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NRC INFORMATION NOTICE 99-10: DEGRADATION OF PRESTRESSING TENDON SYSTEMS IN PRESTRESSED CONCRETE CONTAINMENTS

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Addressees

All holders of operating licenses for nuclear power reactors.

Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice to alert addressees to degradation of prestressing systems components of prestressed concrete containments (PCCs). The specific items addressed are (1) prestressing tendon wire breakage, (2) the effects of high temperature on the prestressing forces in tendons, and (3) trend analysis of prestressing forces. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. However, suggestions contained in this information notice are not NRC requirements; therefore, no specific action or written response is required.

Description of Circumstances

Results of inspections of PCCs and PCC tendons have identified a number of concerns related to the degradation of prestressing tendon systems in PCCs and the ability of the containment structure to perform its function. The relevant findings associated with these concerns are discussed below.

Prestressing Tendon Wire Breakage

Recent observations related to containment prestressing systems have revealed conditions that may precipitate tendon wire breakage. Conditions such as uneven shim stack heights on the anchor-heads, spalling and cracking of concrete beneath the anchor-head base plates, free water in the bottom grease caps, poorly drained top anchorage ledges, and the absence of filler grease in various areas can lead to corrosion of tendons and eventually to wire breakage. Specific plant observations and instances of failure of tendons and associated anchorages are detailed in Attachment 1.

Effects of High Temperature on the Prestressing Forces in Tendons

Licensees at a number of plants have reported lower than predicted prestressing forces for vertical, hoop, and dome tendons. Investigations and analyses have indicated that the prestressing tendon relaxation losses range from 15.5 to 20 percent over 40 years at an average sustained temperature of 32 °C (90 °F) around the tendons. However, the tendon relaxation loss values used in PCCs vary between 4 to 12 percent. These values were determined at the presumed ambient temperature of 20 °C (68 °F). The relevant plant observations and discussions are reported in Attachment 2.

Comparison and Trending of Prestressing Forces

The use of the provisions of Regulatory Guide 1.35.1 ("Determining Prestressing Forces for Inspection of Prestressed Concrete Containments") or equivalent methods are important to maintaining the safety function of the prestressing tendon system and the concrete containment. Moreover, proper comparison and trending analysis is critical in determining the future trends in prestressing force in PCCs. Licensees have reported losses using the average forces determined from the liftoff testing, thereby masking the true variation in the loss of prestressing forces. An analysis using the individual lift-off forces for regression analysis gives results that are statistically valid. Attachment 3 contains the staff's discussion of the variation in trend analysis of tendon prestressing forces.

Discussion

As nuclear power plants continue to age, in particular, plants with a PCC, the management and mitigation of effects of degradation as a result of aging become increasingly more important. The containment structure serves as the final barrier against the release of fission products to the environment under postulated design-basis accident conditions. Therefore, it is essential that its integrity be maintained. Focus on the prestressing tendon system for containment integrity is based on the vital role it plays. However, other components that make up the system also need to be examined. The observations detailed in the three attachments, and the observations made during the Oconee site visit (see Attachment 1), indicate that other contributions to the degradation of containment could potentially compromise its effectiveness.

PCC degradations, such as concrete spalling, water infiltration into tendon galleries, and concrete cracking in the containment and the containment dome, all affect the containment's ability to function properly. It remains important to ensure that the cumulative effects of degradation mechanisms do not compromise the safety of the containment. The attributes discussed in the three attachments will be useful in identifying the potential problem areas and in evaluating the results of the inservice inspections of containments.

This information notice requires no specific action or written response. However, recipients are reminded that they are required to consider industry-wide operating experience (including NRC information notices), where practical, when setting goals and performing periodic evaluations under Section 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," of Part 50 of Title 10 of the Code of Federal Regulations. If you have any questions about the information in this notice, please contact one of the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

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Attachments:
1. Prestressing Tendon Wire Breakage
2. Effects of High Temperature on the Prestressing Forces in Tendons
3. Comparison and Trending of Prestressing Forces
4. List of Recently Issued Information Notices

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ATTACHMENT 1

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Prestressing Tendon Wire Breakage

During the 20th-year surveillance of the prestressing system of Calvert Cliffs Nuclear Power Plant, Unit 1, in June-July 1997, the licensee (Baltimore Gas & Electric Company--BG&E) found a low lift-off value compared to the prestressing force for one of the three randomly selected vertical tendons. The low lift-off value was attributed to the uneven shim stack heights on the two opposite sides of the anchor-head. In accordance with the plant's Technical Specifications (TSs) requirement, the licensee tested two additional vertical tendons adjacent to this tendon. However, during the lift-off testing of one of these tendons, noises were heard that indicated that some of the tendon wires might have broken. A visual examination of the tendon indicated that three wires had broken at 12.7-17.2 centimeters (5-7 inches) below the bottom of the button-heads. Further examination of the wires at the top of other vertical tendons revealed additional wire breakage. The licensee expanded the lift-off testing and visual examination to 100 percent of the vertical tendons. Similar degradation of other vertical tendons was found. As a part of its corrective action, the licensee is planning to replace 63 of the 202 vertical tendons in Unit 1 and 64 of the 204 vertical tendons in Unit 2.

NRC's Information Notice 85-10, dated February 1985, and its supplement of March 1985, "Post-Tensioned Containment Tendon Anchor-Head Failure," described prestressing tendon anchor-head failures at both units of the Joseph M. Farley Nuclear Plant. The root cause analysis of that event indicated that there were several factors contributing to it, such as, free water in the grease caps at the bottom of the vertical tendons, high hardness of the anchorage material, and high stresses in the anchor-heads. The failures had resulted from hydrogen embrittlement of the anchor-head material. The free water in the bottom grease caps of the vertical tendons may have accumulated (through a number of years) from the poorly drained top anchorage ledge of the vertical tendons (similar to the condition at the Calvert Cliffs containments). However, at Farley, wire failures did not occur.

In general, American Society for Testing and Materials (ASTM) A-421 ("Uncoated Stress-Relieved Wire for Prestressed Concrete") wires (used at both Farley and Calvert Cliffs) are not susceptible to hydrogen-induced cracking. However, BG&E's engineering evaluation indicated brittle hydrogen-induced cracking on a third of the broken wires. All of the brittle fractures were preceded by severe corrosion. The engineering evaluation also indicates that some of the brittle fractures may have occurred earlier but were not found during the periodic inspections. To ensure that the stressing washers (anchor-heads) are not affected, BG&E visually examined the anchor-heads at both ends of the vertical tendons and found no visible cracks or fractures. The lessons learned from these two events indicate that the prestressing wires and anchor-heads of the button-headed prestressing systems are susceptible to cracking from tensile stress and hydrogen-induced corrosion. The severity and the extent of corrosion depend upon the ability of the moisture to reach unprotected areas, the duration of exposure, and the material characteristics.

In April 1998, the NRC staff visited the Oconee Nuclear Station (OCN) to discuss issues related to the licensee's license renewal technical report. As part of the visit, the staff performed a walkdown inspection of the OCN containments and other structures. The following observations are related to the prestressing system degradations reported by the staff:

- At Tendon 12V6, the concrete beneath the 5.1-centimeter (2-inch) thick anchor-bearing plate had spalled along the outer edge; a cavity existed below the plate. Cracks in the concrete beneath the outer edge of the bearing plates were observed for a number of tendons.
- Tendon grease had leaked from a significant number of hoop tendons in the containments of all three units at OCN.
- The Unit 1 tendon access gallery showed water infiltration and standing water at several locations. The licensee indicated that the Unit 2 tendon access gallery at one time held as much as 51 centimeters (20

inches) of water. The licensee is periodically purging the tendon galleries of all three units to remove water.

The licensee addressed these and similar degradations under the requirements of its TSs or in accordance with Criterion XVI of 10 CFR Part 50, Appendix B.

ATTACHMENT 2

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Effects of High Temperature on the Prestressing Forces in Tendons

In 1979-1980, the licensee of the Robert E. Ginna Nuclear Power Plant, Rochester Gas & Electric Corporation, reported lower than predicted forces for several of the vertical tendons in its partially prestressed containment structure. Extensive analysis and testing performed by the licensee indicated the cause of the consistently lower prestressing forces to be appreciably higher (than estimated) relaxation of prestressing steel as a result of the average high temperatures around the tendons. The 1000-hour and 10,000-hour testing performed at the Fritz Engineering Laboratory of Lehigh University of the wires taken from some of the vertical tendons showed that the 40-year relaxation could be between 15.5 and 20 percent at 32 °Celsius (°C) (90 °Fahrenheit [°F]), an average temperature around the tendons during the summer. The wire relaxation assumed in the design was 12 percent.

During the fourth surveillance of tendon forces in February 1990 at Virgil C. Summer Nuclear Station, the licensee, South Carolina Electric & Gas Co., discovered that the forces in the 115 vertical tendons were lower than expected. Because the wires used in the prestressing tendons were of the same size, type, and relaxation property as those used in the Ginna tendons, the licensee concluded that the reason for low prestressing forces was the higher (than considered) relaxation of prestressing wires. As in the case of the Ginna containment, the average temperature around the tendons was determined to be 32 °C (90 °F). To remedy the situation, the licensee retensioned the vertical tendons at an average lock-off force of 0.685 of the guaranteed ultimate tensile strength of the wires.

During the performance of 20th-year tendon surveillance in November-December 1992 at Turkey Point Station, Units 3 and 4, the licensee, Florida Power & Light Co., found that the measured prestressing forces of a number of randomly selected tendons in both units were appreciably lower than the predicted forces. The lower tendon forces were found in hoop, vertical, and dome tendons. The licensee, with the assistance of its consultant, investigated the root cause and implemented necessary corrective actions. The root cause investigation indicated that the most probable cause for lower prestressing forces (higher prestressing losses) was an increased tendon wire steel relaxation resulting from the sustained high temperatures around the tendons. Analysis of the meteorological data indicated that the average sustained temperatures around the tendons could be estimated as 32 °C (90 °F). The supplier of the prestressing wire had provided 8 percent as the wire relaxation loss at 20 °C (68 °F) and had indicated higher relaxation losses at higher temperatures. In estimating prestressing forces, the utility had used 8 percent of the prestressing force in the tendons as the loss due to relaxation.

Many of the prestressed concrete containments in the United States are typically subjected to average tendon temperatures greater than 32 °C (90 °F) during hot weather or year around. Although only three plants reported lower prestresssing forces (than the predicted) due to higher (than considered in the design) relaxation, this condition may exist at many other plants with PCCs. However, plants may not experience more than projected loss of prestressing force due to (1) conservative estimates of losses in the design, (2) frequent unsystematic retensioning of tendons, (3) improper use of a method of trending measured tendon forces, or (4) a combination of Items (1), (2), and (3).

Regulatory Guide (RG) 1.35.1, "Determining Prestressing Forces for Inspection of Prestressed Concrete Containments" (July 1990), provides a simple method of documenting the installation forces, potential initial losses in the prestressing force, and a method of incorporating the time-dependent losses. The basic concept recommended in the guide is to establish predicted forces for all the tendons at various times since the complete installation of tendons. As the initial elastic shortening losses could vary from tendon to tendon, the individual tendon predicted forces can be tabulated for comparison with the measured lift-off forces.

Sometimes the measured lift-off forces are adjusted to account for the initial elastic shortening loss or the time-dependent losses. This adjustment defeats the purpose of making a correct comparison. Sometimes the measured lift-off force is computed using the effective unbroken wires in the tendon, thus making the comparison inappropriate. Calculation of the average effective wire forces in the tendon from the measured tendon force is made only to ensure that it does not exceed 70 percent of the guaranteed ultimate tensile strength of the wire.

In the United States, the main cause for the lower than predicted prestressing forces has been identified as the high relaxation of the tendon steel. However, in France, where the prestressing tendons are grouted and their prestressing forces could not be directly measured, the cause for the indirectly estimated low prestressing forces has been identified as creep and shrinkage of the containment concrete. The basic creep of the concrete could also be higher (than estimated) at higher temperatures, giving rise to higher loss of the prestressing force. These two effects on prestressing forces could not be separated without substantial research. On the basis of the results of the relaxation tests on the prestressing steel, it appears that the dominant contributing factor is the higher relaxation of the prestressing steel. Nevertheless, the containment integrity has to be demonstrated on the basis of the availability of the minimum required prestressing force.

ATTACHMENT 3

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Comparison and Trending of Prestressing Forces

In 1994, during the 20th-year tendon surveillance of Three Mile Island Nuclear Station, Unit 1 (TMI-1), prestressed concrete containment (conforming to Regulatory Guide [RG] 1.35 [Revision 3]) and TMI-1 Technical Specifications, the licensee, General Public Utilities Nuclear Corporation, subjected a total of 11 tendons (5 hoop, 3 vertical, and 3 dome) to lift-off testing. On the basis of the data from this lift-off testing, in conjunction with data from the previous surveillance tests for each group of tendons, the licensee originally performed a trending analysis for each group of tendons and concluded that none of the tendon groups would go below each group's minimum required force during the 40-year plant life. However, the licensee subsequently performed a linear regression analysis using individual lift-off forces rather than the average of the lift-off forces and found that the hoop tendons would go below the minimum required force beginning in the 25th year.

The licensee of the Oconee Nuclear Station, Duke Power Company, performed the sixth tendon surveillance on Oconee Unit 3 in the summer of 1995. The licensee, using the averages of the lift-off forces obtained to that date, plotted them on a graph on which the predicted upper bound and lower bound are shown and concluded that the mean lift-off force for each group fell below the required values (i.e., the lower bound). A subsequent trending analysis on the basis of individual lift-off forces indicated that the dome tendon force began to go below the minimum required force about 8 years after the structural integrity test (SIT). For other tendon groups in Unit 3, the tendon forces were not predicted to go below the minimum required value until 40 years or more after the SIT. Since Oconee Units 1 and 2 are identical to Oconee Unit 3, the licensee performed a trend analysis for each of these units and found that the vertical tendon forces in Unit 1 and Unit 2 were predicted to go below the minimum value at 30 years and 10 years after the SIT, respectively. These results were caused by additional wire breakage of other vertical tendons. The licensee expanded the lift-off testing and visual examination to 100 percent of the vertical tendons. Similar degradation of other vertical tendons was found. As a part of the licensee's corrective action, the licensee used the same tendons for lift-off testing, thus subjecting the tendons to cyclic loading. A more appropriate methodology is the random selection of tendons to be tested.

In 1996, the V. C. Summer licensee, South Carolina Electric & Gas Co., performed the 15-year (fifth) tendon surveillance. For each group of tendons, the licensee used the averages of the lift-off forces from each surveillance and plotted the five points from the five surveillances on a graph. The five points are joined by line segments. On the basis of this graph, the licensee concluded that the tendon force levels in the three groups of tendons would be acceptable beyond the 20-year surveillance. A subsequent linear regression analysis using individual lift-off forces, instead of the averages, indicated that the dome and hoop tendons would not go below the minimum required forces until 32 years after the SIT. The vertical tendons that had been retensioned were predicted not to go below the minimum required force until 42 years after the SIT.

In 1993, the licensee of the Crystal River Nuclear Plant, Unit 3, Florida Power Corporation, performed the fifth tendon surveillance. A detailed study that considered both the average and the individual lift-off forces was performed. On the basis of the results of linear regression analysis, the licensee concluded that with the exception of the vertical tendons' result, which gave a slightly steeper slope for the individual data points, there was no difference between the two methods for the hoop and dome tendons. The prestressing forces in the three groups of tendons were indicated to be above the minimum required forces well beyond the 40-year plant life.

The simple regression model is a mathematical way of stating the statistical relationship that exists between two variables. In this case, the tendon force (TF) is a dependent variable that varies with time (T), the independent variable. The two principal elements of a statistical relationship are (1) the tendency of the dependent variable TF to vary in a systematic way with the independent variable T, and the scattering of points about the "curve" that represents the relationship between TF and T. For a small sample size (2% of the population), using the average of the TF for each surveillance test masks the true variation between TF and T. Therefore, an analysis using the individual lift-off forces for the regression analysis gives results that could be statistically validated.

On the basis of experience, as evidenced from the examples presented and the statistical analysis, it is evident that the appropriate method for evaluating the adequacy of the tendon force is the regression analysis using the individual lift-off forces as the data for the trend analysis.