouting to reduce uplift pressure and seepage). Regular surveillance is essential to detect such defects.

Some dams may become weaker after years of operation and then need expert professional care. Examples of this phenomenon include concrete dams that were weakened by a chemical reaction between the alkalis of the cement and the silica of the aggregate (Ref. 10) and dams that experienced progressive failure in earthfill embankments (Ref. 11). The weakening of a dam or its foundation may occur after many years of safe operation. Consequently, regular monitoring and analysis of performance data are necessary to ensure the detection of adverse conditions, including peripheral phenomena such as subsidence and landslide (Refs. 11 and 12). Because each structure or site has its own characteristics and its own susceptibilities to problems, the surveillance programs should be tailored to account for such variations.

Thorough physical examination is an essential part of the surveillance program. The optimal frequency of inspections depends on the size, age, and condition of the facilities; the character of the foundation; and the regional geological setting. The proximity of the dam facility to populated areas should also be considered when formulating inspection periodicity.

The search for superficial signs of distress such as longitudinal and transverse cracks is only one phase of the examination. Possible internal degradation may be probed by various portable instruments (Refs. 13 and 14) such as soniscopes, hydrophones, television, and bore-hole cameras. It is important that these observations be correlated closely with measurements from embedded devices, if any are present.

Embankments that are placed against or are covered by structures are particularly vulnerable areas that should be monitored. They may be a highly susceptible to internal erosion at the planes of contact. Dams have failed because of piping along abutments and underneath superimposed structures such as fish ladders and spillways (Ref. 15).

Attention should also be focused on the slopes of the reservoir behind the dam where unstable terrain may be a problem (Ref. 11). Early stages of slope failure may be manifested in various ways, including buckling of concrete and asphaltic linings, leaning of trees and poles, and cracking and bulging of walls (Ref. 16). Thorough surveillance of suspected unstable areas is essential when disturbance could jeopardize the safety of the dam (Ref. 15). These areas require careful and frequent inspection, sometimes supplemented by periodic measurement of precise level and triangulation nets, reading of slope indicators or tiltmeters, and study of aerial photographs.

Before filling a reservoir, records of piezometric levels, ground elevations, and background seismicity at the site should be compiled so that a comparison can be made with the effects of water loading. As soon as filling begins, the inspection and maintenance program for structures and operating equipment should be initiated. This program includes regular patrol of the dam and its abutments and observations of seepage flows, piezometric levels, and structural and foundation movements. These readings should be plotted and correlated with concurrent reservoir water levels. An increase in seepage flow and turbidity is a common symptom of piping as a result of impounded water penetrating and flushing out foundation openings (Ref. 5).

Although the most critical time in the life of a reservoir may be during its first filling when the design is checked against actual performance, several years may pass before the foundation and structures have fully adjusted to the loads. Thereafter, deformation will continue in response to cyclical load variations. Attention should be focused on inspection and data collection during relatively rapid changes in reservoir water surface elevations, and year-to-year conditions at high and low seasonal levels should be compared. Data should also be collected on changes occurring since project construction that may influence the safety and function of the facilities. It is important that abnormalities affecting facility safety be met with quick corrective action.

The service water channels should be examined for any conditions such as channel bank erosion, aggradations, or degradations that may impose constraints on the function of the cooling system and present a potential hazard to the safety of the plant. Submerged dams and emergency canals (e.g., artificially dredged canals at the river bed or the bottom of the reservoir) should be examined for any conditions (e.g., blockage caused by sedimentation, debris, or slope instability) that may impair the function of the canals under extreme low-flow conditions.

Appendix A to this guide provides a list of a few dam failures indicating the typical causes of dam failures. This regulatory guide also includes a list of references and a bibliography that the licensee may find useful in developing an inspection program. However, the listing of these references does not constitute a blanket endorsement of their contents by the NRC staff.

C. REGULATORY POSITION

This guide applies only to water control structures (e.g., dams, reservoirs, and conveyance facilities) specifically built for use in conjunction with a nuclear power plant and whose failure could trigger the failure of the plant's emergency cooling systems, thereby endangering the plant and possibly resulting in a release of radioactive material to the environment. Such structures may be located onsite or offsite and may have been built, wholly or in part, for the purpose of controlling or conveying water for either normal and emergency cooling operation or flood protection of the plant. Essentially, the embankments and other appurtenant structures addressed by this guide are those typically built to provide or protect the ultimate heat sink. The NRC staff may consider the recommendations of this guide fulfilled by the applicant or licensee if the structure is regulated by another agency or State that enforces a comparable inspection program (e.g., a hydroelectric pumped-storage project built as part of a nuclear power plant and regulated by the Federal Energy Regulatory Commission).

The inspection should be conducted under the direction of qualified engineers experienced in the investigation, design, construction, and operation of these types of facilities. The field inspection team should include engineers, engineering geologists, or other specialists who can recognize and assess signs of possible distress (e.g., structural joint movement, piezometric fluctuations, seepage variations, settlement and horizontal misalignments, slope movement, cracking of concrete, erosion, and corrosion of equipment and conduits) and recommend appropriate mitigating measures.

Inservice inspection should be performed at periodic intervals to check the condition of the water-control structures and evaluate their structural safety and operational adequacy. A detailed, systematic inspection program should include, but not necessarily be limited to, the features and items described below.

1. Engineering Data Compilation

Engineering data related to the design, construction, and operation of the water-control structures should be collected and, to the extent practicable, included in the initial inspection report.[2] These data should include the following items, where available and appropriate:

a. General Project Data

(1) a regional vicinity map showing the project location and the upstream and downstream drainage areas;

(2) as-built drawings of important project features, including details such as instrumentation, internal drainage, transition zones, or relief wells; and

(3) construction progress and as-built photographs of concrete surfaces, points of contact between structures or between structures and earth embankments, and foundation conditions.

b. Hydrologic and Hydraulic Data

(1) drainage area and basin characteristics;

(2) storage and surcharge capacities, including dead storage;

(3) elevation of the maximum design pool and freeboard height;

(4) spillway characteristics (location, type, width, and crest length and elevation); and

(5) location and description of flashboards, fuse plugs, and emergency spillways.

c. Other Types of Data

(1) foundation data and geological features, including boring logs, geological maps, profiles and cross-sections, and reports of foundation treatment;

(2) properties of embankment and foundation materials, including the results of laboratory tests, field tests, construction control tests, and assumed design material properties;

(3) concrete properties, including the source and type of aggregate, the cement used, mix design data, and test results during construction;

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[2] Most engineering data are information presented in preliminary safety analysis reports and final safety analysis reports. To aid the inspectors, the initial inspection report should either incorporate this information or reference in detail its location in the safety analysis reports.

(4) electrical and mechanical equipment type; the rating of normal and emergency power supplies, hoists, cranes, valves, and valve operators; and control and alarm systems that could affect the safe operation of the water-control structure;

(5) pertinent construction records, including construction problems, alterations, modifications, and maintenance repairs;

(6) a water-control plan, including a regulation plan under normal conditions and during flood events or other emergency conditions;

(7) an earthquake history, including a summary of significant earthquakes in the vicinity; and

(8) principal design assumptions and analyses, including hydrologic and hydraulic analyses, stability and stress analyses, and seepage and settlement analyses.

2. Onsite Inspection Program

The onsite inspection program of water-control structures 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 for the project structures to document the observations of each significant structural and hydraulic feature, including electrical and mechanical control equipment. Particular attention should be given to detecting evidence of leakage, erosion, seepage, slope instability, undue settlement, displacement, tilting, cracking, deterioration, and the improper functioning of drains and relief wells; to verifying the adequacy and quality of maintenance and operating procedures; and to observing significant post-construction changes.

The use of photographs for comparison of previous and present conditions and the documentation of new or progressive problems are encouraged. The inspection program should include a review of previous inspection records. The inspection should include appropriate features and items, including, but not limited to, the following:

a. Concrete Structures in General

Concrete structures should be examined for the following potential problems:

(1) <u>Concrete Surfaces:</u> The condition of the concrete surfaces should be examined to evaluate the deterioration and continuing serviceability of the concrete. Descriptions of concrete conditions should conform with the appendix to American Concrete Institute (ACI), ACI 201.1r-92, "Guide for Making a Condition Survey of Concrete in Service," updated in 1992 and re-approved it in 1997 (Ref. 17).

(2) <u>Structural Cracking:</u> Concrete structures should be examined for structural cracking resulting from overstress caused by applied loads, shrinkage and temperature effects, or differential movements.

(3) <u>Movement - Horizontal and Vertical Alignment:</u> Concrete structures should be examined for evidence of any abnormal settlements, heaving, deflections, or lateral movements.

(4) Junctions: The conditions at the junctions of the structure with abutments or embankments should be determined.

(5) Drains—Foundation, Joint, and Face: All drains should be examined for the purpose of ensuring that they can perform their design function.

(6) Water Passages: All water passages and other concrete surfaces subject to running water should be examined for erosion, cavitation, obstructions, leakage, or significant structural cracks.

(7) Seepage or Leakage: The faces, abutments, and toes of the concrete structures should be examined for evidence of seepage or abnormal leakage, and records of the flow of downstream springs should be reviewed for unusual variation with the reservoir pool level. The sources of seepage should be determined, if possible.

(8) Monolithic Joints—Construction Joints: All monolithic construction joints should be examined to determine the condition of the joint and filler material, any movement of joints, or any indication of distress or leakage.

(9) Foundation: The foundation should be visually examined to the extent possible for damage or for the possible undermining of the downstream toe.

(10) Abutments: The abutments should be examined for signs of instability or excessive weathering.

b. Embankment Structures

Many Federal and State government agencies (see the bibliography) have published guidelines for the inspection of earth embankments. Dams must be inspected according to intervals specified by the regulatory agency under normal conditions and after unusual events (such as extreme rainfall and earthquakes). Such inspections will provide the best opportunity for the early detection of potential problems, including the following:

(1) Settlement: The embankments and downstream toe areas should be examined for any evidence of unusual localized or overall settlement, depressions, or sink holes.

(2) Slope Stability: Embankment slopes should be examined for irregularities in alignment and variances from originally constructed slopes, unusual changes from original crest alignment and elevation, evidence of movement at or beyond the toe, and surface cracks that indicate movement.

(3) Seepage: The downstream face of abutments, embankment slopes and toes, contacts between the embankment and structure, and the downstream valley areas should be examined for evidence of existing or past seepage. The sources of seepage should be investigated to determine cause and potential severity affecting dam safety under all operating conditions. The presence on slopes of animal burrows and vegetative growth that might cause detrimental seepage should be examined.

(4) Drainage Systems: All drainage systems should be examined to determine whether the systems can freely pass discharge and ensure that the discharge water is not carrying embankment or foundation material. Systems used to monitor drainage should be examined to ensure that they are operational and functioning properly.

(5) Slope Protection: The slope protection should be examined for erosion-formed gullies and wave-formed notches and benches that have reduced the embankment cross-section or exposed less wave-resistant materials. The adequacy of slope protection against waves, currents, and surface runoff that may occur at the site should be evaluated. The condition of vegetative or any other protective covers should be evaluated, where pertinent.

c. Spillway Structures and Outlet Works

The spillway examination should cover the structures and features, including bulkheads and flashboards, of all service and auxiliary spillways for any condition that may impose operational constraints on the functioning of the spillway. The outlet works examination should include all structures and features designed to release reservoir water below the spillway crest through or around the dam. The spillway structures and outlet works should be examined for the following potential problems:

(1) Control Gates and Operating Machinery: The structural members, connections, hoists, cables, and operating machinery and the adequacy of normal and emergency equipment should be examined and tested to determine the structural integrity and verify the operational adequacy of the equipment. In areas where cranes will used for handling gates and bulkheads, the capacity and operating condition of the cranes and lifting beams should be ascertained. Operability of control systems and protective and alarm devices such as limit switches, sump high-water alarms, and drainage should be ascertained.

(2) Unlined Saddle Spillways: If unlined saddle spillways are used, they should be examined for evidence of erosion and any conditions that may impose constraints on the functioning of the spillway.

(3) Approach and Outlet Channels: The approach and outlet channels should be examined for any conditions that may impose constraints on the functioning of the spillway and the outlet works.

(4) Stilling Basin (Energy Dissipators): Stilling basins, including baffles, flip buckets, or other energy dissipators, should be examined for any conditions that may impose constraints on the ability of the stilling basin to prevent downstream scour or erosion that may create or present a potential hazard to the safety of the dam. The existing condition of the channel downstream of the stilling basin should be examined.

(5) Intake Structure: The structure and all features should be examined for any conditions that may impose operational constraints on the outlet works. Entrances to the intake structure should be examined for conditions such as silt or debris accumulation that may reduce the discharge capabilities of the outlet works.

(6) Conduits, Sluices, and Water Passages: The interior surfaces of conduits should be examined for erosion, corrosion, cavitation, cracks, joint separation, and leakage at cracks or joints.

(7) Drawdown Facilities: Facilities provided for the drawdown of the reservoir to avert impending failure of the dam or to facilitate repairs in the event of stability or foundation problems should be examined for any conditions that may impose constraints on their functioning as planned.

d. Reservoirs

The following features of the reservoir should be examined for any conditions that may impose operational constraints on the cooling system or that may be hazardous to the safety of the dam:

(1) Shore Line: The landforms around the reservoir should continually be examined for indications of major active or inactive landslide areas and for their susceptibility, at any later date, to massive landslides of sufficient magnitude to significantly reduce reservoir capacity or create waves that might overtop the dam.

(2) Sedimentation: The reservoir and drainage area should be examined for excessive sedimentation or recent developments in the drainage basin that could cause a sudden increase in sediment load, thereby reducing the reservoir capacity with an attendant increase in the maximum outflow and maximum pool elevation.

(3) Potential Upstream Hazard Areas: The reservoir area should be examined for changes with a potential for hazardous backwater flooding.

(4) Watershed Runoff Potential: The drainage basin should be examined for any extensive recent alterations to the surface of the drainage basin such as changed agricultural practices, timber clearing, railroad or highway construction, or real estate developments that might adversely affect the runoff characteristics. Upstream projects that could have an impact on the safety of the dam should be identified.

e. Cooling Water Channels and Canals and Intake and Discharge Structures

The cooling water channels and canals and intake discharge structures should be examined for the following potential problems:

(1) Channels and Canals: The water conveyance channels and canals should be examined for channel bank erosion, bed aggradation or degradation and siltation, undesirable vegetation, or any unusual or inadequate operational behavior.

(2) Intake and Discharge Structures: The structures and all features should be examined for any conditions that may impose operational constraints on the cooling facilities such as silt or debris accumulation at the water intake or discharge.

f. Safety and Performance Instrumentation

Instruments that have been installed to measure the behavior of the structures should be examined and tested for proper functioning. The available records and readings of installed instruments should be reviewed to detect any unusual performance or distress of the structure. The adequacy of the installed instrumentation to measure the performance and safety of the dam should be determined. Records of the following instrumentation should be examined to determine any potential problems:

(1) Headwater and Tailwater Gages: The existing records of the headwater and tailwater gage measurements should be examined to determine the relationship between these and other instrumentation measurements such as stream flow, uplift pressures, alignment, and drainage system discharge with the upper and lower water surface elevations.

(2) Horizontal and Vertical Alignment Instrumentation (Concrete Structures): The existing records of alignment and elevation surveys and measurements from inclinometers, inverted plumb bobs, gage points across cracks and joints, or other devices should be examined to determine any change from the original position of the structures.

(3) Horizontal and Vertical Movement, Consolidation, and Pore-Water Pressure Instrumentation (Embankment Structures): The existing records of measurements from settlement plates or gages, surface reference marks, slope indicators, and other devices should be examined to determine the movement history of the embankment. Existing piezometer measurements should be examined to determine if the pore-water pressures in the embankment and foundation would, under given conditions, impair the safety of the dam. Survey methods are also used to monitor the magnitude and rate of horizontal and vertical deformations of the surface monuments on and at the toes of embankment dams.

(4) Uplift Instrumentation: The existing records of uplift measurements should be examined for the purpose of determining if the uplift pressures for the maximum pool would impair the safety of the dam.

(5) Drainage System Instrumentation: The existing records of measurements of the drainage system flow should be examined to confirm the normal relationship between pool elevations and discharge quantities or to detect any changes that have occurred in this relationship.

(6) Seismic Instrumentation: The existing records of seismic instrumentation should be examined to determine the seismic activity in the area and the response of the structures to recent earthquakes.

(7) Remote-Monitoring Instrumentation: The use of such instrumentation should be considered to provide remote access and alert for a wide variety of instruments.

g. Operation and Maintenance Features

The following operation and maintenance features should be examined:

(1) Reservoir Regulation Plan: The actual practices in regulating the reservoir and discharges under normal and emergency conditions should be examined to determine if these practices comply with the designed reservoir regulation plan.

(2) Maintenance. The maintenance of the operating facilities and features that pertain to the safety of the dam should be examined to determine the adequacy and quality of the maintenance procedures followed in maintaining the dam and facilities in a safe operating condition.

h. Post-Construction Changes

Data should be collected on changes that have occurred since project construction that might influence the safety of the project.

3. Technical Evaluation

When findings of the engineering data review and onsite inspection indicate that significant changes have occurred, an evaluation of the existing conditions of the water-control structures should be made as suggested below. The evaluation should include the assessment of the hydraulic and hydrologic capacities and the structural stability based on the changes or affected parameters.

a. Hydraulic and Hydrologic Design Capacities

Hydraulic and hydrologic design capacities should be evaluated in accordance with applicable portions of Regulatory Guide 1.59, "Design-Basis Floods for Nuclear Power Plants," Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," and Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants." The evaluation should consider all constraints on water control such as blocked entrances, restrictions on the operation of spillway and outlet works, inadequate energy dissipators, restrictive channel conditions, and significant reduction in reservoir capacity by sedimentation and other factors.

b. Stability Assessments

Stability assessments should use in situ properties of the structures, including foundation and pertinent geologic information, to determine the existence of changes to or the continuation of conditions that are hazardous or that might develop into safety hazards over time and to formulate recommendations pertaining to the need for additional investigations, analyses, or remedial measures. References 18–26 provide generally acceptable methods for the analyses of structural stability.

The likelihood of soil liquefaction after a seismic event is another important aspect of the stability of embankments that should be assessed. References 27–32 provide guidance for conducting such post earthquake stability assessments using the residual strength of the soils comprising the embankments.

4. Frequency of Inspections

The inspection intervals suggested below are for general guidance in developing projected inspection schedules. These intervals in no way preclude more frequent inspections if deemed necessary or less frequent inspections (not to exceed each 5 years) for those structures in which conditions or structural integrity warrant such relaxation. NOTE: The directions in the licensing documents govern the frequency of inspections. If no frequency is specified, the NRC may use the following guidance when evaluating the ISI and surveillance programs.

a. Initial Inspection

The first general onsite inspection should be carried out immediately after topping out for new earth and rockfill dams and before the impoundment of reservoir water for new concrete structures. For existing facilities that are now in operation, onsite inspection should be carried out as soon as practicable if no inspection comparable with that described in this guide has been performed.

b. Subsequent Inspections

The second inspection of earth and rockfill dams should be performed at a reasonable stage of reservoir filling but in no case later than at the attainment of the normal operating pool level. The second inspection of concrete structures should be performed when the reservoir water attains the normal operating pool level but in no case later than 1 year after initial impoundment has begun. Subsequent inspections should be made at 1-year intervals for the next 4 years and at 2-year intervals for the following 4 years; these inspections may then be extended to each 5 years if the results of the previous inspections warrant this extension.

c. Special Inspections

Special inspections should be performed immediately after the dam has passed unusually large floods and after the occurrence of significant earthquakes, hurricanes, tornadoes, intense local rainfalls, or other unusual events. Such inspections should be followed by an engineering evaluation of the structural stability of the embankment using the appropriate (possibly degraded) material properties of the embankments, and the results of the evaluation should be communicated to the appropriate regulatory authorities.

d. Inspections by the NRC Dam Safety Officer

In addition to the inspections by the owner and the regulatory staff as part of their normal duties, the NRC dam safety officer will also perform routine inspections of the water-control structures at the nuclear power plants biannually, as required by the Dam Safety Act referred to earlier in this guide.

5. Inspection Report

A technical report should be prepared to present the results of each general inspection. 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 in accordance with the Commission's regulations, as summarized in Regulatory Guide 1.16, "Reporting of Operating Information—Appendix A Technical Specifications." The content of the reports is described below.

a. Initial Report

In addition to a general description of water-control structures, major elements of the report should include the following:

(1) results of the visual inspection of each project feature, including photographs, where appropriate;

(2) results of the instrumentation observations;

(3) an evaluation of the operational adequacy of the reservoir regulation plan and the maintenance of the dam and operating facilities, including the warning system;

(4) a technical assessment of the causes of distress or abnormal conditions and an evaluation of the behavior, movement, deformation, or loading of the structure; and

(5) conclusions and recommendations for additional investigations, remedial measures, or future inspections, where appropriate.

b. Subsequent Reports

These reports should include information, as described in items 5.a(1)–5.a(5) above, relative to changes or to the continuation of an abnormality in conditions noted since the previous inspection. The reports should also include any extreme events that have occurred since the last inspection, such as floods or seismic events.

D. IMPLEMENTATION

The purpose of this section is to provide information on how applicants and licensees may use this guide and information regarding the NRC's plans for using this regulatory guide. In addition, it describes how the NRC staff has complied with the Backfit Rule, 10 CFR 50.109, and any applicable finality provisions in 10 CFR Part 52.

Use by Applicants and Licensees

Applicants and licensees may voluntarily use the information in this regulatory guide to develop applications for initial licenses, amendments to licenses, requests for exemptions, or NRC regulatory approval. Licensees may use the information in this regulatory guide for actions which do not require prior NRC review and approval (e.g., changes to a facility design under 10 CFR 50.59 which do not require prior NRC review and approval). Licensees may voluntarily use the information in this Regulatory Guide or applicable parts to resolve regulatory or inspection issues (e.g., by committing to comply with provisions in the regulatory guide).

Current licensees may continue to use the guidance that was found acceptable for complying with specific portions of the regulations as part of their license approval process, which may be a previous version of this regulatory guide.

A licensee who believes that the NRC staff is inappropriately imposing this regulatory guide as part of a request for a license amendment or request for a change to a previously issued NRC regulatory approval may file a backfitting appeal with the NRC in accordance with applicable procedures.

NRC Staff Use

The NRC staff does not intend or approve any imposition or backfitting of the guidance in this regulatory guide. The staff does not expect any existing licensee to use or commit to using the guidance in this Regulatory Guide in the absence of a licensee-initiated change to its licensing basis. The NRC staff does not expect or plan to request licensees to voluntarily adopt this regulatory guide to resolve a generic regulatory issue. The NRC staff does not expect or plan to initiate NRC regulatory action which would require the use of this regulatory guide (e.g. issuance of an order requiring the use of the regulatory guide, requests for information under 10 CFR 50.54(f) as to whether a licensee intends to commit to use of this regulatory guide, generic communication, or promulgation of a rule requiring the use of this regulatory guide) without further back-fit consideration.

During inspections of specific facilities, the staff may suggest or recommend that licensees consider various actions consistent with staff positions in this regulatory guide as one acceptable means of meeting the underlying NRC regulatory requirement. Such suggestions and recommendations would not ordinarily be considered backfitting even if prior versions of this regulatory guide are part of the licensing basis of the facility with respect to the subject matter of the inspection. However, the staff may not represent to the licensee that: (1) the licensee's failure to comply with the positions in this regulatory guide constitutes a violation; (2) the licensee may avoid the violation only by agreeing to comply with this regulatory guide; or (3) the only acceptable way for the licensee to address the NRC-identified non-compliance or violation is to commit to this regulatory guide (i.e., including this regulatory guide in the facility's licensing basis).

If an existing licensee seeks an amendment or change in an already approved area of NRC regulatory concern and (1) the NRC staff's consideration of the request involves a regulatory issue directly relevant to this new or revised regulatory guide and (2) the specific subject matter of this regulatory guide is an essential consideration in the staff's determination of the acceptability of the licensee's request; then, as a prerequisite for NRC approval of the license amendment or change, the staff may require the licensee to either follow the guidance in this regulatory guide or to provide an equivalent alternative method that demonstrates compliance with the underlying NRC regulatory requirements. This is not considered backfitting as defined in 10 CFR 50.109(a)(1) or a violation of any of the issue finality provisions in 10 CFR Part 52.

Conclusion

This regulatory guide is not being imposed upon current licensees and may be voluntarily used by existing licensees. In addition, this regulatory guide is issued in conformance with all applicable internal NRC policies and procedures governing backfitting. Accordingly, the issuance of this regulatory guide by the NRC staff is not considered backfitting, as defined in 10 CFR 50.109(a)(1), nor is it deemed to be in conflict with any of the issue finality provisions in 10 CFR Part 52.

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3 All publicly available NRC documents listed herein are available electronically through the Electronic Reading room on the NRC’s public Web site at: http://www.nrc.gov/reading-rm/doc-collections/. The documents can also be viewed on-line for free or printed for a fee from the NRC’s Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone 301-415-4737 or (800) 397-4209; fax (301) 415-3548; and e-mail PDR.Resource@nrc.gov.

4 Federal Emergency Management (FEMA) documents may be obtained from FEMA’s Web site (http://www.fema.gov/) by mail at Federal Emergency Management Agency, P.O. Box 10055, Hyattsville, MD 20782; telephone (800) 745-0243; fax (800) 827-8112.

5 Documents from the International Commission on Large Dams (ICOLD) are available through their Web site (http://www.icold-cigb.net/); by contacting their central office at CIGB/ICOLD 61, Avenue Kléber, 75116, Paris, France; telephone +33.1.47.04.17.80; fax +33.1.53.75.18.22.

6 Documents from the American Society of Civil Engineers (ASCE) are available through their Web site (http://www.asce.org/); by contacting their home office at American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA, 20191; telephone (800) 548-2723.

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APPENDIX A

CAUSES OF DAM FAILURES

The National Research Council's publication, "Safety of Existing Dams: Evaluation and Improvement," provides a good description of the causes of dam failures and describes the three main causes of failures as (1) overtopping, (2) foundation defects, and (3) piping. Tables A-1, A-2, A-3, A-4, A-5, and A-6 [12] provide an excellent summary of the main causes of dam failures and suggest possible preventive measures.

Table A-1. Types of Erosion

Form	Characteristics
Erosion by Overtopping	Flow over the top of embankment washing out dam
Erosion by Waves	Erosion of upstream face
Erosion by Outlet Discharge	Erosion of embankment toe near spillway or low-level outlet
Erosion by Rainfall	Erosion of downstream face of dam by rainfall and surface runoff

Table A-2. Surface Erosion Failure

Causes	Possible preventive measures
Inadequate spillway capacity	Design spillway for larger flood.
Clogging of spillway with debris	Install trash racks where possible or periodically remove debris.
Insufficient freeboard due to settlement of embankment	Regrade crest to design elevation.
Insufficient rip-rap or incorrect grading	Place well graded rip-rap and filters.
Spillway outlet or low-level outlet located too close to dam	Discharge water away from the embankment. Provide toe protection adjacent to all outlets.
Poor surface drainage and lack of adequate grass cover on the downstream slope	Provide drains or ensure adequate grass cover on downstream face.

Table A-3. Piping Failure

Form	Characteristic
Piping	Progressive internal erosion of material from downstream side of dam or foundation in an upstream direction, eventually leading to a breach through the dam.

Table A-4. Sliding Failure

Form	Characteristic
Foundation slide	Sliding of upstream and/or downstream slope with heave of foundation in direction of movement
Upstream slide	Slide in upstream face
Downstream slide	Slide in downstream face

12 "Guidelines on Inspecting Small Dams," the New Zealand Society on Large Dams, November 1997.

Table A-5. Internal Erosion (Piping) Failures

Causes	Possible preventive measures
Concentrated seepage from downstream slope	Install toe drains or filters.
Seepage along low-level outlet/dam fill interface	Grout along outside of outlet to fill voids, install filter and drainage protection around downstream section of outlet, replace outlet using proper construction techniques.
Leaking low level outlets	Seal joints.

Table A-6. Embankment Slumping Failures (Slides)

Causes	Possible preventive measures
Soft or weak foundation	Flatten slope. Construct berms.
Excess water pressure in foundation	Provide drains and filters.
Steep slope	Flatten slope. Construct berms.
Rapid reservoir drawdown	Avoid lowering reservoir by large amount over a short time period.
Steep slope	Flatten slope. Construct berms.
Saturation of slope by seepage	Provide proper drainage by installing toe filters.

APPENDIX B

LIST OF DAM FAILURES

The following table lists a few dam failures and shows the typical causes of these failures.

DAM/INCIDENT	YEAR	LOCATION	TYPICAL CAUSES OF FAILURES
Dale Dike Reservoir	1864	South Yorkshire, England	Defective construction; a small leak in the wall grew until the dam failed.
South Fork Dam	1889	Johnstown, Pennsylvania, United States	Blamed locally on poor maintenance by owners; a court deemed it an "Act of God." Followed exceptionally heavy rainfall.
St. Francis Dam	1928	Los Angeles, California, United States	Geological instability that could not have been detected combined with human error that assessed developing cracks as "normal" for a dam of that type.
Malpasset	1959	Côte d'Azur, France	Geological fault possibly enhanced by explosives work during construction; initial geological-study was not thorough.
Baldwin Hills Reservoir	1963	California, United States	Subsidence caused by overexploitation of a local oil field.
Vaiont Dam	1963	Italy	Strictly not a dam failure, since the dam structure did not collapse and is still standing. Filling the reservoir caused geological failure in the valley wall, leading to a 110-kilometer-per-hour landslide into the lake. Water escaped in a mega tsunami. The valley had been (incorrectly) assessed as stable.
Buffalo Creek Flood	1972	West Virginia, United States	Unstable, loosely constructed dam created by local coal mining company, collapsed in heavy rain.
Banqiao and Shimantan Dams	1975	China	Extreme rainfall beyond the planned design capability of the dam.
Teton Dam	1976	Idaho, United States	Water leakage through an earthen wall, leading to dam failure.
Kelly Barnes Dam	1977	Georgia, United States	Unknown, possibly design error as owners raised the dam several times to improve power generation.
Lawn Lake Dam	1982	Rocky Mountain National Park, United States	Outlet pipe erosion; dam undermaintained because of its location.
Val di Stava Dam collapse	1985	Italy	Poor maintenance and low margin for error in design; outlet pipes failed, leading to pressure on the dam.
Vodní nádrž Soběnov	2002	Soběnov, Czech Republic	Extreme rainfall during the 2002 European floods.
Shakidor Dam	2005	Pakistan	Unexpectedly extreme rain.
Taum Sauk Upper Reservoir	2005	Missouri, United States	Overtopped by misoperation of pumping for power production.
Black Rock Dam	1909	New Mexico, United States	Piping failure.
Lyman Dam	1915	Arizona, USA	Piping failure.