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# REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

## REGULATORY GUIDE 1.90

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# INSERVICE INSPECTION OF PRESTRESSED CONCRETE CONTAINMENT STRUCTURES WITH GROUTED TENDONS

## A. INTRODUCTION

This regulatory guide describes methods that the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in developing an appropriate inservice inspection (ISI) program for prestressed concrete containment structures with grouted tendons.

The design requirements for the testing and inspection of reactor containments are described in General Design Criterion (GDC) 53, "Provisions for Containment Testing and Inspection," 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). GDC 53 requires, in part, that the reactor containment shall be designed to permit (1) appropriate periodic inspection of all important areas, and (2) an appropriate surveillance program.

Regulatory requirements for ISI of Class CC and Class MC containment structures are provided in 10 CFR 50.55a "Codes and Standards." Paragraph (g)(4) "Inservice Inspection Requirements" of 10 CFR 50.55a requires, in part, that: "Components which are classified as Class MC pressure retaining components and their integral attachments, and components which are classified as Class CC pressure retaining components and their integral attachments must meet the requirements, except design and access provisions and preservice examination requirements, set forth in Section XI of the ASME B&PV Code and addenda that are incorporated by reference in paragraph (b) of this section, subject to the conditions listed in paragraph (b)(2)(vi) of this section and the conditions listed in paragraphs (b)(2)(viii) and (b)(2)(ix) of this section, to the extent practical within the limitation of design, geometry and materials of construction of the components." Essentially, 10 CFR 50.55a(g)(4) requires that the ISI program for Class CC and Class MC containment structures meets the requirements set forth in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, "Rules for

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The NRC issues regulatory guides to describe and make available to the public methods that the NRC staff considers acceptable for use in implementing specific parts of the agency's regulations, techniques that the staff uses in evaluating specific problems or postulated accidents, and data that the staff needs in reviewing applications for permits and licenses. Regulatory guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions that differ from those set forth in regulatory guides will be deemed acceptable if they provide a basis for the findings required for the issuance or continuance of a permit or license by the Commission.

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Inservice Inspection of Nuclear Power Plant Components," (Ref. 2) Subsection IWL, "Requirements for Class CC Concrete Components of Light-Water-Cooled Plants," and Subsection IWE, "Requirements for Class MC and Metallic Liners of Class CC Components of Light-Water-Cooled Plants," subject to the associated Code conditions. Prestressed concrete containment structures with grouted tendons are classified as Class CC concrete components. However, ASME B&PV Code, Section XI, Subsection IWL currently includes examination requirements only for post-tensioning systems with ungrouted tendons. This RG provides guidance on an approach acceptable to the NRC to meet the ISI requirements in 10 CFR 50.55a(g)(4) and the associated design requirements in GDC 53 for Class CC prestressed concrete containments with grouted tendons.

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. This regulatory guide is a rule as designated in the Congressional Review Act (5 U.S.C. 801–808). However, OMB has not found it to be a major rule as designated in the Congressional Review Act.

## B. DISCUSSION

### Background

Regulatory Guide 1.90, Revision 1, "Inservice Inspection of Prestressed Concrete Containment Structures with Grouted Tendons," (Ref. 3) was issued in 1977. Since then, the industry and the NRC have been involved in research and testing to determine and evaluate the effectiveness of containment ISI programs, particularly the reliability of installed instrumentation and the use of periodic pressure tests. In addition, the NRC has reviewed containment tendon ISI programs as part of license applications. Furthermore, requirements for ISI of Class CC and Class MC containment structures in accordance with the ASME Code, Section XI, have been incorporated into the regulations at 10 CFR 50.55a. Revision 2 of RG 1.90 was developed in response to these developments. This revision provides an ISI program that is based on a real-time, multiple-strategy approach (i.e., appropriate grout design and installation, installed instrumentation, periodic pressure tests, ungrouted test tendons, and visual examination).

The International Atomic Energy Agency (IAEA) has established a series of safety guides and standards constituting a high level of safety for protecting people and the environment. IAEA safety guides present international good practices and increasingly reflect best practices to help users achieve high levels of safety. Pertinent to this regulatory guide, IAEA Safety Guide NS-G-1.10, "Design of Reactor Containment Systems for Nuclear Power Plants," issued September 2004 (Ref. 4) and NS-G-2.6, "Maintenance, Surveillance, and In-service Inspection in Nuclear Power Plants," issued October 2002 (Ref. 5), provide guidance and recommendations on maintenance, surveillance and in-service inspection activities to ensure that safety related structures, systems, and components (SSCs) perform as designed. This regulatory guide incorporates similar guidelines and is consistent with the basic safety principles provided in IAEA Safety Guide NS-G-1.10, and NS-G-2.6.

The ISI of prestressed concrete containment structures is necessary to verify, at specific intervals, that operating and environmental conditions have not reduced the safety margins on prestress levels provided in the design of the containment structures, and that the leaktightness and structural integrity of the containment is maintained (Ref. 6). A prediction of the time-dependent behavior of concrete, particularly creep and shrinkage, is very important because of its potential impact on the prestress level.

Only two nuclear power plants in the United States have used grouted tendons: Three Mile Island Nuclear Station, Unit 2 (which is permanently shut down), and H.B. Robinson Steam Electric Plant (vertical tendons only). However, in France, Belgium, South Korea, Canada, and China, the use of grouted tendons in nuclear power plant containment structures has been more common (Refs. 6–10). In addition, at least one U.S. reactor design certification application has proposed grouted tendons, AREVA's Evolutionary Power Reactor (EPR).

This guide is for the ISI of containment structures that have grouted tendons of sizes with an ultimate strength of approximately 15,346 kilonewtons (1,725 tons) and that consist of parallel wires of several strands, which represent the current industry standard. The detailed recommendations of this guide do not apply directly to grouted tendon containment structures that have bar tendons. However, licensees may develop a modified ISI program for grouted tendon containment structures with bar tendons using the principles provided in this guide. The NRC staff will review such programs on a case-by-case basis. This guide does not address the ISI of prestressing foundation anchors. If these anchors are used, the NRC staff will review the associated ISI program on a case-by-case basis. Finally, this guide does not address the ISI of the containment liner and penetrations.

This guide outlines a detailed inspection program applicable to a sphere-torus dome containment with cylindrical walls that are up to 50 meters (165 feet) in diameter and that have an overall height up to 67 meters (220 feet) with three groups of tendons (i.e., hoop, vertical, and dome or gamma). This guide refers to such containment as the "reference containment." Some plants may use gamma tendons to prestress the dome. The gamma tendon is a tendon type that is anchored at the base of the containment in the tendon gallery and extends vertically up and over the dome and is anchored at the dome ring girder. The licensee may develop the number of locations to be monitored for an ISI program using the concepts outlined in this guide and the guidelines provided in Appendix A. However, locations including geometrical and analytical critical areas should be included in addition to those provided in Appendix A.

## Monitoring Containment Structures with Grouted Tendons

After the application of prestress to any containment structure that uses tendons (either grouted or ungrouted), the prestress level decreases over time because of several factors, including the following:

1. stress relaxation of the prestressing steel,
2. volumetric changes in the concrete (creep, shrinkage),
3. differential thermal expansion or contraction between the tendon, grout, and concrete, and
4. possible reduction in the cross-sectional area of the tendon wires because of corrosion, including possible fracture of the wires.

The major unique concern in containment structures with grouted tendons is the possibility that corrosion of the tendon steel could occur and remain undetected. In addition, once grouted, the tendons cannot be retensioned or replaced. The major factors influencing the occurrence of corrosion are (1) the susceptibility of the tendon steel to corrosion, (2) the degree of exposure of the tendon steel to a deleterious environment, (3) the extent of temperature variations, and (4) the quality of the grout and its installation. Licensees can significantly reduce the likelihood and effects of widespread corrosion by following the guidance in Regulatory Guide 1.107, "Qualifications for Cement Grouting for Prestressing Tendons in Containment Structures" (Ref. 11).

However, the mechanism of corrosion in all conditions and situations is not fully understood. Because many parameters can influence the development of general corrosion or stress corrosion, an area of uncertainty with regard to the corrosion of tendon steel always exists. Therefore, containment structures must be monitored in a manner that would reveal the existence of potentially detrimental corrosion. The applicant or licensee should demonstrate that tendon performance maintains an adequate safety margin in the containment. The inspection provisions in ASME Code, Section XI, Subsection IWL, for Class CC concrete containment structures (Ref. 2) remain applicable to containment structures with grouted tendons except those provisions which are limited by the use of grouted tendons.

One way of monitoring prestressed concrete structures is to periodically ascertain the amount of prestress at certain strategically located sections in the structure. This can be done by using various installed instrumentation. The effectiveness of this approach depends on the number of instruments and their locations. Several ISI reports and published papers (Refs. 6, 7, 8, and 12) show that available instrumentation (i.e., strain gauges, stress meters, vibrating wire strain gauges, and strain meters) for concrete has remained in place and functional 65 to 90 percent of the time during a 10- to 25-year observation period. The literature also reports that the reliability of vibrating wire strain gauges is higher than that of strain gauges and meters. Given this variable reliability, multiple types of instrumentation should be used to monitor the prestress level.

Another way to monitor the integrity of the containment structure is to subject it to a periodic pressure test and measure its deformation under pressure.

Some papers have proposed real-time monitoring of the strength of the containment structure as a means to ascertain the prestress level (Refs. 9 and 10). However, industry practice over the past 30 years and test programs conducted since 2000 on the durability and safety of grouted tendons (Refs. 10, 12, 13, and 14) have indicated that an ISI program should be based on a real-time, multiple-strategy approach (i.e., appropriate grout design and installation, installed instrumentation, periodic pressure tests, and visual examination) for assuring the safe performance of the containment. The strategy should also incorporate the monitoring of reference test tendons that are left ungrouted to help evaluate changes in the concrete structure. An ISI program should therefore include the following three elements.

## 1. Force Monitoring of Ungrouted Test Tendons

Some tendons (otherwise identical) are left ungrouted and are protected from corrosion with grease. The changes observed in these tendons are not intended to represent the changes resulting from environmental or physical effects (with respect to corrosion) in the grouted tendons; instead, these test tendons are used as reference tendons to evaluate the extent of concrete creep and shrinkage and relaxation of the tendon steel.

The measurement of forces in ungrouted test tendons provides a quantitative means of verifying the design assumptions with regard to prestress losses due to volumetric changes in concrete and the relaxation of prestressing steel. If some lift-off readings indicate values lower than the expected lower bound values, the licensee should determine whether such values are caused by the corrosion of the wires of ungrouted tendons or by an underestimation of prestressing losses. These tendons may also serve as an investigative tool for assessing the structural condition of the concrete containment after certain incidents that could affect the containment.

## 2. Monitoring Alternatives for Performance of Grouted Tendons

This guide includes the force monitoring of ungrouted test tendons and the tendon performance assessment accomplished using either of two acceptable methods for inspecting containment structures with grouted tendons: (1) an ISI program based on monitoring the prestress level using instrumentation and on periodic pressure testing of the containment structure or (2) an ISI program based on periodic pressure testing the containment structure. For both methods, periodic pressure tests are needed, and a pressure test should be performed at 1, 3, and 5 years during the initial 5 year life of the containment structure. The frequency of pressure tests after the initial 5-year period is determined by the particular method selected.

*Monitoring Containment Prestress Level using Instrumentation and Pressure Testing (Alternative A)*

A combination of the following two methods should be used to monitor the prestressing force imparted to the containment structure by a grouted tendon system:

1. monitoring the tensile strains in the wires of a grouted tendon; and
2. evaluating the prestress level at a section in the containment structure from readings of appropriately located strain gauges or strain or stress meters at the section (Refs. 7, 8, 12, 15, 16, and 17).

Method 1 above is useful for the direct monitoring of prestressing force in a tendon. However, this method requires careful attention during the installation of the strain-measuring instrumentation and the grouting of the tendons. An allowance for the relaxation of prestressing steel can be based on relaxation data for the prestressing steel used.

For both methods above, an evaluation of strain gauge and vibrating wire responses and stress meter readings requires a complete understanding of the contributing factors to the observed response (e.g., elastic shortening, shrinkage, creep, and thermal strain or stress components). Strain gauge readings will comprise contributions from elastic strains that correspond to the prestressing stress in concrete and from strains that result from creep and shrinkage of concrete. Strains from the creep and shrinkage of concrete can vary between 1.5 and 2.5 times the elastic strains in concrete. However, the licensee can use specific methods, including the following, to isolate contributions from these effects:

- Estimate average creep and shrinkage strains from the time-dependent losses measured on the ungrouted tendons.
- Use stress meters at sections where strain gauges are used.
- Use special strain meters that respond only to volumetric and temperature changes in concrete (Ref. 18).

The number of instruments and their locations play a critical role in ensuring an effective prestress monitoring program. Instrumentation should be installed in sufficient numbers at strategic locations in the containment structure so that loss in prestress levels can be detected. For example, if corrosion occurs at locations away from the instrumented sections, the corrosion would have to spread to the location within the instrument sensing area before the instrumentation readings would detect the degradation.

A sufficient number of temperature sensors or thermocouples installed at the sections where a strain-measuring instrument is located can be useful in isolating the thermal effects. The raw instrument readings can be deceptive, and adjustments may be necessary to account for the calibration constants and temperature effects. The interpretation and evaluation of the results will be simplified if the instrument is located at sections away from structural discontinuities. Licensees should provide sufficient redundancy in the instrumentation to evaluate anomalous readings and to isolate a malfunctioning measurement gauge.

After appropriate methods and instruments are employed for measurement, the measured data should be analyzed to determine an average stress and an average prestressing force at a section. Even though the predicted prestressing force that corresponds to a specific time may adequately consider the creep of concrete and the relaxation of prestressing steel, the likelihood is small that the measured value will compare well to the predicted value. Hence, a band of acceptable prestress levels similar to that illustrated in Figure 1 should be established. The bandwidth should not exceed 8 percent (Appendix B of Ref. 19) of the initial prestressing force at a section after considering the loss resulting from elastic shortening, anchorage takeup, and friction. The 8-percent bandwidth approximately corresponds to between 40 and 60 percent of the total time-dependent losses, which the staff has found to provide sufficient margin (Ref. 19).

The performance of installed instrumentation should be evaluated during all pressure tests. Many of these instruments must be initially built into the structure in such a manner that the licensee cannot replace or recalibrate them. As discussed previously in this section of the guide, available instrumentation has remained functional 65 to 90 percent of the time over a 10 to 25 years observation period. Hence, under this alternative, the interval between pressure tests following the initial 5 year interval should not exceed 10 years (Ref. 20 and Figure 2). However, if at any time the instrumentation does not remain functional, then containment integrity must be monitored using the method in Alternative B, including the performance of pressure tests every 5 years.

*Monitoring Containment Deformation during Pressure Tests (Alternative B)*

Testing the containment under pressure and evaluating its elastic response is an acceptable means of assessing the integrity of the containment. The elastic response under pressure testing is primarily a function of the stiffness of the structure. Prestressing steel is designed and used to control the extent and width of cracks under accident pressure load. Any significant decrease in the stiffness of the structure because of a loss of prestress could result in cracking of the structure under pressure. Under this alternative, after the initial 5 year period, pressure tests should be performed every 5 years.

Because of the insensitive and indirect relationship between the prestressing force and the elastic response of the structure, this method does not directly establish the existing prestress level in various sections. However, a basis for evaluating the functionality of the structure can be obtained by comparing the condition and deformation of the structure resulting from ISI pressure testing to those resulting from the pressure testing conducted during the Initial Structural Integrity Test (ISIT) . The NRC staff has accepted this method previously[1] on the condition that the design of the containment has sufficient margin, as required by the design criteria, such that no cracking (or only slight cracking at the discontinuities) will occur under the required peak test pressure. Division 2, “Code for Concrete Reactor Vessels and Containments,” of Section III, “Rules for Construction of Nuclear Power Plant Components,” of the ASME Code, also known as American Concrete Institute (ACI) Standard 359 (Ref. 21), permits an increase in the allowable stress in tensile reinforcement under a test condition. The NRC staff has accepted this allowance provided that it is only a one-time loading (i.e., during the ISIT). However, if the licensee performs such testing a number of times during the life of the containment structure, it should not use this allowance to avoid or minimize the gradual propagation of cracking during subsequent pressure tests.

The locations selected to measure deformation during the pressure test should ensure that measurements will be useful. For a meaningful comparison of the deformations, the locations where the deformations are to be recorded should have deformations greater than 1.5 millimeters (0.06 inches) under the calculated peak containment internal pressure associated with the design-basis accident, and these locations should be approximately the same during the ISIT and the subsequent ISIs. Thus, these locations should be away from the areas of structural discontinuities.

[1] The NRC accepted this method for Three Mile Island Nuclear Station, Unit 2, which is permanently shut down.

If an analysis of the effects of parameters such as (1) normal losses in prestressing force, (2) increases in the modulus of elasticity of concrete with age, and (3) differences in temperatures during various pressure tests indicate that they could affect the deformations of the selected locations, the evaluation that compares the deformations during various pressure tests should consider these parameters as well.

**3. Visual Examination**

A visual examination of structurally critical areas should be conducted consisting of the areas of structural discontinuities and the areas of heavy stress concentration (e.g., load points, support locations, connections, changes of geometry, and changes of section). Furthermore, a visual examination of concrete and tendon anchorage should be performed in accordance with the provisions of ASME Code, Section XI, Subsection IWL, factoring in the considerations discussed in this guide. ACI 201.1R "Guide for Making a Condition Survey of Concrete in Service" (Ref. 22), provides acceptable guidance for reporting the condition of concrete.

Numerous examples exist on the use of the sonic pulse velocity technique to obtain information concerning the general quality of concrete. Based on operational experience and experimental data (Refs. 23-25), a pulse velocity of 4,500 meters per second (14,760 feet per second) or greater indicates good to excellent concrete quality. However, for normal weight concrete, a pulse velocity of 4,000 meters per second (13,120 feet per second) or lower could indicate concrete of questionable quality, so additional verification of mechanical properties beyond a visual examination may be needed (e.g., impact hammer or pullout test). Thus, the technique provided in Reference 26 can be used as part of the inspection of concrete containment structures when the visual examination reveals the presence of a high density of wide (greater than 0.25 millimeter (0.01 inch)) cracks or otherwise heavy degradation.

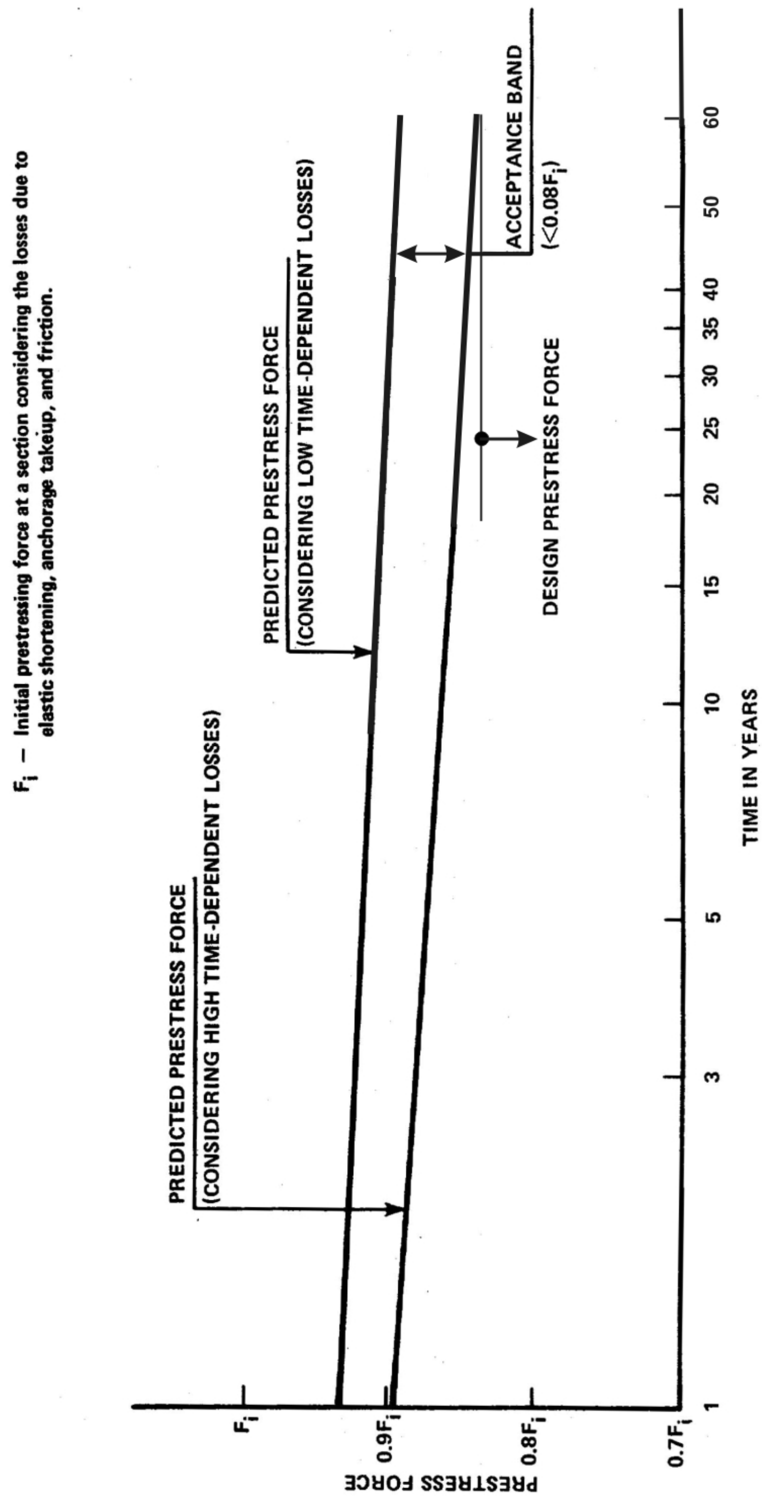



**Figure 1 Typical band of acceptable prestress levels**

# C. STAFF REGULATORY GUIDANCE

## 1. General

a All prestressed concrete containment structures with grouted tendons should be subjected to an ISI program, consistent with the requirements of GDC 53 and 10 CFR 50.55a.

b The specific guidelines provided in this section are for the "reference containment" sphere-torus dome containment with cylindrical walls described in Section B and the Glossary of this guide. For containments that differ from the reference containment, the program described in this section may serve as the basis for developing a comparable ISI program. Appendix A to this guide offers general guidelines for the development of such a program.

c If the containment foundation is prestressed, the NRC staff will evaluate the licensee's proposed ISI program on a case-by-case basis as part of a license application review.

## 2. The ISI program should consist of the following three elements:

1. force monitoring of ungrouted test tendons,
2. monitoring the prestress level using instrumentation and pressure testing (Alternative A) or monitoring deformation under pressure (Alternative B), and
3. visual examination.

2.1 Force Monitoring of Ungrouted Test Tendons

a. The following ungrouted test tendons should be installed in a representative manner if applicable:

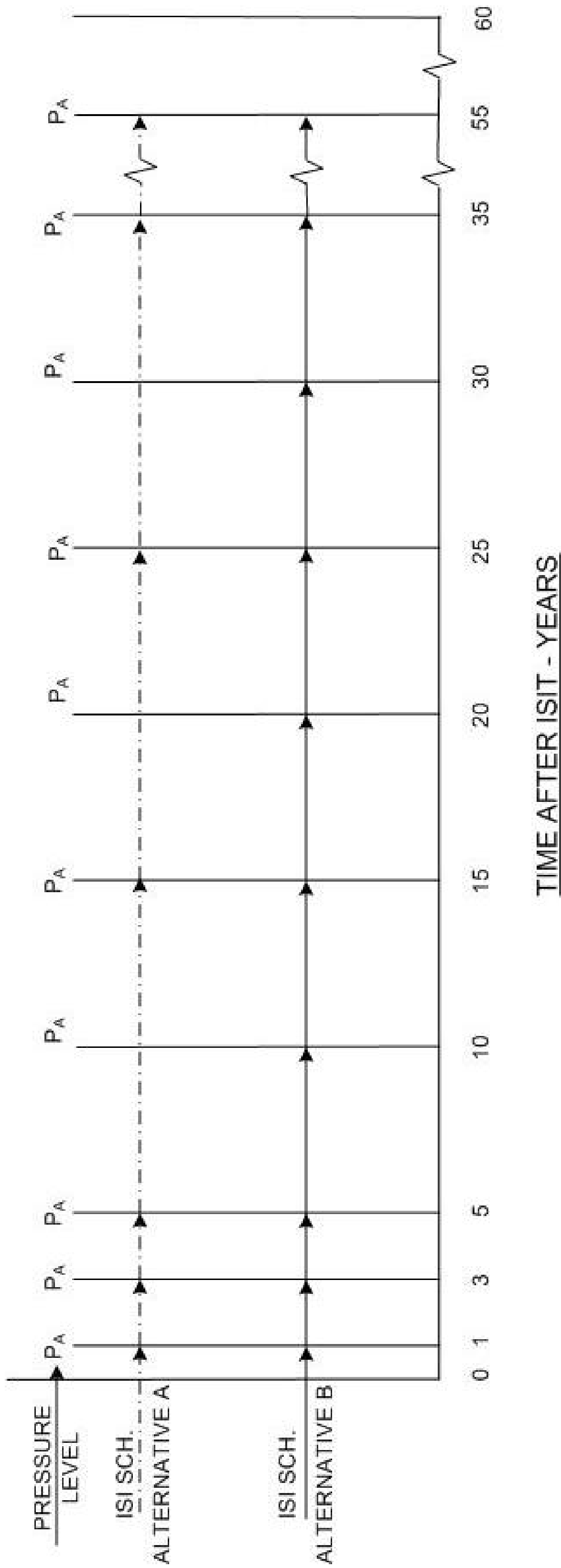
(1) three vertical tendons,
(2) three hoop tendons,
(3) three dome tendons for the design using three 60-degree families of tendons, and
(4) four gamma tendons for the design using two 90-degree families of tendons.

b. The ungrouted test tendons and their anchorage hardware should be identical to the grouted tendons and their hardware.

c. The ungrouted test tendons should be subjected to force measurement by lift-off testing or an equivalent test to assess the effects of concrete shrinkage and creep and the relaxation of the tendon steel using the Alternative B schedule in figure 2. ASME Code, Section XI, Subsection IWL (Ref. 2) provides details for how to inspect greased tendons. The greased (ungrouted) tendons should not be detentioned normally. The licensee should evaluate these data in conjunction with the overall structural condition of the containment evident from the other direct examinations.

2.2 Monitoring Alternatives for Performance of Grouted Tendons

This guide provides two alternative methods for monitoring the performance of containment with grouted tendons. The first method uses installed instrumentation to monitor the containment prestress level, and the second method measures containment deformation when under pressure.




KEY

$P_A$ – Calculated Peak Internal Pressure Associated with the Design Basis Accident
$P_D$ – Containment Design Pressure

ILRT – Integral Leak Rate Testing

ISIT – Initial Structural Integrity Testing

ISI – Inservice Inspection

Note:
1. Visual examinations and examination of ungrouted tendons should follow the schedule and method of ASME Section XI, IWL-2400 and IWL-2500.
2. During the ISIT, instrument readings should be taken at both the test pressure ($1.15P_D$) as well as $P_A$. $P_A$ readings should be also taken during the preoperational ILRT. These $P_A$ readings will provide a reference for future data comparison.
3. The grace period as stated in ASME Section XI, IWL-2410 (b) and (c) is acceptable, however not shown in the Figure above for simplification

**Figure 2 Schedules for ISIs (Alternative A and Alternative B)**

For both methods, periodic pressure tests are needed, and a pressure test should be performed at 1, 3, and 5 years during the initial 5-year period following the ISIT. The frequency of pressure tests after the initial 5-year period is every 5 years for Alternative B, and every 10 years for Alternative A if instrumentation to monitor prestress levels remains functional. This is shown in Figure 2.

2.2.1 Monitoring Containment Prestress Level using Instrumentation and Pressure Testing (Alternative A)

*2.2.1.1 Installation of Instrumentation*

a. The prestressed cylindrical wall and dome should be instrumented for stress and strain measurements. The licensee should select the instrument types, locations, and quantities to provide the best representation of the prestress level in the structure. The licensee should also install a sufficient number of temperature sensors or thermocouples to isolate and evaluate the effects of variations in temperature gradients on the instrument readings. Redundancy of the embedded instrumentation should be based on a conservative estimate of the probability of a malfunction of the instrumentation to be installed.

b. The licensee should arrange and distribute the instruments in the concrete in such a manner as to permit the evaluation of the prestressing levels and should locate them as follows if applicable:

(1) at horizontal planes to measure the hoop prestressing levels,
(2) parallel to vertical tendons to measure vertical prestress levels,
(3) parallel to dome tendons for the design using three families of 60-degree tendons, and
(4) parallel to gamma tendons for the design using two families of 90-degree tendons.

c. At the horizontal, vertical, and dome sections, the licensee should monitor the prestress levels using a combination of various types of instruments to measure stress, strain, temperature, pressure, and other parameters in concrete, rebar, and tendons. For a containment that is similar to the reference containment, the industry has used approximately 250 to 300 instruments (Ref. 7). Figure 3 delineates the minimum requirements of the typical planes and tendons for pressure testing. These minimum locations (area) need a very large redundancy to confirm measurement error, to detect any abnormal structural behavior if suspected, and to manage durability of the instruments. These local instruments are complemented by other devices, such as invar wire located near the "minimum areas" for validation.

*2.2.1.2 Characteristics of Instrumentation*

a. Instruments used to determine the concrete prestress level should have the capability of being effectively used over the life of the containment structure within specified operational limits under the following conditions, unless otherwise defined by the designer and approved by the NRC staff:

(1) humidity: 0 to 100 percent, (2) temperature: -18 degrees Celsius (0 degrees Fahrenheit) to 93 degrees Celsius (200 degrees Fahrenheit), and (3) cyclic loading: 500 cycles of 4.2 megapascals (600 pounds per square inch) stress variation in compression

b. The licensee should protect the instruments against adverse effects of the expected environment (e.g., electrolytic attack, including the effects of stray electric currents of a magnitude that may be encountered at the particular site and structure). These instruments should be protected from potential temperature extremes while the containment is under construction.

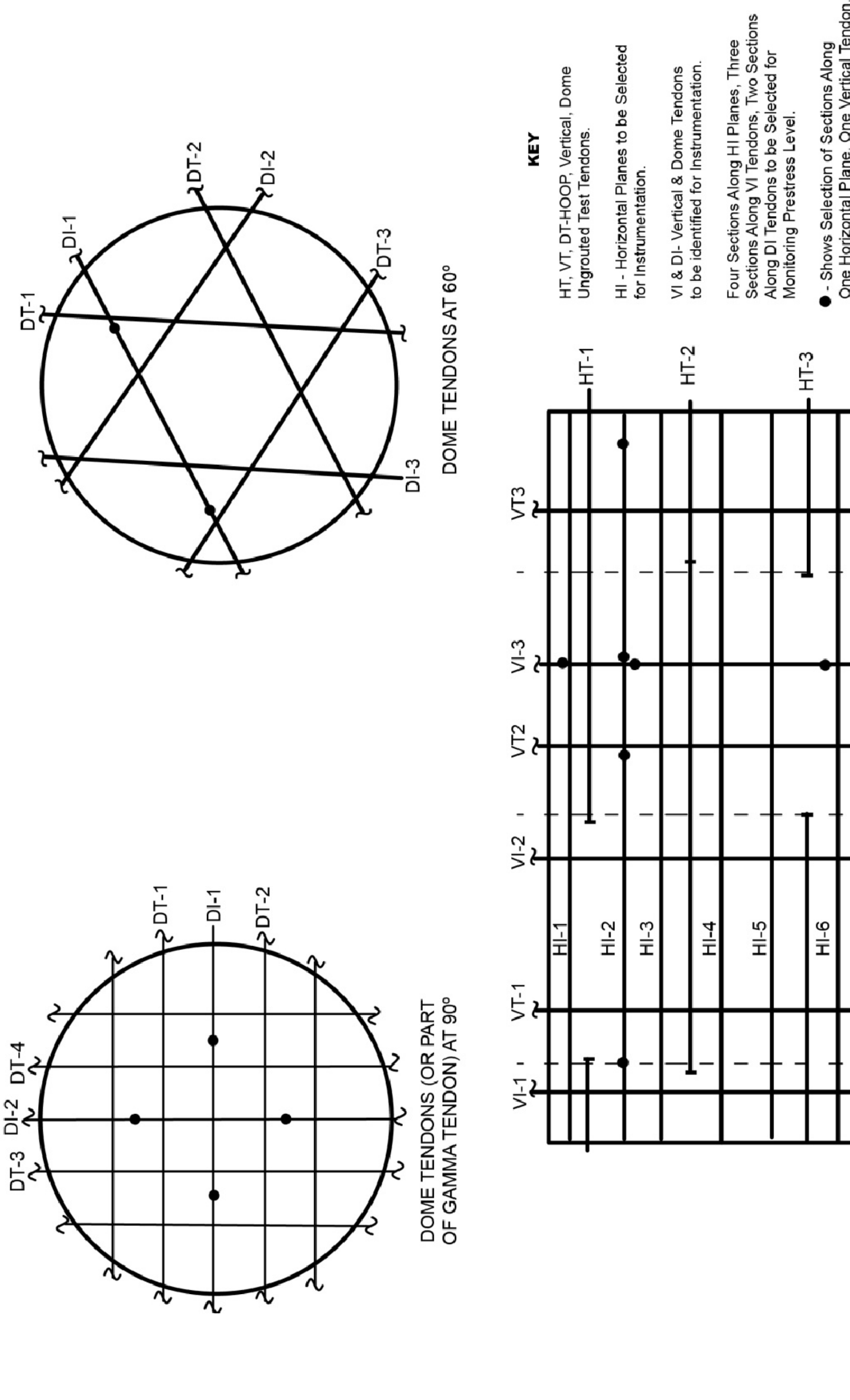



**Figure 3 Containment diagram showing typical locations of test tendons and instrumentation**

c. The licensee should specify the sensitivity of the strain gauges. The licensee should account for the drift or the stability, under the conditions in a and b above, in the specified limits or should recalibrate the gauges in service.

d. The stress meters should be able to measure compressive stresses up to 17.2 megapascals (2,500 pounds per square inch).

*2.2.1.3 Monitoring Instrumentation Functionality*[2]

a. After the installation of the instrument, the licensee should collect the readings of all embedded instruments continuously. The licensee should interpret (review recorded data to determine prestress level) the readings every 2 months until it performs the ISIT. The response of the instrumentation during prestressing and pressure testing (ISIT) should be used to confirm its functionality. After the ISIT, the licensee should continue monitoring the instrumentation and interpret the readings every 2 months to reconfirm its functionality until the first ISI. Thereafter, it may reduce the interpretation frequency to once every 6 months, unless local conditions or special circumstances dictate more frequent monitoring. The functionality of the instrument should also be confirmed during subsequent pressure tests. If the licensee obtains anomalous readings, it should determine the reason for such readings. If the licensee determines that the anomalous readings result from defective gauges, it should justify the basis for such a determination.

b. To provide an initial baseline, during the ISIT, instrumentation readings should be recorded corresponding to both the test pressure ($1.15P_D$) as well as $P_A$. The instrument readings corresponding to $P_A$ should also be recorded during the preoperational integrated leak rate testing (ILRT).

*2.2.1.4 Monitoring Deformation under Pressure*

In addition to monitoring containment prestress level using instrumentation, containment performance should also be verified periodically by measuring containment deformation under pressure. This periodic verification is the same as conducted under Alternative B, but after the initial ISI at 1-, 3-, and 5-year intervals, a licensee may relax the frequency of pressure testing to 10 years as shown in Figure 2 if the installed instrumentation is functional and effective at monitoring prestress level in the concrete. However, if at any point during the life of the structure, the installed instrumentation is not considered functional and effective at monitoring containment prestress level, the licensee should substitute Alternative B for Alternative A

2.2.2 Monitoring Containment Deformation under Pressure Tests (Alternative B)

*Pressurization*

During the pressure tests, the containment structure should be subjected to a maximum internal pressure equal to the calculated peak internal pressure associated with the postulated design-basis accident, $P_A$ (Figure 2).

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2 The term "functionality" is used in lieu of "operability"; the latter is a term used for the systems in plant technical specifications

*Instruments and Deformations*

a. The licensee should install instruments similar to those used during the ISIT before pressure testing of the structure to obtain a measurement of the overall deformations at the selected points.

b. An error band should specify the limit of the accuracy of the readings of the instruments to be used to obtain a meaningful comparison of the deformations measured during the ISIT and ISI.

c. The licensee should determine the locations for mounting the instruments used to measure the radial displacements in six horizontal planes in the cylindrical portion of the shell with a minimum of four locations in each plane (see Figure 3).

d. The licensee should determine the locations for mounting the instruments used to measure the vertical (or radial) displacements as follows:

(1) at the top of the cylinder relative to the base at a minimum of four approximately equally spaced azimuths, or
(2) at the apex of the dome and one intermediate location between the apex and the springline on at least three equally spaced azimuths.

e. The intermediate pressure levels at which the deformations at the selected locations will be measured should correspond to those for the ISIT.

f. To provide an initial baseline, during the ISIT, instrumentation readings for deformation should be recorded corresponding to both the test pressure ($1.15P_D$) as well as $P_A$. The instrument readings corresponding to $P_A$ should also be recorded during the preoperational ILRT.

## 2.3 Visual Examination

2.3.1 Visual examinations should be performed in accordance with the provisions of ASME Code, Section XI, Subsection IWL, as modified by Staff Regulatory Guidance C.2.3.2 and C.2.3.3, below.

2.3.2 Structurally Critical Areas

a. The licensee should perform a visual examination of the following exposed, structurally critical areas:

(1) areas at structural discontinuities (e.g., junction of the dome and cylindrical wall or the wall and basemat),
(2) areas around large penetrations (e.g., equipment hatch and airlocks) or a cluster of small penetrations,
(3) local areas around penetrations that transfer high loads to the containment structure (e.g., around high-energy fluid system lines),
(4) other areas where heavy loads are transferred to the containment structure (e.g., crane supports), and
(5) areas of high predicted stresses under the critical design-basis load combinations.

b. During all pressure tests, the licensee should conduct a visual examination of structurally critical areas as identified when the containment is at its maximum test pressure, even if the licensee has conducted visual examinations of these areas at other times.

### 2.3.3 Anchorage Assemblies

a. The licensee should visually examine exposed portions of the tendon anchorage assembly hardware or the permanent protection thereon (whether it be concrete, grout, or a steel cap) by sampling in the following manner if applicable:

   (1) a minimum of six dome tendons, two of which are located in each 60-degree group (three families of tendons), randomly distributed to provide representative sampling,
   (2) a minimum of five vertical tendons randomly, but representatively, distributed,
   (3) a minimum of 10 hoop tendons randomly, but representatively, distributed, and
   (4) a minimum of six gamma tendons, three of which are located in each 90-degree group (two families of tendons), randomly distributed to provide representative sampling.

b. For each succeeding examination, the licensee should select tendon anchorage areas that it will examine on a random, but representative basis so that the sample group will change each time.

c. The ISI program should define the defects that the inspector should look for during his or her visual examination of the exposed anchor hardware and the protection medium and should establish the corresponding limits and tolerances. The licensee should pay special attention to the concrete that supports the anchor assemblies and should evaluate any observed crack patterns at these locations.

## 3 Reportable Conditions

The conditions listed below could indicate a possible abnormal degradation of the containment structure. The licensee should report any such conditions to the Commission in accordance with the plant technical specifications contained in the license, as required to meet 10 CFR 50.36, “Technical Specifications,” paragraph (c)(5), “Administrative Controls.”

### 3.1 Monitoring of Ungrouted Test Tendons

The force monitoring (by lift off or equivalent test) of ungrouted test tendons indicates a prestress force below the acceptable band (see Figure 1).

### 3.2 Inspections Using Alternative A

a. The average prestress force in the direction of the tendon (post-tensioning direction) falls below the acceptable band (see Figure 1).

b. The prestress force determined at any section falls below the design prestress force.

c. The deformation measured under the maximum test pressure at any location exceeds 5 percent of that measured during the ISIT under the same pressure. The 5-percent allowance is in excess of acceptable instrument tolerance.

### 3.3 Inspections Using Alternative B

The deformation measured under the maximum test pressure at any location exceeds 5 percent of that measured during the ISIT under the same pressure. The 5-percent allowance is in excess of acceptable instrument tolerance.

3.4 Visual Examinations

a. Any crack pattern observed at the structurally critical areas, which indicates a significant decrease in the spacing, or an increase in the widths of cracks compared to those observed during the ISIT at zero pressure after depressurization.

b. The anchor hardware indicates obvious movement or degradation of the anchor hardware.

c. The anchor hardware is covered by permanent protection and the visual examination reveals a degradation (e.g., extensive cracks or corrosion stains) that could potentially challenge the integrity and effectiveness of the protection medium.

## D. IMPLEMENTATION

The purpose of this section is to provide information on how applicants and licensees[3] 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[4] use the guidance in this document to demonstrate compliance with the underlying NRC regulations. Methods or solutions that differ from those described in this regulatory guide may be deemed acceptable if they provide sufficient basis and information for the NRC staff to verify that the proposed alternative demonstrates compliance with the appropriate NRC regulations. Current licensees may continue to use guidance the NRC found acceptable for complying with the identified regulations as long as their current licensing basis remains unchanged. The acceptable guidance may be a previous version of this regulatory guide.

Licensees may use the information in this regulatory guide for actions which do not require NRC review and approval, such as changes to a facility design under 10 CFR 50.59, "Changes, Tests and Experiments." Licensees may use the information in this regulatory guide or applicable parts to resolve regulatory or inspection issues. This regulatory guide is not being imposed upon current licensees and may be voluntarily used by existing licensees.

**Use by NRC Staff**

The staff may discuss with licensees, various actions consistent with staff positions in this regulatory guide, as one acceptable means of meeting the underlying NRC regulatory requirement. Such discussions would not ordinarily be considered backfitting even if prior versions of this regulatory guide

[3] In this section, "licensees" refers to licensees of nuclear power plants under 10 CFR Parts 50 and 52; and the term "applicants," refers to applicants for licenses and permits for (or relating to) nuclear power plants under 10 CFR Parts 50 and 52, and applicants for standard design approvals and standard design certifications under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 28).

[4] In this section, "voluntary" and "voluntarily" means that the licensee is seeking the action of its own accord, without the force of a legally binding requirement or an NRC representation of further licensing or enforcement action.

are part of the licensing basis of the facility. However, unless this regulatory guide is part of the licensing basis for a facility, the staff may not represent to the licensee that the licensee's failure to comply with the positions in this regulatory guide constitutes a violation.

If an existing licensee voluntarily seeks a license amendment or change 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 the staff may request that the licensee either follow the guidance in this regulatory guide or provide an equivalent alternative process 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.

The NRC staff does not intend or approve any imposition or backfitting of the guidance in this regulatory guide. The NRC staff does not expect any existing licensee to use or commit to using the guidance in this regulatory guide, unless the licensee makes a 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. Examples of such unplanned NRC regulatory actions include 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 backfit consideration.

Additionally, an existing applicant may be required to adhere to new rules, orders, or guidance if 10 CFR 50.109(a)(3) applies.

If a licensee believes that the NRC is either using this regulatory guide or requesting or requiring the licensee to implement the methods or processes in this regulatory guide in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfit appeal with the NRC in accordance with the guidance in NUREG-1409, "Backfitting Guidelines" and NRC Management Directive 8.4, "Management of Facility-specific Backfitting and Information Collection".

# GLOSSARY

**controlled environment —**Where the possibility of corrosion does not exist at any time during construction and operation.

**elastic shortening—**When the steel is pretensioned, a reduction of the initial stress in the steel occurs at the transfer of the prestressing force since, as soon as the concrete is compressed, an elastic shortening of the concrete takes place. This is accompanied by an equal reduction in the length of the steel, with a consequent reduction in the initial prestress. Regulatory Guide 1.35.1, "Determining Prestressing Forces for Inspection of Prestressed Concrete Containments" (Ref. 19), provides guidance for calculating the elastic shortening.

**reference containment —** A sphere-torus dome containment with cylindrical walls that are up to 50 meters (165 feet) in diameter and that have an overall height up to 67 meters (220 feet) with three groups of tendons (i.e., hoop, vertical, and dome or gamma).

**vibrating wire strain gauge—**Devices whose natural period is modified in case of concrete deformation (contraction or dilation) (Ref. 8).

# REFERENCES[5]


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2. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Division 1, "Rules for Inspection and Testing of Components of Light-Water-Cooled Plants," Subsection IWL, "Requirements for Class CC Concrete of Light-Water-Cooled Plants" (as incorporated by reference into 10 CFR 50.55a), American Society of Mechanical Engineers, New York, NY.[6]

3. Regulatory Guide 1.90, Revision 1 (August 1977), "Inservice Inspection of Prestressed Concrete Containment Structures with Grouted Tendons," U.S. Nuclear Regulatory Commission, Washington, DC.

4. IAEA Safety Guide NS-G-1.10, "Design of Reactor Containment Systems for Nuclear Power Plants," September 2004.[7]

5. IAEA Safety Guide NS-G-2.6, "Maintenance, Surveillance, and In-service Inspection in Nuclear Power Plants," October 2002.[6]

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[5] Publicly available NRC published documents are available electronically through the NRC Library on the NRC's public web site at: http://www.nrc.gov/reading-rm/doc-collections/. The documents can also be viewed on-line or printed for a fee in 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.

[6] Copies of American Society of Mechanical Engineers (ASME) standards may be purchased from ASME, Three Park Avenue, New York, NY 10016-5990; telephone (800) 843-2763. Purchase information is available through the ASME Web-based store at http://www.asme.org/Codes/Publications/.

[7] Copies of International Atomic Energy Agency (IAEA) documents may be obtained through the organization's Web site: www.IAEA.org/ or by writing to the International Atomic Energy Agency, P.O. Box 100, Wagramer Strasse 5, A-1400, Vienna, Austria. Telephone (+431) 2600-0, Fax (+431) 2600-7, or E-Mail at Official.Mail@IAEA.Org.

[8] Copies of OECD publications may be purchased from the Organisation for Economic Co-operation and Development, Nuclear Energy Agency, Paris, France, telephone (33-1) 44 07 47 70 (OECD Publications, 2, rue Andre-Pascal, 75775 Paris Cedex 16, France).

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[10] A copy of this publication can be purchased from RILEM Publications Sarl, the Publication Company of RILEM, F-94235 Cachan Cedex, France; fax (33-1) 47 40 01 13; and e-mail sg@rilem.ens-cachan.fr.

[11] Copies of the Center for Transportation Research publications can be purchased at the Center for Transportation Research, University of Texas at Austin, Austin, TX; telephone (512) 232-3126; and e-mail ctrlib@uts.cc.utexas.edu.

[12] Copies of U.S. Department of Transportation publications can be purchased from Turner-Fairbank, Highway Research Center, 6300 Georgetown Pike, McLean, VA 22101-2296; e-mail www.tfhrc.gov.

[13] Copies may be obtained from the Bureau of Reclamation, Denver Federal Center, Denver, CO.

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[17] Copies of American Concrete Institute (ACI) publications may be purchased from ACI, P.O. Box 9094, Farmington Hills, MI 48333; telephone (248) 848-3700; fax (248) 848-3710. Purchase information is available through the ACI Web site at http://www.concrete.org.

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# APPENDIX A

# GUIDELINES FOR DEVELOPING THE INSERVICE INSPECTION PROGRAM FOR CONTAINMENTS WITH GROUTED TENDONS

## A-1. Ungrouted Tendons

Three ungrouted tendons should be provided in each type of tendon. The tendon type is defined by its geometry and position in the containment.

### A-2. Monitoring the Prestress Level and Pressure Testing (Alternative A)

The following criteria should be used to determine the number of sections (N) to be monitored for each group of tendons:

$$N = \frac{\text{Actual Area Prestressed by a Group of Tendons}}{\text{K} \times \text{Area Monitored by a Set of Instruments at a Section (determined as } S \times L)},$$

where

S = spacing of tendons in meters (feet),

L = length of a tendon monitored by a set of instruments (may be considered as 3.66 meters (12 feet)), and

K is determined as follows:

a. For containments that are under an uncontrolled environment and that have continuous tendon curvature, $K \leq 100$.
b. For containments that are under an uncontrolled environment and that have essentially straight tendons, $K \leq 160$.
c. For containments that are under a controlled environment and that have either straight or curved tendons, $K \leq 200$.

For periodic pressure testing of the containment, follow the guideline provided in Section A-3.

## A-3. Monitoring Deformation under Pressure (Alternative B)

The number of locations (N) to be selected for measuring the deformations under pressure should be determined as follows:

a. For radial deformations of the cylinder,

$$N = \frac{\text{Surface Area of Cylinder in Square Meters (Square Feet)}}{250\,(2{,}700)},$$

but not less than 12.

b. For vertical deformations of the cylinder, $N = 4$.

c. For radial or vertical deformations of the dome,

$$N = \frac{\text{Surface Area of Dome in Square Meters (Square Feet)}}{250\ (2{,}700)},$$

but not less than 4.