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May 31, 2024

U. S. Nuclear Regulatory Commission		Serial No.	24-123
Attention: Document Control Desk		NRA/JHH	R0
Washington, DC 20555		Docket No.	50-395
		License No.	NPF-12

DOMINION ENERGY SOUTH CAROLINA, INC. (DESC)
VIRGIL C. SUMMER NUCLEAR STATION (VCSNS) UNIT 1
PROPOSED ALTERNATIVE REQUEST RR-24-123, CONTAINMENT UNBONDED POST-TENSIONING SYSTEM INSERVICE INSPECTION REQUIREMENTS

In accordance with 10 CFR 50.55a, "Codes and Standards," paragraph (z)(1), Dominion Energy South Carolina, Inc. (DESC) requests Nuclear Regulatory Commission (NRC) approval of proposed inservice inspection alternative request RR-24-123 for Virgil C. Summer Nuclear Station (VCSNS) Unit 1.

Section XI, Subsection IWL of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code requires periodic visual examination of containment building concrete in accordance with Table IWL-2500-1 (L-A), as well as visual examination and physical testing of unbonded post-tensioning systems in accordance with Table IWL-2500-1 (L-B). Examination and testing to date have indicated the post-tensioning system at VCSNS will continue to maintain its safety-related function through the period of extended operation (August 6, 2042). Therefore, DESC proposes to extend the post-tensioning system examination and testing interval from 5 years to 10 years. DESC also proposes to eliminate the requirement for tendon wire extraction and testing, as well as limit the testing of the corrosion protection medium (CPM) to measurement of absorbed water content.

The above proposed alternatives relate only to pre-stressed tendon tests (Category L-B) and the associated examinations that require close-in access to tendon end anchorage areas. Visual examination of the exposed areas of the containment concrete surface, exposed areas of the tendon bearing plates and tendon end caps required by Category L-A, will continue to be performed at 5-year intervals in accordance with ASME IWL requirements. These examinations, along with other enhancements to the visual examination program, will identify conditions that would allow water intrusion into the tendons and leakage of CPM which would be precursors for indicating an environment that could allow corrosion of the tendon wires or inaccessible tendon hardware covered by the tendon end cap.

This proposed alternative to the requirements of ASME B&PV Code Section XI, Subsection IWL, will maintain an acceptable level of quality and safety, while also reducing personnel exposure to industrial safety hazards.

The proposed alternative request is provided in Attachment 1. The technical basis for deviations from the frequency of IWL-2420(a) examination and testing requirements included in Table IWL-2500-1, Examination Category L-8, is provided in Enclosure 1.

This proposed alternative request has been approved by the VCSNS Facility Safety Review Committee. DENC respectfully requests NRC approval of this alternative request by May 31, 2025.

Should you have any questions regarding this submittal, please contact Julie Hough at (804) 273-3586.

Sincerely,

James E. Holloway
Vice President - Nuclear Engineering and Fleet Support

Commitments made in this letter: None

Attachments:

1. Proposed Alternative Request RR-24-123, Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

Enclosure:

1. Proposed Alternative Request RR-24-123, Containment Post-Tensioning System Inservice Inspection .Technical Report, Revision 1, October 24, 2022

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ATTACHMENT 1

Proposed Alternative Request RR-24-123
Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

VIRGIL C. SUMMER NUCLEAR STATION UNIT 1
DOMINION ENERGY SOUTH CAROLINA

Proposed Alternative Request RR-24-123
Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

--In Accordance with 10 CFR 50.55a(z)(1), Acceptable Level of Quality and Safety--

1. ASME Code Component(s) Affected

Code Class: CC

Reference: IWL-2420, IWL-2520, Table IWL-2500-1

Examination Category: Table IWL-2500-1, Category L-B

Item Number: L2.10, L2.20, L2.30, L2.40, and L2.50

Description: Examination of Unbonded Post-Tensioning System

Component Number: Virgil C. Summer Unit 1 (VCSNS) Containment Building

2. Applicable Code Edition and Addenda

The following table identifies the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Section XI Code of Record for performing Inservice Inspection (ISI) activities at VCSNS.

Plant	10-Year IWL Interval	ASME Section XI Edition / Addenda	Interval Start	Interval End
VCSNS	3rd	2007 Editions, 2008 Addenda	January 1, 2017	December 31, 2026

3. Applicable Code Requirements

Subsection IWL-2420 states that:

(a) Unbonded post-tensioning systems shall be examined in accordance with IWL-2520 at 1, 3, and 5 years following the completion of the containment Structural Integrity Test and every 5 years thereafter.

(b) The 1, 3, and 5 year examinations shall commence not more than 6 months prior to the specified dates and shall be completed not more than 6 months after such dates. If plant operating conditions are such that examination of portions of the post-tensioning system cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

(c) The 10 year and subsequent examinations shall commence not more than 1 year prior to the specified dates and shall be completed not more than 1 year after such dates. If plant operating conditions are such that examination of portions of the post-tensioning system cannot be completed within this stated time interval, examination of those portions may be deferred until the next regularly scheduled plant outage.

VCSNS is currently required to examine the Post-Tensioning System every 5 years.

Subsection IWL-2500 requires examinations be performed in accordance with the requirements of Table IWL-2500-1.

- Table IWL-2500-1, Item Number L2.10 requires that selected tendon force and elongation be measured.
- Table IWL-2500-1, Item Number L2.20 requires that tendon single wire samples be removed and examined for corrosion and mechanical damage as well as tested to obtain yield strength, ultimate tensile strength, and elongation on each removed wire. The selected tendons are subsequently re-tensioned as required per IWL-2523.3 because wire removal requires de-tensioning in order to safely obtain wire samples.
- Table IWL-2500-1, Item Number L2.30 requires that a detailed visual examination be performed on selected tendon anchorage hardware and adjacent concrete extending 2 feet from the edge of the bearing plate. The quantity of free water released from the anchorage end cap as well as any which drains from the tendon during examination shall be documented.
- Table IWL-2500-1, Items Number L2.40 and L2.50 require that samples of selected tendon corrosion protection medium (CPM) and free water be obtained and analyzed.

4. Reason for Request

ASME B&PV Code Section XI, Subsection IWL requires periodic visual examination of containment building concrete as well as physical testing of post-tensioning systems. The examination and testing to date have indicated the post-tensioning system is expected to maintain its safety-related function through the end of the renewed facility operating license which expires on August 6, 2042, which is well past the January 2032 deadline for completion of the next examination if the interval is extended to 10 years.

This alternative request proposes to perform visual examination only of the concrete containment and accessible steel hardware visible without tendon cover removal. Physical testing would be performed only if visual examination results indicate a need for such testing, as determined by the Responsible Engineer (IWL-2330). Based on the dates of the Structural Integrity Test (January 2, 1981), the 50th year examination/testing would be required to be completed no later than January 1, 2032.

While this alternative request is based on maintaining an acceptable level of quality and safety, there are additional benefits associated with not performing physical testing. Physical testing requires exposing plant personnel to industrial safety hazards. Removing the tendon end caps and load testing or de-tensioning/re-tensioning the tendons also unnecessarily cycles the tendons. Below are specific hazards and undesirable conditions that would be reduced by this proposed alternative:

- Most tendons are located well above ground level and require work to be performed at heights, with the inherent risks associated with such work.
- This work is often performed from hanging platforms. The platform must be moved to a parked location to exit the platform safely.
- Some work areas are in difficult-to-reach locations that have only one small access point.
- The testing requires working with high pressure hydraulics.
- The testing requires working in the vicinity of high energy plant systems.
- The testing requires working with solvents and hot petroleum products and associated fumes.
- The testing requires working with containers and pressurized lines filled with a heated CPM (grease).
- The testing requires working in the vicinity of high levels of stored elastic energy in the tendons. Sudden rotation during force measurement has resulted in high-speed shim ejections.
- The work includes the handling of heavy loads (i.e., test equipment) that expose test personnel and equipment to hazards.
- While tendon testing is not often performed in radiation areas, there are occasionally some tendons tested in areas that involve radiation fields.

Performing examination/testing on a reduced frequency reduces the repetitive loading required for force measurement and/or de-tensioning/re-tensioning. Reducing the frequency of tendon end cap removal will reduce environmental waste (e.g., solvents, used grease, other consumables).

5. Proposed Alternative and Basis for Use

In accordance with 10 CFR 50.55a(z)(1), DESC is proposing alternative examination requirements on the basis that these alternative requirements will provide an acceptable level of quality and safety.

The proposed alternative to the applicable ASME Section XI, IWL requirements is as follows and is evaluated in Enclosure 1. The proposed alternative will:

- Extend the interval of the post-tensioning system examinations/tests and detailed visual examination of concrete adjacent to the tendon bearing plates from 5 years to 10 years.
- Eliminate de-tensioning/re-tensioning of tendons, sample wire removal, and sample wire testing.
- Reduce the number of CPM chemical tests.

The proposed alternative is applicable only to pre-stressed tendon tests and the associated examinations that require close-in access to tendon end anchorage areas. Visual examination of the exposed areas of the containment concrete surface, exposed areas of the tendon bearing plates, and tendon end caps will continue to be performed at 5-year intervals in accordance with ASME IWL requirements.

The reduced frequency of post-tensioning system physical testing will continue to provide an acceptable level of quality and safety based on projected system performance and a requirement for implementation of additional physical testing if visual examination results indicate a need for additional testing.

VCSNS proposes to perform a general visual examination and detailed visual examination (when required) of accessible concrete and exposed steel hardware as required by Section XI, Table IWL-2500-1, Item Numbers L 1.11 and L 1.12, as modified by 10 CFR 50.55a. The examination and physical testing requirements of Section XI, Table IWL-2500-1, Item Numbers L2.10, L2.20, L2.30, L2.40, and L2.50 will only be performed if the general visual examination and detailed visual examination identify conditions indicating potential degradation of tendon hardware, as documented by the Responsible Engineer in an engineering evaluation.

Example conditions that could require removal of a tendon end cap and further examination per Item Numbers L2.10, L2.20, L2.30, L2.40, and L2.50 are:

- Evidence of possible damage to the enclosed post-tensioning hardware as indicated by conditions such as end cap deformation found during external visual examination. Conditions observed by removal of the end cap would determine the extent of additional examinations per L2.10, L2.20, L2.30, L2.40, or L2.50.
- Active corrosion on a bearing plate or end cap that requires further investigation

as determined by the Responsible Engineer in an engineering evaluation.

- Evidence of CPM leakage will be evaluated and a plan developed that requires further investigation and corrective actions as defined in an engineering evaluation documented by the Responsible Engineer.

IWL Post-Tensioning System Examination and Physical Testing Requirements and Justification for Deviation

Enclosure 1 provides a detailed discussion of the historical basis for examination and testing of containment post-tensioning systems. Enclosure 1 also includes the VCSNS-specific observations that provide a basis for requesting this alternative to the Section XI examination and testing requirements included in Table IWL-2500-1, Examination Category L-B.

Additional Supporting Actions

ASME B&PV Code Section XI, Subsection IWL program at VCSNS is credited for managing containment building degradation. The Examination Category L-A visual examinations (every 5 years) are expected to identify any conditions that would allow water intrusion into the tendons or leakage of CPM, which are precursors indicating an environment that could allow corrosion of the tendon wires or inaccessible tendon hardware covered by the tendon end cap. Such conditions would be evaluated by the Responsible Engineer to determine what additional actions are necessary to assure no corrosive environmental conditions exist.

The mean pre-stresses for VCSNS are predicted to be acceptable well beyond the August 6, 2042 expiration date of the renewed facility operating license. The average tendon forces are predicted to remain above the lower limits for required mean force beyond T=100 years. Therefore, extending the examination/test frequency from 5 to 10 years will continue to provide an acceptable level of quality and safety.

Summary and Conclusions

The results of the post-tensioning system in-service examinations conducted at VCSNS Unit 1, between 1982 and 2020 have shown that the system continues to perform its intended function. Enclosure 1 shows that the system is expected to continue to perform its specified design function until well past the August 6, 2042 expiration of the renewed facility operating license.

6. Duration of Proposed Alternative

The provisions of this alternative are applicable to the remainder of the VCSNS Third 10-year IWL ISI interval which ends on December 31, 2026. The next, and final IWL examination within this interval is scheduled to occur with completion of the 45th year examination on January 2, 2026, plus or minus one year. It is noted that the 45th year IWL examination is projected to occur in the spring of 2026, with completion prior to the end of the Third 10-year IWL ISI interval.

7. Precedents

1. **ADAMS Accession Number ML22124A241.** NRC approval dated May 12, 2022. Palo Verde Nuclear Generating Station Units 1, 2, and 3, Relief Request 67, “Request for Alternative Frequency to Containment Unbonded Post-Tensioning System Inservice Inspection,” dated July 29, 2021 (ML21210A300).
2. **ADAMS Accession Number ML21190A004.** NRC approval dated September 2, 2021. Calvert Cliffs Nuclear Power Plant, Units 1 and 2, “Relief Request CISI-03-01 Concerning Containment Unbonded Post-Tensioning System Inservice Inspection Requirements,” dated October 6, 2020 (ML20280A508).
3. **ADAMS Accession Number ML21134A006.** NRC approval dated August 3, 2021. Braidwood Station, Units 1 and 2 (Relief Request I4R-11) and Byron Station, Unit Nos. 1 and 2 (Relief Request I4R-18), “Alternative to Containment Unbonded Post- Tensioning System Inservice Inspection Requirements,” dated July 24, 2020 (ML20206L135).
4. **ADAMS Accession Number ML20287A471.** NRC approval dated October 20, 2020. Millstone Power Station, Unit 2, “Proposed Alternative Request RR-05-05, Containment Unbonded Post-Tensioning System Inservice Inspection Requirements,” dated December 17, 2019 (ML19352B898).
5. **ADAMS Accession Number ML19226A023.** NRC approval dated September 19, 2019. Three Mile Island Nuclear Station, Unit 1, “Submittal of Relief Request RR-18- 01 Concerning Containment Unbonded Post-Tensioning System Inservice Inspection Requirements,” dated October 16, 2018 (ML18289A363).

8. References

ASME Boiler and Pressure Vessel Code, Section XI, 2007 Edition with the 2008 Addenda.

ENCLOSURE 1

Proposed Alternative Request RR-24-123
Containment Post-Tensioning System Inservice Inspection Technical Report

Revision 1

October 24, 2022

DOMINION ENERGY SOUTH CAROLINA
VIRGIL C. SUMMER NUCLEAR STATION UNIT 1

VIRGIL C. SUMMER NUCLEAR STATION

UNIT 1

CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION

TECHNICAL REPORT

BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL

Report Prepared by:

Howard T. Hill, PhD, P.E. (California Civil Certificate C 22265)

BCP Engineers and Consultants

Revision 1
October 24, 2022

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LIST OF ABREVIATIONS

ACI	American Concrete Institute
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CPM	Corrosion protection medium
EF	Elongation at failure
kip	Kilo-pound (1,000 pounds)
ksi	Kips per square inch
LCL	Lower confidence limit
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ppm	Parts per million
RE	Responsible Engineer
SIT	Structural Integrity Test
USNRC	United States Nuclear Regulatory Commission
UTS	Ultimate tensile strength
VCSNS	Virgil C. Summer Nuclear Station

VIRGIL C. SUMMER NUCLEAR STATION

UNIT 1

CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION

TECHNICAL REPORT

BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL

1. PURPOSE, CONTAINMENT / ISI PROGRAM DESCRIPTION AND ORGANIZATION

This report provides the technical evaluation and justification supporting a request for relief to allow departure from certain containment inservice inspection (ISI) requirements specified in USNRC Regulation 10CFR50.55a (Reference 7.1) and, by reference therein, ASME Section XI, Subsection IWL (Reference 7.2). The current V. C. Summer Nuclear Station (VCSNS) containment ISI program is consistent with these regulatory and code requirements.

1.1 Containment Description

The VCSNS Unit 1 containment is a reinforced and post-tensioned concrete pressure vessel that serves as the final barrier (after fuel cladding and the reactor coolant system pressure boundary) against release of radioactive material from the reactor core to the outside environment.

The major structural elements of the containment are a cylinder wall, a ring girder, a shallow dome roof and a flat foundation mat. The cylinder and dome are reinforced and pre-stressed; the foundation mat is conventionally reinforced (not pre-stressed). The ring girder serves as a transition between the cylinder and the dome and provides anchorage for both vertical and dome pre-stressing tendons. The cylinder incorporates three equally spaced buttresses that provide anchorage for the circumferential pre-stressing tendons.

A carbon steel liner covers the inside surface of the containment and ensures a high degree of leak tightness during operating and accident conditions.

Principal containment dimensions, as given in VCSCS Safety Analysis Report Chapter 3 (Reference 7.3) Paragraphs 3.8.1.1.1.1, 3.8.1.1.1.2 and 3.8.1.1.2.1, and on Drawing E-511-101 (Reference 7.4) are as follow.

Cylinder inside diameter: 126'

Cylinder height from top of base mat to dome spring line: 149'

Cylinder wall thickness: 4'

Dome spherical cap inside radius: 81'-4½"

Dome spherical cap thickness: 3'

Dome transition inside radius: 30'

Foundation mat thickness: 12'

Liner thickness: ¼" (increased at support brackets and penetrations)

The containment wall and dome are pre-stressed using 170 wire BBRV (wires anchored by cold formed button heads) tendons. The ASTM A421 (Reference 7.5) wires have a diameter of 0.250 inches.

The cylindrical wall is pre-stressed with both vertical and circumferential (hoop) direction tendons.

Wall circumferential (hoop) pre-stressing consists of 3 sub-groups each having 50 tendons and spanning 240 degrees. Sub-groups are offset by 120 deg to provide continuous overlap of pre-stressing force. Circumferential tendons anchor at the buttress faces.

Wall vertical pre-stressing consists of 115 tendons. Vertical tendons anchor at the top of the ring girder and the bottom of the base mat. A tunnel (the tendon access gallery) below the base mat provides access to the lower anchorages.

Dome pre-stressing consists of 3 layered sub-groups each having 33 parallel (in plan view) tendons. The layers intersect at 60 degrees. Dome tendons anchor at the vertical face of the ring girder.

Containment tendons were initially tensioned to a mean seating force of about 1,440 kips (Reference 7.6) which is equivalent to 72% of the specified minimum ultimate strength. Current forces are less due to elastic shortening, concrete shrinkage, concrete creep and pre-stressing wire relaxation losses. After tendons were tensioned, the duct and end anchorage caps were filled with a micro-crystalline wax for corrosion protection.

1.2 Containment ISI Program Summary Description

Continuing containment structural[1] integrity is verified through regular examinations and tests performed every 5 years in accordance with Engineering Services Specification SP-228 (Reference 7.6). This specification incorporates the requirements of USNRC Regulation 10CFR50.55a (Reference 7.1) and, by reference therein, ASME Section XI, Subsection IWL (Reference 7.2). The ISI program requires visual examination of the entire accessible containment concrete surface and examination and testing of small samples (nominally 2% of the tendon group population) of hoop, vertical and dome tendons. Each sample includes tendons selected at random from the population as well as one tendon in each group common to consecutive examinations. Tendon examinations and tests are performed in accordance with the requirements of Subsection IWL. Concrete surface visual examinations follow the applicable guidelines given in the American Concrete Institute (ACI) reports referenced in IWL.

Tendon examinations and tests consist of the following.

- Visual examination to detect corrosion and damage at tendon end anchorages (including concrete adjacent to bearing plates) and along the length of wire extracted for strength and ductility testing
- Measurement of tendon force applied at the end anchorage
- Measurement of the strength and ductility of sample wires extracted from designated tendons
- Laboratory analysis of corrosion protection medium samples to determine absorbed water content, concentration of corrosive ions and reserve alkalinity
- Laboratory analysis to determine the pH of free water found in tendon end caps and ductwork

[1] Containment liner ISI, performed to assess leak tight integrity, is covered by ASME Section XI Subsection IWE and is not addressed in this technical report.

1.3 Report Organization

The remainder of this report consists of the following 7 parts and an attachment.

- **Part 2** – Summary of Proposed Program Changes, Visual Examination Program Enhancements and Conclusions
- **Part 3** – Background of Current ISI Requirements and Basis for Proposed Departures
- **Part 4** – VCSNS Unit 1 Examination History and Results Analysis / Evaluation
- **Part 5** – Overall Summary, Conclusions and Recommendations
- **Part 6** – Future Examinations and Testing Enhancements
- **Part 7** – References
- **Part 8** – Tables and Figures

2. SUMMARY OF PROPOSED PROGRAM CHANGES, VISUAL EXAMINATION PROGRAM ENHANCEMENTS AND CONCLUSIONS

[Note: This report and the Relief Request that it supports address only proposed departures from the inservice inspection requirements covered by ASME Section XI, Subsection IWL Table IWL-2500-1 Examination Category L-B. Category L-A concrete examinations will continue to be performed as required by Subsection IWL and with the enhancements described in 2.2 below. Also, containment liner and penetration assembly inservice inspection requirements specified in Subsection IWE will continue to be implemented in accordance with the current ISI plan.]

Proposed containment pre-stressing system examination program changes, containment visual examination program enhancements and associated conclusions are summarized in 2.1, 2.2 and 2.3 which follow.

2.1 Proposed Program Changes

The following departures from current ISI requirements are proposed and evaluated in this report.

- (Subsection IWL Table IWL-2500-1, Examination Category L-B, Items L2.10, L2.20, L2.30, L2.40 and L2.50) Extend the interval between post-tensioning system examinations and tests and detailed visual examination of concrete adjacent to tendon bearing plates from 5 years to 10 years with future examinations to be performed 50 years after the pre-operational structural integrity test (SIT) and every 10 years thereafter.
- (Subsection IWL Table IWL-2500-1, Examination Category L-B, Item 2.20) Eliminate de-tensioning / re-tensioning of tendons, sample wire removal and sample wire testing unless such testing is specified by the Responsible Engineer.
- (Subsection IWL Table IWL-2500-1, Examination Category L-B, Item L2.40) Limit corrosion protection medium (CPM) chemical tests to the determination of sample absorbed water content unless measured water content exceeds the Table IWL-2525-1 acceptance limit and / or conditions at the anchorage where the sample was collected are judged by the Responsible Engineer to justify additional tests.

The above proposed departures relate only to pre-stressing tendon tests and the associated examinations that require close-in access to tendon end anchorage areas. Visual examination of the exposed areas of the containment concrete surface, exposed areas of the tendon bearing plates and tendon end caps will continue to be performed at 5 year intervals in accordance with past practice.

2.2 Visual Examination Program Enhancements

Visual examination procedures will be enhanced to ensure that unexpected post-tensioning system problems are identified in a timely manner. Enhancements will include the following.

- General visual examination, as defined in IWL-2310(a), will cover tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and corrosion protection medium leakage. Examinations will be performed from roofs, floors, platforms, ladders and other means of achieving relatively close in access to the anchorage area and with sufficient illumination to detect deleterious conditions. If close in access is not possible, remote examination techniques (e.g., optical aids and drone mounted cameras) will be used.
- Detailed visual examination, as defined in IWL-2310(b), will be performed at those areas identified during general visual as areas with conditions requiring close in examination.
- If an end anchorage area examination uncovers a condition indicative of possible damage to the enclosed post-tensioning system hardware or an anchor head failure, the end cap will be removed and the anchorage area examined by the Responsible Engineer[2] (RE). Additional actions will be taken as specified by the RE.
- If an end anchorage area examination uncovers active corrosion on a bearing plate or end cap, the condition will be evaluated by the RE. Additional actions will be taken as specified by the RE.
- If an end anchorage area examination uncovers concrete cracks that are considered by the RE to have potential structural significance, a detailed examination of the condition will be performed and additional actions taken as specified by the RE.
- Examinations will be performed to detect CPM leakage. Observed leakage will be evaluated by the RE who will determine if corrective action (e.g., end cap gasket replacement and duct refilling / top-off) is needed. If further action is required, the RE will prepare, and initiate implementation of, a corrective action plan.

[2] A registered professional engineer qualified, as defined in accordance with IWL-2330, to prepare concrete containment examination programs, certify examination personnel, direct examinations and evaluate examination results.

2.3 Conclusions

The evaluations addressed in Parts 3 and 4 of this technical report, with the visual examination program enhancements discussed in Part 6, support the conclusion that the proposed departures from the current requirements of Subsection IWL, as described in Section 2.1 above, can be implemented with no adverse impact on the safe operation of the plant.

In addition, it is concluded the proposed examination interval extension, elimination of wire testing and reduction of CPM tests will enhance personnel safety, limit potential degradation of containment structural integrity and reduce the risk of damage to plant equipment.

3. BACKGROUND OF CURRENT ISI REQUIREMENTS AND BASIS FOR PROPOSED DEVIATIONS

Containment inservice inspection (also referred to herein as surveillance and inservice examination) requirements originated with the issuance of Regulatory Guide 1.35 (Reference 7.7) in the early 1970's and are currently mandated by ASME Section XI, Subsection IWL, which is incorporated by reference into USNRC Regulation 10CFR50.55a. A brief history of current requirement development is summarized in 3.1, 3.2 and 3.3 below. The basis for the proposed departure from the current requirement is discussed in 3.4.

3.1 Regulatory Guide 1.35

In February 1973 the U. S. Atomic Energy Commission issued the initial version of Regulatory Guide 1.35, *Inservice Surveillance of Ungrouted Tendons in Prestressed Concrete Containment Structures*. This document, drafted at about the time that the first pre-stressed concrete containment structures were being placed into service and well before the accumulation of prototype containment pre-stressing system performance data, described the following as an acceptable basis for system examinations.

- Examination schedule - 1, 3 and 5 years after the preoperational structural integrity test and every 5 years thereafter.
- Examination sample size – 6 dome, 5 vertical and 10 hoop tendons.
- Wire extraction – one wire from a tendon in each group (dome, vertical, hoop); extraction requires de-tensioning.

- Visual examinations for damage, deterioration and corrosion – corrosion protection medium, end anchorage hardware, anchorage area concrete and extracted wires.
- Physical tests – tendon liftoff force and extracted wire strength and elongation at failure.

The regulatory guide does not discuss the basis for the examination interval, the sample size or the various tests and examinations to be included in an acceptable program (these probably represent consensus opinions reached, at the time, among the individuals involved in guide development). Also, it does not address the possible need for changes as future operating experience accumulated.

Subsequent revisions to Regulatory Guide 1.35 added procedures for corrosion protection medium chemical analyses (added in Revision 3), substantially changed the sampling process and included numerous other additions and clarifications but retained the examination interval and wire testing program as described in the original 1973 issue. The final revision, Revision 3, was issued in July 1990.

Neither the initial issue of the regulatory guide nor later revisions addressed the use of past performance[3] as a basis for increasing examination intervals or reducing specific examination and testing requirements.

Regulatory Guide 1.35 was withdrawn in August 2015 following the incorporation, by reference, of ASME Section XI, Subsection IWL into NRC Regulation 10CFR50.55a.

3.2 ASME Section XI / Subsection IWL

The 1989 edition of the ASME Boiler and Pressure Vessel Code included in Section XI, for the first time, Subsection IWL which provided comprehensive and detailed requirements for a concrete containment inservice inspection program. During the development of IWL[4], which commenced in the 1970's, it was concluded that NRC acceptance and endorsement (by reference in 10CFR50.55a) of the document would be expedited if departures from the program described in Regulatory Guide 1.35 were minimized. For this reason, the examination interval, strength / elongation testing of wire samples and relatively extensive chemical testing of corrosion protection medium

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[3] Appendix J to 10CFR50, which addresses containment leakage rate testing, provides an example of performance-based examination / testing requirements.

[4] The author of this technical report has been a member of the IWL working group since the 1970's (when it was still being developed as an addition, CC-9000, to ASME Section III, Division 2) and served as chair of the working group during its later development and much of the period leading up to its incorporation into Section XI in 1989.

samples mandated in IWL are unchanged from those identified in Regulatory Guide 1.35, Rev. 3.

Subsection IWL has been revised numerous times since its initial incorporation into Section XI in 1989. None of these revisions have altered the examination interval or the basic requirement to test wire and corrosion protection medium samples.

3.3 USNRC Regulation 10CFR50.55a

The 1996 amendment to 10CFR50.55a incorporated, by reference and with specified exceptions and additions, the ISI requirements given in the 1992 edition, with 1992 addenda, of ASME Section XI, Subsection IWL. Subsequent amendments have referenced later editions / addenda of IWL but none have addressed changes to either the examination interval or the requirements for testing wire and corrosion protection medium samples.

3.4 Basis for Proposed Deviations / Relief from 10CFR50.55a and IWL Requirements

This section of the technical report includes a generalized summary of post-tensioning system performance observed during 4 decades of periodic examinations conducted at 24 U. S. nuclear plant sites with 41 pre-stressed concrete containments. It is intended to show that most containment post-tensioning systems are continuing to perform well and that, in general, system examination intervals could be significantly increased without compromising safe operation of the plant.

This summary, intended to be qualitative, is based on the author’s experience as described below.

- Participation in containment post-tensioning system examinations at U. S. and foreign sites.
- USNRC funded research, performed under contract to ORNL, on age related decrease in pre-stressing force and other age-related effects using performance data documented for ~20 U. S. containments.
- Four decades of interacting with fellow members of the IWL working group.
- Review of USNRC informational bulletins and generic letters.
- Review of system performance history in connection with preparation of program basis documents for license renewal applications.
- Forecasting tendon forces in connection with the preparation of minimum required pre-stressing force calculations.

- Work on a USNRC funded project to review and recommend updates to Regulatory Guides 1.35, 1.35.1 and 1.90, which address inservice inspection of pre-stressed containments.
- A three-year association with the Crystal River 3 containment repair project; assignments included evaluating the condition of tendons not affected by the repair work.

As the summary is qualitative, specific references are not cited as the bases for generalized statements regarding post-tensioning system performance.

As noted in 3.1, 3.2 and 3.3 above, the examination intervals and wire testing addressed in the 1973 original issue of Regulatory Guide 1.35 are now, 45 years later, still incorporated effectively unchanged into the current edition of ASME Section XI, Subsection IWL.

In addition, the current edition of ASME Section XI, Subsection IWL specifies corrosion protection medium chemical testing procedures that are effectively unchanged from those described in Regulatory Guide 1.35, Revision 3.

The results of unbonded post-tensioning system examinations performed over the last 4 decades at the 41 nuclear units with pre-stressed containments provide ample evidence, as discussed below, that prescriptive requirements currently in IWL are, in many cases, overly conservative and that an acceptable level of quality and safety can be maintained by performing Table IWL-2500-1 Examination Category L-B examinations at intervals greater than 5 years and by relaxing certain specific testing requirements.

Containment ISI programs should be based on individual plant performance and not bound by requirements that were established without the benefit of the accumulated operating experience available today.

The lessening of certain containment ISI requirements, as addressed in this report and the associated Relief Request that it supports, provides the following benefits.

- It reduces personnel radiation exposure.
- It reduces personnel and equipment safety hazards associated with working at heights, handling of heavy loads, working with high pressure hydraulic equipment, working close to tendon end anchorages that can suddenly release stored mechanical energy, working with hot petroleum products under pressure and working in proximity to high energy plant systems.

- It reduces the potentially deleterious cycling of tendon loads that occurs during de-tensioning / re-tensioning for wire removal and to a lesser extent during the measurement of lift-off forces.

The technical justification for the proposed deviations is based on industry wide operating experience accumulated over the past 4 decades during examination of 41 containments having unbonded post-tensioning systems and, in particular, the operating experience documented during the post-tensioning system examinations performed at VCSNS Unit 1 between 1982 and 2020. The general conclusions regarding post-tensioning system performance are listed below. Conclusions specific to VCSNS Unit 1 are addressed in detail in Parts 4 and 5 of this report.

3.4.1 Pre-Stressing Force Trend

Containment design criteria typically require that the post-tensioning system provide sufficient pre-stressing force at the end of 40 years (period of initial licensure considered to be the plant operating lifetime when design work on existing plants commenced) to maintain membrane compression in the walls and dome under specified accident conditions.

Post-tensioning system design was based on a postulated linear decrease in pre-stressing force with the logarithm of time (log-linear decrease). The log-linear function was selected as this provided a reasonably good fit to the results of relatively short-term creep, shrinkage and relaxation tests and was consistent with expectations based on the calculated response of theoretical models that represent materials as an assemblage of linear springs and dashpots. Concrete creep and shrinkage tests were typically conducted for 180 days and pre-stressing steel relaxation tests for 1000 hours (~40 days). Designing for a 40-year plant operating lifetime required extrapolating concrete test durations by a factor of 80 and steel test durations by a factor of almost 400.

Post-tensioning system examination data have shown, with relative consistency, that the rate of change of pre-stressing force with the logarithm of time tends to decrease with time. Within 20 to 25 years after the completion of pre-stressing operations, the force time trend becomes essentially flat[5]. Given this general trend, it can be stated with a high degree of confidence that the examination interval may be increased beyond 5 years with no compromise of safety function if the following conditions are satisfied.

[5] As discussed in Section 4 of this report, scatter of measured tendon forces tends to obscure the true trend of the mean. The conclusion regarding flattening of the trend is based on statistical analysis rather than an observed characteristic of the plotted data.

- The current mean pre-stressing force (hoop, vertical or dome), computed using both the trend of individual tendon force data acquired to date and the mean of the most recently acquired data, exceeds the minimum required level by significant margins. The margin deemed significant is established through an evaluation by the Responsible Engineer. If the trend of the mean is considered to be a log-linear function, data acquired during the year 1, 3 and 5 examinations may be omitted from the trend computation[6].
- The forecast mean pre-stressing forces (hoop dome and vertical), determined using the data acquired to date and computed, for conservatism, at the 95% lower confidence limit, remain above the minimum required levels until well past the deadline for completion of the subsequent examination.
- Common tendon force trend lines (see Figures 3, 5 & 8), adjusted up or down, as applicable, to current group mean force levels, indicate that group means will remain above required minima with acceptable margins through the deadline for completion of the subsequent examination.

3.4.2 System Hardware Condition History

There have been relatively few significant issues associated with post-tensioning system hardware (tendon wire / strand[7], anchor heads, wedges, shims and bearing plates).

Active corrosion is typically found only on the parts of bearing plates exposed to outside atmospheric conditions.

Instances of deformation, damage and degradation are rare and almost always associated with singular fabrication, construction or operational events. Missing button heads are occasionally reported but affect only an inconsequential fraction of the total number of wires comprising the containment tendons.

Most exceptions to the above are the result of unique situations that are plant specific and not indicative of an industry wide problem. Two widely reported exceptions, one involving wire corrosion and the other, anchor head material, are described below. Occurrences have been limited to the plants where these were first observed.

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[6] Industry wide data tend to show that mean force (vs. log time) decreases significantly more rapidly during the first 10 years following completion of pre-stressing operations than it does during subsequent years. In addition, measurements made during the early years of plant life are often known to be less accurate than those made later using improved technology.

[7] The only U. S. containments with strand tendons, anchored with hardened wedges rather than cold formed button heads, are Rancho Seco, San Onofre (2 & 3) and Vogtle (1 & 2). Of these, only the Vogtle units are currently operating.

- Debris blocked the drains at the perimeter of a shallow dome resulting in flooding that submerged the caps at the upper end of the vertical tendons. The hold down bolt holes in the tops of the caps were not well sealed. Storm water and snow melt entered the caps through these holes and submerged the short lengths of wire, located just below the anchor heads, that were not coated with CPM. A number of wires were severely corroded and found to be no longer effective as pre-stressing elements.

  New maintenance procedures to prevent future flooding above the ring girder were implemented. The condition has not recurred.

- A unique combination of steel chemistry and high hardness led to the failure of anchor heads in both units of a two-unit plant. Several failures have occurred at random times over the past 4 decades. Industry wide evaluations established that anchor heads of this type are not in use elsewhere.

  The problem has been addressed by implementing an enhanced examination program. Corrective action consists of replacing failed or cracked anchor heads as these are found.

3.4.3 Wire Test Results

Wire sample tests, performed by certified laboratories using appropriate equipment and procedures as specified in the applicable ASTM standards, show that strength and elongation at failure do not degrade with time. While past industry data often show reported strength and elongation to vary significantly from examination to examination, close evaluation of the data suggests that such fluctuations can generally be attributed to variations in the testing, specifically:

- Many of the earlier tests were performed using vendor procedures that differ from those specified by the applicable ASTM standards.
- Testing equipment was often vendor fabricated and did not meet ASTM specifications.
- Personnel assigned to the testing work did not always have the requisite experience.

In general, tests that conform to ASTM specifications and that are performed by experienced technicians show that both strength and elongation are reasonably close to, but exceed, the minima (240 ksi and 4%, respectively) specified for ASTM A421 (Reference 7.5) wire.

As there is no evidence that either strength or elongation (at failure) decrease with time under load, it is concluded that there is no benefit to ongoing tests to measure these parameters. And, it is to be noted that there is no precedent across the broader (beyond nuclear power plants) industry to periodically evaluate the continuing mechanical properties of pre-stressing system hardware and other steel structural members.

Deleting the requirement for wire tests, when justified by evaluation of specific plant operating experience, eliminates the unnecessary reduction of the number of wires in a tendon as well as the unnecessary and deleterious cycling of tendon force resulting from the de-tensioning and re-tensioning needed to allow wire removal. It also reduces the industrial hazard associated with the de-tensioning and re-tensioning operation.

3.4.4 Corrosion Protection Medium Test Results

Effectively all US containments that have ungrouted tendons use a corrosion protection medium (CPM) product supplied by the Viscosity Oil Company. CPM formulations have changed over time but the basic product remains the same, i.e., a microcrystalline wax that provides the following protective functions.

- An essentially waterproof coating on tendon wires and end anchorage hardware.
- A bulk fill to limit water intrusion into tendon ductwork.
- A chemically built-in alkalinity to neutralize acid conditions that could lead to corrosion.

There is no industry operating experience to indicate that the CPM used in US containments has degraded over time in such a manner as to result in tendon or end anchorage hardware corrosion. Such hardware problems as have been found are attributable to either gross loss of medium from the ductwork, end anchorage design features that prevent full coverage of metallic components at the time of CPM injection or, metallurgical characteristics of certain anchor-head production batches.

Current CPM testing requirements mandate relatively complex procedures, as described or referenced in ASME Section XI (Reference 7.2) Table IWL-2525-1, to determine absorbed water content, corrosive ion concentration and residual reserve alkalinity. Corrosive ions cannot enter the ductwork in the absence of water intrusion and reserve alkalinity cannot be brought into play if there are no acid ions present in the bulk CPM. Therefore, there is little or no benefit gained by testing CPM samples for ion concentrations and reserve alkalinity unless there is evidence of free water in end caps or ducting or a significant quantity of absorbed water in CPM samples.

Consequently, industry experience would suggest that CPM samples collected during end anchorage examinations should be initially tested only to determine absorbed water content. Additional tests should be conducted only if there is evidence of free water[8] in end caps / ducting or sufficient absorbed water in CPM samples to establish potentially corrosive conditions or, if specific unit / plant test data indicate a history of problems with the CPM. Modifying testing programs accordingly would reduce the environmental problems associated with disposal of the reagents used in these processes (the procedure for determining water content does not require use of reagents).

4. V. C. SUMMER NUCLEAR STATION UNIT 1 EXAMINATION HISTORY AND RESULTS EVALUATION

The VCSNS containment post-tensioning system examination program is consistent with the guidance in USNRC Regulatory Guide 1.35 (through the 20-year or 6th consecutive, examination) or the requirements of 10CFR50.55a and, as cited therein, ASME Section XI, Subsection IWL (starting with the 25-year or 7th consecutive, examination). The program consists of the following examination activities.

- Visual examination of the concrete exterior surface (as previously discussed, this activity will continue to be performed in accordance with past practice and, with the exception of specified enhancements, is not addressed further in this report).
- Measurement of force applied by the sample tendons at the end anchorage.
- Testing of wires, extracted from designated tendons, to determine ongoing tensile strength and ductility.
- Visual examination of sample tendon end anchorage hardware and concrete surrounding the bearing plates to detect cracking, deformation, corrosion, missing button heads or broken wires, water intrusion into tendon ductwork and other indications of degradation.
- Testing of corrosion protection medium (CPM) samples for the presence of corrosive ions (specifically, chloride, nitrate and sulfide) and absorbed water and, to verify continuing reserve alkalinity[9].

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[8] Free water is always collected and tested to determine pH in accordance with the requirements of Subsection IWL.

[9] The CPM is formulated to neutralize strong acids that would otherwise have the potential to attack post-tensioning system hardware.

For each surveillance, a specified number of sample tendons is selected at random from the overall population and, with the exception of one tendon in each group (hoop, vertical, dome) that is common to several surveillances, excludes tendons previously examined[10].

VCSNS has completed 10 pre-stressing system examinations. These examinations were based on Regulatory Guide 1.35 or 10CFR50.55a / ASME Section XI Subsection IWL as shown below.

Examination No.	Year Performed	Time, Years, from January 1981 SIT to Surveillance Mid-Point[a]	Governing Document(s)
1	1982	1.2	Reg Guide 1.35
2	1983	2.8	Reg Guide 1.35
3	1985	4.9	Reg Guide 1.35
4	1990	9.1	Reg Guide 1.35
5	1996	15.2	Reg Guide 1.35
6	2000	19.8	10CFR50.55a / IWL
7	2006	25.8	10CFR50.55a / IWL
8	2011	30.2	10CFR50.55a / IWL
9	2015	34.8	10CFR50.55a / IWL
10	2020	39.2	10CFR50.55a / IWL

Note a: Most surveillance reports indicate only the months during which the surveillance begins and ends. However, a few list the beginning and ending dates. For consistency, and to simplify time computations, all surveillances are treated as beginning and ending at mid-month. For timing purposes, each surveillance is treated as being performed at a single point in time midway between the beginning and end. The SIT date is treated as mid-January 1981.

The following subsections, 4.1 through 4.5, of this report provide a comprehensive evaluation of VCSNS post-tensioning system examination results as documented in the 1, 3, 5, 10, 15, 20, 25, 30, 35 and 40-year examination reports (References 7.8 through 7.17). These address the following aspects of examination results.

Subsection 4.1 – Tendon Force Trends and Forecasts
Par. 4.1.1 - Hoop Tendon Force Trends and Forecasts
Par. 4.1.2 - Vertical Tendon Force Trends and Forecasts

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[10] As subsequently noted, a few tendons (other than the common tendons) have been included in more than one surveillance sample.

Par. 4.1.3 - Dome Tendon Force Trends and Forecasts
Par. 4.1.4 - Tendon Mean Force Trend Summary and Conclusions

Subsection 4.2 – Wire Examination and Test Results Evaluation

Par. 4.2.1 - Wire Visual Examination and Condition
Par. 4.2.2 - Wire Tensile Strength
Par. 4.2.3 - Wire Elongation at Failure
Par. 4.2.4 - Wire Visual Examination / Test Summary

Subsection 4.3 – End Anchorage Hardware / Concrete Condition

Par. 4.3.1 - Corrosion
Par. 4.3.2 – Free Water
Par. 4.3.3 - Missing / Discontinuous Wires
Par. 4.3.4 - Load Bearing Component Damage / Distortion
Par. 4.3.5 - Concrete Cracking Adjacent to Bearing Plates
Par. 4.3.6- End Anchorage Condition Summary and Conclusions

Subsection 4.4 – Corrosion Protection Medium Testing

Par. 4.4.1 - Corrosive Ion Concentrations
Par. 4.4.2 – Reserve Alkalinity / Neutralization Number
Par. 4.4.3 - Water Content
Par. 4.4.4 - CPM Test Summary and Conclusion

The proposed extension of the tendon surveillance interval to 10 years is justified if it can be shown with a high degree of confidence that the post-tensioning system with its several components will continue to perform its intended function and meet examination acceptance criteria until well beyond the end of the extended interval. Justification of the proposed extension is demonstrated by the evaluations and analyses presented in 4.1 through 4.4 below.

4.1 Tendon Force Trends and Forecasts

[Note: The tendon anchor head transfers force to the concrete structure through a stack of split shims. The shims are not machined but are cut from hot rolled plate. Therefore, the shim halves may vary somewhat in thickness and, as a result, one side of the stack may carry slightly more load than the other. Until the 30-year surveillance, lift-off forces were reported as the average of the jacking forces measured when the first and second shim stack sides became loose. In fact, lift-off is the force at which all load is carried by the stressing jack and none is transferred to the structure. The overly conservative lift-off values documented in the 10-year through 25-year surveillance reports are corrected so that the lift-off values used in this report reflect the force at which the second side of the shim stack became loose. Not all of the 1, 3 and 5-year surveillance field data sheets

showing the individual shim stack side lift-off forces are included in the archived reports; therefore, tendon lift-off values documented in the 1, 3 and 5-year reports are not corrected.]

Force (lift-off force or the force required to separate the anchor head from the shim stack) in designated sample tendons, and additional tendons as mandated by procedure or specified by the Responsible Engineer, is measured during each examination. Measured force trends and forecasts provide ample evidence that mean pre-stressing in the containment wall and dome will remain above the lower limits specified in DC0305C-009 (Reference 7.21, pages 259-260) and DC0304B-008 (Reference 7.22, page 3) until well after the January 2032 deadline for completion of the next surveillance if the interval is extended to 10 years. Hoop, vertical and dome tendon force trends and forecasts are developed and evaluated in 4.1.1, 4.1.2 and 4.1.3 below.

The purpose of a lift-off force measurement is to determine how the initial seating force in a tendon (used as a measure of the pre-stressing force contributed by the tendon) has been reduced by elastic shortening and time dependent losses. Reported tendon force is the single lift-off force measured at the upper end of a vertical tendon or the average of the lift-off forces measured at the two anchorages of a hoop or dome tendon. The mean of a number of tendon forces then serves as a reasonable estimate of the overall mean pre-stressing force provided by the applicable tendon group (i.e., hoop, vertical or dome).

The hoop and dome tendons are, with the exception of the few that have been de--tensioned and re-tensioned during surveillances, effectively undisturbed; forces measured at the ends of the tendons in these groups reflect the losses due to elastic shortening[11], concrete creep, concrete shrinkage and tendon wire stress relaxation. For the hoop (hoop tendon forces increased slightly during re-tensioning of the verticals as discussed below) and dome groups, force trends and trend projections can be determined using essentially all surveillance data.

All of the vertical tendons were re-tensioned following the 10-year surveillance. This activity is documented in Reference 7.18. End anchorage forces that reflect elastic shortening were not measured at the completion of re-tensioning work and are, therefore, unknown. For this reason, vertical tendon group force trends and projections addressed in this report use only the 15-year through 40-year surveillance results.

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[11] Elastic shortening loss is the loss in tendon force resulting from the strain induced in the concrete by subsequent tendon tensioning. It is generally greatest for the first tendon tensioned and zero for the last tendon tensioned.

As noted above, re-tensioning of the 115 vertical tendons increased hoop tendon force. The mean increase in vertical tendon force, computed using as-found and as-left lift-off forces listed in Reference 7.18 and without adjusting for elastic shortening losses, is 176 kip. The corresponding increase in concrete stress is $176 * 115 / [\pi * (804^2 - 756^2)] = 0.086$ ksi where 804" and 756" are containment cylinder outside and inside radii in inches (see containment description in Part 1 above). For a postulated (approximate) concrete modulus and Poisson's ratio of 5,000 ksi and 0.25, respectively, the resulting cylinder wall hoop strain is $0.25 * 0.086 / 5{,}000 = 4.3 * 10^{-6}$. The increase in hoop tendon force due to this strain is, with a tendon modulus of 29,000 ksi and area of 8.3 in^2, $4.3 * 10^{-6} * 29{,}000 * 8.3 = 1.0$ kip. As this increase is quite small relative to the nominal 1,000+ kip force in the hoop tendons, its effect is neglected in subsequent computations.

Hoop, vertical and dome force trends are addressed separately in sub-sections 4.1.1 through 4.1.3 below. The following characteristics of the trends are evaluated in each of these sub-sections.

- Log-Linear Trends and LCL's

  Concrete creep strain, concrete shrinkage strain and pre-stressing steel stress relaxation are shown by relatively short-term tests[12] to vary more or less linearly with the logarithm of time. The log-linear characteristics established by these tests are used in containment design. For this reason, mean pre-stressing force trends are treated in this report as log-linear functions.

  A log-linear mean force trend and 95% lower confidence limit (LCL) on trend line values are computed for hoop and dome tendon groups using all applicable lift-off force data acquired during the 1-year through 40-year surveillances. In addition, trend and LCL are computed using only the 10-year through 40-year data to address the generally observed tendency for the downward slope of the force vs log time trend to flatten over time. As the vertical tendons were re-tensioned following the 10-year surveillance and the lift-off force was not measured after elastic shortening had taken place, the mean force trend for this group is computed using only the data acquired during and following the 15-year surveillance.

  The log-linear trend slope and intercept as well as LCL values are computed using the methods developed in *Probability and Statistics for Engineers* by Irwin Miller and John E. Freund (Reference 7.19).

  Trends and LCL's are plotted and evaluated. LCL's, (and, by default, trends) are shown to remain above minimum required group mean force levels for more than 40

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[12] Creep and shrinkage tests are typically conducted for 6 months and relaxation tests for 1,000 hours (just under 42 days). These time frames are short relative to the expected service life of a containment (40, 60 or possibly even 80 years if a second license extension is granted).

years after the deadline for completion of the next surveillance if the interval is extended to 10 years. This demonstrates that extension of the examination interval will not compromise the safety of the plant.

- Common Tendon Trend Based Forecast

  As can be seen on Figures 1, 2, 4, 6 and 7, and as discussed below, surveillance data exhibits a significant degree of scatter. Reasons for the scatter, which is typical regardless of the containment, are not well understood. A lower confidence limit is constructed and used to account for, in a statistical sense, this scatter. The use of a 95% confidence limit is based on a precedent set in the standard (ANSI / ANS 56.8, Reference 7.20) that governs the conduct of another safety related activity, the containment integrated leakage rate test.

  Figures 3, 5 and 8 are plots of common tendon lift-off forces. These plots exhibit relatively little scatter. Since the scatter of the common tendon force data is small, it is reasonable to postulate that the true trend of group mean force is relatively close to the common tendon force trend (it is assumed, without accounting for tendon geometry, that all tendons in a group tend to lose force at about the same rate). This postulate leads to the following alternative approach to determining the trend of group mean force.

  - A logarithmic mean of times, T_M, associated with each lift-off force measurement shown in Table 2, 3 or 4, is computed as:

    $$T_M = \text{Exp}\left[(1 / n) * \sum_{i=1}^{n} \text{Log}_{10}(T_i)\right]$$

  - It is postulated that there is sufficient data such that the true mean force, F_{MTrue}, at T_M is equal to the mean of the measured lift-off forces, F_M, then the alternative mean force, F_{MAlt}, is defined as:

    $$F_{MAlt} = F_{MTrue} - b_c * [\text{Log}_{10}(T) - \text{Log}_{10}(T_M)]$$

    where b_c is the slope (kip per unit logarithmic interval) of the common tendon trend line (computed using surveillance year 10 - 40 data for the hoop and dome groups and surveillance year 15 – 40 for the vertical group)

  Alternative hoop and dome mean force trends are computed using the 10-year through 40-year surveillance data; alternative vertical tendon trends are computed using the 15-year through 40-year data. F_{MTrue} and $\text{Log}_{10}(T_M)$ values (T_M in years) for hoop, vertical and dome tendon groups are tabulated below.

	Tendon Group		
	Hoop	Vertical	Dome
F_{MTrue}	1,109.7	1,292.0	1,115.6
Log_{10} (T_M)	1.2398	1.4175	1.2955

In the following discussions and evaluations, all computed mean forces and LCL's are rounded to a whole kip value. Computed values ending in (.5) are rounded to the nearest even number.

4.1.1 Hoop Tendon Trends and Forecasts

Hoop tendon forces measured during each of the 10 surveillances are listed in Table 2 and plotted on Figures 1, 2 and 3.

4.1.1.1 Hoop Tendon Mean Force Trend / All Data

The measured force data listed in Table 2 are plotted on Figure 1 which also includes the extrapolated log-linear trend of the mean, the LCL curve and a line indicating the 1,000-kip minimum acceptable mean hoop tendon force. The measured force points on the plot exhibit a relatively large scatter which is typical of lift-off data. Scatter is the result of variations in initial seating force and elastic shortening loss as well as factors such as anchorage temperature (affects the thickness of the shim stack which has a direct bearing on the force in the short length of tendon between the anchor head and inflection point) that are generally not quantified.

The trend line, computed based on the postulate that the true mean is a log-linear function of time and using the method of least squares, as developed in Reference 7.19, suggests that mean hoop tendon force is defined by the equation:

$$F_{HM} = 1{,}252.7 - 110.75 * Log_{10}(T)$$

where T is, as earlier noted, years since the January 1981 SIT.

The trend line, which is based on the previously stated postulate, remains well above the minimum line at T = 100[13], which is 49 years after the latest date for completion of the

[13] T = 100, represented by a major grid line on the logarithmic abscissa scale, is a convenient reference point and is not otherwise intended to have particular significance.

next surveillance if the interval is extended to 10 years. If the examination interval is extended from 5 years to 10 years, the latest time for completion of the next examination is T = 51, the SIT anniversary date plus the one-year tolerance allowed by IWL-2420(c). The forecast trend line ordinates at T = 51 and T = 100 years are 1,064 kip and 1,031 kip, respectively. The LCL at T = 51 years is 1,046 kip, 46 kip above the 1,000- kip lower limit. The LCL at T = 100 years is 1,010 kip, 10 kip above the 1,000-kip lower acceptance limit.

The forecast trend line and LCL ordinates at T = 51 and T= 100 years are summarized below along with margins between ordinates and the 1,000-kip lower limit on mean hoop tendon force.

Trend or LCL	T = 51		T = 100	
	Ordinate, kip	Margin, kip	Ordinate, kip	Margin, kip
Trend Line	1,064	64	1,031	31
95% LCL	1,046	46	1,010	10

The extrapolated trend and LCL values at T = 51 and T = 100 years, computed using all surveillance data, support the proposed extension of the examination interval.

4.1.1.2 Hoop Tendon Mean Force Trend / From Surveillance Year 10

Figure 2 is a plot of hoop tendon forces measured during the 10-year and subsequent surveillances, the trend line extrapolated to T = 100, the LCL curve and the 1,000-kip lower limit line.

The trend line equation is:

$$F_{HM} = 1{,}151.4 - 33.66 * \text{Log}_{10}(T)$$

The trend line is flatter (slope is -33.66 kip / unit logarithmic interval) than that the -110.75 kip / unit logarithmic interval slope computed for the All Data case above. This is consistent with expectations based on general industry trends. The equation yields T = 51 and T = 100 mean force values of 1,094 kip and 1,084 kip respectively. Both are greater than the All Data mean forces computed for the same points in time. The LCL ordinates at T = 51 and T = 100 years are 1,065 kip and 1,040 kip, respectively.

The forecast trend line and LCL ordinates at T = 51 and T= 100 years are summarized below along with margins between ordinates and the 1,000-kip lower limit on mean hoop tendon force.

Trend or LCL	T = 51		T = 100	
	Ordinate, kip	Margin, kip	Ordinate, kip	Margin, kip
Trend Line	1,094	94	1,084	84
95% LCL	1,065	65	1,040	40

The extrapolated trend and LCL values at T = 51 and T = 100 years, computed using data from the 10-year and later surveillances, support the proposed extension of the examination interval.

4.1.1.3 Hoop Common Tendon Force Trend and Alternative Trend

Tendon H-46AC was examined during the 10, 25, 30, 35 and 40-year surveillances and is treated here as a common tendon. It was not examined during the 1, 3, 5, 15 and 20-year surveillances.

Figure 3 is a plot of common hoop tendon H-46AC measured forces and includes the log-linear trend line. The lower limit on hoop tendon mean force is not shown on the plot as it is not applicable to individual tendons, half of which are, per design, expected to fall below the minimum, and half above, at the end of the initially specified plant operating life time of 40 years. Scatter is seen to be small relative to that illustrated in Figures 1 and 2. The trend line equation is:

$$F_{HC} = 1{,}295.5 - 155.24 * \text{Log}_{10}(T)$$

The alternative mean force, $F_{HM}(T)$, defined by F_{MTrue}, $\text{Log}_{10}(T_M)$ and common tendon trend line slope b_c = -155.24 kip per logarithmic interval is:

$$F_{HM}(T) = F_{MTrue} + b_c * [\text{Log}_{10}(T) - \text{Log}_{10}(T_M)]$$

$$= 1{,}109.7 - 155.24 * [\text{Log}(T) - 1.2398]$$

Forecast alternative mean hoop tendon forces at T = 51 years and T = 100 years are, from the above equation:

$$F_{HMAlt}(51) = 1{,}109.7 - 155.24 * [\text{Log}_{10}(51) - 1.2398] = 1{,}037\text{-kip}$$

$$F_{HMAlt}(100) = 1{,}109.7 - 155.24 * [\text{Log}_{10}(100) - 1.2398)] = 992\text{-kip}$$

The forecast T = 51 mean of 1,037-kip is 37- kip above the 1,000-kip lower acceptance limit. The forecast T = 100 mean of 992-kip is 8-kip below the lower limit. A rearrangement of the above equation shows that the alternative trend line crosses the lower limit line at a time T of:

$$T = \text{Exp}\,[(1{,}109.7 - 1{,}000) / (155.24) + 1.2398] = 88.4 \text{ years}$$

The above analysis shows, subject to the assumptions used in its development, that hoop tendon mean force will remain above the lower limit for 37.3 years beyond the deadline for completion of the next surveillance. Therefore, this alternative trend analysis also supports the extension of examination interval to 10 years.

4.1.1.4 Hoop Tendon Force Evaluation Summary and Conclusions

It is concluded, based on the statistical analyses and other evaluations discussed above, that mean hoop tendon force will, with a high degree of probability, remain above the 1,000 kip lower limit for at least 40 years beyond the T = 51 deadline for completion of the next surveillance if the interval is extended to 10 years

This conclusion is supported by the following.

a) The hoop tendon mean force trend, computed using all measured force data acquired during the 10 examinations conducted to date, does not cross the lower limit line until after T = 100 (years since the January 1981 structural integrity test).

b) The hoop tendon mean force trend, computed using measured force data acquired during the 10-year and subsequent examinations, does not cross the lower limit line until after T = 100.

c) The 95% lower confidence limit on hoop tendon mean force, computed using measured force data acquired during the 10 surveillances completed to date, remains above the 1,000 kip minimum beyond T = 100.

d) The 95% lower confidence limit on hoop tendon mean force, computed using measured force data acquired during the 10-year and subsequent examinations, remains above the 1,000 kip minimum beyond T = 100.

e) Hoop tendon mean force, computed using the slope of the common tendon (H-46AC) measured force trend and the surveillance means, remains above the lower limit until T = 88.4 years.

The foregoing analyses and evaluations, and the conclusions derived therefrom, support the proposed extension of the interval between containment post-tensioning system examinations to 10 years from the current 5 years.

4.1.2 Vertical Tendon Trends and Forecasts

Vertical tendon forces measured during each of the 15-year through 40-year surveillances (as noted above, all vertical tendons were re-tensioned following the 10-year surveillance; forces measured prior to re-tensioning cannot be meaningfully combined with those measured during year 15 and later) are listed in Table 3 and plotted on Figures 4 and 5.

4.1.2.1 Vertical Tendon Mean Force Trend

The measured force data listed in Table 3 for the 15-year and later surveillances (earlier surveillance data are shown for information only) are plotted on Figure 4 which also includes the extrapolated log-linear trend of the mean, the LCL curve and a line indicating the 1,160-kip minimum acceptable mean vertical tendon force.

The measured force points on the plot exhibit a relatively small scatter which reflects the effect of re-tensioning in 1990 as documented in Reference 7.18. Vertical tendons were tensioned from a mean force of 1,196 kip to a mean of 1,372 kip with a minimum lock-off of 1,351 kip and a maximum of 1,390 kip; overall, mean force was increased (excluding the effect of elastic shortening) by 176 kip or about 15% of the as-found value. Since tendon forces were increased by a relatively small percentage, final lock-off forces were relatively uniform and only vertical tendons were re-tensioned, elastic shortening losses were minimal. Therefore, there was relatively little variation in vertical tendon forces following the completion of re-tensioning.

The trend line, computed based on the postulate that the true mean is a log-linear function of time and using the method of least squares, as developed in Reference 7.19, suggests that mean vertical tendon force is defined by the equation:

$$F_{VM} = 1{,}429.5 - 97.01 * \text{Log}_{10}(T)$$

The trend line, which is based on the previously stated postulate, remains well above the 1,160-kip lower line at T = 100. If the examination interval is extended from 5 years to 10, the latest time for completion of the next examination is T = 51, the SIT anniversary date plus the one-year tolerance allowed by IWL-2420(c). The extrapolated trend line ordinate at T = 51 is 1,264 kips, 104 kips above the 1,160-kip lower limit. The extrapolated trend line ordinate at T = 100 is 1,235 kips or 75 kips above the lower limit. The LCL at T = 100 is 1,211 kips, 51 kips above the lower limit.

The forecast trend line and LCL ordinates at T = 51 and T = 100 years are summarized below along with margins between ordinates and the 1,160-kip lower limit on mean vertical tendon force.

Trend or LCL	T = 51		T = 100	
	Ordinate, kip	Margin, kip	Ordinate, kip	Margin, kip
Trend Line	1,264	104	1,235	75
95% LCL	1,253	93	1,215	55

The extrapolated trend and LCL ordinates at T = 51 and T = 100 years, computed using data from the 15-year and later surveillances, support the proposed extension of the examination interval.

4.1.2.2 Vertical Common Tendon Force Trend and Alternative Trend

Tendon V-90 was designated as a common tendon starting with the 15-year surveillance.

Figure 5 is a plot of common vertical tendon V90 measured forces from surveillance year 15 and includes the log-linear trend line. The lower limit on vertical tendon mean force is not shown on the plot as it is not applicable to individual tendons as explained in 4.1.1.3 above. Scatter is seen to be even less than that illustrated in Figure 4. The trend line equation is:

$$F_{VC} = 1,487.4 - 137.03 * Log_{10}(T)$$

The alternative mean force, $F_{VM}(T)$, defined by F_{MTrue}, $Log_{10}(T_M)$ and common tendon trend line slope b_c = -137.03 kip per logarithmic interval is:

$$F_{VM}(T) = F_{MTrue} + b_c * [Log_{10}(T) - Log_{10}(T_M)]$$
$$= 1,292.0 - 137.03 * [Log_{10}(T) - 1.4175]$$

Forecast alternative mean vertical tendon forces at T = 51 years and T = 100 years are, from the above equation:

$$F_{VMAlt}(51) = 1,292.0 - 137.03 * [Log_{10}(51) - 1.4175] = 1,252 \text{ kips}$$
$$F_{VMAlt}(100) = 1,292.0 - 137.03 * [Log_{10}(100) - 1.4175] = 1,212 \text{ kips}$$

The forecast T = 51 mean of 1,252 kips is 92 kips above the 1,160-kip lower limit. The forecast T = 100 mean of 1,212 kips exceeds the lower limit by 52 kips.

The above analysis provides further confirmation that vertical tendon mean force will remain above the lower limit not only beyond the deadline for completion of the next surveillance but also beyond T = 100 years. The alternative trend analysis supports the extension of examination interval to 10 years.

4.1.2.3 Vertical Tendon Force Evaluation Summary and Conclusions

It is concluded, based on the statistical analyses and other evaluations discussed above, that mean vertical tendon force will remain at or above the 1,160-kip lower limit until well beyond T = 100, 49 years after the latest date for completing the next surveillance if the interval is extended to 10 years. This conclusion is supported by the following.

a) The vertical tendon mean force trend, computed using all measured force data acquired during the 6 examinations conducted since vertical tendon re-tensioning, remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,235 kips or 75 kips above the 1,160-kip lower limit.
b) The 95% lower confidence limit on vertical tendon mean force, computed using measured force data acquired during the 6 examinations conducted since vertical tendon re-tensioning, remains above the 1,160-kip minimum until well after T = 100 (forecast LCL at T = 100 is 1,215 kips).
c) The alternative vertical tendon mean force, computed using the slope of the common tendon (V-90) measured force trend and the average of mean forces computed for the 15-year and later surveillances, remains above the lower limit until well beyond T = 100. The forecast alternative mean force at T = 100 is 1,212 kip or 52 kip above the 1,160-kip lower limit.

The results of the analyses and evaluations summarized in a) through c) above provide evidence that vertical tendon mean force will remain above the lower limit until well beyond T = 100 (100 years after the January 1981 SIT), or, 49 years after the latest date for completion of the next surveillance if the interval is extended to 10 years.

These analyses, evaluations and associated conclusions support the proposed extension of the containment post-tensioning system ISI interval to 10 years.

4.1.3 Dome Tendon Trends and Forecasts

Dome tendon forces measured during each of the 9 surveillances performed to date are listed in Table 4 and plotted on Figures 6 through 8.

4.1.3.1 Dome Tendon Mean Force Trend / All Data

The measured force data listed in Table 4 are plotted on Figure 6 which also includes the extrapolated log-linear trend of the mean, the LCL curve and a line indicating the 1,025-kip minimum acceptable mean dome tendon force. The measured force points on the plot exhibit a relatively large scatter which is typical of lift-off data as previously discussed.

The trend line, computed based on the postulate that the true mean is a log-linear function of time and using the method of least squares, as developed in Reference 7.19, suggests that mean dome tendon force is defined by the equation:

$$F_{DM} = 1{,}242.4 - 96.42 * \text{Log}_{10}(T)$$

The trend line, which is based on the previously stated postulate, remains well above the minimum line at T = 100, which is 49 years after the January 2032 deadline for completion of the next surveillance if the examination interval is extended from 5 years to 10. The extrapolated trend line ordinates at T = 51 and T = 100 years are 1,078 kip and 1,050 kip, respectively. The corresponding LCL values are 1,066 kip and 1,034 kip.

The forecast trend line and LCL ordinates at T = 51 and T= 100 years are summarized below along with margins between ordinates and the 1,025-kip lower limit on mean dome tendon force.

Trend or LCL	T = 51		T = 100	
	Ordinate, kip	Margin, kip	Ordinate, kip	Margin, kip
Trend Line	1,078	53	1,050	25
95% LCL	1,066	41	1,034	9

The extrapolated trend and LCL values at T = 51 and T = 100 years, computed using all surveillance data, support the proposed extension of the examination interval.

4.1.3.2 Dome Tendon Mean Force Trend / From Surveillance Year 10

Figure 7 is a plot of dome tendon forces measured during the 10-year and subsequent surveillances, the trend line extrapolated to T = 100, the LCL curve and the 1,025-kip lower limit line.

The trend line equation is:

$$F_{DM} = 1{,}214.0 - 75.96 * \text{Log}_{10}(T)$$

The trend line is flatter (slope is -75.96 kip / unit logarithmic interval) than that the -96.42 kip per unit logarithmic interval slope computed for the All Data case above. This is consistent with expectations based on general industry trends. The equation yields T = 51 and T = 100 mean force values of 1,084 kips and 1,062 kips, respectively. The corresponding LCL values are 1,064 and 1,029 kip.

The forecast trend line and LCL ordinates at T = 51 and T= 100 years are summarized below along with margins between ordinates and the 1,025-kip lower limit on mean dome tendon force.

Trend or LCL	T = 51		T = 100	
	Ordinate, kip	Margin, kip	Ordinate, kip	Margin, kip
Trend Line	1,084	59	1,062	37
95% LCL	1,064	39	1,029	4

The extrapolated trend and LCL values at T = 51 and T = 100 years, computed using data from the 10-year and later surveillances, support the proposed extension of the examination interval.

4.1.3.3 Dome Common Tendon Force Trend and Alternative Trend

Tendon D-213 was included in the 3, 5, 20, 25, 30, 35 and 40-year surveillance examination samples and is, therefore, considered to be the common dome tendon. Tendon D-213 was not examined during the 1, 10 and 15-year surveillances. For consistency with the hoop and vertical tendon group alternative analyses, the common force trend slope applicable to the dome tendon group alternative analysis is based on the 20 through 40-year surveillance results and excludes the 3 and 5-year lift-of values.

Figure 8 is a plot of dome tendon D-213 forces measured during surveillance years 20 through 40 and includes the log-linear trend line. It does not, for the reason given above, include the lower limit line. Scatter is seen to be less than that illustrated in Figures 6 and 7. The trend line equation is:

$$F_{DC} = 1,339.7 – 167.49 * Log_{10} (T)$$

The alternative mean force, $F_{DM}(T)$, defined by F_{MTrue}, Log_{10} (T_M) and common tendon trend line slope b_c = -167.49 kip per unit logarithmic interval is:

$$F_{DM} (T) = F_{MTrue} + b_c * [Log_{10} (T) – Log_{10} (T_M)]$$

$$= 1,115.6 – 167.49 * [Log10 (T) – 1.2955]$$

Forecast alternative mean dome tendon forces at T = 51 years and T = 100 years are, from the above equation:

$$F_{DMAlt} (51) = 1,115.6 – 167.49 * [Log_{10} (51) – 1.2955] = 1,047 \text{ kip}$$

$$F_{DMAlt} (100) = 1,115.6 – 167.49 * [Log_{10} (100) – 1.2955] = 998 \text{ kip}$$

The forecast T = 51 mean of 1,047 kip is 22 kip above the 1,025-kip lower limit. The forecast T = 100 mean of 998 kips is 27 kips below the lower limit. Rearranging terms in the above equation for F_{DMAlt} gives the following expression for the time, T, at which the alternative mean force falls below the minimum required value of 1,025 kip.

$$T = Exp[(1,115.7 – 1,025) / 167.49 + 1.2955] = 68.7$$

The above analysis provides further confirmation that dome tendon mean force will remain above the lower limit not only beyond the deadline for completion of the next surveillance but also until just before T = 69 years. Therefore, this alternative trend analysis also supports the extension of examination interval to 10 years.

4.1.3.4 Dome Tendon Force Evaluation Summary and Conclusions

It is concluded, based on the statistical analyses and other evaluations discussed above, that mean dome tendon force will remain above the 1,025-kip lower limit at least until T = 69, 18 years after the latest date for completing the next surveillance if the interval is extended to 10 years. Four of the 5 parameters (All Data trend, All Data LCL, truncated data trend, truncated data LCL and alternative trend) evaluated show dome tendon mean force remaining above the 1,025-kip lower limit beyond T = 100. Only the alternative trend crosses the lower limit prior to T = 100; it crosses just before T = 69 years. The stated conclusion is supported by the following.

a) The dome tendon mean force trend, computed using all measured force data acquired during the 10 examinations conducted to date, remains above the lower limit beyond T = 100. The forecast mean force at T = 100 is 1,050 kip or 25 kip above the 1,025-kip lower limit.

b) The dome tendon mean force trend, computed using measured force data acquired during the 10-year and subsequent examinations, also remains above the lower limit beyond T = 100. The forecast mean force at T = 100 is 1,062 kips or 37 kips above the 1,025-kip lower limit.

c) The 95% lower confidence limit on dome tendon mean force, computed using measured force data acquired during the 10 examinations completed to date, remains above the 1,025-kip lower limit beyond T = 100. The LCL at T = 100 is 1,034 kip, 9 kip above the lower limit.

d) The 95% lower confidence limit on dome tendon mean force, computed using measured force data acquired during the 10-year and subsequent examinations, also remains above the lower limit beyond T = 100. The LCL at T = 100 is 1,029 kip, 4 kips above the 1,025-kip lower limit.

e) Dome tendon mean force, computed using the slope of the common tendon (D-213) measured force trend and the average of the forces computed for each of the surveillances, remains above the lower limit beyond T = 51, the latest time for completion of the next surveillance if the interval is extended to 10 years. The forecast mean force at T = 51 is 1,047 kip, 22 kip above the 1,025-kip lower limit. The forecast mean force remains above the lower limit until just before T = 69 years, almost 18 years after the deadline for completion of the next surveillance if the interval is extended to 10 years.

The results of the analyses and evaluations summarized in a) through e) above provide evidence that dome tendon mean force will remain above the lower limit until just before T = 69 years (almost 18 years after the latest date for completion of the next surveillance if the interval is extended from 5 to 10 years) and has a high likelihood of remaining above the lower limit beyond T = 100.

These analyses, evaluations and associated conclusions support the proposed extension of the containment post-tensioning system ISI interval to 10 years.

4.1.4 Tendon Mean Force Trend Summary and Conclusions

The trend of the mean force is analyzed separately for the hoop, vertical and dome tendon groups. The hoop and dome tendon group analyses cover the results of the following 5 computations, a) through e), all based on the postulate that mean force varies linearly with the logarithm of time. The vertical tendon group analyses cover only the results of computations c), d) and e), a result of vertical tendon re-tensioning following the 10-year surveillance as previously explained.

a) Trend based on measured forces recorded during the 10 surveillances completed to date.
b) 95% lower confidence limit (LCL) on the trend of measured forces recorded during the 10 surveillances completed to date.
c) Trend based on measured forces recorded during the 10-year (15-year for the vertical tendon group) and subsequent surveillances.
d) 95% lower confidence limit (LCL) on the trend of measured forces recorded during the 10-year (15-year for the vertical tendon group) and subsequent surveillances.
e) Trend using the slope of the common tendon log-linear trend and the average of the mean forces computed for each of the surveillances.

The margins between forecast group mean force and the group lower limit are summarized in the table below. Margins are shown for T = 51 years (the latest time for completion of the next surveillance if the interval is extended to 10 years) and T = 100 years and, for the 5, as applicable, forecast bases listed above.

Summary of Margins between Forecast and Minimum Required Mean Forces			
Tendon Group	**Forecast Basis**	**Margin, kip**	
		T = 51	**T = 100**
Hoop Lower Limit = 1,000 kip	Log-linear trend, all lift-off forces	64	31
	95% LCL, all lift-off forces	46	10
	Log-linear trend, 10 to 40-year lift-off forces	94	84
	95% LCL, 10 to 40-year lift-off forces	65	40
	Common tendon slope / lift-off force mean	37	-8[a]
Vertical Lower Limit = 1,160 kip	Log-linear trend, all lift-off forces	N/A	N/A
	95% LCL, all lift-off forces	N/A	N/A
	Log-linear trend, 15 to 40-year lift-off forces	104	75
	95% LCL, 15 to 40-year lift-off forces	93	55
	Common tendon slope / lift-off force mean	92	52
Dome Lower Limit = 1,025 kip	Log-linear trend, all lift-off forces	53	25
	95% LCL, all lift-off forces	41	9
	Log-linear trend, 10 to 40-year lift-off forces	59	37
	95% LCL, 10 to 40-year lift-off forces	39	4
	Common tendon slope / lift-off force mean	22	-27[b]

Note a: Alternative trend crosses the lower limit at T = 88.4 years

Note b: Alternative trend crosses the lower limit at T = 68.7 years

Eleven of 13 trends / LCL's evaluated show the trend line and LCL curve remaining above the group lower limit beyond T = 100 (years after the SIT), or more than 49 years after the deadline for completion of the next surveillance if the interval is extended to 10 years.

Of the 13 trend / LCL margins listed in the T = 100 column, all but 2 are positive. The exceptions are the alternative hoop and dome tendon mean forces. In each of these cases, the alternative mean force at T = 51, the deadline for completion of the next surveillance if the interval is extended to 10 years, exceeds the lower limit. The alternative mean force margins for the hoop and dome tendon groups at T = 51 are 37 and 22 kips, respectively. The hoop and dome tendon group alternative mean forces reach the lower limit at T = 88.4 and T = 68.7 years, respectively.

Based on the above summary, it is concluded that the proposed extension of the interval to 10 years is fully supported by the analysis of tendon mean force and 95% LCL trends.

4.2 Wire Examination and Test Results Evaluation

During every surveillance, sample wires were extracted from at least one tendon in each group, visually examined for damage / corrosion and tested to determine ultimate strength and elongation at failure. Tests were performed on three (four test specimens were cut from the wires extracted during the 35 and 40-year surveillances) specimens cut from each of the wires. Two of the specimens were located close to the sample wire ends. A third specimen was cut at a location near the center of the wire or, for wires extracted during the 35 and 40-year surveillances, two additional specimens were cut; at the approximate third points for the hoop and dome tendon wires and, for the vertical tendon wire, one close to the center and the other relatively close to one end.

In addition, three of the broken wires found during the 1-year surveillance were extracted and examined for signs of corrosion. Specimens were cut from these wires and tested.

Table 5a with Figure 9 and Table 5b with Figure 10 summarize the results of the tests on unbroken wires extracted for testing. Tables 6a and 6b summarize the result of tests on specimens cut from broken wires.

4.2.1 Wire Visual Examination and Condition

The entire length of each extracted wire was visually examined for signs of damage and corrosion. None of the 33 wires, other than those identified as broken wires, had signs of damage. The condition of most extracted wires was judged to be Level 1 (bright metal, no evidence of corrosion; see table below). Level 2 (light rust with no pitting) conditions were observed on six of the extracted wires. No Level 3 or higher corrosion was found. There is no indication in any of the surveillance reports that observed corrosion was active.

Level	Characteristic
1 or A	Bright metal
2 or B	Light rust with no pitting
3 or C	Rust with pitting up to 0.003” in depth
4 or D	Rust with pitting 0.003” to 0.006” in depth
5 or E	Rust with pitting greater than 0.006” in depth

Wires extracted for testing included the following broken wires.

Surveillance Year	Tendon	Number of Broken Wires Extracted for Testing
1	V-68	1
1	D-220	2

Other broken wires and wires with missing button heads were found during the 1-year surveillance and during later surveillances as discussed in Section 4.3. A number of these were extracted, visually examined and found to be at Levels 1 and 2. However, the surveillance reports do not indicate that broken wires, other than those noted above, were tested for strength and ductility.

As no corrosion beyond Level 2 has been found on extracted wires, it is concluded that tendon wire corrosion should not be a concern in the future.

4.2.2 Wire Tensile Strength

Table 5a lists the ultimate tensile strength (UTS) found for the test specimens cut from each extracted unbroken wire, the mean of the 3 or 4 UTS values (Wire Mean) and the mean of all UTS values listed for the examination year (Exam Mean). Figure 9 is a log-time based plot showing, for each examination year, the maximum, minimum and mean UTS values recorded for each unbroken wire test specimen.

Reported individual specimen tensile strengths varied from 241 to 263 ksi, with all exceeding the ASTM A421 lower limit of 240 ksi. Wire mean strength varied from 243 to 260 ksi while the mean strengths computed for all tests performed during a given surveillance varied over a range of 247 to 260 ksi. These variations are reasonably consistent with those reported for tests on wires extracted for testing at other plants.

The maximum, minimum and mean values plotted on Figure 9 appear to fluctuate in a random manner with no observable tendency to increase or decrease over time. This suggests that at least some of the variation observed may be due to differences in testing equipment and techniques.

With one exception, the UTS values shown for the specimens cut from a specific wire are generally close together as would be expected; this suggests that the testing procedure applicable to a given examination was normally applied in a consistent manner. The difference between the largest and smallest UTS reported for a given wire is, with one exception, 7 ksi or less. The single exception is the 18 ksi difference between the largest and smallest UTS values shown for the specimens cut from the H-25BA wire extracted and tested during the 25-year surveillance.

As all of the 96 (108 if broken wire test results are included) UTS values exceed the 240 ksi lower limit, as there is no trend to the data plotted on Figure 9 and, as the year 1 mean UTS and year 40 mean UTS are effectively the same, it is concluded that wire strength does not change over time. Consequently, there should be no need to continue the strength tests.

Table 6a shows the UTS for specimens cut from the three broken wires extracted during the 1-year surveillance. These values are generally in line with the UTS data shown on Table 5a, verifying that the cause of the break, in each case, was not related to a dispersed metallurgical condition.

The results shown for the tendon V-68 specimens are those obtained during a retest at a Pittsburgh Testing Laboratories facility. The retests were performed after the results of the initial tests were questioned because both UTS (one of three specimens) and elongation at failure (all three specimens) were shown as below acceptance limits. Neither the facility performing the initial tests nor the equipment and procedures used are identified in the surveillance report.

Based on the above discussion, it is concluded that wire tensile strength does not change over time and that it continues to meet the ASTM A421 specified minimum of 240 ksi. Therefore, it is concluded that no valid purpose is served by continuing tensile testing to demonstrate that ongoing tensile strength is acceptable.

4.2.3 Wire Elongation at Failure

Table 5b lists the elongation at failure, EF, documented for the three or four test specimens cut from each unbroken extracted wire, the mean of the 3 (or 4) EF values (Wire Mean) and the mean of all EF values listed for the examination year (Exam Mean). Most of the reported elongations exceed the 4% minimum specified in ASTM A421.

A number of the EF values as well as the computed means recorded for the 5-year, 15-year and 30-year surveillance test specimens are below the 4% lower limit specified in ASTM A421. Since there is no trend (see discussion in the following paragraph) to the EF mean values, the maxima or the minima, it is concluded that the indicated failures at elongations below 4% are the result of unintentional errors in the testing process. It is to be noted that while an accurate measurement of UTS is easily obtained, a significant degree of experience and care is necessary to determine an accurate value of elongation at failure. For this reason, EF tends to exhibit a lot more variability than UTS.

Figure 10 is a log-time based plot showing, for each examination year, the examination mean EF, the maximum EF and the minimum EF. The scatter of the data is readily apparent, especially when Figure 10 is compared to Figure 9 and there is no observable trend to either mean, maximum or minimum EF.

As there is no definitive pattern, i.e., no significant trend for elongation at failure to increase or decrease over time, it is concluded that much of the apparent variation in reported elongation can be attributed to variations in testing procedures / equipment from examination to examination. And, as there is no evidence to the contrary, it is concluded that wire ductility, as measured by elongation at failure, does not change over time.

Table 6b shows the EF values for specimens cut from each broken wire. These are in line with the EF data shown on Table 5b.

Based on the above discussion, it is concluded that wire ductility does not change with time under load and that it does, in fact, continue to meet the ASTM A421 specified minimum (as defined by elongation at failure over a 10-inch gage length of at least 4%). And, it is further concluded that no valid purpose is served by continuing tensile testing to demonstrate that ongoing ductility remains acceptable.

4.2.4 Wire Visual Examination and Test Summary

The above tabulations, plots, analyses and evaluations show that tendon wire strength and ductility are essentially invariant with time. In addition, visual examinations of 34 wires (including 3 broken wires) extracted from hoop, vertical and dome tendons between 1982 and 2020 have uncovered no evidence of in-service damage (damage other than that occurring prior to or at the time of initial tensioning or re-tensioning), active corrosion or an unacceptable level of pre-existing (prior to tendon duct filling) corrosion.

Since examinations and tests conducted over more than 3 decades have shown that wire condition, strength and ductility are not changing over time, it is concluded that there is no merit to retaining the current requirement for wire examination / testing and for the associated de-tensioning[14] of tendons to extract test wires. It is recommended, on the basis of the foregoing conclusion, that this aspect of post-tensioning system surveillance

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[14] On rare occasions, a wire will break as a result of distortions that can be induced by the de-tensioning/ re-tensioning process. While the impact of wire breakage on containment strength is minimal, it is better to avoid such breakage whenever it is reasonable to do so.

be discontinued. Testing could be specified by the Responsible Engineer if wire fracture, end anchorage corrosion, evidence of free water in ductwork or other conditions indicative of actual or potential wire degradation are found during future end anchorage visual examinations or tendon force measurements.

4.3 End Anchorage Hardware / Concrete Condition

During each of the surveillances, end anchorage areas were visually examined for evidence of corrosion, presence of free water, discontinuous wires, damage to / distortion of load bearing components and cracks in concrete adjacent to bearing plates. Results of these examinations are summarized in 4.3.1 through 4.3.5.

The VCSNS tendon anchorage end caps are well sealed and not prone to leakage. Leakage of CPM has not been a problem at VCSNS but will be monitored during the quintennial visual examinations of the containment exterior as well as at other times as discussed in Part 6 below.

4.3.1 Corrosion

Load bearing components were visually examined for corrosion and assigned a condition Level as defined in the following table. The same definitions were used to categorize the condition of extracted wires as discussed in 4.2.1 above.

Level	Characteristic
1 or A	Bright metal
2 or B	Light rust with no pitting
3 or C	Rust with pitting up to 0.003” in depth
4 or D	Rust with pitting 0.003” to 0.006” in depth
5 or E	Rust with pitting greater than 0.006” in depth

Levels 1 and 2 are acceptable and Level 3 is generally acceptable. Levels 4 and 5 require evaluation prior to acceptance. Depth of pitting, associated with Levels 3 – 5, is usually a judgment call based on visual examination of a corroded area.

No active corrosion was observed on anchor heads, shims, button heads, wires or areas of bearing plates that are enclosed by the end cap gasket and protected by CPM. As no free water was found within the end caps or ductwork (see 4.3.2 below), it is concluded that all corrosion observed on load bearing components and on protected areas of bearing plates occurred prior to and / or during construction and before installation of CPM.

Corrosion documented in the surveillance reports is summarized below. All but the items noted were determined to be at Level 1 or Level 2.

1-Year Surveillance (70 anchorages examined)	Level 3 found on one or more button heads at 2 anchorages Areas of Level 3 found on 4 anchor heads Areas of Level 3 found on shims at 1 anchorage Areas of Level 3 found on 8 bearing plates (whether inside or outside of endcap gasket not noted)
3-Year Surveillance (50 anchorages examined)	No corrosion above Level 2 found
5-Year Surveillance (74 anchorages examined)	Level 3 found on one or more button heads at 2 anchorages Areas of Level 3 found on 2 anchor heads Areas of Level 3 found on 3 bearing plates; all outside the end cap gasket
10-Year Surveillance (65 anchorages examined)	Areas of Level 3 found on 1 anchor head Areas of Level 3 found on 25 bearing plates; all outside the end cap gasket Areas of Level 4 found on 13 bearing plates; all outside the end cap gasket and all but 2 of the bearing plates on the top shelf of the ring girder
15-Year Surveillance (19 anchorages examined)	Areas of Level 3 found on 1 anchor head bushing Areas of Level 3 found on 4 bearing plates (whether inside or outside of endcap gasket not noted) Areas of Level 4 found on 2 bearing plates (whether inside or outside of endcap gasket not noted)
20-Year Surveillance (19 anchorages examined)	Areas of Level 3 found on 14 bearing plates; all outside the end cap gasket
25-Year Surveillance (20 anchorages examined)	No corrosion above Level 2 found
30-Year Surveillance (18 anchorages examined)	No corrosion above Level 2 found
35-Year Surveillance (22 anchorages examined)	No corrosion above Level 2 found
40-Year Surveillance (18 anchorages examined)	No corrosion above Level 2 found

The above summary indicates that the incidence of Level 3 and 4 corrosion has decreased over time. This could result from the random selection of surveillance samples. However, as the assessment of corrosion level is subjective based visual examination, it is more likely that the apparent reduction in corrosion level with time is the result of different examiners being assigned to the task of evaluating their observations. The early examiners appear to have been more conservative in their evaluations, particularly in respect to the condition of bearing plates which are hot rolled and have a naturally rough surface.

Viewed as a whole, the above summary of corrosion observed during the 10 surveillances conducted to date leads to the following conclusions.

- Corrosion on system components enclosed by end caps (and inside the end cap gasket ring) is inactive and occurred prior to or during construction and prior to CPM installation.
- While there is evidence that anchor heads, shims and a few button heads experienced corrosion during construction or earlier, any such corrosion is now inactive and minor in nature. It does not have a negative impact on the structural integrity of the post-tensioning system.
- Recent surveillance reports (20-year and later) indicate that bearing plate corrosion is minor and has no impact on structural integrity.
- As there is no evidence of significant active corrosion occurring since the completion of construction and the injection of CPM into the tendon end caps and ducting, there is no need to continue examining for corrosion at 5-year intervals; increasing the examination interval to 10 years will not result in a failure to uncover an unacceptable condition that has developed over the interval.

4.3.2 Free Water

Free water (as distinct from water absorbed by CPM) is not mentioned in the 1 and 3-year surveillance reports; it is presumed that none was found. The remaining reports specifically note that no free water was observed during any of the examinations performed. As the end caps are well sealed and as there has been no evidence of water seepage through the concrete (there is no backfill against the VCSNS containment wall) and into the ductwork, it is concluded that there is no need to continue examining for free water at 5-year intervals. And, it is further concluded that the interval between such examinations can be extended to 10 years with no significant risk of missing a potentially deleterious condition resulting from free water accumulation.

4.3.3 Missing / Discontinuous Wires

Missing or discontinuous (broken / missing button heads) wires found during a surveillance and not previously documented (i.e., at the time of initial tensioning, during vertical tendon re-tensioning or during a prior surveillance) are listed below. During the examinations for missing / discontinuous wires, a number were found to be protruding beyond the anchor heads. Many of these were checked for continuity and all were found to be continuous. It was concluded that protrusion, in these cases, was the result of the wire being tightly bound in the tendon bundle such that force was transferred through friction at the perimeter rather than through seating of the button head. As no protruding wires were found to be broken it is concluded that those not checked for continuity are also not broken. For this reason, protruding wires are treated as effective in carrying load and are not listed below.

1-Year Surveillance (36 tendons examined)	4 button heads reported as missing and 2 broken wires found; wires extracted for examination and testing as described in Section 4.2 above; ***considered 6 new ineffective wires***
3-Year Surveillance (25 tendons examined)	1 button head reported as missing (4 additional reported for tendon D-220 but these were noted in the 1-year report); 3 wires reported as protruding or broken with no indication as to whether or not these were, in fact, broken; ***considered 1 new ineffective wire***
5-Year Surveillance (37 tendons examined)	4 button heads reported as missing but 3 wires previously documented as broken; also, one wire broke during re-tensioning; ***considered 2 new ineffective wires***, one broken wire not previously documented and one broken during re-tensioning
10-Year Surveillance (35 tendons examined)	4 button heads reported as missing; ***considered 4 new ineffective wires***
15-Year Surveillance (10 tendons examined)	1 broken wire or 1 button head reported as missing; ***considered 1 new ineffective wire***
20-Year Surveillance (10 tendons examined)	1 broken wire or 1 button head reported as missing; ***considered 1 new ineffective wire***
25-Year Surveillance (10 tendons examined)	1 broken wire or 1 button head reported as missing; ***considered 1 new ineffective wire*** (NCR FN986-001)
30-Year Surveillance (9 tendons examined)	1 broken wire or 1 button head reported as missing after re-tensioning; ***considered 1 new ineffective wire*** (NCR FN1069-002)
35-Year Surveillance (11 tendons examined)	No broken wires or missing button heads not previously documented
40-Year Surveillance (9 tendons examined)	1 protruding button head, not previously reported, found at the shop end of tendon H49CB

Approximately 190 tendons were examined for broken wires / missing button heads during the 10 surveillances completed to date. During these examinations, 17 wires not previously documented as discontinuous, were found to be broken or missing button heads and, consequently, ineffective as load carrying elements.

A tendon has 170 wires (less any that are broken or otherwise ineffective) and the ~180 (a few tendons were examined more than once) tendons included in the above examinations have an aggregate of over 30,000 wires. Of these, 17 or less than 0.06% were found to be ineffective. This fraction is too small to be of structural significance. Therefore, it is concluded that wire breakage / button head detachment in service can be adequately monitored by examinations performed at intervals of 10 years rather than the current 5 years.

4.3.4 Load Bearing Component Damage / Distortion

No damaged, cracked or distorted load bearing components (bearing plates, anchor heads, shims) have been found during the 10 surveillances conducted to date.

4.3.5 Concrete Cracking Adjacent to Bearing Plates

All concrete cracks noted in tendon end anchorage areas were concluded to have no structural significance. Shrinkage cracks radiating out from the corners (stress risers) of a bearing plate are expected and, unless these are of sufficient length and width to be indicative of a shear cone failure in the heavily reinforced concrete below the plate, are not structurally relevant.

Cracks having widths over 0.010” require evaluation. Only 2 areas with cracks meeting this criterion were found during the 10 surveillances conducted to date.

During the 5-year surveillance, a crack measuring up to 0.015” was found at the Buttress C end of tendon H-31AC. This crack was accepted by evaluation as documented in SCE&G NCN No. 1478.

Dome pocket areas contain numerous stress risers and thin sections of concrete where rapid drying induces shrinkage cracking. During the 20-year surveillance, two areas of cracks up to 0.020” wide were found on the face of the 11.5” wide vertical dividers on either side of the dome tendon D-208 anchorage pocket. The dividers carry essentially no load and are not considered structural members. Therefore, these cracks were considered to have no structural significance and were, presumably (no NCR is cited in the surveillance report), accepted without further evaluation.

No other cracks having a width over 0.010” were reported.

The tendon gallery ceiling concrete is covered by steel plate and cannot be examined.

On the basis of the above discussion, it is concluded that cracking of concrete adjacent to tendon end anchorage bearing plates is not an issue at VCSNS and that close in examinations of these areas at intervals of 10 years is adequate to monitor this condition.

4.3.6 End Anchorage Condition Summary and Conclusions

Tendon end anchorage hardware and adjacent concrete have performed well throughout the life of the plant (through the 40-year surveillance performed in 2020) and show no trends of deteriorating condition.

No free water has been found at tendon end anchorages or in adjacent ducting. There have been no findings of active corrosion (see following paragraph) on extracted wire or anchorage hardware that could be indicative of water intrusion into tendon duct and / or end caps.

There have been no findings of active corrosion on bearing plates areas within the end cap gasket ring, anchor heads, shims or wires. Corrosion observed on exposed areas of bearing plates is minor and has no structural significance. All observed corrosion has been found acceptable with no indication that the incidence of corrosion is increasing over time.

Only 17 discontinuous wires (broken wires or wires with missing button heads) not previously reported have been found. These represent only a miniscule fraction (<0.06%) of the ~30,000 wires comprising the ~180 tendons examined.

No damage, cracking or distortion has been found during visual examinations of bearing plates, anchor heads and shims.

Cracking of concrete adjacent to bearing plates is limited to that resulting from shrinkage and presence of stress risers (plate corners, dome pocket concrete edges) or that due to rapid drying following initial placement of thin sections in pocket areas. There has been no evidence of structural cracks (those caused by applied loads) in the vicinity of surveillance sample tendon end anchorages. Only two areas with cracks wider than 0.010” have been found.

Considering the above, it can be concluded that the end anchorage conditions are stable and unlikely to change significantly before the January 2032 deadline for completion of the next surveillance if the interval is extended to 10 years. And therefore, it can be concluded that the end anchorage examination interval can be extended to 10 years without compromising the safety of the plant.

4.4 Corrosion Protection Medium Testing

Corrosion protection medium (CPM) test samples were collected at the ends of sample tendons during each of the 10 surveillances. Sample test results are listed in Tables 7a, 7b and 7c. Except where noted in the tables, each CPM sample was tested for the presence of three corrosive ions (chlorides, nitrates and sulfides), absorbed water content and neutralization number. Testing for neutralization number commenced with the 15-year surveillance. No neutralization number tests were performed on 1, 3, 5 and 10-year CPM samples.

No test data are shown for the 30-year surveillance. The neutralization numbers listed in the CPM test report submitted for that surveillance are on the order of 5 and are consistent with those expected for the Visconorust 2090 P-2 formulation. The numbers shown in the 15, 20, 25 and 35 and 40-year surveillance reports vary between 19.5 and 76.9 and are consistent with what is expected for tests performed on the 2090 P-4 formulation used at VCSNS. Because of this large difference, it was concluded that the results reported for the 30-year surveillance are those for samples from another project. This is addressed in Condition Report CR-20-00663.

Corrosion protection medium test results are summarized below and addressed in detail in subsections 4.4.1 through 4.4.3. Conclusions and recommendations for future testing are included in 4.4.4.

- All tested samples met the Table IWL-2525-1 10 ppm upper limit on chloride, nitrate and sulfide ion concentration[15].
- All tested samples met the Table IWL-2525-1 10% upper limit on water content.
- All tested samples met the Table IWL-2525-1 criteria for reserve alkalinity[16].

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[15] Ion concentrations are determined for a water extraction prepared in accordance with the procedures described in Subsection IWL Table IWL-2525-1 and do not represent concentration in the bulk CPM sample.

[16] For the 2090 P-4 material used at VCS, the neutralization number must be at least 17.5 which is 50% of the specified minimum as-supplied value of 35.

4.4.1 Corrosive Ion Concentrations

Table 7a lists the following summary data applicable to the ion concentrations documented for CPM samples.

- Surveillance year / No. of samples tested
- Maximum, mean and minimum chloride concentration
- Maximum, mean and minimum nitrate concentration
- Maximum, mean and minimum sulfide concentration

Most of the results reported for chloride and sulfide concentrations are shown as less than what is presumed to be the threshold of resolution used by the laboratory. Nitrate concentrations shown for the 25, 35 and 40-year surveillances are also shown as below the threshold of resolution.

Because test procedures and analytical chemistry techniques have improved over the years, the later data are considered to be more representative of actual conditions. For this reason, the maximum values noted below are for the 89 (excludes results of tests on the 18 samples collected during the 30-year surveillance as previously discussed) samples tested during the 15-year and later surveillances. These maxima are:

- Chlorides – <0.50 ppm
- Nitrates – 2.64 ppm
- Sulfides – <0.50 ppm

In all cases, maximum concentrations are well below the 10-ppm limits specified in Table IWL-2525-1.

And, none of the Table 7a columns indicate a definitive trend over time.

Considering the above discussion of ion concentration patterns, the fact that the values reported for the 89 samples tested during the 15-year and later surveillances, are all low relative to the 10-ppm limit, the absence of free water and the lack of active corrosion on end anchorage hardware and extracted wires, it is concluded that the presence of corrosive ions in surveillance tendon CPM is not a concern.

In addition, it is concluded that there is no need to continue testing CPM samples for corrosive ions unless the Responsible Engineer specifies such tests following observations of corrosion, water intrusion into tendon end anchorage areas or ducting or, a significant level of absorbed water in CPM samples.

4.4.2 Reserve Alkalinity / Neutralization Number

Neutralization number test results are listed in Table 7b. All results are above the lower limit acceptance criterion of 17.5 applicable to the 2090 P-4 material used for corrosion protection at VCSNS. And, there is no definitive trend with time.

Considering that numbers reported for the 89 samples tested during the 15-year and later surveillances are all above the acceptance limit and that there is no trend indicating loss of reserve alkalinity with time, it is concluded that there is no need to continue testing CPM samples for neutralization number unless the Responsible Engineer specifies such tests following observations of corrosion or acidic water intrusion into tendon end anchorage areas or ducting.

4.4.3 Absorbed Water Content

Results of tests to determine absorbed water content are listed in Table 7c. All reported water contents are below the 10% upper limit. The 3-year results differ significantly from all of the others and are considered questionable. In addition, the 0.027% minimum value shown for the 10-year surveillance samples is below the 0.05% value that is indicated (with a ‘< ‘sign) as the threshold of resolution which raises a question about how the results for that surveillance were documented. For this reason, the following statements regarding absorbed water content are based on results reported for CPM samples collected during the 15-year and later surveillances.

- Maximum absorbed water content is 0.48% or, less than $1/20^{th}$ of the 10% upper limit specified in Table IWL-2525-1.
- Absorbed water content shows no definitive trend with time.

As absorbed water content provides an early indication of potential corrosive conditions, the requirement to collect and test CPM samples for absorbed water during each future surveillance will be retained.

4.4.4 CPM Test Summary and Conclusions

Post-tensioning system end anchorage hardware and extracted wires have been examined for damage and corrosion during 10 surveillances spanning a period of 38 years from 1982 to 2020. Corrosion protection medium samples collected during these surveillances (results of the 30-year surveillance samples are considered invalid as previously discussed) have been tested for the presence of corrosive ions, reserve alkalinity and absorbed water.

- There has been no evidence of active corrosion; observed corrosion was concluded to have occurred during handling, shipping, storage or installation of tendon hardware or otherwise prior to filling of the tendon ductwork with CPM. This supports the conclusion that the CPM is performing effectively.
- Corrosive ion (chlorides, nitrates, sulfides) concentration in sample extractions is below the 10-ppm limit and shows no trend of increasing over time.
- Sample neutralization number (base number) samples meet the acceptance criterion and show no trend indicating that the corrosion protection characteristics of the CPM are degrading over time.
- Absorbed water content is below the 10% (of dry weight) limit and shows no trend of increasing over time.

An evaluation of the CPM test results, as summarized above, leads to the conclusion that the interval between such tests can be extended to 10 years with no adverse consequences.

In addition, unless evidence of active corrosion is found during visual examinations of end anchorage hardware and extracted wires, there is evidence of free water intrusion or the quantity of absorbed water is found to have increased over time, there should be no need to perform the tests for corrosive ions and neutralization number. It is concluded that these tests need be done only if corrosion or moisture conditions favoring corrosion are found; tests will be performed as specified by the Responsible Engineer. Free water, if found, will continue to be collected and analyzed to determine pH as required by Subsection IWL.

5. OVERALL SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A summary of post-tensioning system surveillance results, conclusions based thereon and recommendations for surveillance program scope reductions follow.

5.1 Summary of Surveillance Results

The results of the 10 post-tensioning system inservice examinations conducted at VCSNS between 1982 and 2020 show that the system is continuing to perform its intended function and that it can be expected to do so until well past the January 2032 deadline for completion for the next surveillance if the interval is extended to 10 years. Performance of the system, determined by evaluations of the visual examination findings / test results as detailed in Part 4 of this technical report, is summarized below.

a) Tendon Force

The mean force in each of the tendon groups is projected by log-linear regression and 95% confidence limit computations to remain above the specified minimum until well beyond January 2032.

b) Condition of End Anchorage Hardware and Extracted Wires

End anchorage hardware within the end cap gasket ring and tendon wires extracted for tensile testing show no signs of damage or active corrosion. Corrosion that has been observed is concluded to have occurred prior to filling of the tensioned tendon duct with corrosion protection medium. Corrosion on exposed areas of bearing plates is minor and concluded to have no structural significance.

Broken wires were concluded to have been the result of singular conditions and not indicative of system degradation.

The small number of missing button heads documented in the surveillance reports represents an inconsequential (and acceptable) fraction of the total. Occasional button head loss is normal for BBRV[17] tendons (wires anchored by cold formed button heads) and generally occurs during or shortly after tensioning. Nothing in the surveillance reports indicates that the number of missing button heads is increasing over time.

No free water has been found at the anchorages or in the ductwork of any tendon.

c) Tendon Wire Strength and Ductility

Tensile tests on samples cut from extracted wires show that ultimate tensile strength meets the ASTM A421 (Reference 7.5) acceptance criteria and is essentially unchanged over time. While the indicated elongation at failure for several test specimens fell below the ASTM A421 minimum of 4%, it was concluded that reported values are probably the result of incorrect testing procedures. Given that these reported elongations may be not represent true values, there is nothing in the test data to suggest that either tensile strength or elongation degrade with time under load.

d) Corrosion Protection Medium Characteristics

Results of corrosion protection medium (CPM) tests to determine absorbed water content, corrosive ion concentrations and neutralization number confirm that

[17] The BBRV system, which uses cold formed button heads to anchor individual wires, was introduced by the Swiss engineering firm BBR in the 1940's.

acceptance criteria have been met and that there are no discernible trends over time. In particular:

- All reported absorbed water content values are below the 10% (of dry weight) upper limit.
- All corrosive ion concentrations are below the 10-ppm upper limit and many are below the indicated limit of resolution applicable to the ion.
- All neutralization numbers are acceptable. There is no apparent trend to the neutralization number data which leads to the conclusion that the corrosion protection characteristic of the CPM is not degrading with time.

5.2 Conclusions

Based on the evaluations detailed in Part 4 of this technical report and summarized above, it is concluded that the VCSNS Unit 1 containment post-tensioning system will continue to perform its design function until well after the January 2032 deadline for completion of the next surveillance if the interval is extended to 10 years and, in particular, that:

- Tendon group mean force will remain above the specified minimum.
- End anchorage hardware and tendon wire will remain free of active corrosion.
- Tendon wire tensile strength and ductility will not change over time.
- Structurally significant cracks will not develop in the vicinity of tendon end anchorage areas.
- Corrosion protection medium will retain its protective properties with no degradation over time.
- Free water will not be a concern.

5.3 Recommendations

On the basis of the above conclusions, it is recommended that the VCSNS containment ISI program incorporate the following alternatives to ASME Section XI, Subsection IWL post-tensioning system examination and testing requirements.

- (Subsection IWL Table IWL-2500-1 Examination Category L-B Items L2.10, L2.20, L2.30, L2.40 and L2050) Extend the interval between post-tensioning system examinations and tests and detailed visual examination of concrete adjacent to tendon bearing plates from 5 years to 10 years with future examinations to be performed 50 years after the pre-operational structural integrity test (SIT) and every 10 years thereafter.

- (Subsection IWL Table IWL-2500-1, Examination Category L-B, Item 2.20) Eliminate de-tensioning / re-tensioning of tendons, sample wire removal and sample wire testing unless such testing is specified by the Responsible Engineer.
- (Subsection IWL Table IWL-2500-1, Examination Category L-B, Item L2.40) Limit corrosion protection medium (CPM) chemical tests to the determination of sample absorbed water content unless measured water content exceeds the Table IWL-2525-1 acceptance limit and / or conditions at the anchorage where the sample was collected are judged by the Responsible Engineer to justify additional tests.

Interval extension and the elimination of wire tests will maintain an acceptable level of quality and safety as well as provide the following benefits.

- Reducing personnel exposure to a number of industrial safety hazards associated with system examination / testing. These include:
    - Working at heights;
    - Working in a de facto confined space (the tendon gallery);
    - Working with high pressure hydraulic systems;
    - Working near high energy plant systems;
    - Working around solvent and hot petroleum product fumes;
    - Working close to containers and pressurized lines filled with hot petroleum products;
    - Close in exposure to high levels of stored elastic energy in tendons (sudden rotation during force measurement has resulted in high-speed shim ejection);
    - Handling heavy loads, often in the vicinity of critical plant components.
- Reducing personnel radiation exposure (generally a minor concern but still an ALARA issue).
- Reducing potentially damaging repetitive loading on tendons during de-tensioning / re-tensioning as well as during implementation of force measurement procedures.

Eliminating routine ion concentration and neutralization number testing has the benefit of reducing the quantity of hazardous reagents to be disposed of by the testing laboratory.

6. FUTURE EXAMINATIONS AND TESTING ENHANCEMENTS

As noted in Part 2 of this technical report, visual examinations of the containment exterior (Subsection IWL, Table IWL-2500-1, Examination Category L-A, Items L1.10, L1.11 and L1.12) will continue at intervals of 5 years in accordance with IWL-2410. These will include enhanced examinations of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and CPM leakage.

General visual examination, as defined in IWL-2310(a), of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and corrosion protection medium leakage will be performed from roofs, floors, platforms, ladders and other means of achieving relatively close in access to the anchorage area and with sufficient illumination to detect deleterious conditions. If close in access is not possible, remote examination techniques (e.g., optical aids or drone mounted cameras) will be used.

Detailed visual examination, as defined in IWL-2310(b), will be conducted at those areas identified by the Responsible Engineer during general visual as areas with conditions requiring close in examination.

If an end anchorage area examination uncovers a condition indicative of possible damage to the enclosed post-tensioning system hardware or an anchor head failure, the end cap will be removed for further examination and evaluation by the Responsible Engineer (RE). Following the evaluation, additional actions will be taken as specified by the RE.

If an end anchorage area examination uncovers active corrosion on a bearing plate or end cap, the condition will be evaluated by the RE who will perform an evaluation and specify corrective measures as deemed appropriate.

The RE will evaluate end anchorage area concrete cracks for structural significance and perform a detailed examination of any judged to be structurally significant. Following this examination, the RE will perform additional evaluations, specify further analysis and specify corrective measures as deemed appropriate.

Visual examinations will also focus on leakage of CPM. Observed leakage will be evaluated by the RE who will determine whether or not corrective action is needed. If needed, a corrective action (e.g., end cap gasket replacement and duct refilling / top-off) plan will be prepared by, and implemented in accordance with the requirements of, the RE.

If free water is found during examinations it will be analyzed for pH as required by Subsection IWL. In addition, the RE will evaluate the condition and specify additional examinations and tests as deemed necessary to determine if the free water has caused corrosion.

7. REFERENCES

7.1 USNRC Regulation 10CFR50.55a, *Codes and Standards*.

7.2 ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWL, 2007 Edition w / 2008 Addenda.

7.3 *V.C. Summer Power Station / Safety Analysis Report / Design of Structures, Components, Equipment, and Systems / Chapter 3*, Revision 22.01--Updated Online 09/15/22.

7.4 Virgil C. Summer Nuclear Station Drawing E-511-101, *Reactor Building / Liner Plate / Bottom Plan and Section*, Revision 4, 09 April 2007.

7.5 ASTM A421 *Specification for Uncoated Stress Relieved Wire for Prestressed Concrete*, published by the American Society for Testing and Materials.

7.6 Virgil C. Summer Nuclear Station Engineering Services Specification SP-228, *Surveillance of Reactor Building Post Tension System*, Revision 16, 23 May 2022.

7.7 USNRC Regulatory Guide 1.35, *Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containments,* Revisions 1, 2 & 3.

7.8 *V. C. Summer Unit 1 Nuclear Power Station / Reactor Containment Building / First Tendon Surveillance*, report prepared by Gilbert Associates, Inc., 29 April 1983.

7.9 *Three Year Physical Tendon Surveillance of the V. C. Summer Nuclear Station Unit 1 / Surveillance Report*, report prepared by the INRYCO Engineering Department Concrete Systems Division, Revision 1, 16 March 1984.

7.10 *Fifth Year Physical Surveillance of the V. C. Summer Unit 1 Containment Building / Surveillance Report*, report prepared by the INRYCO Engineering Department Concrete Systems Division, Revision 0, 30 January 1986.

7.11 *10th Year Physical Surveillance of the V. C. Summer Unit 1 Reactor Building / Surveillance Report*, report prepared by the Precision Surveillance Corporation, Revision 0, 20 June 1990.

7.12 *Fifteenth Year Physical Surveillance of the V. C. Summer Unit 1 Containment Building / Surveillance Report*, report prepared by the Precision Surveillance Corporation, Revision 0, 15 July 1996.

7.13 Twentieth Fifteenth Year Physical Surveillance of the V. C. Summer Unit 1 Containment Building, report prepared by the Precision Surveillance Corporation, Revision 0, 22 November 2002.

7.14 *Twenty-Fifth Year Physical Surveillance of the V. C. Summer Nuclear Station Containment Building / Post Tensioning Surveillance Report*, report prepared by the Precision Surveillance Corporation, Revision 0, 23 April 2007.

7.15 *Final Report for the 30th Year Tendon Surveillance at V. C. Summer*, report prepared by the Precision Surveillance Corporation, Revision 0, 12 July 2011.

7.16 *Final Report for the 35th Year Tendon Surveillance at Virgil C. Summer Nuclear Station Unit 1*, report prepared by the Precision Surveillance Corporation, Revision 0, 17 December 2015.

7.17 Final Report for the 40th Year Tendon Surveillance at the V. C. Summer Nuclear Station, report prepared by the Precision Surveillance Corporation, Revision 0, 21 July 2020.

7.18 *Vertical Tendon Retensioning of the V. C. Summer Unit 1 Reactor Building / Retensioning Report*, report prepared by the Precision Surveillance Corporation, Revision 0, 20 June 1990.

7.19 Miller, Irwin and John E. Freund, *Probability and Statistics for Engineers*, Prentice-Hall, Englewood Cliffs, NJ, 1965.

7.20 ANSI / ANS 56.8, *Containment System Leakage Testing Requirements*, published by the American Nuclear Society.

7.21 V. C. Summer Calculation DC0305C-009, *Reactor Building Tendon Surveillance*, Revision 1, Approved 13 December 1993.

7.22 V. C. Summer Calculation DC0304B-008, *Ring Girder and Dome Analyses for Minimum Dome Prestress*, Revision 0

8. TABLES AND FIGURES

Tables and figures cited in the above text follow.

Table 1 – List of US Containments[1] with Ungrouted Pre-stressing Systems	
Plant / Unit	**Containment Type[2] / Notation[3]**
Millstone 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Ginna	Vertical tendons only; anchored in rock; B
TMI 1	Shallow dome w / hoop, vertical & dome tendon groups; B; N
Calvert Cliffs 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
V. C Summer	Shallow dome w / hoop, vertical & dome tendon groups; B
Oconee 1, 2 & 3	Shallow dome w / hoop, vertical & dome tendon groups; B
Vogtle 1 & 2	Hemispherical dome w / hoop & inverted U tendon groups; S
Crystal River 3	Shallow dome w / hoop, vertical & dome tendon groups; B; N
Turkey Point 3 & 4	Shallow dome w / hoop, vertical & dome tendon groups; B
Farley 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Palisades	Shallow dome w / hoop, vertical & dome tendon groups; B; N
Zion 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B: N
Braidwood 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Byron 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
LaSalle 1 & 2	BWR Mark II (cylinder – cone) containment w / hoop & vertical tendon groups; B
Point Beach 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
Callaway	Hemispherical dome w / hoop & inverted U tendon groups; B
ANO 1 & 2	Shallow dome w / hoop, vertical & dome tendon groups; B
South Texas 1 & 2	Hemispherical dome w / hoop & inverted U tendon groups; B
Wolf Creek	Hemispherical dome w / hoop & inverted U tendon groups; B
Ft. Calhoun	Shallow dome with spiral and dome tendon groups; B; N
Palo Verde 1, 2 & 3	Hemispherical dome w / hoop & inverted U tendon groups; B
San Onofre 1 & 2	Hemispherical dome w / hoop & inverted U tendon groups; S; N
Rancho Seco	Shallow dome w / hoop, vertical & dome tendon groups; S; N
Trojan	Hemispherical dome w / hoop & inverted U tendon groups; B; N

Note 1: Bellefonte 1 & 2, which are still under construction, Midland 1 & 2, which were terminated prior to fuel load and Robinson & TMI 2, which have grouted tendon systems, are not listed.

Note 2: All units are PWR’s except LaSalle (BWR).

Note 3: B – BBRV system with button headed wires; S – strand system with wedge anchors; N – unit(s) are no longer in operation.

Table 2, Sh. 1 of 3 - Summary of Hoop Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
1	1.2	H-7BA	1,298
		H-8BA	1,242
		H-9BA	1,266
		H-37BA	1,276
		H-38BA	1,205
		H-39BA	1,270
		H-13CB	1,265
		H-27CB	1,247
		H-28CB	1,223
		H-29CB	1,278
		H-3AC	1,313
		H-35AC	1,250
		H-36AC	1,210
		H-37AC	1,178
		H-38AC	1,183
		H-39AC	1,240
		H-40AC	1,231
		H-41AC	1,263
3[1]	2.8	H-12BA	1,192
		H-13BA	1,203
		H-14BA	1,173
		H-27BA	1,245
		H-28BA	1,185
		H-29BA	1,197
		H-17CB	1,215
		H-18CB	1,176
		H-19CB	1,228
		H-33CB	1,216
		H-3AC	1,270
		H-41AC	1,215

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Note 1: Tendon H-36AC, included in the 3-year sample, is not listed here. It was de-tensioned / re-tensioned during the 1-year surveillance and no longer meets the criteria for an undisturbed sample.

Table 2, Sh. 2 of 3 - Summary of Hoop Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
5	4.9	H-17BA	1,154
		H-18BA	1,097
		H-19BA	1,165
		H-32BA	1,154
		H-33BA	1,171
		H-34BA	1,173
		H-7CB	1,201
		H-8CB	1,140
		H-9CB	1,183
		H-37CB	1,183
		H-38CB	1,114
		H-39CB	1,216
		H-2AC	1,264
		H-3AC	1,234
		H-4AC	1,204
		H-27AC	1,208
		H-28AC	1,167
		H-29AC	1,194
10[2]	9.1	H-15BA	1,150
		H-16BA	1,086
		H-34CB	1,104
		H-7AC	1,184
		H-12AC	1,128
		H-13AC	1,142
		H-14AC	1,029
		H-32AC	1,102
		H-33AC	1,124
		H-34AC	1,058
		H-43AC	1,172
		H-46AC	1,145

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Note 2: Tendons H-17BA and H-8CB, included in the 10-year sample, are not listed here. There were de-tensioned / re-tensioned during the 5-year surveillance and no longer meet the criteria for undisturbed samples.

Table 2, Sh. 3 of 3 - Summary of Hoop Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
15[3]	15.2	H-43BA	1,128
		H-30CB	1,089
20[4]	19.8	H-46BA	1,071
		H-3CB	1,196
		H-40AC	1,075
		H-41AC	1,086
		H-42AC	1,098
25	25.8	H-3BA	1,201
		H-25BA	1,108
		H-46AC	1,074
30	30.2	H-49BA	1,136
		H-43CB	1,107
		H-46AC	1,079
35	34.8	H-46CB	1,081
		H-16AC	1,066
		H-46AC	1,055
40	39.2	H-49CB	1,133
		H-46AC	1,040
		H-49AC	1,153

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Note 3: Tendon H-13AC, included in the 15-year sample, is not listed here. It was de-tensioned / re-tensioned during the 10-year surveillance and no longer meets the criteria for an undisturbed sample.

Note 4: Tendon H-39AC, included in the 20-year sample, is not listed here. It was de-tensioned / re-tensioned during the 1-year surveillance and no longer meets the criteria for an undisturbed sample.

Table 3, Sh. 1 of 2 - Summary of Vertical Tendon Forces

Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip
1	1.2	V-23	1,318
		V-46	1,315
		V-66	1,306
		V-67	1,296
		V-68	1,303
		V-92	1,282
		V-115	1,297
3	2.8	V-23	1,286
		V-30	1,229
		V-53	1,283
		V-76	1,267
		V-99	1,254
5	4.9	V-22	1,231
		V-23	1,242
		V-24	1,240
		V-37	1,247
		V-59	1,231
		V-60	1,219
		V-61	1,231
		V-83	1,258
		V-106	1,231
10[1]	9.1	V-1	1,172
		V-2	1,162
		V-3	1,187
		V-4	1,196
		V-5	1,193
		V-6	1,147
		V-7	1,197
		V-51	1,204
		V-63	1,216
		V-90	1,188
		V-94	1,219

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Note 1: Tendon V-83, included in the 10 year sample, is not listed here. It was de-tensioned / re-tensioned during the 5 year surveillance and no longer meets the criteria for an undisturbed sample.

Table 3, Sh. 2 of 2 - Summary of Vertical Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
15	15.2	V-8	1,306
		V-40	1,318
		V-90	1,318
20	19.8	V-11	1,278
		V-73	1,322
		V-90	1,321
25	25.8	V-26	1,298
		V-90	1,294
		V-101	1,272
30	30.2	V-48	1,294
		V-90	1,279
		V-104	1,284
35	34.8	V-14	1,278
		V-78	1,293
		V-90	1,283
40	39.2	V-20	1,278
		V-90	1,264
		V-110	1,276

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Table 4, Sh. 1 of 2 - Summary of Dome Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
1	1.2	D-103	1,215
		D-104	1,234
		D-105	1,251
		D-128	1,264
		D-129	1,206
		D-130	1,235
		D-218	1,249
		D-219	1,207
		D-220	1,259
		D-327	1,229
3[1]	2.8	D-125	1,174
		D-213	1,199
		D-219	1,168
		D-228	1,217
		D-324	1,233
5	4.9	D-107	1,174
		D-108	1,195
		D-109	1,162
		D-120	1,200
		D-121	1,152
		D-122	1,208
		D-213	1,170
		D-315	1,194
		D-316	1,198
		D-317	1,166

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Note 1: Tendons D-218 and D-220, included in the 3 year sample, are not listed here. These were de-tensioned / re-tensioned during the 1 year surveillance and no longer meet the criteria for undisturbed samples.

Table 4, Sh. 2 of 2 - Summary of Dome Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
10[2]	9.1	D-116	1,163
		D-117	1,008
		D-118	1,131
		D-119	1,154
		D-211	1,152
		D-226	1,144
		D-303	1,153
		D-332	1,187
15	15.2	D-112	1,146
		D-226	1,132
		D-325	1,083
20	19.8	D-206	1,141
		D-207	1,126
		D-208	1,135
		D-209	1,106
		D-213	1,106
		D-302	1,171
25	25.8	D-126	1,105
		D-213	1,134
		D-232	1,130
30	30.2	D-115	1,086
		D-213	1,087
		D-223	1,094
35	34.8	D-213	1,079
		D-215	1,077
		D-216	1,099
		D-217	1,103
		D-319	1,069
40	39.2	D-202	1,121
		D-213	1,066
		D-322	1,097

Note: Highlighted tendons de-tensioned / re-tensioned during the indicated surveillance.

Note 2: Tendon D-108, included in the 10-year sample, is not listed here. It was de-tensioned / re-tensioned during the 5-year surveillance and no longer meets the criteria for an undisturbed sample.

Table 5a - Wire Test Results / Ultimate Tensile Strength - Designated Tendons							
Exam Year	Tendon	Ultimate Tensile Strength, ksi				Wire Mean, ksi	Exam Mean, ksi
		Specimen 1	Specimen 2	Specimen 3	Specimen 4		
1	H-38AC	249	245	250	N/A	248	247
	V-46	246	242	246	N/A	245	
	D-105	249	250	246	N/A	248	
3	H-28BA	247	248	246	N/A	247	250
	V-76	248	250	250	N/A	249	
	D-228	253	252	253	N/A	253	
5	H-18BA	255	258	255	N/A	256	251
	V-83	243	246	244	N/A	244	
	D-316	251	253	251	N/A	252	
10	H-43AC	247	249	250	N/A	249	252
	V-51	255	257	252	N/A	255	
	D-332	255	254	252	N/A	254	
15	H-43BA	247	247	249	N/A	248	248
	V-8	252	250	247	N/A	250	
	D-226	247	244	250	N/A	247	
20	H-3CB	259	260	259	N/A	259	260
	V-11	259	259	262	N/A	260	
	D-302	261	259	259	N/A	260	
25	H-25BA	245	263	257	N/A	255	257
	V-101	258	257	260	N/A	258	
	D-126	257	254	261	N/A	257	
30	H-43CB	254	250	254	N/A	253	250
	V-48	251	246	244	N/A	247	
	D-223	252	250	252	N/A	251	
35	H-46CB	253	249	252	250	251	248
	V-14	248	255	248	252	251	
	D-319	243	242	241	247	243	
40	H-49AC	245	248	249	250	248	247
	V-110	245	247	247	246	246	
	D-322	244	247	247	244	246	

Table 5b - Wire Test Results / Elongation at Failure - Designated Tendon							
Exam Year	Tendon	Elongation at Failue, %				Wire Mean, %	Exam Mean, %
		Specimen 1	Specimen 2	Specimen 3	Specimen 4		
1	V-46	4.0	4.0	5.0	N/A	4.3	4.3
	H-38AC	4.0	4.0	5.1	N/A	4.4	
	D-105	4.2	4.3	4.0	N/A	4.2	
3	H-28BA	4.0	4.1	4.0	N/A	4.0	4.4
	V-76	4.2	5.1	5.3	N/A	4.9	
	D-228	4.7	4.2	4.1	N/A	4.3	
5	H-18BA	5.6	3.5	3.5	N/A	4.2	3.9
	V-83	3.6	4.0	2.8	N/A	3.5	
	D-316	4.2	4.0	4.0	N/A	4.1	
10	H-43AC	4.3	4.6	4.2	N/A	4.4	4.2
	V-51	4.1	4.2	4.2	N/A	4.2	
	D-332	4.1	4.2	4.2	N/A	4.2	
15	H-43BA	4.2	4.0	3.7	N/A	4.0	3.9
	V-8	4.0	4.1	3.9	N/A	4.0	
	D-226	4.1	3.8	3.6	N/A	3.8	
20	H-3CB	4.9	5.0	4.1	N/A	4.7	4.5
	V-11	4.1	4.1	4.1	N/A	4.1	
	D-302	4.1	5.0	5.1	N/A	4.7	
25	H-25BA	4.2	4.1	4.2	N/A	4.2	4.1
	V-101	4.1	4.2	4.0	N/A	4.1	
	D-126	4.0	4.1	4.2	N/A	4.1	
30	H-43CB	4.3	3.5	3.8	N/A	3.9	3.8
	V-48	3.8	3.3	3.4	N/A	3.5	
	D-223	4.7	4.1	3.7	N/A	4.2	
35	H-46CB	7.0	6.0	4.8	6.0	6.0	6.2
	V-14	5.0	9.5	8.0	4.0	6.6	
	D-319	5.0	5.0	8.5	5.5	6.0	
40	H-49AC	4.0	5.0	4.0	5.8	4.7	4.6
	V-110	5.0	4.2	4.8	5.0	4.8	
	D-322	4.5	4.3	4.0	4.0	4.2	

Table 6a - Wire Test Results / Ultimate Tensile Strength - Broken Wires

Exam Year	Tendon	Ultimate Tensile Strength, ksi						Wire Mean, ksi	Exam Mean, ksi
		Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6		
1	V-68	246	244	244	246	246	250	246	248
	D-220[a]	251	253	251	N/A	N/A	N/A	252	
	D-220[a]	248	250	250	N/A	N/A	N/A	249	

Note a: Test specimens cut from two different broken wires.

Table 6b - Wire Test Results / Elongation at Failure - Broken Wires

Exam Year	Tendon	Elongation at Failure, %						Wire Mean, %	Exam Mean, %
		Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6		
1	V-68	4.7	4.1	4.2	4.2	4.1	4.9	4.4	4.9
	D-220[a]	4.2	4.0	9.4	N/A	N/A	N/A	5.9	
	D-220[a]	4.3	4.3	5.5	N/A	N/A	N/A	4.7	

Note a: Test specimens cut from two different broken wires.

Table 7a - CPM Sample Corrosive Ion Concentrations									
Surveillance Year / No. of Samples	**Ion Concentration, ppm**								
	Chloride			**Nitrate**			**Sulfide**		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
1 / 30	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3 / 34	<10	<10	<10	<1.0	1.21	3.4	<1.0	1.44	6.0
5 / 30	0.03	0.047	0.08	0.010	0.0223	0.036	0.10	0.127	0.20
10 / 42	<0.044	0.0919	0.220	<0.050	0.0612	0.300	<0.025	0.0332	0.044
15 / 19	<0.50	<0.50	<0.50	0.43	1.169	2.64	<0.50	<0.50	<0.50
20 / 16	<0.50	<0.50	<0.50	<0.50	1.201	2.10	<0.50	<0.50	<0.50
25 / 18	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
30 / 18	Reported test results deemed invalid; see discussion in text Section 4.4								
35 / 18	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
40 / 18	<0.50	<0.50	<0.50	<1.0	<1.0	<1.0	<0.50	<0.50	<0.50

General Note: Means are computed using threshold values for all test results reported as <(threshold value); e.g., a test result reported as <0.50 is treated as 0.50 when computing the mean.

General Note: Sample test results listed exactly as shown in the surveillance reports. Mean values shown with one additional significant figure for consistency with standard practice.

Table 7b – CPM Sample Neutralization Number			
Surveillance Year / Number of Samples	**Min**	**Mean**	**Max**
1 / 30	Neutralization number test not performed		
3 / 34	Neutralization number test not performed		
5 / 30	Neutralization number test not performed		
10 / 42	Neutralization number test not performed		
15 / 19	20.3	40.13	61.5
20 / 16	19.5	38.08	58.6
25 / 18	48.1	57.94	72.4
30 / 18	Reported test results deemed invalid; see discussion in text Section 4.4		
35 / 18	20.9	36.77	50.3
40 / 18	26.9	48.7	76.9

General Note: Sample test results listed exactly as shown in the surveillance reports. Mean values shown with one additional significant figure for consistency with standard practice.

Table 7c – CPM Sample Water Content			
Surveillance Year / No. of Samples	**Water Content, %**		
	Min	**Mean**	**Max**
1 / 30	<0.1	<0.1	<0.1
3 / 34	1	2.7	6
5 / 30	0.08	0.215	0.36
10 / 42	0.027	0.1449	0.92
15 / 19	0.10	0.201	0.48
20 / 16	<0.10	0.173	0.39
25 / 18	<0.10	0.128	0.29
30 / 18	Reported test results deemed invalid; see discussion in text Section 4.4		
35 / 18	<0.10	0.144	0.20
40 / 18	<0.10	0.149	0.37

General Note: If one or more reported test results exceeds the threshold limit (result shown as < the threshold value), the mean value is computed using the indicated threshold value (0.50, 0.2 or other as applicable) for all test results shown with a < symbol.

General Note: Sample test results listed exactly as shown in the surveillance reports. Mean values shown with one additional significant figure for consistency with standard practice.

Figure 1 - Hoop Tendon Force Trend & LCL / 1 - 40 Year Surveillance Results

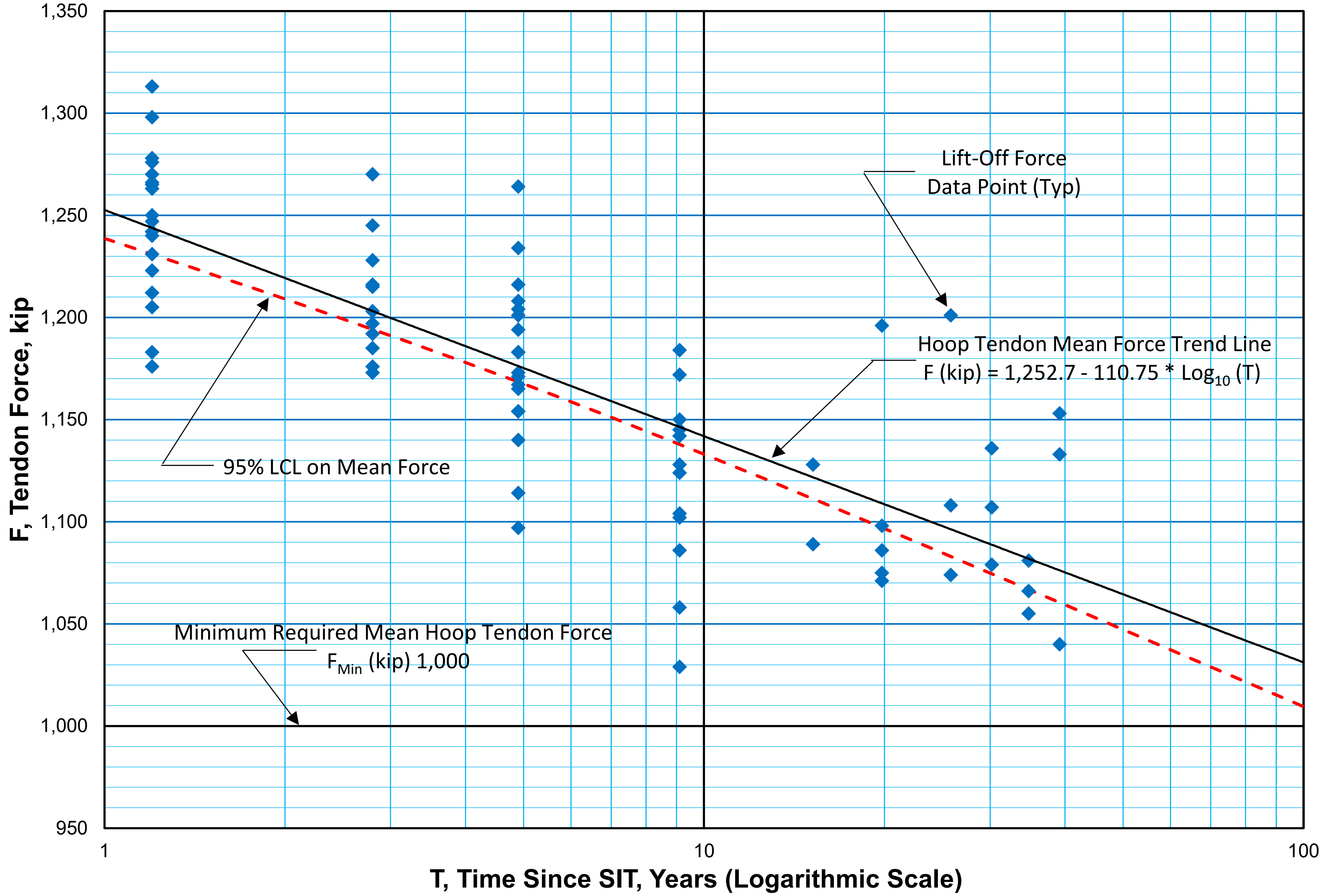


Figure 2 - Hoop Tendon Force Trend & LCL / 10 - 40 Year Surveillance Results

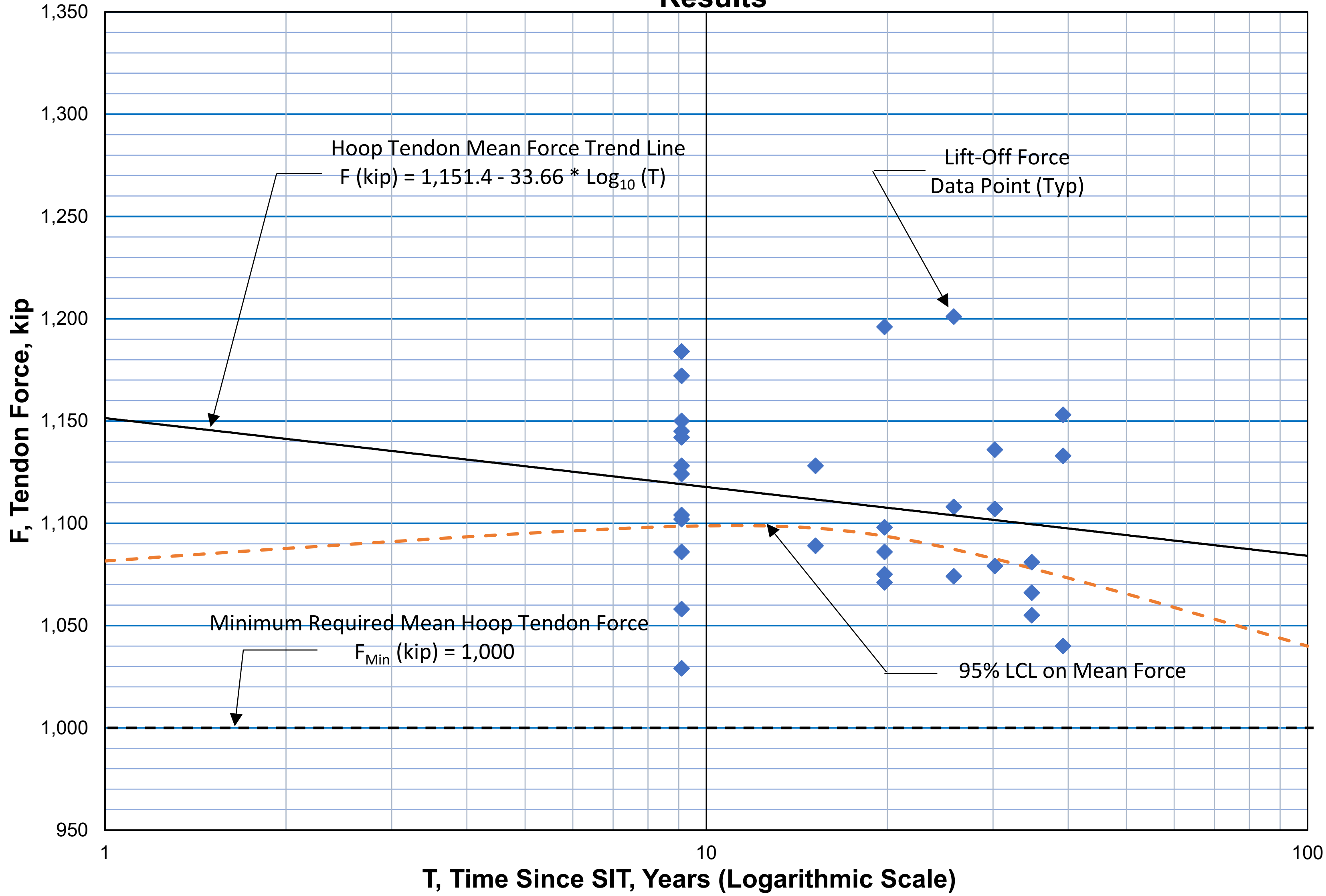
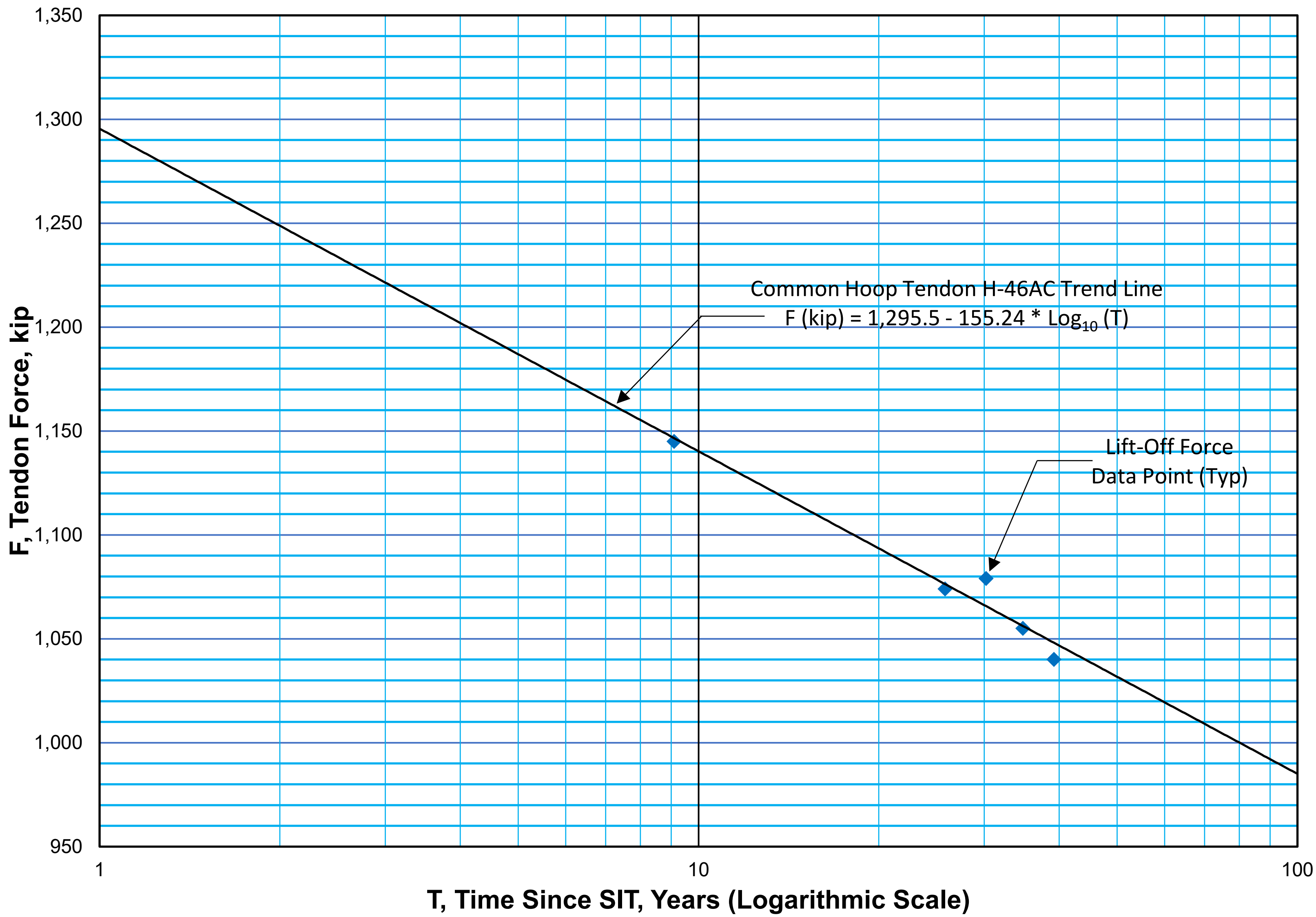


Figure 3 - Common Hoop Tendon H-46AC Trend



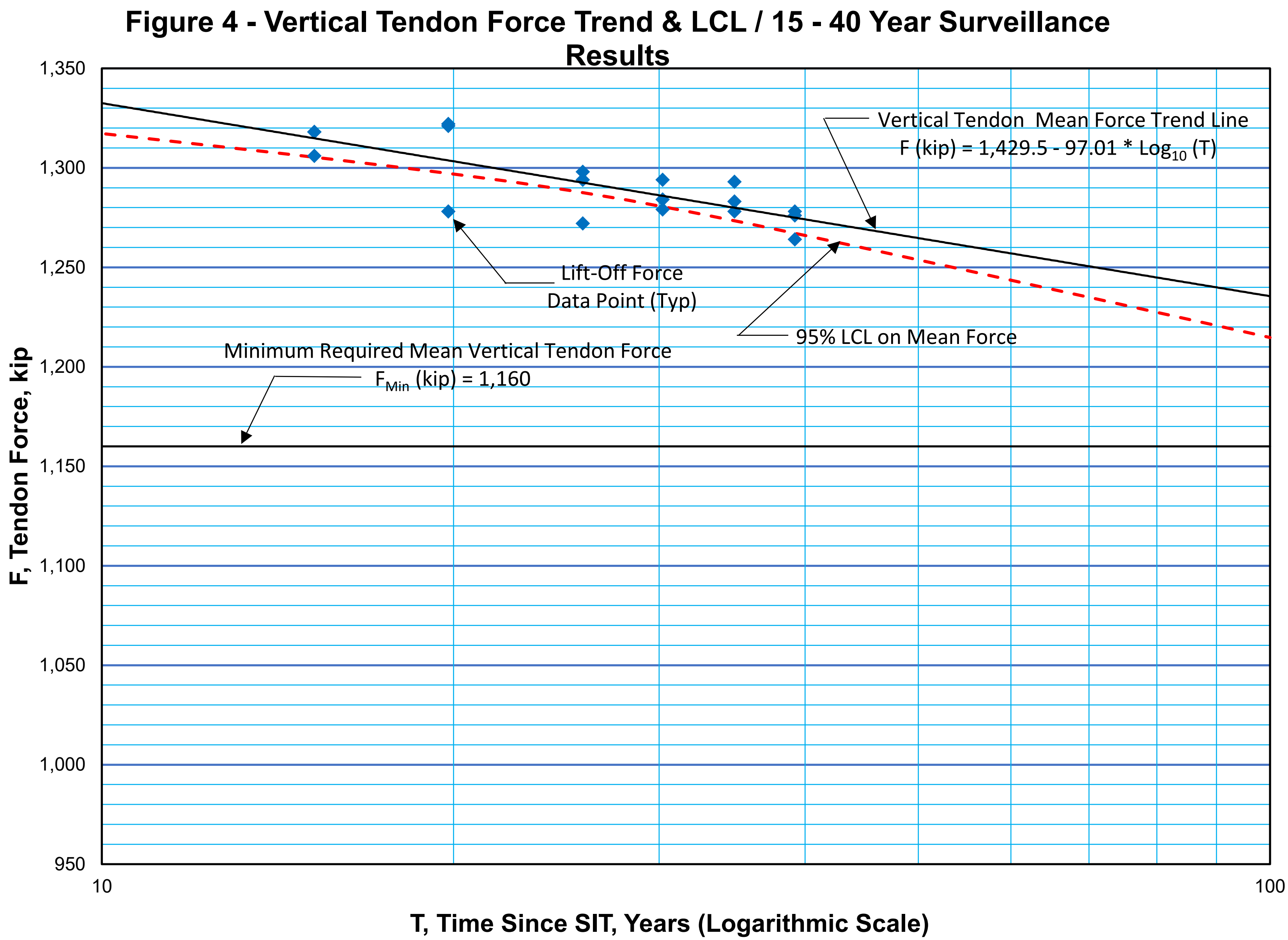


Figure 4 - Vertical Tendon Force Trend & LCL / 15 - 40 Year Surveillance Results
F, Tendon Force, kip
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
10
100
T, Time Since SIT, Years (Logarithmic Scale)
Vertical Tendon Mean Force Trend Line
F (kip) = 1,429.5 - 97.01 * Log10 (T)
Lift-Off Force
Data Point (Typ)
95% LCL on Mean Force
Minimum Required Mean Vertical Tendon Force
FMin (kip) = 1,160

Figure 5 - Common Vertical Tendon V-90 Trend

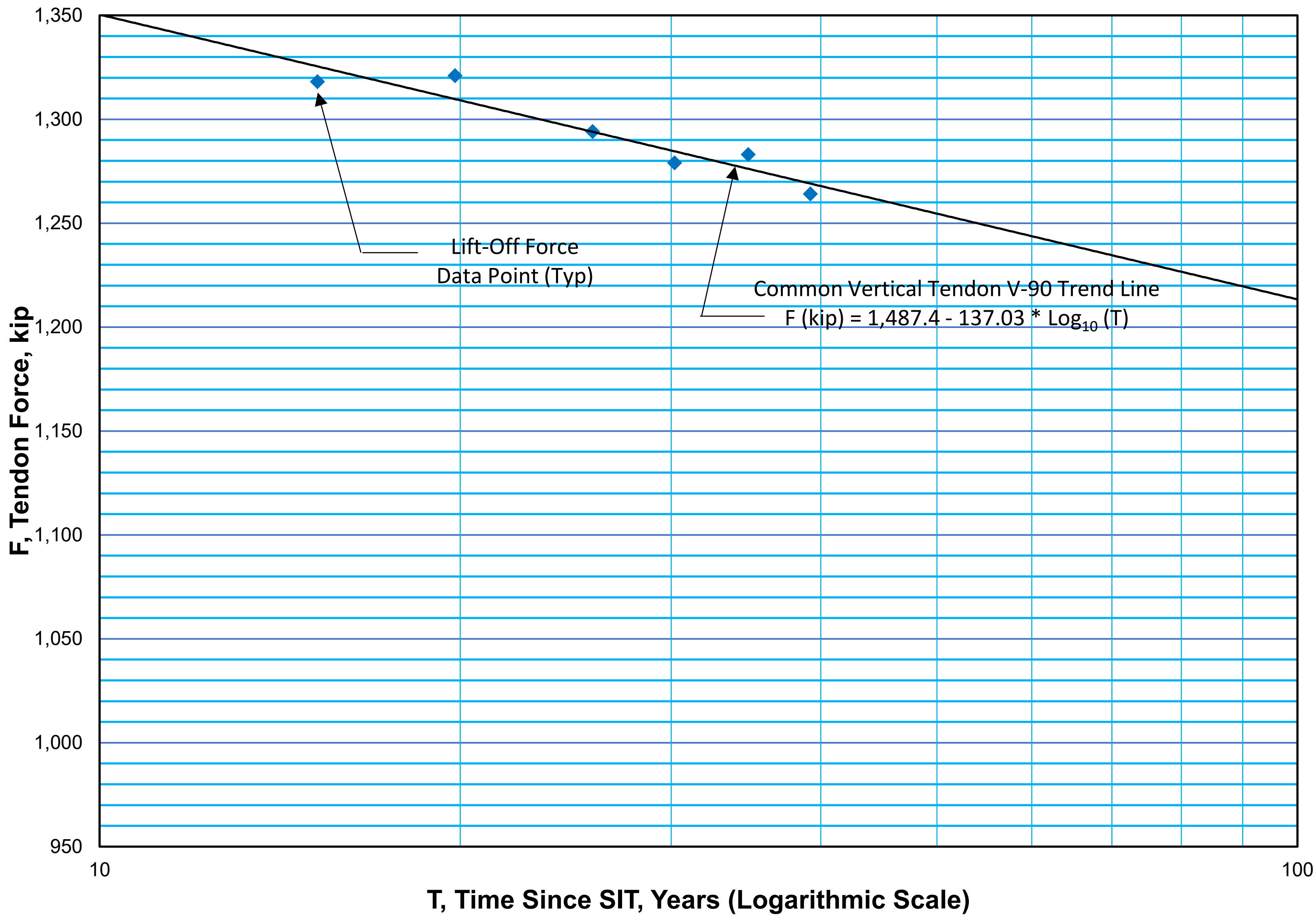


Figure 6 - Dome Tendon Force Trend & LCL / 1 - 40 Year Surveillance Results

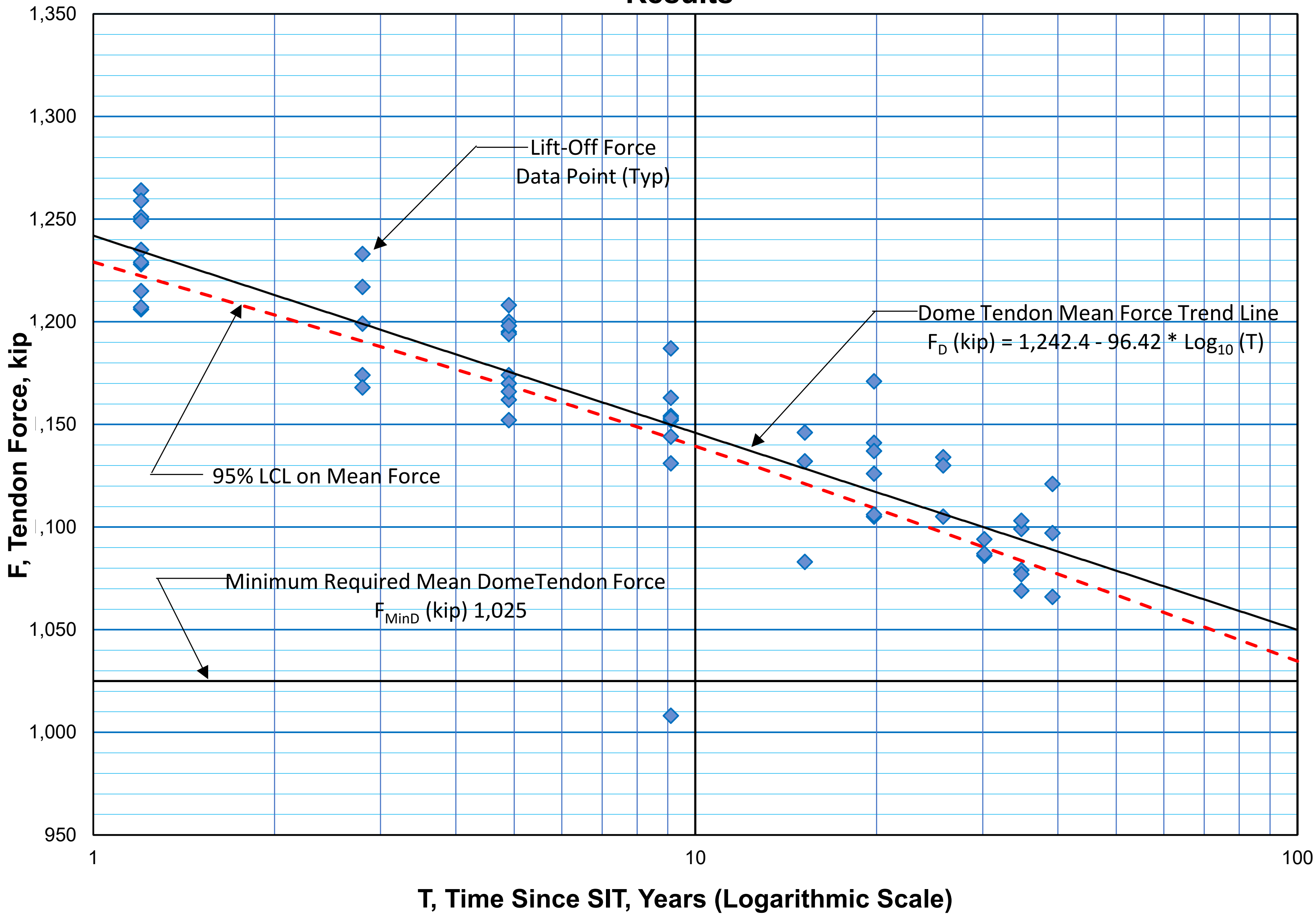


Figure 7 - Dome Tendon Force Trend & LCL / 10 - 40 Year Surveillance Results

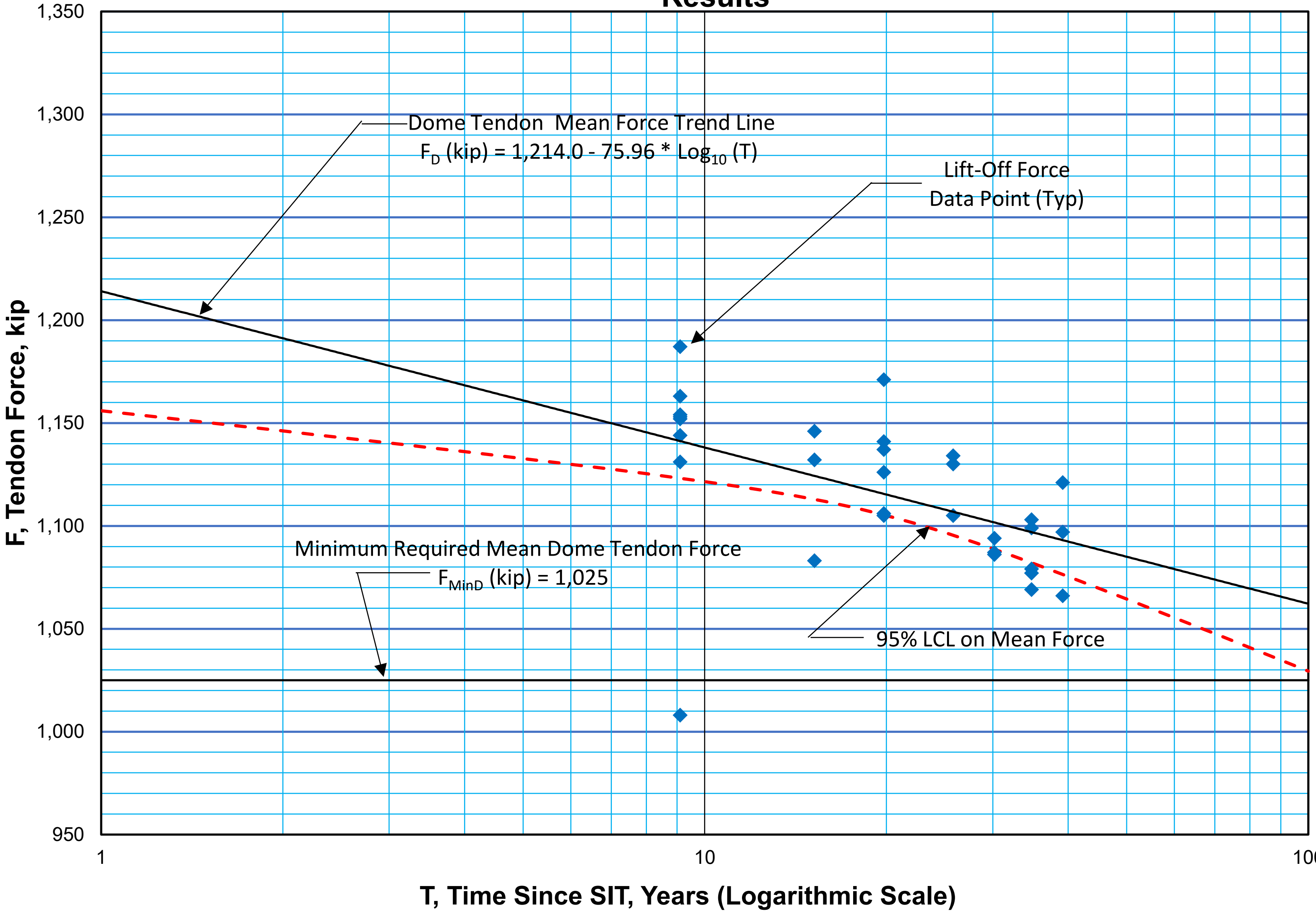


Figure 8 - Common Dome Tendon D-213 Trend / 20 - 40 Year Surveillance Results

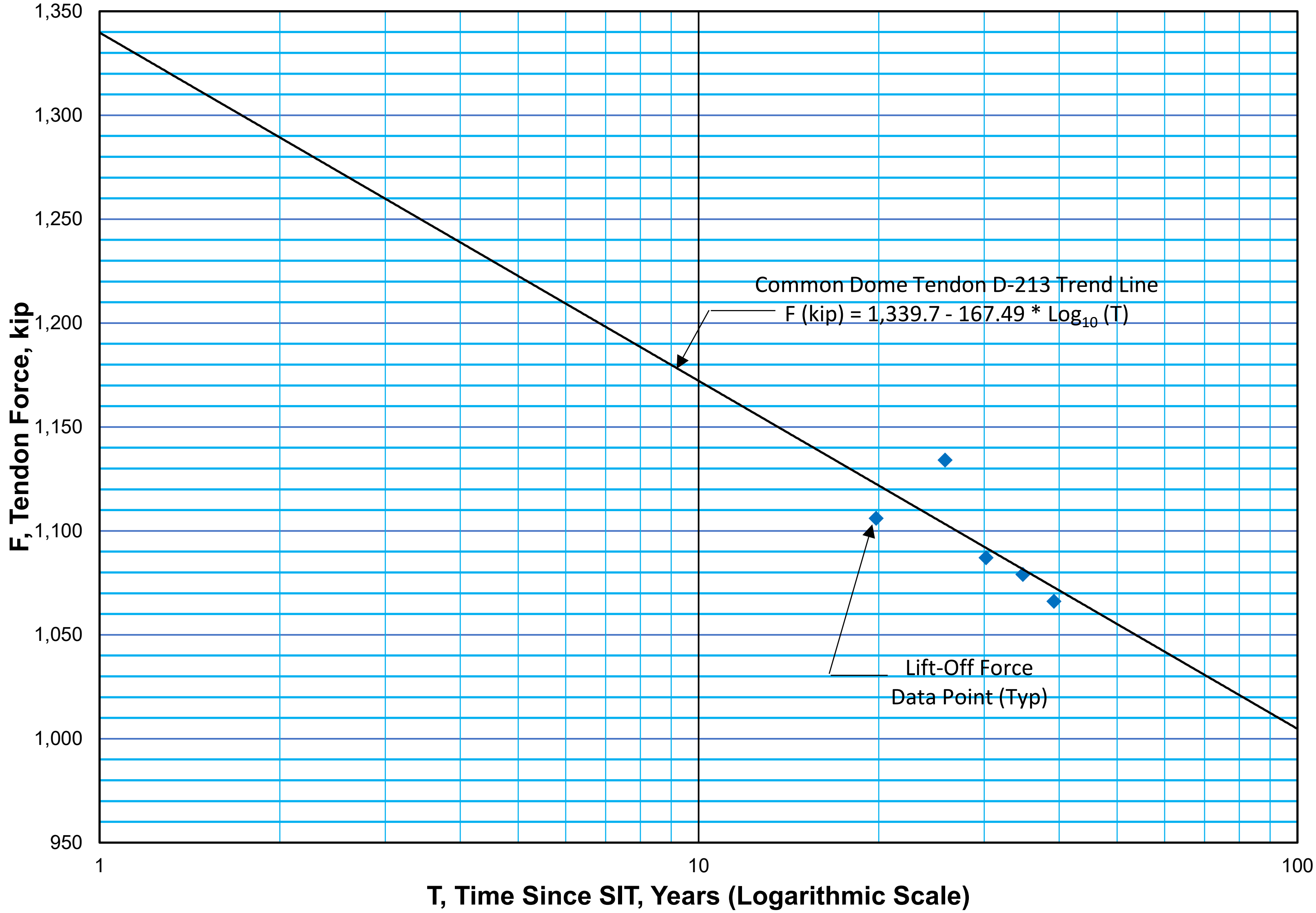


Figure 9 - Wire Test Results / Ultimate Tensile Strength

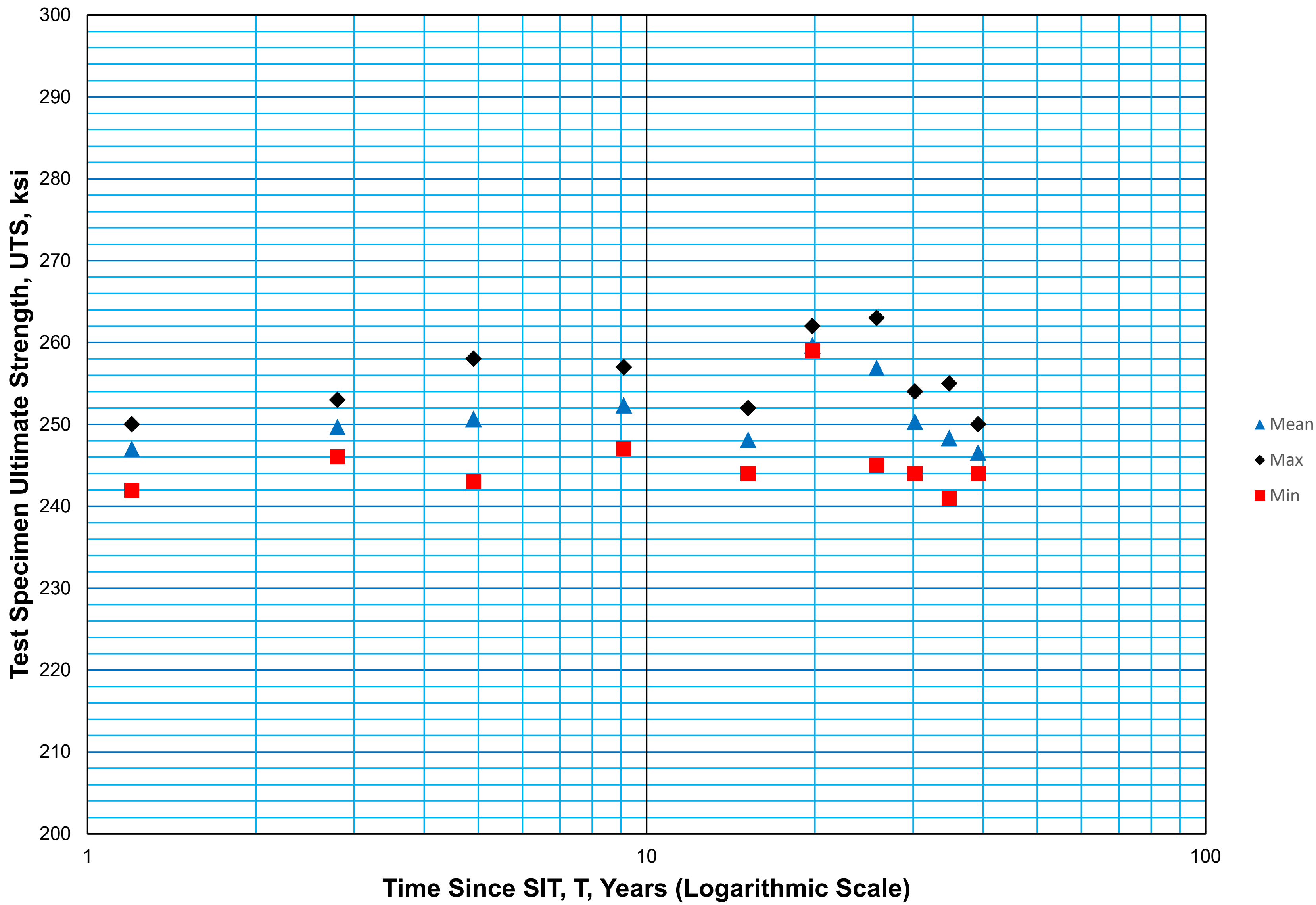


Figure 10 - Wire Test Results / Elongation at Failure