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December 17, 2019

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Serial No.	19-467
NRA/SS	R0
Docket No.	50-336
License No.	DPR-65

DOMINION ENERGY NUCLEAR CONNECTICUT, INC.
MILLSTONE POWER STATION UNIT 2
PROPOSED ALTERNATIVE REQUEST RR-05-05, CONTAINMENT UNBONDED POST-TENSIONING SYSTEM INSERVICE INSPECTION REQUIREMENTS

In accordance with 10 CFR 50.55a, "Codes and Standards," paragraph (z)(1), Dominion Energy Nuclear Connecticut, Inc. (DENC) requests Nuclear Regulatory Commission (NRC) approval of proposed inservice inspection alternative request RR-05-05 for Millstone Power Station Unit 2 (MPS2).

Section XI, Subsection IWL of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code requires periodic visual examination and physical testing of containment building concrete in accordance with Table IWL-2500-1 (L-A), as well as 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 MPS2 will continue to maintain its safety-related function through the period of extended operation (July 2035). Therefore, DENC proposes to extend the post-tensioning system examination and testing interval from 5 years to 10 years. DENC also proposes to eliminate the requirement for 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-B, are provided in Attachment 2.

This proposed alternative request has been approved by the Millstone Facility Safety Review Committee. DENC respectfully requests NRC approval of this alternative request by December 31, 2020.

Should you have any questions regarding this submittal, please contact Shayan Sinha at (804) 273-4687.

Sincerely,

Mark D. Sartain

Vice President – Nuclear Engineering and Fleet Support

Commitments made in this letter: None

Attachments:

1. Proposed Alternative Request RR-05-05, Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

2. Millstone Power Station Unit 2, Containment Post-Tensioning System Inservice Inspection Technical Report

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ATTACHMENT 1

Proposed Alternative Request RR-05-05
Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

MILLSTONE POWER STATION UNIT 2
DOMINION ENERGY NUCLEAR CONNECTICUT, INC. (DENC)

Proposed Alternative Request RR-05-05
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:	Millstone Power Station Unit 2 (MPS2) 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 MPS2.

Plant	10-Year IWL Interval	ASME Section XI Edition / Addenda	Interval Start	Interval End
MPS2	3rd	2013 Editions, No Addenda	March 8, 2020	March 7, 2030

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.

(d) Tendons affected by repair/replacement activities shall be examined in accordance with the requirements of IWL-2521.2.

MPS2 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 retensioned as required per IWL-2523.3 because wire removal requires detensioning 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, Item 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 and physical testing 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 period of extended operation until July 31, 2025. This alternative 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 date of the last examination, the 45th year surveillance is required to be completed no later than March 8, 2021.

While this alternative is based on maintaining an acceptable level of quality and safety, there are additional benefits to eliminating physical testing. Physical testing requires exposing test 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 eliminated by this proposed alternative:

1. Most tendons are located at heights well above ground level that require working at heights and the inherent risks associated with such work.

2. This work is often performed from hanging platforms. The platform must be moved to a parked location in order to exit the platform safely.

3. Some areas are located in difficult-to-reach locations that have only one small access point.

4. The testing requires working with high pressure hydraulics.

5. The testing requires working in the vicinity of high energy plant systems.

6. The testing requires working with solvents and hot petroleum products and associated fumes.

7. The testing requires working with containers and pressurized lines filled with heated corrosion protection medium (grease).

8. 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 ejection.

9. The work includes the handling of heavy loads (i.e., test equipment) that expose test personnel and equipment to hazards.

10. While tendon testing is most often not 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 or de-tensioning/re-tensioning. Elimination 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), DENC is proposing alternative examination requirements on the basis that these alternative actions will provide an acceptable level of quality and safety.

The requested departure from applicable ASME Section XI, IWL requirements is as follows and is evaluated in Attachment 2. The requested departure will:

- Extend the interval of the post-tensioning system examinations and tests and detailed visual examination of concrete adjacent to 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 corrosion protection medium (CPM) chemical tests.

The above proposed departures relate 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 elimination of the physical testing of the post-tensioning system will continue to provide an acceptable level of quality and safety based on projected performance and implementation of physical testing should visual examination results indicate a need for such testing.

DENC 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 where observations indicate there could be degradation of tendon hardware, as documented by the Responsible Engineer in an engineering evaluation. Example conditions that could require removal of the 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 corrosion protection medium 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

Attachment 2 provides a detailed discussion of the historical basis for examination and testing of containment post-tensioning systems. Attachment 2 also includes the MPS2-specific observations that provide a basis for deviation from 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 MPS2 is credited for managing containment building degradation. The Examination Category L-A visual examinations (every 5 years) being performed are expected to be capable of identifying conditions that would allow water intrusion into the tendons and leakage of CPM which would be precursors for providing 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 identify required additional actions to assure no corrosive environmental conditions exist.

The mean pre-stresses for MPS2 are predicted to be acceptable well beyond the July 31, 2035 expiration of the extended operating period license. The tendons are predicted to remain above the lower limit for required mean force well beyond T=100 years; therefore, extending the surveillance from 5 to 10 years will continue to provide an acceptable level of quality and safety.

Summary and Conclusions

Four decades (i.e., 1976 through 2016) of post-tensioning system ISI examinations at MPS2 have shown the post-tensioning system continues to perform its intended function. Attachment 2 shows it can be expected to do so until well past the July 31, 2035 expiration of the extended operating period license.

6. Duration of Proposed Alternative

The provisions of this alternative are applicable to the MPS2 third 10-year IWL ISI interval which will begin on March 8, 2020 and end on March 7, 2030. The last examination within this interval is scheduled to occur with completion of the 50th year surveillance on March 8, 2025, plus or minus a year.

7. Precedents

This submittal is similar to:

1. The alternative request that was approved for Vogtle Units 1 and 2 on July 11, 2019 (ADAMS Accession No. ML19182A077)

   One noteworthy difference from the Vogtle Units 1 and 2 request and the MPS2 request is that their containments use a stranded-type system.

2. The relief request that was approved for Three Mile Island Unit 2 on September 19, 2019 (ADAMS Accession No ML19226A023).

Another noteworthy difference from the Vogtle Units 1 and 2 and Three Mile Island Unit 2 requests is that MPS2 specified the same tendon sample and required that each sample tendon be de-tensioned and re-tensioned for the 1, 3, 5, and 10 year surveillances. Section 4.1 of Attachment 2 further describes the approach used for MPS2 and provides a method for evaluating this difference.

8. References

ASME Boiler and Pressure Vessel Code, Section XI, 2013 Edition.

ATTACHMENT 2

Millstone Power Station Unit 2
Containment Post-Tensioning System Inservice Inspection Technical Report

MILLSTONE POWER STATION UNIT 2
DOMINION ENERGY NUCLEAR CONNECTICUT, INC. (DENC)

MILLSTONE POWER STATION
UNIT 2[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
December 12, 2019

[1] The Millstone Power Station has three nuclear units (two of which are currently operating). Only Unit 2 has a pre-stressed concrete containment.

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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

MILLSTONE POWER STATION
UNIT 2[2] CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION

TECHNICAL REPORT
BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL

Report Prepared by:
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BCP Engineers and Consultants
27 November 2019

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 Millstone Unit 2 containment ISI program conforms to these regulatory and code requirements.

1.1 Containment Description

The Millstone Unit 2 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. A rectangular steel framed, metal sided building completely encloses the containment and isolates it from outside atmospheric conditions.

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 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.

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[2] The Millstone Power Station has three nuclear units (two of which are currently operating). Only Unit 2 has a pre-stressed concrete containment.

Principal containment dimensions, as shown on Figure 5.2-1 of the Millstone Unit 2 FSAR (Reference 7.3), are as follow.

Cylinder inside diameter: 130'

Cylinder height from top of base mat to dome spring line: 132'-5"'

Cylinder wall thickness: 3'-9" (lower thickness increased by a 10' high haunch)

Dome spherical cap inside radius: 94'-6"

Dome spherical cap thickness: 3'-3"

Dome transition inside radius: 35'-6"

Foundation mat thickness: 8'-6"

Liner thickness: ¼"

The containment wall and dome are pre-stressed using 186 wire BBRV (wires anchored by cold formed button heads) tendons. The ASTM A421 (Reference 7.4) wires have a diameter of 0.250 inches.

The pre-stressing tendon arrangement is shown on Millstone Unit 2 Drawing 25203-11170 Sheets 16 – 19 (Reference 7.5).

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 39 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 124 tendons. These are arranged in 2 concentric circles each with 62 tendons spaced at nominally equal intervals around the containment circumference. 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 26 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 nominal seating force of 1,570[3] kips (equivalent to 72% of the specified minimum wire tensile 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[4] integrity is verified through regular examinations and tests performed at intervals of 5 years in accordance with 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 containment concrete surface and examination and testing of small samples of hoop, vertical and dome tendons. Each sample includes tendons selected at random from the population as well as one tendon 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

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[3] Reference 7.6 Table 2-1 lists a mean seating stress of just over 172 ksi. This is equivalent to 1,570 kip for a tendon with 186 ¼ inch diameter wires.

[4] 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.

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 – Millstone Unit 2 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.

- Extend the interval of 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.
- Eliminate de-tensioning / re-tensioning of tendons, sample wire removal and sample wire testing.
- Reduce the number of corrosion protection medium (CPM) chemical 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), of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and corrosion protection medium leakage. Examinations are to 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), of 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[5] (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.

2.3 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.

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[5] 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.

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 as a basis 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[6], 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 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

In 1996, the NRC amended 10CFR50.55a to include the containment ISI requirements[7] given in the 1992 edition (with the 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.

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[6] 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.

[7] The 10CFR50.55a amendment includes additional examination requirements and also takes certain exceptions to IWL.

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 domestic 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 qualitative summary 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 at ~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 intended to be 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.

Therefore, it is reasonable to base containment ISI programs on individual plant performance and to reduce the level of examination effort when it is shown that this can be done with no reduction in the margin of safety provided by the containment structure.

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 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 Millstone Unit 2 between 1976 and 2106. The general conclusions regarding post-tensioning system performance are listed below. Conclusions specific to Millstone Unit 2 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[8]. 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.

- 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[9].
- 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, 6 & 9), adjusted up or down, as applicable, to current group mean force levels, indicate that group means will remain

[8] 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.

[9] 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.

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[10], 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 construction 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.

- 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.

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[10] 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.

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 7.4) 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 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. As corrosive ions cannot enter the ductwork in the absence of water intrusion and reserve alkalinity cannot be brought into play in the absence of acid ion presence in the bulk CPM, there is little or no benefit gained by testing CPM samples for ion concentrations and reserve alkalinity unless there is evidence of free or absorbed water in the end cap or ducting.

Consequently, industry experience would suggest that CPM samples collected during end anchorage examinations should be initially tested only to determine absorbed water content and that additional tests should be conducted only if there is evidence of sufficient water 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. MILLSTONE UNIT 2 EXAMINATION HISTORY AND RESULTS EVALUATION

The Millstone Unit 2 post-tensioning system examination program consists of two parts. The first part generally conforms to 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 second part, which relates to conditions identified in FSAR Paragraph 5.9.3.3.4 and Appendix 5F, covers separate examinations, tests and other actions that address those hoop tendons that are below the highest level of the ground water table and, as a consequence, subject to water infiltration into the ducting[11].

Results of the two parts of the program are, in some cases, evaluated separately in the material that follows. Tendons examined under the first part of the program are identified as surveillance sample tendons and are those selected in accordance with the requirements of Regulatory Guide 1.35 or Subsection IWL. Those designated for examination and other actions under the second part of the program are identified as augmented sample tendons or, alternatively, as below grade tendons and are those selected specifically to evaluate water seepage into the ductwork and its effect on the pre-stressing system hardware.

The surveillance sample tendons are selected by random sampling techniques from the overall population of tendons (excluding those included in prior surveillance samples) and often include below grade tendons. As a result, there is some overlap of surveillance and below grade tendon samples.

The visual examination results and test data used in the evaluations that follow are those documented in the inservice inspection reports, References 7.8 through 7.17.

Millstone Unit 2 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.

[11] Tendons are sheathed in spiral seamed sheet metal ducting that serves principally to maintain an opening (for later tendon installation) during concrete placement. Duct seams are not watertight and allow infiltration of water that seeps through minute shrinkage cracks in the concrete. Ducting below the water table is subject to infiltration into any areas that are not completely filled with corrosion protection medium.

Examination No.	Year Performed	Time, Years, from March 1974 SIT to Surveillance Mid-Point	Governing Document(s)[a]
1	1976	1.3	Reg Guide 1.35
2	1978	3.0	Reg Guide 1.35
3	1980	5.2	Reg Guide 1.35
4	1986	10.9	Reg Guide 1.35
5	1992	16.9	Reg Guide 1.35
6	1995 - 1996	20.9	Reg Guide 1.35
7	2001	26.4	10CFR50.55a / IWL
8	2006	31.4	10CFR50.55a / IWL
9	2010	35.7	10CFR50.55a / IWL
10	2016	40.9	10CFR50.55a / IWL

Note a: ISI Programs conforming to IWL are also in conformance with Reg. Guide 1.35, Revision 3.

The following subsections, 4.1 through 4.5, of this report provide a comprehensive evaluation of Millstone Unit 2 post-tensioning system examination results documented in the 1, 3, 5, 10, 15, 20, 25, 30, 35, and 40-year examination reports as well as the supplemental reports covering below grade tendon examinations and CPM replacement activities. These address the following aspects of examination results acquired and corrective measures implemented over the 40-year period.

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
- 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 - Below Grade Tendon Wire Examination and Testing Results
- Par. 4.2.5 - 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 Components Damage / Distortion
Par. 4.3.5 - Concrete Cracking Adjacent to Bearing Plates
Par. 4.3.6 - Below Grade Hoop Tendon End Anchorage Condition
Par. 4.3.7- End Anchorage Condition Summary and Conclusions

Subsection 4.4 – Corrosion Protection Medium Testing

Par. 4.4.1 - Corrosive Ion Concentrations – Surveillance Sample Tendons
Par. 4.4.2 – Reserve Alkalinity / Neutralization Number – Surveillance Sample Tendons
Par. 4.4.3 - Water Content – Surveillance Sample Tendons
Par. 4.4.4 - Corrosive Ion Concentrations – Below Grade Tendons
Par. 4.4.5 – Reserve Alkalinity / Neutralization Number – Below Grade Tendons
Par. 4.4.6 - Water Content – Below Grade Tendons
Par. 4.4.7 - Summary and Conclusion - CPM Test Results

Subsection 4.5 – Below Grade Tendon CPM Replacement and Pressurization

Par. 4.5.1 – Corrosion Protection Medium Replacement
Par. 4.5.2 - Continuous Pressurization System

The proposed extension of the tendon surveillance interval to 10 years is justified it can be shown with a high degree of confidence 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 4.5 below.

4.1 Tendon Force Trends and Forecasts

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 SP 21140 (Reference 7.18) until well after the 31 July 2035 expiration of the extended operating license. 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 procedures used for the 1, 3, 5-and 10-year surveillances specified the same tendon sample and required that each sample tendon be de-tensioned and re-tensioned. As a result, all tendons selected for the 1-year surveillance sample were de-tensioned and re-tensioned not only during that surveillance but also during each of the next three surveillances.

The purpose of a lift-off force measurement is to determine how the initial seating force in a tendon has been reduced by elastic shortening and time dependent losses. The average of a number of such measurements then serves as a reasonable estimate of the overall mean pre-stressing force in the applicable tendon group (i.e., hoop, vertical or dome). For this reason, the 3, 5- and 10-year surveillance lift-off forces, all of which have been affected by one or more cycles of de-tensioning / re-tensioning, cannot be used in computing a meaningful group mean or in trending the mean. Therefore, as the 3, 5- and 10-year lift-off forces are effectively meaningless for trend evaluation purposes, these are not included in the tables and plots discussed in the following paragraphs.

Measured forces documented for the 1-year examination and 15- through 40-year examinations are listed in Tables 2 through 4 and plotted in Figures 1 through 9. Three separate plots, as discussed below, are provided for each of the three tendon groups (hoop, vertical and dome).

The first of the three plots shows forces measured during the 1 year examination and the 15 year through 40 year examinations and the log-linear trend line (which represents expected group mean) fitted to these by the method of least squares, as developed in Reference 7.19, and extrapolated to T (years since the SIT) = 100. It also includes a curved line representing the 95% lower confidence limit (LCL)[12] on mean force. The LCL values are computed using the procedures given in Reference 7.19.

The second plot shows measured forces for tendons examined in surveillance years 15 through 40 and, the (extrapolated) log-linear trend and the LCL curve computed using the truncated data set.

The third plot shows common tendon (one tendon in each group that is included in consecutive surveillance samples) measured forces with a log-linear trend line.

In the following material, all computed mean forces and LCL's are rounded (down to maintain a conservative approach) to a whole kip value.

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[12] Subject to the constraints (e.g., assumption of normally distributed scatter) inherent in theoretical statistics, there is a 95% probability that the mean force at any point in time is greater than the 95% LCL computed for that same point in time.

4.1.1 Hoop Tendon Trends and Forecasts

Hoop tendon forces measured during each of the 7 surveillances (as explained at the beginning of Section 4.1, no data are shown for the 3, 5-and 10-year surveillances) are listed in Table 2 and plotted on Figures 1 through 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 1,308 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. All measured forces plot well above minimum line.

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:

$$F_{HM} = 1{,}586.2 - 70.01 * \mathrm{Log}_{10}(T)$$

where T is, as earlier noted, years since the March 1975 SIT.

The trend line, which is based on the previously stated postulate, remains well above the minimum line at T = 100[13], which is well after 31 July 2035 expiration of the extended operating license. 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 extrapolated trend line ordinate at T = 51 is 1,466 kip which is well above the 1,308 kip minimum. The LCL at T = 100 is 1,423 kip, which is also well above minimum. The extrapolated trend and LCL values at T = 100, 49 years after the deadline for completion of the next surveillance if the interval is extended to 10 years, both support the proposed extension of the examination interval.

[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.

4.1.1.2 Hoop Tendon Mean Force Trend / From Surveillance Year 15

Figure 2 is a plot of hoop tendon forces measured during the 15 year and subsequent surveillances, the trend line extrapolated to T = 100, the LCL curve and the 1,308 kip lower limit line.

The trend line is relatively close to that shown in Figure 1. The trend line equation is:

$$F_{HM} = 1{,}566.8 - 56.35 * \mathrm{Log}_{10}(T)$$

This equation yields a T = 51 mean force of 1,470 kip, which is comparable to the 1,466 kip computed in 4.1.1.1 above. The LCL at T = 100 is 1,374 kip.

The T = 100 trend line and LCL values computed using the truncated data set provide further support for the proposed interval extension.

4.1.1.3 Hoop Tendon Common Tendon Force Trend

Tendon 32H32 was designated as a common tendon starting with the 20-year surveillance. It was not examined during the 15-year surveillance.

IWL-2521(b) specifies that common tendons be selected from the first examination sample. It does not address the situation in which all tendons in the first-year sample were de-tensioned / re-tensioned (as was often done in the 1970's and early 1980's, primarily to allow wire continuity testing). Procedures in place during the year 1, 3, 5- and 10-year Millstone 2 surveillances required that each sample tendon be de-tensioned and re-tensioned which eliminated the possibility of designating common (or control) tendons from the samples selected for these examinations. The surveillance reports do not explain why a common hoop tendon was not chosen from the 15-year surveillance sample.

Figure 3 is a plot of common hoop tendon 32H32 measured forces from surveillance year 20 and includes the log linear trend line. Scatter is seen to be small relative to that illustrated in Figures 1 and 2. The trend line equation is:

$$F_{HC} = 1{,}907.8 - 297.49 * \mathrm{Log}_{10}(T)$$

This equation suggests that common tendon force will cross the T = 100 abscissa at F_{HC} = 1,312 kip, or just above the 1,308 minimum[14]. The slope, 297.49 kip per logarithmic

[14] The 1,308 kip minimum is shown here for information only; it applies to the mean of the tendon group forces and not to an individual tendon.

interval, of the common tendon trend line is over 5 times the 57.50 kip per logarithmic interval slope of the trend line computed in 4.1.1.2 above. This cannot be ascribed to the observed scatter. Also, back-casting to T = 1 would suggest that the initial force in the tendon was in excess of 1,900 kip, which is not possible.

But, with only 5 data points, it is not possible to draw a definitive conclusion regarding the true behavior of 32H32. Scatter that is not apparent as such probably has an outsized effect on the computed trend line equation. If, for example, the 35- and 40-year points each represent downward scatter of 50 kip, a trendline accounting for this would be reasonably close to that shown on Figure 2.

4.1.1.4 Hoop Tendon Mean Force Projected Using Common Tendon Trend Slope

As there is no common tendon data for the early surveillances, the following analysis is based on tendon forces measured during years 15 through 40.

If hoop tendon mean force is postulated to follow a log-linear trend, the mean value at any time, $F_{HM}(T)$, is defined by the following relationship.

$$F_{HM}(T) = F_{HM}(T_o) + b * [Log_{10}(T) - Log_{10}(T_o)]$$

where $F_{HM}(T_o)$ is the true mean at T_o and b is the slope of the trend

The 17 lift-off forces values listed in Table 2 for surveillance years 15 through 40 and plotted on Figure 2 cover a time range of 16.9 years to 40.9 years. The logarithmic mid-point, T_{mid}, of this time range is:

$$T_{mid} = 10 \wedge \{[Log_{10}(16.9) + Log_{10}(40.9)] / 2\} = 26.3 \text{ years}$$

Of the 17 lift-off forces, 7 were measured prior to T = 26.3 years, 3 were measured at T = 26.4 years, which is essentially at the 26.3-year mid-point, and 7 were measured after that time. Therefore, it is reasonable to postulate that the true mean force at T = 26.3 is close to the numerical average of all 17 (a reasonably large sample) lift-off forces plotted on Figure 2. This average is 1,489.2 kip.

Using, for conservatism, the 297.49 kip per logarithmic interval slope of the common hoop tendon force trend, the above equation for hoop tendon mean force becomes:

$$F_{HM}(T) = 1,487.6 - 297.49 * [Log_{10}(T) - Log_{10}(26.3)]$$

Forecast mean hoop tendon force at T = 100 years is, from the above equation:

$$F_{HM}(100) = 1{,}487.6 - 297.49 * [\mathrm{Log}_{10}(100) - \mathrm{Log}_{10}(26.3)] = 1{,}315 \text{ kip}$$

The above forecast T = 100 mean exceeds the 1,308 kip lower limit. The forecast mean hoop tendon force at T = 51 years, the latest date for completion of the next surveillance if the examination period is extended to 10 years, is:

$$F_{HM}(51) = 1{,}487.6 - 297.49 * [\mathrm{Log}_{10}(51) - \mathrm{Log}_{10}(26.3)] = 1{,}402 \text{ kip}$$

The forecast T = 51 mean of 1,402 kip is 94 kip above the 1,308 kip minimum.

The above conservative (i.e., using the extreme slope of the hoop common tendon trend) analysis provides further confirmation that hoop 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.

4.1.1.5 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 1,308 kip lower limit until at least March 2075 (T = 100), ~39.6 years after the expiration of the extended operating license and 49 years after the proposed March 2026 deadline for completion the next surveillance. This conclusion is supported by the following.

a) The hoop tendon mean force trend, computed using all measured force data acquired during the 7 examinations conducted to date, does not cross the lower limit line until after T = 100 (years since the March 1975 structural integrity test).

b) The hoop tendon mean force trend, computed using measured force data acquired during the 15 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 7 surveillances (excludes the 3, 5- and 10-year surveillances as previously discussed) completed to date, remains above the 1,308 kip minimum beyond T = 100.

d) The 95% lower confidence limit on hoop tendon mean force, computed using measured force data acquired during the 15 year and subsequent examinations, remains above the 1,308 kip minimum beyond T = 100.

e) Hoop tendon mean force, computed using the slope of the common tendon (32H32) measured force trend and the average of all forces recorded for the 15 year and later surveillances, remains above the lower limit beyond T = 100.

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.

Barring observed wire breakage or severe wire corrosion, with a corresponding reduction in cross sectional area, there is no reason why force in below grade hoop tendons[15] should decrease more rapidly than that in tendons located above the water table and not subject to potential ground water intrusion. As subsequently discussed in 4.2.4 below, the condition of below grade hoop tendon wires is essentially the same as that of the wires in hoop tendons above the water table. And, as can be seen on Table 2, there is no tendency for the force in below grade tendons to differ from that in the other tendons listed.

4.1.2 Vertical Tendon Trends and Forecasts

Vertical tendon forces measured during each of the 7 surveillances (as explained at the beginning of Section 4.1 above, no data are shown for the 3, 5- and 10-year surveillances) are listed in Table 3 and plotted on Figures 4 through 6.

4.1.2.1 Vertical Tendon Mean Force Trend / All Data

The measured force data listed in Table 3 are plotted on Figure 4 which also includes the extrapolated log-linear trend of the mean, the LCL curve and a line indicating the 1,308 kip minimum acceptable mean vertical 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 vertical tendon force is defined by the equation:

$$F_{VM} = 1{,}611.9 - 67.37 * \text{Log}_{10}(T)$$

The trend line, which is based on the previously stated postulate, remains well above the minimum line (see 4.1.1 footnote) at T = 100, which is well after 31 July 2035 expiration of the extended operating license. 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 1,496 kip which is 188 kip above the 1,308 kip minimum. The LCL

[15] Below grade hoop tendons were initially identified (in the 1-year surveillance report, Reference 7.8) as 12H01 through 12H12, 31H01 through 31H13 and 32H01 through 32H12. The ranges of tendons included in the below grade group are generally smaller in later surveillance reports.

at T = 100 is 1,439 kip, which is also above the minimum. The extrapolated trend and LCL values at T = 100 both support the proposed extension of the examination interval.

4.1.2.2 Vertical Tendon Mean Force Trend / From Surveillance Year 15

Figure 5 is a plot of vertical tendon forces measured during the 15 year and subsequent surveillances, the trend line extrapolated to T = 100, the LCL curve and the 1,308 kip lower limit line.

The trend line equation is:

$$F_{VM} = 1{,}806.2 - 203.02 * \text{Log}_{10}(T)$$

This trend differs significantly from that illustrated on Figure 4 in that the T = 1 ordinate is much higher and the (negative) slope is much greater. The difference can be ascribed, in part, to scatter which is more pronounced than that shown for hoop tendon forces on Figure 2. Back-casting the trend to T = 1 yields a mean vertical tendon force of 1,806 kip, a highly improbable result.

The (negative) slope of the trend seems excessively high when compared with the trend shown on Figure 4. However, the ordinate of the trend at T = 26.3, the logarithmic mid-point of the plotted data, is 1,517.9 kip. This is very close to the corresponding T = 26.3-year ordinate, 1,516.2 kip, of the Figure 4 trend which incorporates the 1 year surveillance data. This leads to the conclusion that the Figure 4 trend provides a more reasonable basis on which to forecast vertical tendon mean force. And, the conclusion that using the Figure 5 trend provides a conservative forecast for values of T > 26.3 years.

The above trend line equation yields a T = 51 (latest date to complete the next surveillance if the interval is extended to 10 years) mean force of 1,459 kip, 151 kip above the 1,308 kip minimum.

The T = 100 forecast values of F_{VM} and the corresponding LCL are 1,400 kip and 1,307 kip, respectively. The first is 92 kip above the 1,308 kip minimum. The second is effectively equal to the minimum (computed value before rounding is 1,307.8 kip).

The trend line and LCL values computed, using the truncated data set, for both T= 51 years and T = 100 years provide further support for the proposed interval extension.

4.1.2.3 Vertical Tendon Common Tendon Force Trend

Tendon 31V24 was designated as a common tendon starting with the 15-year surveillance.

Figure 6 is a plot of common vertical tendon 31V24 measured forces from surveillance year 15 and includes the log linear trend line. Scatter is seen to be significantly less than that illustrated in Figures 4 and 5. The trend line equation is:

$$F_{VC} = 1{,}626.4 - 110.48 * Log_{10}(T)$$

This equation suggests that common tendon force will cross the T = 100 abscissa at F_{VC} = 1,405 kip, or, 97 kip above the1,308 kip minimum (noting, as before, that the minimum applies to the mean and not to any individual tendon). The slope, 110.48 kip per logarithmic interval, is between those of the trend lines shown on Figures 4 and 5.

4.1.2.4 Vertical Tendon Mean Force Projected Using Common Tendon Trend Slope

As there is no common tendon data for the early surveillances, the following analysis is based on tendon forces measured during years 15 through 40.

If vertical tendon mean force is postulated to follow a log-linear trend, the mean value at any time, $F_{VM}(T)$, is defined by the following relationship.

$$F_{VM}(T) = F_{VM}(T_o) + b * [Log_{10}(T) - Log_{10}(T_o)]$$

where $F_{VM}(T_o)$ is the true mean at T_o and b is the slope of the trend

The 20 lift-off forces values listed in Table 3 for surveillance years 15 through 40 and plotted on Figure 5 cover a time range of 16.9 years to 40.9 years. The logarithmic mid-point, T_{mid}, of this time range is:

$$T_{mid} = 10 \wedge \{[Log_{10}(16.9) + Log_{10}(40.9)] / 2\} = 26.3 \text{ years}$$

Of the 20 lift-off forces, 8 were measured prior to T = 26.3 years, 3 were measured at T = 26.4 years, which is essentially at the 26.3-year mid-point, and 9 were measured after that time. Therefore, it is reasonable to postulate that the true mean force at T = 26.3 is close to the numerical average of all 20 (a reasonably large sample) lift-off forces plotted on Figure 2. This average is 1,518.5 kip.

Using the 110.48 kip per logarithmic interval slope of the common vertical tendon force trend as a reasonable proxy for that of the tendon group, the above equation for vertical tendon mean force becomes:

$$F_{VM}(T) = 1{,}518.5 - 110.48 * [Log_{10}(T) - Log_{10}(26.3)]$$

Forecast mean vertical tendon force at T = 100 years is, from the above equation:

$$F_{VM}(100) = 1{,}518.5 - 110.48 * [Log_{10}(100) - Log_{10}(26.3)] = 1{,}454 \text{ kip}$$

The above forecast T = 100 mean exceeds the 1,308 kip lower limit by 146 kip. The forecast mean vertical tendon force at T = 51 years, the latest date for completion of the next surveillance if the examination period is extended to 10 years, is:

$$F_{VM}(51) = 1{,}518.5 - 110.48 * [Log_{10}(51) - Log_{10}(26.3)] = 1{,}486 \text{ kip}$$

The forecast T = 51 mean of 1,486 kip (rounded down to maintain a conservative approach) is 178 kip above the 1,308 kip minimum.

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.

4.1.2.5 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 1,308 kip lower limit at least until T = 100, 49 years after the latest date for completing the next surveillance if the interval is extended to 10 years and ~39.6 years after the 31 July 2035 expiration of the extended operating license. This conclusion is supported by the following.

a) The vertical tendon mean force trend, computed using all measured force data acquired during the 7 examinations conducted to date, remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,477 kip or 169 kip above the 1,308 kip lower limit.

b) The 95% lower confidence limit on vertical tendon mean force, computed using measured force data acquired during the 7 examinations completed to date, remains above the 1,308 kip minimum until well after T = 100 (forecast LCL at T = 100 is 1,439 kip).

c) The vertical tendon mean force trend, computed using measured force data acquired during the 15 year and subsequent examinations, also remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,400 kip or 92 kip above the 1,308 kip lower limit.

d) The 95% lower confidence limit on vertical tendon mean force, computed using measured force data acquired during the 15 year and subsequent examinations, remains at or above the 1,308 kip minimum until T is effectively equal to 100 (forecast LCL at T = 100 is 1,307.8 kip).

e) Vertical tendon mean force, computed using the slope of the common tendon (31V24) measured force trend and the average of all forces recorded for the 15 year and later surveillances, remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,454 kip or 136 kip above the 1,308 kip lower limit.

The results of the analyses and evaluations summarized in a) through e) above provide evidence that vertical tendon mean force will remain above the lower limit until at least T = 100 (100 years after the March 1975 SIT), or, 49 years after the latest date for completion of the next surveillance if the interval is extended to 10 years and ~39.6 years after the 31 July 2035 expiration of the extended operating license.

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 7 surveillances (as explained above, no data are shown for the 3, 5- and 10-year surveillances) are listed in Table 4 and plotted on Figures 7 through 9.

4.1.3.1 Dome Tendon Mean Force Trend / All Data

The measured force data listed in Table 4 are plotted on Figure 7 which also includes the extrapolated log-linear trend of the mean, the LCL curve and a line indicating the 1,308 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:

$$F_{DM} = 1{,}573.6 - 76.08 * \text{Log}_{10}(T)$$

The trend line, which is based on the previously stated postulate, remains well above the minimum line at T = 100, which is ~39.6 years after 31 July 2035 expiration of the extended operating license. If the examination interval is extended from 5 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 extrapolated trend line ordinate at T = 51 is 1,443 kip which is 135 kip above the 1,308 kip minimum. The LCL at T = 100 is 1,403 kip, which is also above the minimum.

The extrapolated trend and LCL values at T = 100 both support the proposed extension of the examination interval.

4.1.3.2 Dome Tendon Mean Force Trend / From Surveillance Year 15

Figure 8 is a plot of dome tendon forces measured during the 15 year and subsequent surveillances, the trend line extrapolated to T = 100, the LCL curve and the 1,308 kip lower limit line.

The trend line equation is:

$$F_{DM} = 1{,}625.4 - 112.04 * \text{Log}_{10}(T)$$

This trend differs somewhat from that illustrated on Figure 7 in that the T = 1 ordinate is higher and the (negative) slope is greater. The differences which are not particularly great, can be ascribed, in part, to scatter.

The above trend line equation yields a T = 51 (latest date to complete the next surveillance if the interval is extended to 10 years) mean force of 1,434 kip, 126 kip above the 1,308 kip minimum.

The T = 100 forecast values of F_{DM} and the corresponding LCL are 1,401 kip and 1,374 kip, respectively. The first is 93 kip above the 1,308 kip minimum while the LCL is 66 kip above the minimum.

The trend line and LCL values computed, using the truncated data set, for both T= 51 years and T = 100 years provide further support for the proposed interval extension.

4.1.3.3 Dome Tendon Common Tendon Force Trend

Tendon 1D24 was designated as a common tendon starting with the 15-year surveillance.

Figure 9 is a plot of common dome tendon 1D24 measured forces from surveillance year 15 and includes the log linear trend line. Scatter is seen to be significantly less than that illustrated in Figures 7 and 8. The trend line equation is:

$$F_{DC} = 1{,}749.3 - 211.05 * Log_{10}(T)$$

This equation suggests that common tendon force will cross the T = 100 abscissa at F_{DC} = 1,327 kip, or, 19 kip above the1,308 kip minimum (noting, as before, that the minimum applies to the mean and not to any individual tendon). Both the T = 1 ordinate and the slope are greater than those shown on Figures 7 and 8.

4.1.3.4 Dome Tendon Mean Force Projected Using Common Tendon Trend Slope

As there is no common tendon data for the early surveillances, the following analysis is based on tendon forces measured during years 15 through 40.

If dome tendon mean force is postulated to follow a log-linear trend, the mean value at any time, $F_{DM}(T)$, is defined by the following relationship.

$$F_{DM}(T) = F_{DM}(T_o) + b * [Log_{10}(T) - Log_{10}(T_o)]$$

where $F_{DM}(T_o)$ is the true mean at T_o and b is the slope of the trend

The 17 lift-off forces values listed in Table 4 for surveillance years 15 through 40 and plotted on Figure 8 cover a time range of 16.9 years to 40.9 years. The logarithmic mid-point, T_{mid}, of this time range is:

$$T_{mid} = 10 \wedge \{[Log_{10}(16.9) + Log_{10}(40.9)] / 2\} = 26.3 \text{ years}$$

Of the 17 lift-off forces, 6 were measured prior to T = 26.3 years, 3 were measured at T = 26.4 years, which is essentially at the 26.3-year mid-point, and 8 were measured after that time. Therefore, it is reasonable to postulate that the true mean force at T = 26.3 is close to the numerical average of all 17 (a reasonably large sample) lift-off forces plotted on Figure 8. This average is 1,465.4 kip.

Using the 211.05 kip per logarithmic interval slope of the common dome tendon force trend as a reasonable proxy for that of the tendon group, the above equation for dome tendon mean force becomes:

$$F_{DM}(T) = 1465.4 - 211.05 * [Log_{10}(T) - Log_{10}(26.3)]$$

Forecast mean dome tendon force at T = 100 years is, from the above equation:

$$F_{DM}(100) = 1,465.4 - 211.05 * [\text{Log}_{10}(100) - \text{Log}_{10}(26.3)] = 1,342 \text{ kip}$$

The above forecast T = 100 mean exceeds the 1,308 kip lower limit by 34 kip. The forecast mean dome tendon force at T = 51 years, the latest date for completion of the next surveillance if the examination period is extended to 10 years, is:

$$F_{DM}(51) = 1,465.4 - 211.05 * [\text{Log}_{10}(51) - \text{Log}_{10}(26.3)] = 1,404 \text{ kip}$$

The forecast T = 51 mean of 1,404 kip (rounded down to maintain a conservative approach) is 96 kip above the 1,308 kip minimum.

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 beyond T = 100 years.

4.1.3.5 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 1,308 kip lower limit at least until T = 100, 49 years after the latest date for completing the next surveillance if the interval is extended to 10 years and ~39.6 years after the 31 July 2035 expiration of the extended operating license. This conclusion is supported by the following.

a) The dome tendon mean force trend, computed using all measured force data acquired during the 7 examinations conducted to date, remains above the lower limit beyond T = 100. The forecast mean force at T = 100 is 1,421 kip or 113 kip above the 1,308 kip lower limit.

b) The dome tendon mean force trend, computed using measured force data acquired during the year 15 and subsequent examinations, also remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,401 kip or 93 kip above the 1,308 kip lower limit.

c) The 95% lower confidence limit on dome tendon mean force, computed using measured force data acquired during the 7 examinations completed to date, remains above the 1,308 kip minimum until well after T = 100. The LCL at T = 100 is 1,403 kip, 95 kip above the minimum.

d) The 95% lower confidence limit on dome tendon mean force, computed using measured force data acquired during the 15 year and subsequent examinations, remains above the 1,308 kip minimum beyond T = 100. The LCL at T = 100 is 1,345 kip, 37 kip above the minimum.

e) Dome tendon mean force, computed using the slope of the common tendon (1D24) measured force trend and the average of all forces recorded for the 15 year and later surveillances, remains above the lower limit beyond T = 100. The forecast mean force at T = 100 is 1,342 kip or 24 kip above the 1,308 kip lower limit.

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 beyond T = 100 (100 years after the March 1975 SIT), or, 49 years after the latest date for completion of the next surveillance if the interval is extended to 10 years and ~39.6 years after the 31 July 2035 expiration of the extended operating license.

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. Each analysis includes the following 5 computations, all based on the postulate that mean force varies linearly with the logarithm of time.

- Trend based on measured forces recorded during the 7 surveillances (data documented during the 3, 5- and 10-year surveillances is not used as previously explained) completed to date and providing valid tendon force data.
- 95% lower confidence limit (LCL) on the trend of measured forces recorded during the 7 surveillances providing valid tendon force data.
- Trend based on measured forces recorded during the 15 year and subsequent surveillances.
- 95% lower confidence limit (LCL) on the trend of measured forces recorded during the 15 year and subsequent surveillances.
- Trend using the slope of the common tendon log-linear trend and the mean of the 15- through 40-year surveillance lift-off forces.

The margins between forecast group mean force and the 1,308 kip minimum required mean force 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), T = 60.4 years (31 July 2035 expiration of the extended operating license) and T = 100 years and for the 5 forecast bases listed above.

Summary of Margins between Forecast and Minimum Required Mean Forces				
Tendon Group	Forecast Basis	Margin, kip		
		T = 51	T = 60.4	T = 100
Hoop	Log-linear trend, all lift-off forces	158	153	138
	95% LCL, all lift-off forces	140	134	115
	Log-linear trend, 15 – 40-year lift-off forces	162	158	146
	95% LCL, 15 – 40-year lift-off forces	119	106	66
	Common tendon slope / lift-off force mean	94	72	7
Vertical	Log-linear trend, all lift-off forces	188	183	169
	95% LCL, all lift-off forces	159	152	131
	Log-linear trend, 15 – 40- year lift-off forces	151	136	92
	95% LCL, 15 – 40-year lift-off forces	101	76	(-)1
	Common tendon slope / lift-off force mean	178	170	146
Dome	Log-linear trend, all lift-off forces	135	130	113
	95% LCL, all lift-off forces	121	114	95
	Log-linear trend, 15 – 40-year lift-off forces	126	117	93
	95% LCL, 15 – 40-year lift-off forces	97	82	66
	Common tendon slope / lift-off force mean	96	81	34

The 15 trends / LCL's evaluated all show the trend line and LCL curve remaining above the group lower limit through T = 51 (years after the SIT), which is the deadline for completion of the next surveillance if the interval is extended to 10 years, as well as through T = 60.4 years which is when the extended operating license expires. The minimum margin shown in the T = 51 column is 94 kip and that in the T = 60.4 column is 72 kip.

Of the 15 trend / LCL margins listed in the T = 100 column, all but 1 are positive. The lone exception is the LCL computed for vertical tendon data documented during the 15 year and subsequent surveillances. This LCL is 1,307.8 kips at T = 100, a value essentially equal to the 1,308 kip minimum force.

Measured force trends and forecasts evaluated in the preceding paragraphs provide ample evidence that mean pre-stressing in the containment wall and dome will remain above the lower limits specified in SP 21140 (Reference 7.18) until well after the 31 July 2035 expiration of the extended operating license.

Therefore, 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 trends.

4.2 Wire Examination and Test Results Evaluation

During each 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 specimens cut from each of the wires. Two of the specimens were located close to the sample wire ends and one was near the center.

In addition, wires found to be broken during a surveillance were extracted. Specimens were cut from these wires and tested.

Table 5A with Figure 10 and Table 5B with Figure 11 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 39 wires, other than the 7 identified as broken wires, had signs of damage and, with few exceptions, no corrosion. All observed corrosion was concluded to be inactive.

With two exceptions[16], observed corrosion consisted of Level 2 (see level definitions in 4.3.1 below), defined in the examination procedures as light rusting with no pitting. As none of the surveillance reports indicated that there was water in contact with any of the extracted wires, it is concluded that the Level 2 corrosion observed is not active and that it occurred prior to the time that the tendon duct was filled with CPM during construction and, possibly, before the completed tendons were dipped in a protective coating bath at the fabrication facility.

Small isolated areas of inactive Level 3 corrosion, defined in the examination procedures as corrosion with pits up to 0.003 inches in depth, were documented during the visual examination of the wires extracted from 12H01 during the 15- and 20-year surveillances. Tests on samples cut from these wires showed breaking strength (Table 5A) and

[16] One additional instance of Level 3 wire corrosion is documented in the 5-year surveillance report. During this surveillance, a small area of Level 3 corrosion was observed on a visible segment (seen through the anchor head center hole) of wire during the examination of the 31H19 Buttress 1 end anchorage. The corrosion was accepted as is and no further examinations or corrective actions were taken.

elongation at failure (Table 5B) values to be in line with the values recorded for other test wires.

Wires extracted for testing included the following broken wires.

Surveillance Year	Tendon(s)	No. of Broken Wires
1	31V34	1
3	1D21	1
10	1D23	1
15	12H08	3
20	2D03	1

Most, if not all, broken wires appeared to have been bent during initial tensioning or re-tensioning, possibly as a result of anchor head rotation, with the subsequent breaks occurring in the segments weakened by bending. Testing of specimens cut from undamaged lengths of these wires showed tensile strength and elongation at failure to be in the expected range[17]; i.e., there was no indication that the broken wires were metallurgically deficient.

As no damage, other than that noted above, and neither active nor unacceptable levels of corrosion have been found on the wires extracted during the 10[18] surveillances completed to date, it is concluded that tendon wire damage / corrosion should not be a concern over the remaining life of the plant.

4.2.2 Wire Tensile Strength

Table 5A lists the ultimate tensile strength (UTS) found for the three test specimens cut from each extracted unbroken wire, the mean of the 3 UTS values (Wire Mean) and the mean of all UTS values listed for the examination year (Exam Mean). Figure 10 is a log-time based plot showing, for each examination year, the UTS values recorded for each unbroken wire test specimen and the log-linear trend line fitted to the test data.

Each of the 96 specimens has an ultimate tensile strength greater than the specified 240 ksi minimum. The trend line shown on the plot is essentially flat indicating that mean UTS does not vary with time under load.

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[17] Tensile strengths of the specimens cut from broken wire 2D03 are relatively low compared to those of all other specimens tested. Nonetheless, all 3 specimens broke at stress levels above the required minimum of 240 ksi.

[18] While lift-off data recorded during the 3, 5- and 10-year surveillances cannot be used in trending pre-stressing force, the results of tests on wires extracted during these surveillances are valid.

The UTS values shown for the three 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 generally 5 ksi or less with only 3 differences (7, 8, & 16 ksi) greater than 5 ksi.

The mean, maximum and minimum UTS values and ranges reported for consecutive surveillances exhibit more variation than would normally be expected. As there is no pattern, i.e., no trend for UTS to increase or decrease over time, it is concluded that much of the variation can be attributed to changes in testing procedures / equipment from examination to examination.

As all of the 96 UTS values exceed the 240 ksi lower limit, as there is no trend to the data plotted on Figure 10 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 beyond year 40.

Table 6A shows the UTS for specimens cut from each broken wire. These are 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 (on extremely rare occasions a wire will break at the location of a slag inclusion) that affected tensile strength.

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 A421specified 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 test specimens cut from each unbroken extracted wire, the mean of the 3 EF values (Wire Mean) and the mean of all EF values listed for the examination year (Exam Mean). All 96 elongations shown on the table are greater than or, in a few cases, just equal to, the 4% minimum specified in ASTM A421.

The elongations measured during testing of the 10-year surveillance specimens are documented only as >4%. Also, 3 of the elongations (shown in the shaded cells) recorded during testing of the 5-year surveillance samples were identified as minimum values recorded prior to failure of the specimen outside the instrumented gage length. Had failure occurred within the gage length, elongation at failure would have exceeded 4% by an unknown margin.

With 2 exceptions, all defined EF values are in the 4.0% to 6.1% range. The exceptions are a 6.5% and a 7.1% EF reported for tests conducted in year 40. Of course, as noted, the 10-year surveillance report listed all EF values as >4%. Nothing else regarding the 10-year values can be concluded.

Figure 11 is a log-time based plot showing, for each examination year, the examination mean EF, the maximum & minimum EF values and the log-linear trend of the mean.

As shown on the figure, there is no significant trend to the elongations. The tabulated (Table 5B) 1 year and 40-year surveillance exam means, 5.7% and 5.8%, respectively, differ by only 0.1%. The trend line values over the same time interval decreased from 5.3% to 4.9%, which is, considering the scatter of the elongation values, deemed not statistically significant.

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.

Table 6B shows the EF values for specimens cut from each broken wire. These are in line with the EF data shown on Table 6A, verifying that the cause of the break, in each case, was not related to a dispersed metallurgical condition (on extremely rare occasions a wire will break at the location of a slag inclusion) that affected ductility.

Based on the above discussion, it is concluded that wire ductility does not change with time under load and that it continues 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 Below Grade Tendon Wire Examination and Testing Results

Below grade tendon wire examination results are summarized on Table 8F. Extracted wires as well as short lengths of wire examined through anchor head center holes did not show active corrosion[19]. Inactive corrosion consisted mostly of level 2, with small areas of level 3 reported for the wire extracted from 12H01 during the 10-and 20-year

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[19] A small area of nascent corrosion is reported to have been observed on one wire examined through a below grade tendon anchor head center hole during the 1-year surveillance. The 1-year surveillance report states that the corrosion product was inadvertently removed by a touch of the examiner's finger during the process of cleaning the wires of CPM for a more extensive look. The observed condition, if actual corrosion, is considered to be insignificant and is not counted as active corrosion.

surveillances. Button head corrosion, as distinct from that on the drawn wires, is discussed separately in Section 4.3 below.

All wire test results are summarized on Tables 5A, 5B, 6A and 6B and discussed above. Nine of the wires tested were extracted from below grade tendons during the 3, 5, 15, 20- and 30-year surveillances. The tendons from which the wires were extracted and the mean breaking strengths (UTS) of the three samples cut from each are tabulated below.

Wire From	Mean UTS		Wire From	Mean UTS		Wire From	Mean UTS
12H07	265		12H08	264		12H01	266
12H07	270		12H08	260		12H05	265
12H01	266		12H08	262		31H01	274

These mean breaking strengths fall between the 247 ksi minimum and 279 ksi maximum wire mean values listed on Tables 5A and 6A. Also, mean elongations at failure, as shown on Tables 5B and 6B are all between the maximum and minimum group means listed on these tables.

Based on the visual examination results as well as on the breaking strength and elongation at failure values discussed above, it is concluded that the below grade tendon wires have not been degraded by exposure to ground water infiltration.

4.2.5 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 examination of 39 wires (including 7 broken wires) extracted from hoop, vertical and dome tendons between 1976 and 2016 has 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 almost 4 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[20] of tendons to extract test wires. It is recommended, on the basis of the foregoing conclusion, that this aspect of post-tensioning system surveillance be discontinued. Testing could be specified by the Responsible Engineer if conditions

[20] 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.

indicative of wire degradation are found during future end anchorage visual examinations and / or force measurements.

4.3 End Anchorage Hardware and Concrete Condition

During each of the surveillances, end anchorage areas were visually examined for evidence of corrosion, presence of free water, discontinuous wires and damage to / distortion of load bearing components. Beginning with the 15- year surveillance, concrete adjacent to bearing plates was examined for cracks, spalling and other indications of damage, deterioration and structural distress. Results of these examinations are summarized in 4.3.1 through 4.3.5. Conditions specific to below grade tendons are further summarized in 4.3.6.

4.3.1 Corrosion

In the reports covering the 10 year and later surveillances, observed corrosion is assigned a level using the guidance tabulated below.

Level	Characteristic
1	Bright metal
2	Light rusting with no pitting
3	Rust with pitting up to 0.003" in depth
4	Rust with pitting 0.003" to 0.006" in depth
5	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 is usually a judgment call based on visual examination of a corroded area.

No active corrosion was observed on bearing plates, anchor heads, shims, button heads or wires (a unique exception is addressed in 4.2.4 above). Based on its appearance, all corrosion observed on the exposed areas of bearing plates was, with one exception, judged to have occurred prior to the time that the enclosure building was completed, and the containment was isolated from the outside environment.

The single exception was an observation of corrosion on two dome tendon bearing plates during the 3-year examination that was not noted during the 1-year examination. As the dome tendon bearing plates are protected from corrosive elements, it is probable that the condition noted during the 3-year examination was present but either not noted or not considered recordable during the 1-year examination.

Also, based on its appearance, corrosion on wires, button heads, anchor heads, shims and areas of bearing plates covered by end caps, was judged to have occurred prior to the installation of CPM into the tendon end caps and ducting (as previously noted, a unique exception is addressed in 4.2.4 above).

Documented corrosion on surveillance tendon load bearing elements[21] was, with few exceptions, limited to light rust identified as Level 2. The exceptions are summarized below.

1 Year Surveillance:	Level 3 corrosion observed on 1D23 north end button heads and anchor head
	Level 3 corrosion observed on 23V26 gallery end shims
	Level 3 corrosion observed on 5 (of 43 examined) bearing plates; Level 4 observed on 1 bearing plate (1D21 South end)
3 Year Surveillance:	Level 3 corrosion observed on 1D23 north anchorage button heads and anchor head
	Level 3 corrosion observed on 23V26 gallery end shims
	Level 3 corrosion observed on 5 bearing plates; Level 4 observed on 1 bearing plate (1D21 South end)
5 Year Surveillance:	Level 3 corrosion observed on 12H33 Buttress 2 anchor head
	Small area of Level 3 corrosion observed on visible (through anchor head center hole) segment of wire at 31H19 Buttress 1 anchorage
	Level 3 corrosion observed on 1D23 north end button heads and anchor head
	Level 3 corrosion observed on 23V26 gallery end shims
	Level 3 corrosion observed on 4 bearing plates; Level 4 observed on 1 bearing plate (1D21 South end); Level 5 corrosion observed on 2 bearing plates (3D06 west end & 3D12 west end)
10 Year Surveillance:	Level 3 corrosion observed on 1D23 north end button heads
	Level 3 corrosion observed on 1 bearing plate; Level 5 corrosion observed on 2 bearing plates (23V26 gallery end & 3D12 west end)

[21] The uncoated inside surfaces of many end caps are severely corroded. As these items are not load bearing, the observed corrosion has no adverse significance. While through wall corrosion and subsequent CPM leakage are unlikely, any that did occur would be found (and rectified by appropriate corrective action) during the containment exterior surface examinations mandated by the ISI program.

15 Year Surveillance:	Level 3 corrosion observed on 6 (of 22 examined) anchor heads Small isolated areas of Level 3 corrosion observed on the test wire extracted from 12H01
20 Year Surveillance:	Level 3 corrosion observed on 8 (of 20 examined) anchor heads Small isolated areas of Level 3 corrosion observed on the test wire extracted from 12H01
25 Year Surveillance:	Level 3 corrosion observed on 5 (of 23 examined) anchor heads
30 Year Surveillance:	No Level 3 or higher corrosion observed
35 Year Surveillance:	No Level 3 or higher corrosion observed
40 Year Surveillance:	No Level 3 or higher corrosion observed

The above summary indicates that the incidence of inactive Level 3, 4 and 5 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.

- With the two exceptions previously discussed, no active corrosion has occurred since the post-tensioning system hardware was protected from the outside environment and other corrosive elements by completion of the enclosure building and by injection of CPM into the tendon end cap and ducting. Both exceptions were documented in early surveillance reports and are possibly the result of overly conservative reporting of observed conditions.
- While there is evidence that bearing plates, anchor heads and shims and, possibly, a few tendon wires / 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.
- As there is no evidence of significant active corrosion occurring since the completion of the enclosure building 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 observed and documented during the examination of surveillance sample tendons is summarized below. Free water found during the supplemental examinations of below grade hoop tendon or during CPM replacement activities is addressed in 4.3.6.

1 Year Surveillance:	Trace amount (estimated at <0.05 liter based on description in surveillance report) found in the gallery end cap of 23V26
3 Year Surveillance:	Trace amounts found in the end caps of 31H06 & 32H07
5 Year Surveillance:	Trace amount found in the end cap of 31H06
10 Year Surveillance:	No water found in surveillance sample tendons
15 Year Surveillance:	Trace amount in 12V31 gallery end cap Water in 12H08 end cap addressed in Table 8D Water in 12H01 end caps / ducting addressed in Table 8D
20 Year Surveillance:	Trace amount in 23V20 gallery end cap Water in 12H01 end caps / ducting addressed in Table 8D
25 Year Surveillance:	1 liter in 31V24 gallery end cap
30 Year Surveillance:	Trace amount in 12V12 gallery end cap
35 Year Surveillance:	No water found in surveillance sample tendons
40 Year Surveillance:	No water found in surveillance sample tendons

No water has been observed during examination of dome tendons. Also, no water has been observed during examination of hoop tendons, other than the designated below grade tendons, since the 5-year surveillance.

Top of the CPM fill in the vertical tendon ducts is at about El. 186' (assumed to be 1' above the ring girder top, which is computed to be at El. 185' using the dimensions shown on FSAR Fig. 5.2-1). The maximum water table elevation is ~20' (estimate based on the elevation of the highest hoop tendon refilled with CPM during the 1-year surveillance). If the top of the vertical tendon gallery trumpet (the lowest point at which infiltration can occur) is assumed to be 3'-6" ft above the gallery ceiling or at El. (-) 29', the head of CPM at this point is 186 + 29 = 215 ft.

Conservatively treating the specific gravity of the CPM as 0.8 (estimated from 2090P-4 specification sheet included in Reference 7.8), results in a calculated CPM pressure at the trumpet top of 215 * 0.8 * 62.4 / 144 = 74.5 psi. The maximum ground water pressure at this same point is (29 + 20) * 62.4 / 144 = 21.2 psi.

The above computation shows that CPM pressure in the vertical tendon ducting is at least 53 psi above the maximum ground water pressure. Therefore, ground water cannot infiltrate into the vertical tendons. Any water found in the gallery end caps had to have been there at the time of construction or to have entered after CPM was drained for end anchorage examination and before new material was injected following end cap replacement.

Based on the configuration of the containment, the presence of the enclosure building, the results of tendon examinations and the above computation, the following points can be made in regard to water intrusion into, and free water accumulation in, tendon end caps and ducting.

- Any water in dome tendon end caps (none has been found to date) was there at the time of end cap installation and / or prior to completion of the enclosure building. There is no current source of water to infiltrate the dome tendon ducting.
- Any water found in vertical tendon end caps was there at the time of end cap installation, prior to the time of upper end cap installation if that was done later, prior to the time of CPM filling (initial or following draining of ducting during a surveillance) and / or prior to completion of the enclosure building. Ground water cannot infiltrate into vertical tendon ducting that is filled with CPM.
- Any water found in the end caps or ducting of hoop tendons that are above El. 20' was there at the time of end cap installation.
- Any water found in the end caps or ducting of hoop tendons below El. 20 ft but not designated as below grade tendons is, based on past examination results, considered to have been present at the time of end cap installation (since the 5-year surveillance, no water has been found in any tendon in this category).

Considering the above points as well as the absence of active corrosion on tendon wires, button heads and anchorage hardware, it is concluded that there is no need to conduct end anchorage free water examinations at 5-year intervals. 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 and Discontinuous Wires

The following missing or discontinuous (broken / missing button heads) wires not documented at the time of time of initial tensioning or lift-off / re-tensioning during a surveillance were found during the 20-year and 35-year surveillances.

20 Year Surveillance:	1 wire in 2D03 was found to be broken when the tendon was de-tensioned; condition is addressed in NCR F570-005
35 Year Surveillance:	3 button heads were observed to be missing at the gallery (field) end of 23V23; condition is addressed in NCR 1064-001

No other missing or discontinuous (broken / missing button heads) wires not documented at the time of time of initial tensioning or as a consequence of surveillance operations have been reported.

Four wires, as noted below, were broken during surveillance lift-off and re-tensioning activities.

10 Year Surveillance:	1 wire in 1D23 was broken during re-tensioning
15 Year Surveillance:	3 wires in 12H08 broke when an anchor head rotated during lift-off; condition is addressed in NC / CA No. N398-005

As noted above, a total of 4 missing / discontinuous wires not previously documented or broken during surveillance operations has been reported over the course of the last 10 surveillances.

Sixty-one tendons were examined during the 10 Millstone Unit 2 post-tensioning system surveillances completed to date. Each of these tendons has a nominal 186 wires. The 4 missing / broken wires (not previously documented or broken during surveillance operations) constitute 100 * 4 / (67 * 186) = 0.03% of the wires in the 61 tendons examined. The 0.03% fraction is too small to be structurally significant.

4.3.4 Load Bearing Components Damage and Distortion

No damaged, cracked or distorted load bearing components (bearing plates, anchor heads, shims) have been found.

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.

Dome pocket areas contain numerous stress risers and thin sections of concrete where rapid drying induces shrinkage cracking. Several cracks exceeding 0.010 inched in width have been found during visual examinations of the pocket areas. These are generally either very short or do not originate at the edges of bearing plates. Most of the cracks observed are at the sides of the pockets where concrete stress due to tendon bearing load is small. Considering the nature of the pocket areas and the patterns of cracks, it is concluded that such cracks are the result of concrete shrinkage and not structurally relevant.

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

4.3.6 Below Grade Hoop Tendon End Anchorage Condition

As previously discussed, a number of below grade hoop tendons were examined and / or filled with new CPM following an air purge of CPM in the ducting or by pump through. As is the case for surveillance sample tendons (some of which are also designated as below grade hoop tendons), there are no reported instances of either end anchorage component cracking / distortion or structurally significant cracks in the concrete surrounding bearing plates.

Below grade hoop tendon end anchorage hardware corrosion and free water are addressed in detail in 4.3.6.1 and 4.3.6.2 below.

4.3.6.1 Corrosion

Table 8F summarizes the results of below grade tendon end anchorage and wire examinations. With the minor exception noted, no active corrosion was observed. Most observed corrosion was concluded to have occurred at the time of construction or earlier. None of the reported corrosion was deemed to have occurred after tendon end caps and duct were injected with CPM with the possible exception of one small area on a wire observed through an anchor head center hole during the 1-year surveillance. This small area of nascent corrosion, which was inadvertently removed during the course of the examination, was presumed to have started after CMP had been purged from the anchorage region. It left no permanent mark on the wire after removal.

Areas of Level 3, 4 and 5 corrosion are documented in the 10-year surveillance report. Areas of Level 3, but not Level 4 or 5, are documented in the 15, 20- and 25-year reports. Nothing greater than level 2 is documented in the 30, 35- and 40-year reports. This possibly results from the subjective nature of corrosion classification. As the evaluation of observed corroded areas is based on a visual examination, there is a reasonable probability that different examiners will come to different conclusions as to the corrosion level.

As the examinations conducted in years 30, 35 and 40 uncovered no post-tensioning system components with Level 3 or higher corrosion, it is concluded that corrosion-based degradation of below grade tendon hardware is not an area of concern. This conclusion is supported by the results of tests on sample wires extracted from the below grade tendons as discussed in Section 4.2.

4.3.6.2 Free Water

During examination of tendons in the below grade group, free water found in end caps removed for end anchorage visual examination / CPM sample collection and that expelled during CPM air purge / pump through was documented, collected where possible and quantified.

The designated below grade tendon group changed over time as accumulated examination results showed that certain tendons did not experience ground water infiltration. By the time of the 15-year surveillance, the below grade examination group had been reduced to 12H01 through 12H10, 31H01 through 31H04 and 32H01 through 32H03. At the time of the 40-year surveillance, the below grade examination group consisted of only a single tendon, 12H01. However, other below grade tendons were examined when identified as surveillance sample tendons through random selection as required by in Regulatory Guide 1.35 and Subsection IWL.

During the first 8 surveillances (i.e., through the 30-year surveillance) CPM was replaced in all tendons in the below grade examination group. This process of ongoing replacement continued to purge free water from the ductwork and fill the void spaces. As a result, the amount of free water found during group examinations generally decreased over time.

In addition, activation of the duct pressurization system following the 10-year surveillance (as discussed in Section 4.5) eliminated much of the infiltration that had occurred earlier.

The quantities of free water collected during examination of below grade hoop tendons or during CPM replacement activities are shown in Table 8D, which also notes whether or not CPM was replaced (either by pump through or air purge / refill). To improve clarity, tendons listed in the table are limited to those included in the 15-year examination group. A number of additional below grade hoop tendons were examined or designated for CPM replacement during the 1, 3, 5- and 10-year surveillances. No free water was found during the examinations or replacement activities associated with those tendons.

The table shows that documented water infiltration decreased by a significant amount, from 162 liters[22] at year 10 to 2.5 liters at year 15, following startup of the continuous pressurization system.

Also, as shown on the table, all tendons other than 12H01 were found to be effectively dry during the 20 year and subsequent surveillances (a trace amount noted of for 32H01 during the 30-year surveillance is the lone exception). This reinforces the conclusion that the continuing purge / pump through (through the 25-year surveillance and, for a reduced group of 8 tendons, through the 30 year surveillance) of CPM and the continuous pressurization system are effective in eliminating almost all ground water infiltration into below grade tendon ducting other than that enclosing tendon 12H01.

And, given the otherwise demonstrated effectiveness of the CPM pressurization system, is considered likely that the free water found during the recent 12H01 examinations / CPM purges is either entered the ductwork during a prior purge or is residual from infiltration that occurred before activation of the pressurization system.

4.3.7 End Anchorage Condition Summary and Conclusions

Tendon end anchorage hardware and adjacent concrete have performed well throughout the life of the plant (through the most recent surveillance in 2016) and show no trends of deteriorating condition.

There have been no findings of active corrosion on bearing plates anchor heads, shims or, with the minor exception previously discussed, wires.

Only 4 discontinuous wires (broken wires or wires with missing button heads) not previously reported have been found. These represent only a miniscule fraction (0.03%) of the ~11,300 wires comprising the 61 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

[22] Water quantities are expressed in the various reports using a variety of measurement units. For consistency and to improve clarity of presentation, reported quantities are converted to liters, rounded to the nearest whole number of liters or, for quantities of less than 1 liter, to the nearest 0.1 liter. Quantities less than 0.05 liters are identified as trace amounts (symbol T). The quantities shown in the table should be treated as approximate since many are based on estimates and, even when measurements were made, some free water was inevitably lost during the collection process.

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.

Considering the above, it can be concluded that the end anchorage conditions are stable and unlikely to change significantly before the 31 July 2035 expiration of the extended operating license. 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[23] of sample tendons during each of the 10 surveillances. Sample test results are listed in Tables 7 (surveillance tendons) and 8 (below grade tendons). 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.

The testing procedures for water content and neutralization number use bulk samples and appear to be straight forward as well as consistent over time.

Tests for corrosive ions do not determine the concentration in bulk samples but, rather, the concentration in a quantity of distilled water kept in contact with a prepared CPM surface area for a specified time and at a specified temperature. In addition, the tests for ion concentration in the water sample have changed over time to reflect advances in analytical chemistry techniques as well as other changes to the standardized ASTM and APHA procedures used in testing the water extractions. Also, the corrosive ion test procedures (as well as sample preparation techniques) may have varied among the different laboratories used for this work. This must be accounted for in the evaluation of test results.

Corrosion protection medium test results are summarized below and addressed in detail in subsections 4.4.1 through 4.4.3 for surveillance sample (i.e., not below grade) tendons and 4.4.4 through 4.4.6 for below grade tendons. Conclusions and recommendations for future testing are included in 4.4.7.

- All tested samples met the Table IWL-2525-1 10 ppm upper limit on chloride, nitrate and sulfide ion concentration.

[23] Samples were also collected from CPM purged from the ducting of below grade tendons.

- With a single exception (13.10% determined for a 5-year surveillance sample collected from below grade tendon 32H03), 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 (different criteria apply to different CPM formulations as discussed in 4.4.3 and 4.4.6 below).

4.4.1 Corrosive Ion Concentrations – Surveillance Sample Tendons

Table 7A lists the following summary data applicable to the ion concentrations documented for samples collected at the ends of surveillance sample (i.e., not below grade) tendons.

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

As previously noted, the same tendons were examined during the 1,3, 5- and 10-year surveillances. Each tendon was de-tensioned / re-tensioned during each surveillance and CPM was added as necessary to fill ducting / end caps following re-tensioning. Since the 3, 5- and 10-year samples could have consisted of any combination of original and added CPM, test results are not considered to be meaningful for trend evaluation and are not tabulated.

Of the 7 sets of samples (i.e., those collected during the 1 year and 15- through 40-year surveillances) most are shown on the table to have water extraction ion concentrations below the resolution threshold values. The maxima reported for samples with concentrations above the resolution threshold are as noted below.

- Chlorides – 3 ppm
- Nitrates – <4.4 ppm resolution threshold (1-year surveillance) / 2.4 ppm (later surveillances)
- Sulfides – none above the resolution threshold

None of the Table 7A columns indicate a trend over time.

Considering the above discussion of ion concentration patterns, the fact that the values reported for the 56 samples are all low relative to the 10 ppm limit 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.

4.4.2 Reserve Alkalinity / Neutralization Number – Surveillance Sample Tendons

Neutralization number test results are listed in Table 7B. As noted in the table, no results were reported for the samples collected during the 1, 3, 5- and 10- year surveillances. The remaining results meet the acceptance criterion (not less than zero; see 4.4.5 below) for the 2090 P-2 material injected into the tendon ducting following initial tensioning.

While there is no clearly evident trend, it could be argued that the number is increasing over time. In any case, there is no evidence that it is decreasing.

4.4.3 Water Content – Surveillance Sample Tendons

Results of tests to determine absorbed water content are listed in Table 7C. As noted in the table, no results are reported for the 3, 5- and 10-year surveillances. All reported water contents are below the 10% upper limit.

The maximum water content shown for hoop / dome tendon CPM samples is 1.08% and that for vertical tendon CPM samples is 4.30%. No trend with time is evident.

4.4.4 Corrosive Ion Concentrations – Below Grade Tendons

Table 8A lists the following summary data applicable to the corrosive ion concentrations documented for samples collected at the ends of below grade tendons or from CPM purged from below grade tendons.

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

Of the 9 sets of samples (i.e., those collected during the 3 year through 40-year surveillances) most are shown on the table to have water extraction ion concentrations below the threshold values. The maxima reported for samples with concentrations above the threshold are as noted below.

- Chlorides – 6.7 ppm (10-year surveillance) / 1 ppm (later surveillances)

- Nitrates – 1.32 ppm (20-year surveillance) / <0.50 ppm resolution threshold (later surveillances)
- Sulfides – 2.1 ppm (15-year surveillance) / <0.50 ppm resolution threshold (later surveillances)

None of the Table 8A columns indicate a trend over time.

Considering the above discussion of ion concentration patterns, the fact that the values reported for the 161 samples tested are all below the 10 ppm limit, the fact that concentrations in samples collected during the 25, 30, 35 and 40 year surveillances are (with the one exception noted in the table) below the 0.50 ppm threshold of resolution and, the lack of active corrosion on end anchorage hardware and extracted wires, it is concluded that the presence of corrosive ions in below grade tendon CPM is not a concern.

In addition, the low concentration of the three ions in the extractions from samples collected during more recent surveillances further attests to the effectiveness of the CPM pressurization system in excluding ground water (absorbed ground water is the most likely source of such ions) from the tendon end caps and ducting.

4.4.5 Reserve Alkalinity / Neutralization Number – Below Grade Tendons

CPM in the below grade tendons was partially purged and replaced at various intervals as discussed in 4.5 below. Therefore, the below grade tendon end caps and ductwork contain mixtures of the originally injected 2090 P-2 material and the 2090 P-4 replacement material. Samples collected from end caps and purged CPM can consist of any combination of these materials. New P-2 and P-4 materials have minimum specified neutralization number of 5 and 35, respectively. Corresponding acceptance criteria for samples collected during surveillances are, per Subsection IWL (Reference 7.2) Table IWL-2525-1, 0 and 17.5, respectively. As a result, numbers reported for the below grade tendon CPM samples are provided for information only. Interpretations of reported values, range of values and apparent trends are, for the reasons noted, always open to discussion.

Neutralization number test results are listed in Table 8B. As noted in the table, no results were reported for the samples collected during the 3- and 10-year surveillances. All values shown meet the acceptance criterion (not less than 0) for mixture of 2090 P-2 and 2090 P-4 materials (in the case of a mixture, the lower of the two acceptance limits governs) injected into the tendon ducting.

4.4.6 Water Content – Below Grade Tendons

Results of tests to determine absorbed water content are listed in Table 8C. As noted in the table, no results are reported for the 1- and 3-year surveillances.

All reported water contents, with the exception of the 13.1% reported for the 32H03 sample collected during the 5-year surveillance, are below the 10% upper limit. Water content generally trends down which again demonstrates the effectiveness of the CPM pressurization system in excluding ground water from the tendon end caps and ducting. And, it is easily possible that one, or a few, samples may have absorbed water that seeped into the ducting after CPM purge and prior to refill and reactivation of the pressurization system.

Examination of end anchorage hardware and wires extracted for strength / elongation testing has uncovered no evidence of active corrosion resulting from ground water absorbed into the CPM (or due to any other cause).

4.4.7 CPM Test Summary and Conclusion

Post-tensioning system end anchorage hardware and extracted wires have been examined for damage and corrosion during 10 surveillances spanning a period of 40 years from 1976 to 2016. Corrosion protection medium samples collected during these surveillances have been tested for the presence of corrosive ions, reserve alkalinity and absorbed water. Also, free water found during the examinations was documented and quantified whenever the quantity of water was sufficient to allow measurement. The results of these examinations and tests are summarized below.

- With the minor exception noted (see 4.2.4) and treated as inconsequential, 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.
- Corrosive ion (chlorides, nitrates, sulfides) concentration in sample extractions is below the 10 ppm limit and shows no trend of increasing over time.
- Absorbed water content (with a single exception, 13.1% documented for a 5-year surveillance sample from below grade tendon 32H03) is below the 10% (of dry weight) limit and shows no trend of increasing over time.
- Neutralization numbers (base numbers) vary over a wide range depending on the product formulation and the degree of mixing of different formulations. All samples tested met the acceptance criteria. Test data show no trend indicating that the corrosion protection characteristics of the CPM are degrading 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 or there is evidence that the quantity of absorbed water has 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. However, free water, if found, will be collected and analyzed to determine pH as required by Subsection IWL.

4.5 Below Grade Tendon CPM Replacement and Pressurization

Free water found in the end caps and ducting of several below grade tendons raised concerns about corrosion although, as discussed in Section 4.4 above, no active corrosion (with a unique minor exception[24]) has been found. To minimize the potential for corrosion that could result from ground water infiltration, the following remedial actions were implemented.

- Forced pump through of new CPM (or compressed air blow out of CPM followed by injection of new material) during each surveillance.
- Installation of system to maintain a continuous supply of CPM under pressure at one end of designated tendons.

These topics are covered in 4.5.1 and 4.5.2 below.

4.5.1 Corrosion Protection Medium Replacement

During the 1-year surveillance it was observed that not all tendon ductwork was completely filled with CPM. This observation was based on the noted difference between the amount of CPM removed during surveillance activities and the amount replaced after reinstallation of the end caps.

As part of the evaluation of this condition it was decided to pump new CPM under pressure through the duct of 31H01 at Buttress 3 and observe the discharge at Buttress 1. The light color of the discharged CPM indicated that it contained emulsified water.

This led to purging CPM from all the below grade tendons identified on the 1-year surveillance row of Table 8E. Emulsified water was found in more of the below grade

[24] The single possible exception is inconsequential as previously noted.

tendons which resulted in implementation of a program requiring replacement of CPM in the end caps / ducting of designated tendons (by either pump through of new material or a pressurized air purge of old material followed by refilling with new material) during subsequent surveillances.

The program evolved over time, first expanding and then reducing the number of affected tendons as shown in Table 8E. Reduction of the program scope starting with the 10-year surveillance was based on evaluation of findings during prior surveillances. The program effectively ended after the 35-year surveillance with no replacement activity performed at year 40.

The CPM replacement program accomplished the following 4 objectives.

- Purging of CPM with emulsified water.
- Purging of free water in the end caps and ducting.
- Filling of air voids to limit water infiltration.
- Replacing the original 2090-P2 CPM with 2090-P4, which is formulated to provide better protection for tendons subject to ground water infiltration.

The CPM replacement program, in combination with the continuous pressurization system described below, has almost completely eliminated the accumulation of free and emulsified water in below grade tendon end caps and ducting (the more recent accumulations collected from the 12H01 end caps and ducting constitute an exception as discussed in 4.3.6.2 above).

4.5.2 Continuous Pressurization System

Following the 10-year surveillance, a system to provide continuous pressurization of below grade tendon ducts was placed in service. The system, described in Specification SP-CE-187 (Reference 7.20) consists of a tank, partially filled with CPM under a 10 psig nitrogen blanket, connected through an assemblage of piping and hose to the end caps of 16 below grade tendons (12H01 through 12H06, 12H08 through 12H10, 31H01 through 31H04 and 32H01 through 32H03). The 10 psig nitrogen pressure ensures that the effective head of CPM at the end cap inlet is always well above that of the ground water. If pressure along the length of the of the duct is essentially the same as that at the cap inlet, ground water cannot infiltrate through the duct seams.

The significant reduction of free water following the 10-year surveillance, as documented on Table 8D, provides positive assurance that the pressurization system is effective in greatly reducing, or even eliminating, ground water infiltration.

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 Millstone Unit 2 between 1976 and 2016 show that the system is continuing to perform its intended function and that it can be expected to do so until well past the 31 July 2035 expiration of the extended operating license. 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 after the 31 July 2035 license expiration.

b) Condition of End Anchorage Hardware and Extracted Wires

End anchorage hardware and tendon wires extracted for tensile testing show no signs of damage or active corrosion (the nascent wire corrosion described in the 1-year surveillance report is inconsequential as previously noted). Corrosion that has been observed is concluded to have occurred prior to filling of the tensioned tendon duct with corrosion protection medium[25].

Wires broken during surveillance operations were determined 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[26] 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.

Free water has been found at the anchorages and in the ductwork of various vertical and hoop tendons.

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[25] A single exception, new corrosion reported on two dome tendon bearing plates during the 3-year surveillance, is considered to have been present at the time of the 1 year surveillance but possibly overlooked during the examination performed at that time.

[26] The BBRV system, which uses cold formed button heads to anchor individual wires, was introduced by the Swiss engineering firm BBR in 1944.

The water in vertical tendon end caps / ductwork was limited to small quantities in the lower caps. As the containment is shielded (by the enclosure building) from rain and other atmospheric sources of water and as the head of CPM in vertical tendons precludes entry of ground water, it was concluded that the free water found was present at the time of initial CPM fill.

Water found in the end caps / ductwork of lower hoop tendons was concluded to be from ground water intrusion. This was essentially stopped by a system, installed and activated following the 10-year surveillance, that maintains a pressurized source of CPM to all tendons potentially impacted by seepage of ground water.

There is no evidence that the presence of free water has resulted in corrosion of end anchorage hardware or wires.

c) Tendon Wire Strength and Ductility

Tensile tests on samples cut from extracted wires show that ultimate tensile strength and elongation at failure meet the ASTM A421 (Reference 7.4) acceptance criteria and are essentially unchanged over time. 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 acceptance criteria (with one exception) have been met and that there are no discernible trends over time. In Particular:

- All reported absorbed water content values are, with a single exception, below the 10% (of dry weight) upper limit.
- All corrosive ion concentrations are below the 10 ppm upper limit and most 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 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 Millstone Unit 2 post-tensioning system will continue to perform its design function until well after the 31 July 2035 expiration of the extended operating license 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.
- Corrosion protection medium will retain its protective properties with no degradation over time.
- Free water, which has not resulted in corrosion in the past, will not be a concern.

5.3 Recommendations

On the basis of the above conclusions it is recommended that the post-tensioning system examination and testing interval be extended to 10 years and that the requirement for wire extraction / testing be eliminated. This 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 around 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.

In addition, it is recommended that routine CPM testing be limited to determination of absorbed water content and that additional tests for corrosive ion concentration and neutralization number be performed only if:

- Active corrosion is found on anchorage components and / or tendon wires;
- Free water is found at anchorages;
- CPM absorbed water content exceeds the Table IWL-2525-1 acceptance limit.

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 will continue at 5-year intervals 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 and drone mounted cameras) will be used.

Detailed visual examination, as defined in IWL-2310(b), will be conducted 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 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 deemed 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. 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.

The below grade tendon CPM pressurization system will be monitored in accordance with a surveillance program and maintained as necessary to ensure continuing operation. If it is necessary to disconnect any tendon from the system to correct CPM leaks (generally due to end cap gasket failure), leakage will be corrected, and the pressurization system connection restored to full service without delay in order to minimize the possibility of ground water intrusion.

7. REFERENCES

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

7.2 ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWL, 2013 Edition w / No Addenda.

7.3 Millstone Power Station Unit 2 Final Safety Analysis Report, Revision 37, 27 June 2019.

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

7.5 Millstone Power Station Drawing 25203-11170:

Sheet 16, *ASME Section XI IWL Inspection / Hoop Tendon End Caps Drawing from El. (-) 24'-0" to El. (+) 116'-2"*, Revision 1;

Sheet 17, *ASME Section XI IWL Inspection / Containment Dome and Vertical Tendon End* Caps, Revision 1;

Sheet 18, *ASME Section XI IWL Inspection / Tendon Access Gallery / Vertical Tendon End Caps*, Revision 1;

Sheet 19, *ASME Section XI IWL Inspection / Dome Tendon End Caps*, Revision 1.

7.6 *Millstone Point Company / Millstone Nuclear Power Station / Prestressing Report / Unit 2 Containment Structure*, Prepared by Bechtel Power Corporation, April 1974.

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

7.8 *Report of the In-Service Tendon Surveillance Program Performed on the Tendon System of Millstone Unit No. 2 Containment Structure for Northeast Nuclear Energy Company / WJE No. 74399*, Prepared by Wiss Janney, Elstner & Associates, Inc., February 1977. (1 Year Surveillance Report with supplement dated April 1977.)

7.9 *Report of the In-Service Tendon Surveillance Program Performed on the Tendon System of Millstone Unit No. 2 Containment Structure for Northeast Nuclear Energy Company / WJE No. 77726*, Prepared by Wiss Janney, Elstner & Associates, Inc., August 1978. (3 Year Surveillance Report)

7.10 *Report of the In-Service Tendon Surveillance Program Performed on the Tendon System of Millstone Unit No. 2 Containment Structure for Northeast Nuclear Energy Company / WJE No. 77726Q*, Prepared by Wiss Janney, Elstner & Associates, Inc., July 23, 1981. (5 Year Surveillance Report with supplement dated July 23, 1981.)

7.11 *Report of the Fourth In-Service Tendon Surveillance Program Performed on the Tendon System of Millstone Unit No. 2 Containment Structure for Northeast Nuclear Energy Company / WJE No. 840949Q*, Prepared by Wiss Janney, Elstner & Associates, Inc., September 2, 1986. (10 Year Surveillance Report with supplement dated September 2, 1986)

7.12 *Fifteenth Year Physical Surveillance of the Millstone Nuclear Generating Station / Unit 2 Surveillance Report*, Prepared by Precision Surveillance Corporation, June 26, 1992. (15-year surveillance report with June 26, 1992 supplement titled *Water Tendon Inspection for the Millstone Nuclear Generating Station*.)

7.13 *Twentieth Year Physical Surveillance of the Millstone Nuclear Generating Station / Unit 2 Surveillance Report*, Prepared by Precision Surveillance Corporation, July 23, 1996. (20-year surveillance report with July 23, 1986 supplement titled *Water Tendon Inspection of the Millstone Nuclear Generating Station Unit 2*.)

7.14 *Twenty-Fifth Year Physical Surveillance of the Millstone Unit 2 Power Station Containment Building / Unit 2 Surveillance Report*, Prepared by Precision Surveillance Corporation, January 30, 2002 with addition dated August 15, 2003.

7.15 *30th Year Physical Surveillance of the Unit 2 Containment Building at the Millstone Nuclear Plant / Post Tensioning Surveillance Report*, Prepared by Precision Surveillance Corporation, 2006.

7.16 *Final Report for the Millstone Unit 2 – 9th Period (35th Year) Tendon Surveillance*, Prepared by Precision Surveillance Corporation, February 24, 2011.

7.17 *Final Report for the 40th Year Tendon Surveillance at Millstone Nuclear Station Unit 2*, Prepared by Precision Surveillance Corporation, May 12, 2016.

7.18 Millstone Power Station Engineering Procedure SP21140, *Containment Post-Tensioning System Surveillance*, Revision 007-00.

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

7.20 Specification No. SP-CE-187, Project Assignment No. 81-023, *Technical Specifications for Tendon Greasing System at Millstone Unit No. 2*, Issued by Northeast Utilities Service Company for Northeast Nuclear Energy Company, Revision 2, 10 September 1985.

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
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
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 - Summary of Hoop Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
1	1.3	12H07	1,570
		12H19	1,530
		12H33	1,550
		31H06	1,595
		31H19	1,590
		31H32	1,590
		31H33	1,585
		32H07	1,580
		32H19	1,565
		32H33	1,630
3	3.0	N/A[1]	N/A[1]
5	5.2	N/A[1]	N/A[1]
10	10.9	N/A[1]	N/A[1]
15	16.9	12H01	1,467
		12H08	1,495
		31H21	1,421
		32H37	1,559
20[2]	20.9	12H05	1,520
		31H25	1,506
		32H32	1,498
25	26.4	12H13	1,469
		31H36	1,473
		32H32	1,502
30	31.4	31H01	1,513
		32H13	1,515
		32H32	1,485
35	35.7	12H06	1,541
		12H32	1,473
		32H32	1,432
40[3,4]	40.9	32H32	1,420

Note 1: Tendons in the 3, 5- and 10-year surveillance examination samples are the same as those selected for the 1-year surveillance examination sample. These were de-tensioned and re-tensioned during the 1-year surveillance. As a result, lift-off forces measured during the 3, 5- and 10-year surveillances cannot be used in constructing and evaluating pre-stressing force trends, which are based undisturbed tendon force loss.

Note 2: 12H01 lift-off force was measured prior to de-tensioning for wire removal and testing. As 12H01 was previously de-tensioned for wire removal and re-tensioned during the 15-year surveillance, the 20-year surveillance lift-off values are not valid for trend analysis and are not included in the table.

Note 3: Force (1,505 kip) measured at the accessible Buttress 1 end of 12H03 not included in the table since the meaningful tendon force is the average of the measured lift-off forces at both ends. The Buttress 2 end of this tendon was not accessible for stressing ram installation.

Note 4: Tendon 31H32 and 32H33 are included in the 40-year random sample but not listed in the table above as these were de-tensioned and re-tensioned during the 1, 3- and 5-year surveillances.

Table 3 - Summary of Vertical Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
1	1.3	12V27	1,610
		23V26	1,700
		23V31	1,570
		31V15	1,540
		31V34	1,560
3	3.0	N/A[1]	N/A[1]
5	5.2	N/A[1]	N/A[1]
10	10.9	N/A[1]	N/A[1]
15	16.9	12V31	1,590
		23V29	1,514
		31V22	1,582
		31V23	1,666
		31V24	1,467
20	20.9	12V39	1,569
		23V20	1,540
		31V24	1,486
25	26.4	12V07	1,552
		23V07	1,491
		31V24	1,489
30	31.4	12V16	1,532
		23V11	1,516
		31V24	1,506
35	35.7	12V23	1,428
		23V23	1,462
		31V24	1,432
40	40.9	12V21	1,541
		12V37	1,581
		31V24	1,425

Note 1: Tendons in the 3, 5- and 10-year surveillance examination samples are the same as those selected for the 1-year surveillance examination sample. These were de-tensioned and re-tensioned during the 1-year surveillance. As a result, lift-off forces measured during the 3, 5- and 10-year surveillances cannot be used in constructing and evaluating pre-stressing force trends, which are based undisturbed tendon force loss.

Table 4 - Summary of Dome Tendon Forces			
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**
1	1.3	1D21	1,548
		1D23	1,585
		2D04	1,564
		2D07	1,535
		3D06	1,550
		3D12	1,600
3	3.0	N/A[1]	N/A[1]
5	5.2	N/A[1]	N/A[1]
10	10.9	N/A[1]	N/A[1]
15	16.9	1D24	1,512
		2D05	1,487
		3D05	1,464
20	20.9	1D24	1,437
		2D03	1,474
		3D10	1,495
25	26.4	1D24	1,447
		2D10	1,514
		3D04	1,464
30	31.4	1D24	1,446
		3D03	1,501
		3D13	1,469
35	35.7	1D16	1,422
		1D24	1,428
		1D26	1,471
40[2]	40.9	1D02	1,477
		1D24	1,404

Note 1: Tendons in the 3, 5 and 10-year surveillance examination samples are the same as those selected for the 1-year surveillance examination sample. These were de-tensioned and re-tensioned during the 1-year surveillance. As a result, lift-off forces measured during the 3, 5 and 10-year surveillances cannot be used in constructing and evaluating pre-stressing force trends, which are based undisturbed tendon force loss.

Note 2: Tendon 1D23 is included in the 40-year random sample but not listed in the table above as it was de-tensioned and re-tensioned during the 1, 3, 5- and 10-year surveillances.

Table 5A - Wire Test Results / Ultimate Tensile Strength						
Exam Year	Tendon	Ultimate Tensile Strength, ksi			Wire Mean, ksi	Exam Year Mean, ksi
		Specimen 1	Specimen 2	Specimen 3		
1	32H33	263	266	264	264	265
	31V15	266	266	264	265	
	3D12	265	267	267	266	
3	12H07	270	271	255	265	261
	23V26	259	255	255	256	
	1D23	262	263	263	263	
5	12H07	271	270	270	270	271
	23V26	269	270	270	270	
	3D12	271	271	274	272	
10	31H33	256	253	256	255	258
	12V27	262	267	262	264	
	3D12	256	252	255	254	
15	12H01[1]	266	266	267	266	263
	31H21	259	259	261	260	
	12V31	266	264	264	265	
	2D05	261	261	260	261	
20	12H01[1]	267	265	267	266	259
	12H05	265	266	264	265	
	23V20	253	250	252	252	
	2D03	254	251	252	252	
25	31H36	278	280	280	279	274
	12V07	268	268	267	268	
	3D04	277	274	274	275	
30	31H01	270	278	274	274	269
	12V16	272	270	269	270	
	3D03	259	265	266	263	
35	12H32	268	269	270	269	262
	12V23	265	263	265	264	
	1D26	252	253	252	252	
40	31H32	260	265	262	262	265
	12V37	271	270	270	270	
	1D23	264	262	263	263	

Note 1: 12H01 de-tensioned for wire removal and testing when water was found in end cap.

Table 5B - Wire Test Results / Elongation at Failure						
Exam Year	Tendon	Elongation at Failue, %			Wire Mean, %	Exam Year Mean, %
		Specimen 1	Specimen 2	Specimen 3		
1	32H33	5.7	5.6	5.8	5.7	5.7
	31V15	6.0	6.1	5.8	6.0	
	3D12	5.3	5.8	5.4	5.5	
3	12H07	5.5	5.6	4.4	5.2	5.5
	23V26	5.3	5.5	6.0	5.6	
	1D23	6.1	6.1	5.4	5.9	
5	12H07	4.4	4.8	4.4	4.5	4.3
	23V26[1]	4.4	4.5	4.0	4.3	
	3D12[1]	4.4	4.0	4.0	4.1	
10	31H33	>4	>4	>4	>4	>4
	12V27	>4	>4	>4	>4	
	3D12	>4	>4	>4	>4	
15	12H01[2]	4.7	4.6	4.6	4.6	4.8
	31H21	4.2	4.9	4.6	4.6	
	12V31	4.8	4.7	5.2	4.9	
	2D05	5.2	5.0	5.1	5.1	
20	12H01[2]	4.6	4.9	5.4	5.0	4.9
	12H05	4.9	4.8	4.5	4.7	
	23V20	5.4	4.8	5.2	5.1	
	2D03	4.7	5.0	4.9	4.9	
25	31H36	5.5	5.8	4.7	5.3	5.2
	12V07	5.3	5.1	5.0	5.1	
	3D04	5.0	5.4	5.4	5.3	
30	31H01	4.0	5.1	4.1	4.4	4.3
	12V16	4.6	4.7	4.1	4.5	
	3D03	4.1	4.0	4.3	4.1	
35	12H32	4.6	5.2	5.0	4.4	4.9
	12V23	5.2	5.0	5.4	5.2	
	1D26	5.0	5.0	4.9	5.0	
40	31H32	5.7	5.2	7.1	6.0	5.8
	12V37	5.6	5.1	5.7	5.5	
	1D23	5.8	6.5	5.7	6.0	

Note 1: 4.0% values in shaded cells are minimum elongations recorded prior to specimen failure outside the gage length.

Note 2: 12H01 de-tensioned for wire removal and testing when water was found in end cap.

Table 6A - Broken Wire Test Results / Ultimate Tensile Strength

Exam Year	Tendon	Ultimate Tensile Strength, ksi						Wire Mean
		Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	
1	31V34	260	274	271	258	N/A	N/A	266
3	1D21	263	255	254	255	252	253	255
10	1D23	285	261	268	N/A	N/A	N/A	271
15	12H08	266	263	264	N/A	N/A	N/A	264
	12H08	259	261	260	N/A	N/A	N/A	260
	12H08	262	263	261	N/A	N/A	N/A	262
20	2D03	247	250	245	N/A	N/A	N/A	247

Table 6B - Broken Wire Test Results / Elongation at Failure

Exam Year	Tendon	Elongation at Failure, %						Wire Mean
		Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	
1	31V34	5.8	6.3	5.9	4.8	N/A	N/A	5.7
3	1D21	6.2	6.2	5.0	N/A	5.1	5.2	5.5
10	1D23	>4	>4	>4	N/A	N/A	N/A	>4
15	12H08	5.4	5.2	4.8	N/A	N/A	N/A	5.1
	12H08	5.2	5.0	5.1	N/A	N/A	N/A	5.1
	12H08	4.8	4.9	5.2	N/A	N/A	N/A	5.0
20	2D03	4.3	4.3	4.3	N/A	N/A	N/A	4.3

Table 7A – Surveillance Tendon CPM Sample Corrosive Ion Concentrations

Surveillance Year / No. of Samples	Ion Concentration, ppm								
	Chloride			Nitrate			Sulfide		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
1 / 3	3	1.7	<1	<4.4	4.4	<4.4	<1	1	<1
3	The same tendons were examined during the 1, 3, 5- and 10-year surveillances. As P-4 CPM was added during the 1-year surveillance, the 3, 5- and 10-year analysis results are not addressed in this table.								
5									
10									
15 / 17	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.2	0.2	<0.2
20 / 11	<0.50	0.50	<0.50	1.37	0.58	<0.50	<0.50	0.50	<0.50
25[1] / 8	<0.5	0.5	<0.5	2.4	1.09	<0.5	<0.5	0.5	<0.5
30 / 5	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.5	0.5	<0.5
35 / 8	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.5	0.5	<0.5
40[2] / 4	1.00	0.75	0.50	<0.5	0.5	<0.5	<0.5	0.5	<0.5

General Note: This table is intended to show the ongoing characteristic of the P-2 CPM originally injected into the tendon ducting. Therefore, it excludes results of tests on material that is likely to have been affected by subsequent bulk replacement of CPM with P-4 material or by subsequent addition of P-4 material. Results excluded from the table include those of samples taken from the following.

Hoop tendons 12H01 – 12H15, 12H19, 12H33, 31H01 – 31H17, 31H19, 31H32, 31H33, 32H01 – 32H13, 32H19 & 32H33.

Bottom (field) ends of all vertical tendons except 12V04, 12V08, 12V25, 12V28, 12V37, 31V05, 31V25 & 31V31.

Top ends of vertical tendons 12V04, 12V08, 12V25, 12V28, 12V37, 31V05, 31V25 & 31V31.

Common tendons 31V24 & 1D24 after the 15-year surveillance and 32H32 after the 20-year surveillance.

Otherwise as noted.

General Note: For conservatism, means are computed using actual resolution threshold values (0.50, 0.2 or other as applicable) for all numbers shown with a < symbol.

Note 1: Due to question as to the validity of the sample ID, results reported for the field end of 31V25 are excluded. See Table 7B Note 1.

Note 2: Excludes results for 1D23, 31H32 & 32H33 samples; these tendons were examined during the 1, 3, 5- and 10-year surveillances. The end caps were probably packed or filled with new P-4 material following end anchorage examination and the result of tests on subsequently acquired samples would not necessarily represent the condition of the original P-2 material.

Table 7B – Surveillance Tendon CPM Sample Neutralization Number

Surveillance Year / Number of Samples	Max	Mean	Min
1	Surveillance sample tendon neutralization number not documented in the reports covering the 1, 3, 5- and 10-year surveillances.		
3			
5			
10			
15 / 14	2.22	1.05	0.00
20 / 11	1.77	0.67	<0.50
25[1] / 8	5.55	2.58	<0.50
30 / 5	6.72	3.71	1.15
35 / 8	6.38	3.83	1.85
40[2] / 4	3.48	3.16	2.91

General Note: This table is intended to show the ongoing characteristic of the P-2 CPM originally injected into the tendon ducting. Therefore, it excludes results of tests on material that is likely to have been affected by subsequent bulk replacement of CPM with P-4 material or by subsequent addition of P-4 material. Results excluded from the table include those of samples taken from the following.

Hoop tendons 12H01 – 12H15, 12H19, 12H33, 31H01 – 31H17, 31H19, 31H32, 31H33, 32H01 – 32H13, 32H19 & 32H33.

Bottom (field) ends of all vertical tendons except 12V04, 12V08, 12V25, 12V28, 12V37, 31V05, 31V25 & 31V31.

Top ends of vertical tendons 12V04, 12V08, 12V25, 12V28, 12V37, 31V05, 31V25 & 31V31.

Common tendons 31V24 & 1D24 after the 15-year surveillance and 32H32 after the 20-year surveillance.

Otherwise as noted.

General Note: Means are computed using actual resolution threshold values (0.50, 0.2 or other as applicable) for all numbers shown with a < symbol.

Note 1: The 25-year surveillance report, Table I, shows a 44.7 neutralization number for the 31V25 field (bottom) end sample. This tendon was topped off with 5 gallons of P-4 at the shop end during the 1-year surveillance. The 44.7 value reported for the field end appears anomalous and is not used in populating the table.

Note 2: Excludes results for 1D23, 31H32 & 32H33 samples; these tendons were examined during the 1, 3, 5- and 10-year surveillances. The end caps were probably packed or filled with new P-4 material following end anchorage examination and the result of tests on subsequently acquired samples would not necessarily represent the condition of the original P-2 material.

Table 7C – Surveillance Tendon CPM Sample Water Content						
Surveillance Year / No. of Samples	**Water Content, %**					
	Hoop / Dome Tendons			**Vertical Tendons**		
	Max	**Mean**	**Min**	**Max**	**Mean**	**Min**
1 / 2HD & 3V	0.0	0.0	0.0	0.09	0.06	0
3	Sample water content not documented in the 3, 5- and 10-year surveillance reports.					
5						
10						
15 / 10HD & 8V	1.08	0.21	<0.1	0.3	0.15	<0.1
20 / 10HD & 7V	0.88	0.18	<0.1	0.42	0.16	<0.1
25 / 12HD & 9V	0.16	0.10	<0.10	2.90	0.58	<0.10
30 / 9HD & 6V	0.78	0.35	0.16	2.90	0.63	<0.10
35 / 10HD & 6V	0.59	0.17	<0.10	4.30	1.33	<0.10
40 / 12HD & 6V	0.1	0.1	<0.1	2.90	0.62	<0.10

General Note: For conservatism, mean is computed using 0.10% ppm for sample water contents shown as <0.10%.

General Note: Table excludes results for CPM samples from below grade hoop tendons 12H01–12H10, 31H01-31H04 & 32H01-32H03; these are covered in Table 8.

Table 8A – Below Grade Tendon CPM Sample Corrosive Ion Concentrations

Surveillance Year / No. of Samples	Ion Concentration, ppm								
	Chloride			Nitrate			Sulfide		
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min
1[1]									
3 / 2	<1	1	1	<1	1	<1	<2	1.5	1
5 / 26	3.44	1.94	1.18	<1	1	<1	<1	1	<1
10 / 37	6.7	0.4	<0.1	<1	1	<1	2.1	0.4	<1
15 / 34	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.2	0.2	<0.2
20 / 22	<0.50	0.50	<0.50	1.32	0.76	<0.50	<0.50	0.50	<0.50
25 / 20	<0.50	0.50	<0.50	<0.50	0.50	<0.50	<0.50	0.50	<0.50
30 / 10	<0.50	0.50	<0.50	<0.50	0.50	<0.50	<0.50	0.50	<0.50
35 / 8	<0.50	0.50	<0.50	<0.50	0.50	<0.50	<0.50	0.50	<0.50
40 / 2	1.00	0.75	0.50	<0.50	0.50	<0.50	<0.50	0.50	<0.50

General Note: For conservatism, means are computed using actual resolution threshold values (0.50, 0.2 or other as applicable) for all numbers shown with a < symbol.

Note 1: No below grade tendon sample results documented in the 1-year surveillance report.

Table 8B – Below Grade Tendon CPM Sample Neutralization Number			
Surveillance Year / Number of Samples	**Max**	**Mean**	**Min**
1[1] / 10	42.5	40.0	36.4
3[2]			
5 / 24	35.6	22.9	1.4
10[2]			
15 / 34	63.3	36.2	17.9
20 / 22	76.3	41.3	11.4
25 / 20	54.5	42.7	31.6
30 / 9	57.8	52.8	45.8
35 / 8	56.4	50.7	44.5
40 / 2	42.7	28.8	15.0

General Note: Means are computed using actual resolution threshold values (0.50, 0.2 or other as applicable) for all numbers shown with a < symbol.

Note 1: Samples collected from overflow of new P-4 CPM at the end of pump through; neutralization number values presented for information only.

Note 2: No neutralization number results documented in the 3 year and 10-year surveillance reports.

Table 8C – Below Grade Tendon CPM Sample Water Content, %										
Tendon	**Surveillance Year**									
	1	**3**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
12H01			0.30	5.7	0.3	4.92	8.70	5.40	0.39	4.3
12H02			4.51	4.3	0.2	1.80	1.0	1.40	0.59	
12H03			2.09	3.5	0.2	1.50	2.00	N/A[1]	0.10	0.10
12H04			4.84	3.2	1.4	0.90	0.84	1.20		
12H05			1.98	1.2	0.1	0.72	0.41			
12H06			N/A	2.3	0.1	0.77	0.53		0.50	
12H07			0.20	0.1	0.1	0.20	0.19			
12H08			3.85	2.9	0.1	1.00	0.63			
12H09			1.66	2.7	0.1	1.30	0.92			
12H10			4.30	2.9	0.1	0.80	0.58			
31H01			3.59	4.3	1.4	0.32	1.20	1.60	0.10	
31H02			3.56	2.9	0.1	1.00	0.63	0.96	0.15	
31H03			3.22	1.0	1.5	0.70	0.34			
31H04			2.58	2.0	2.0	0.20	0.41			
32H01			6.10	5.5	1.5	2.00	2.50	2.20	3.00	
32H02			2.95	0.7	0.9	0.21	0.30	1.10		
32H03			13.10	2.5	0.7	0.70	0.69			
Mean			**3.68**	**2.98**	**0.64**	**1.12**	**1.29**	**1.98**	**0.69**	**2.65**
Mean ex 12H01			**3.90**	**2.63**	**0.66**	**0.88**	**0.82**	**1.41**	**0.74**	**0.10**

General Note: Water content shown for a given tendon is the largest of the values determined for 1 or more samples; values reported as <0.1 (<0.10) are, for conservatism, shown above as 0.1 (0.10).

General Note: The number of decimal places shown above are as listed in the applicable surveillance report.

General Note: If cell is shaded, no sample was required.

Note 1: Sample radioactively contaminated; could not be released for offsite testing.

Note 2: Sample reported as missing.

Table 8D – Below Grade Tendon Free Water Quantity / CPM Replacement										
Tendon	Surveillance Year									
	1[1]	3[1]	5	10	15	20	25	30	35	40
12H01	/Y		4/Y	19/Y	2/Y	2/Y	0.6/Y	11/Y	D/Y	0.2/N
12H02	/Y		4/Y	11/Y	D/Y	D/Y	D/Y	D/Y	D/N	D/N
12H03	/Y		4/Y	4/Y	T/Y	D/Y	D/Y	D/Y	D/N	D[2]/N
12H04	/Y		0.2/Y	45/Y	D/Y	D/Y	D/Y	D/Y		
12H05	/Y		38/Y	D/Y	D/Y	D/Y	D/Y			
12H06	/Y		4/Y	D/Y	D/Y	D/Y	D/Y		D/N	D/N[3]
12H07	/Y		D/Y	D/Y	D/Y	D/Y	D/Y			
12H08	/Y		19/Y	11/Y	0.2/Y	D/Y	D/Y			
12H09	/Y		D/Y	3/Y	T/Y	D/Y	D/Y			
12H10	/Y		9/Y	2/Y	D/Y	D/Y	D/Y			
31H01	/Y		T/Y	3/Y	D/Y	D/Y	D/Y	D/Y	D/N	
31H02	/Y		D/Y	D/Y	D/Y	D/Y	D/Y	D/Y	D/N	
31H03	/Y		D/Y	D/Y	D/Y	D/Y	D/Y			
31H04	/Y		D/Y	D/Y	D/Y	D/Y	D/Y			
32H01	/Y		8/Y	26/Y	0.3/Y	D/Y	D/Y	T/Y		
32H02	/Y		D/Y	D/Y	D/Y	D/Y	D/Y	D/Y		
32H03	/Y		0.5/Y	38/Y	D/Y	D/Y	D/Y			

General Note: Table entry format is *Quantity/Replacement*.

As discussed in the above text, reported free water quantities are converted to liters and rounded. D (dry) indicates no free water observed. T (trace) indicates that free water was observed but amount was too small to quantify.

Y signifies that CPM was replaced either by pump through or by air blow out followed by refill. N signifies no replacement. Table 8E summarizes hoop tendon CPM replacement activity.

General Note: Shaded cell indicates that the applicable tendon was not examined for free water and that CPM was not replaced.

Note 1: Water quantities not documented in the 1-year surveillance report; supplemental report covering 3 year below grade tendon surveillance not found.

Note 2: Buttress 2 anchorage of 12H03 inaccessible for examination; dry condition reported applies only to Buttress 1 anchorage.

Note 3: Gasket repair; examined only at Buttress 1.

Table 8E – Hoop Tendon CPM Replacement	
Surveillance Year	**Tendons**
1	12H-01 through 12H12 31H-01 through 31H13 32H-01 through 32H12
3[1]	
5	12H01 through 12H15, 12H19, 12H33 31H01 through 31H17, 31H19, 31H32, 31H33 32H01 through 32H13, 32H19, 32H33
10	12H01 through 12H14 31H01 through 31H04 32H01 through 32H07
15	12H01 through 12H10 31H01 through 31H04 32H01 through 32H03
20	12H01 through 12H10 31H01 through 31H04 32H01 through 32H03
25	12H01 through 12H10 31H01 through 31H04 32H01 through 32H03
30	12H01 through 12H04 31H01, 31H02 32H01, 32H02
35	12H01
40	None

General Note: CPM replaced by pump through or by air blow followed by refill.

Note 1: Supplemental report covering 3 year below grade tendon surveillance not found.

Table 8F – Below Grade Tendon End Anchorage / Wire Examination Results	
Surveillance Year	**Examination Results Summary**
1	Minor corrosion noted on 2 wires examined through anchor head center holes, one concluded to date from construction or earlier and the other to have initiated after the CPM was purged; nothing else noted.
3[1]	
5	Area of corrosion, possibly from construction or earlier, observed on the 12H10 Butt. 2 anchor head.
10	Small localized area of Level 3 observed on button heads, anchor heads, shims and bearing plates; small localized areas of Level 4 observed on 2 anchor heads; small localized areas of Level 5 observed on 12H02 Butt. 2 button heads and anchor head; areas of Level 2 observed on wire extracted from 12H01. No conclusion as to time of occurrence.
15	Areas of Level 3 observed on 20 of 34 anchor heads. Below grade tendon report supplement text with conclusions, if any, not found.
20	Small areas of Level 3 observed on 12H01 & 12H05 Butt. 2 anchor heads; Level 2 with small areas of Level 3 observed on wire extracted from 12H01; all presumed on the basis of appearance to have occurred at time of construction or earlier.
25	Areas of Level 3 observed on 1D24 Shop, 3D04 Field, 31H36 Butt. 1, 32H32 Butt. 2 & 12H01 Butt. 2 anchor heads. No conclusion as to time of occurrence.
30	No Level 3 or higher corrosion observed; wire extracted from 31H01 Level 1.
35	No Level 3 or higher corrosion observed.
40	No Level 3 or higher corrosion observed.

General Note: All corrosion observed inactive unless otherwise noted.

General Note: Corrosion level not stated in applicable report if not noted on the table.

General Note: Level 2 corrosion not noted on the table unless active or observed on wire extracted for testing.

Note 1: Supplemental report covering 3 year below grade tendon surveillance not found.

Figure 1 - Hoop Tendon Force Trend & LCL

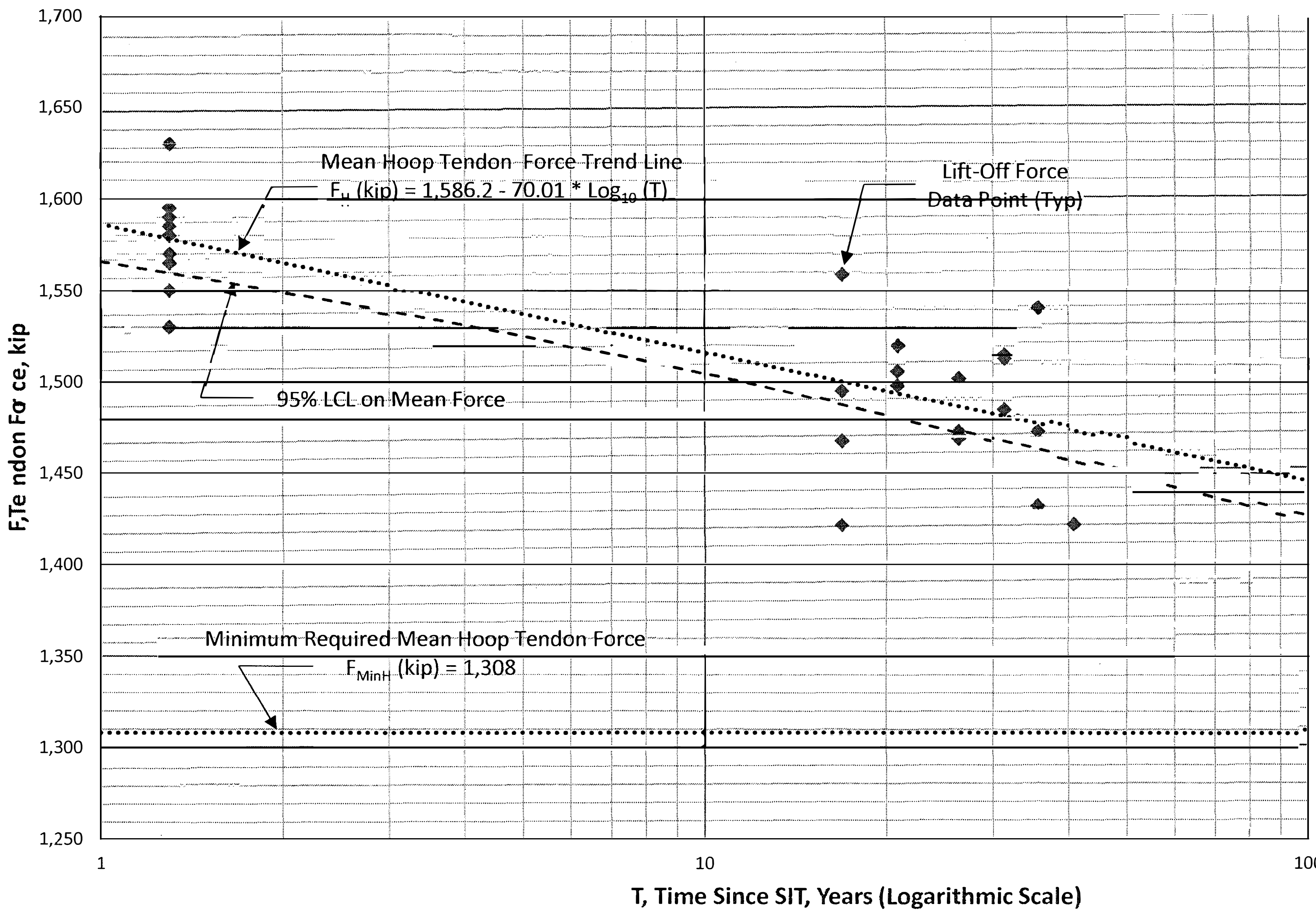


Figure 2 - Hoop Tendon Force Trend & LCL / 15 - 40 Year Survillance Results

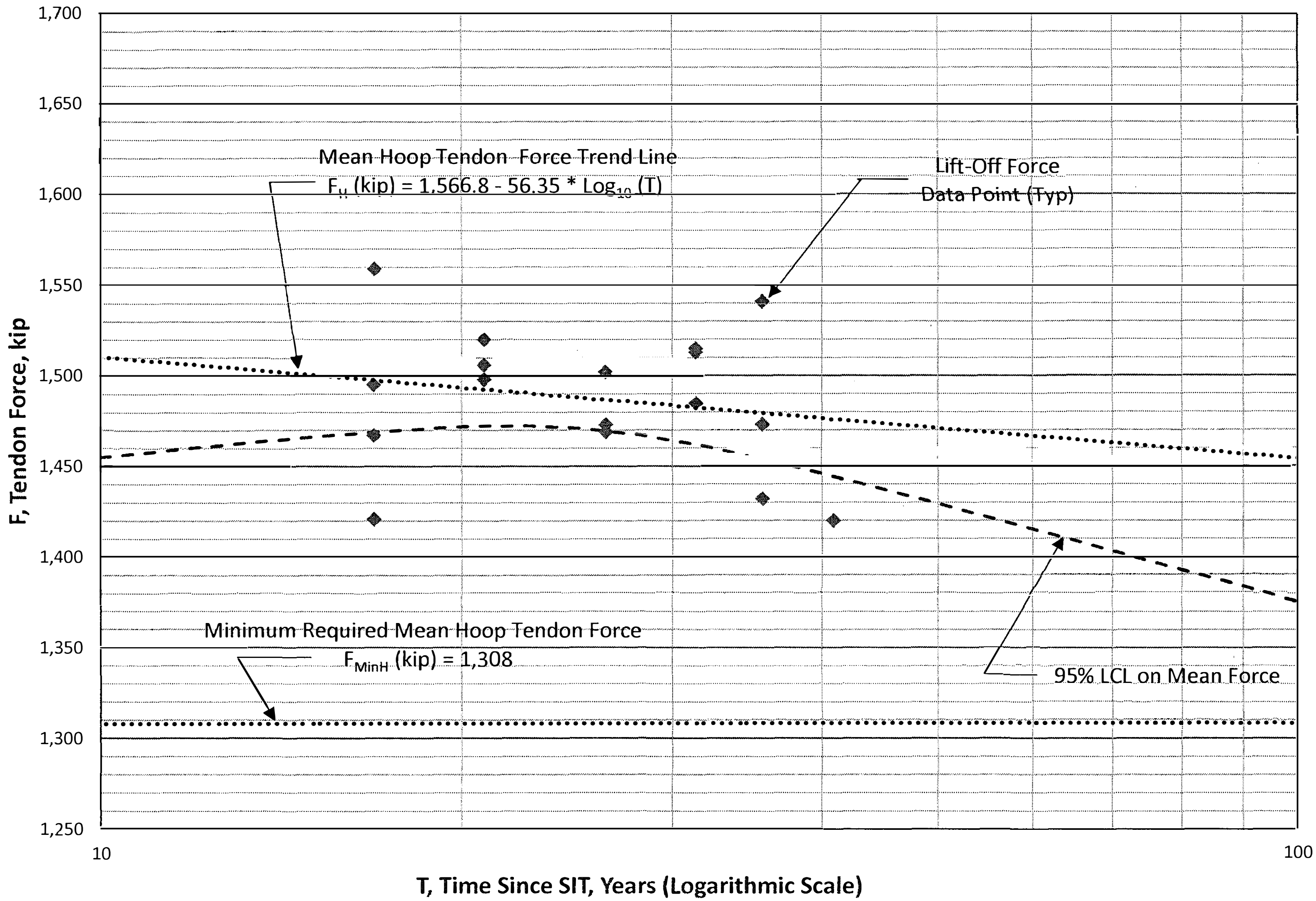


Figure 3 - Common Hoop Tendon Force Trend

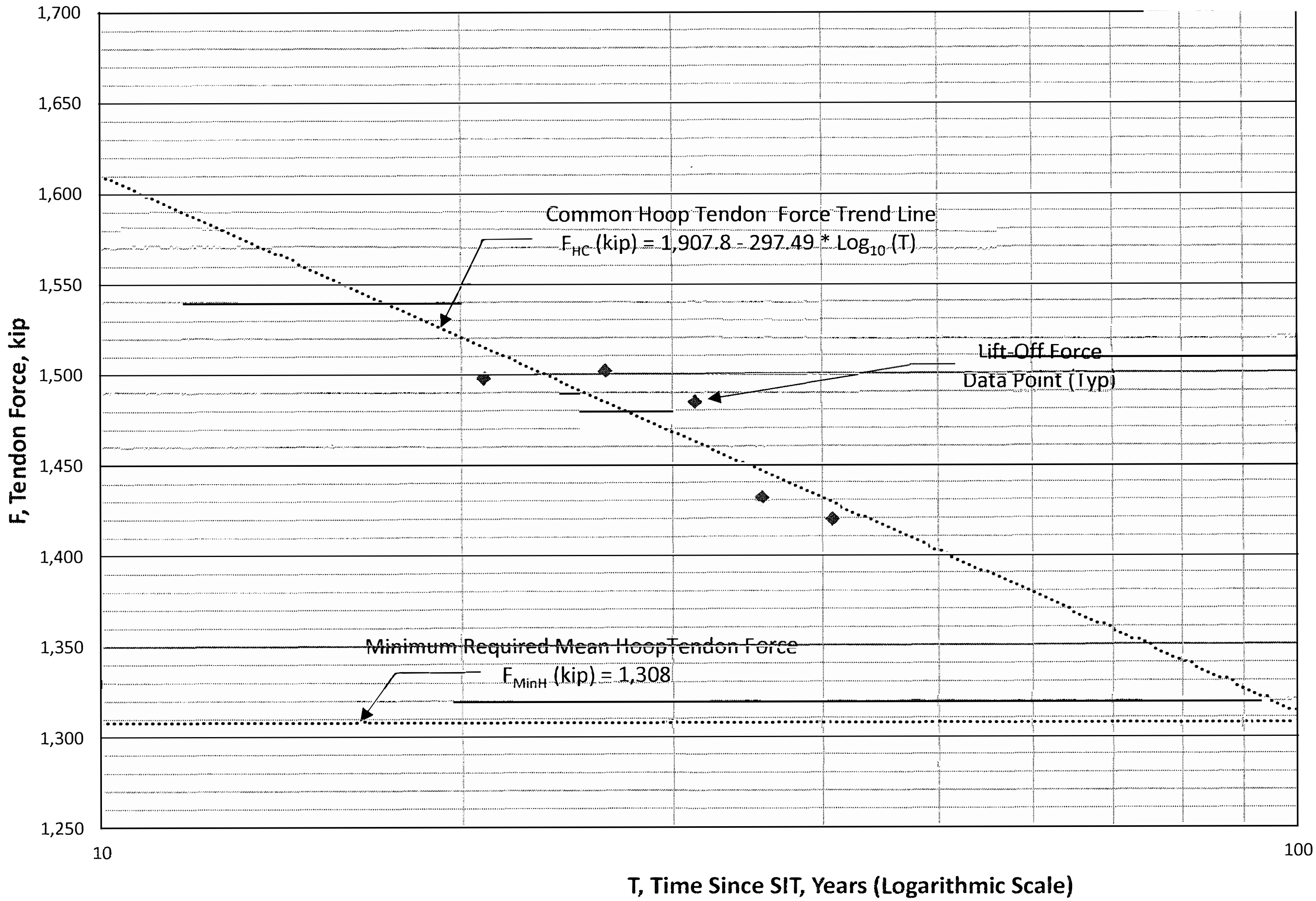


Figure 4 - Vertical Tendon Force Trend & LCL

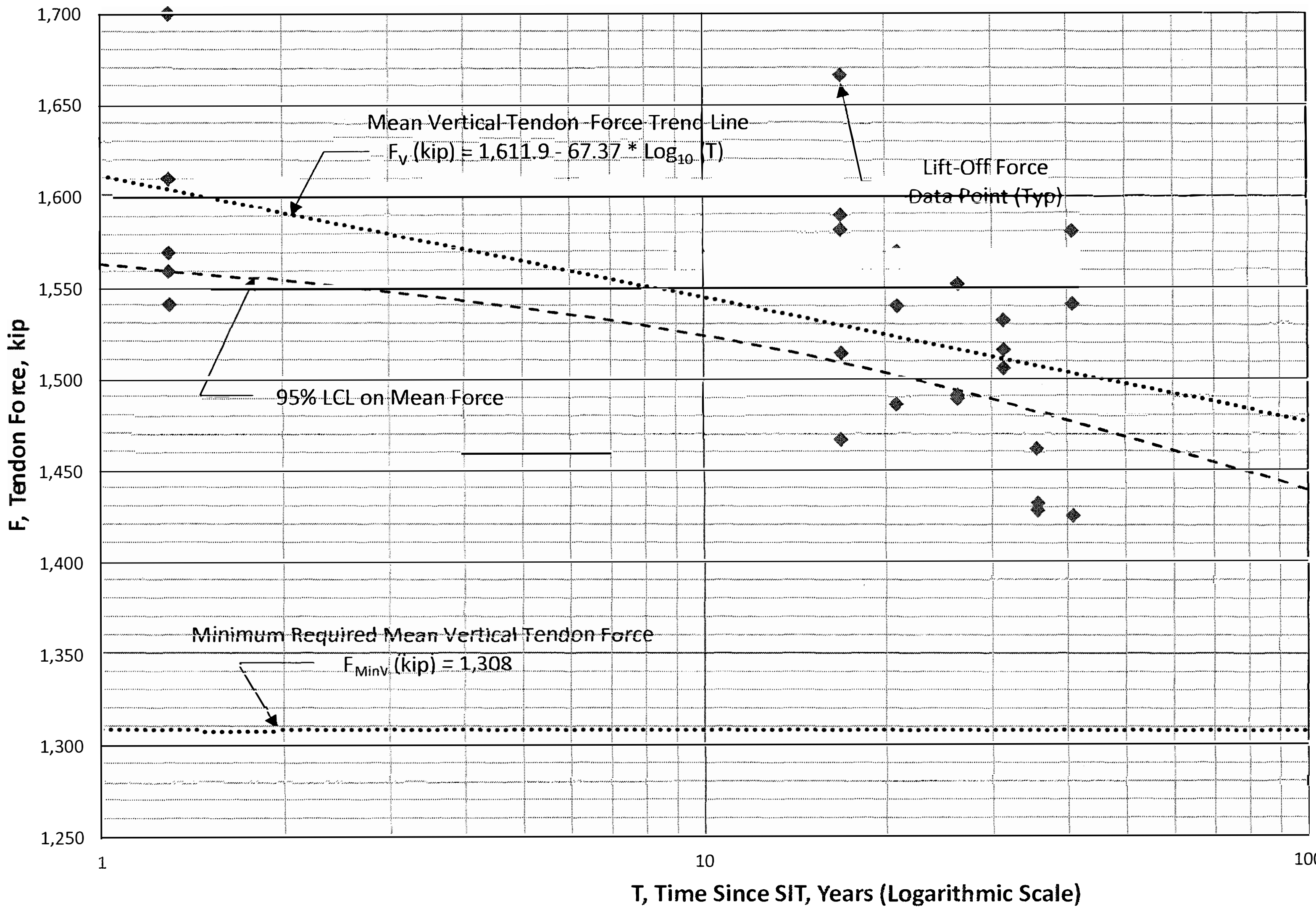


Figure 5 - Vertical Tendon Force Trend & LCL / 15 - 40 Year Surveillance Results

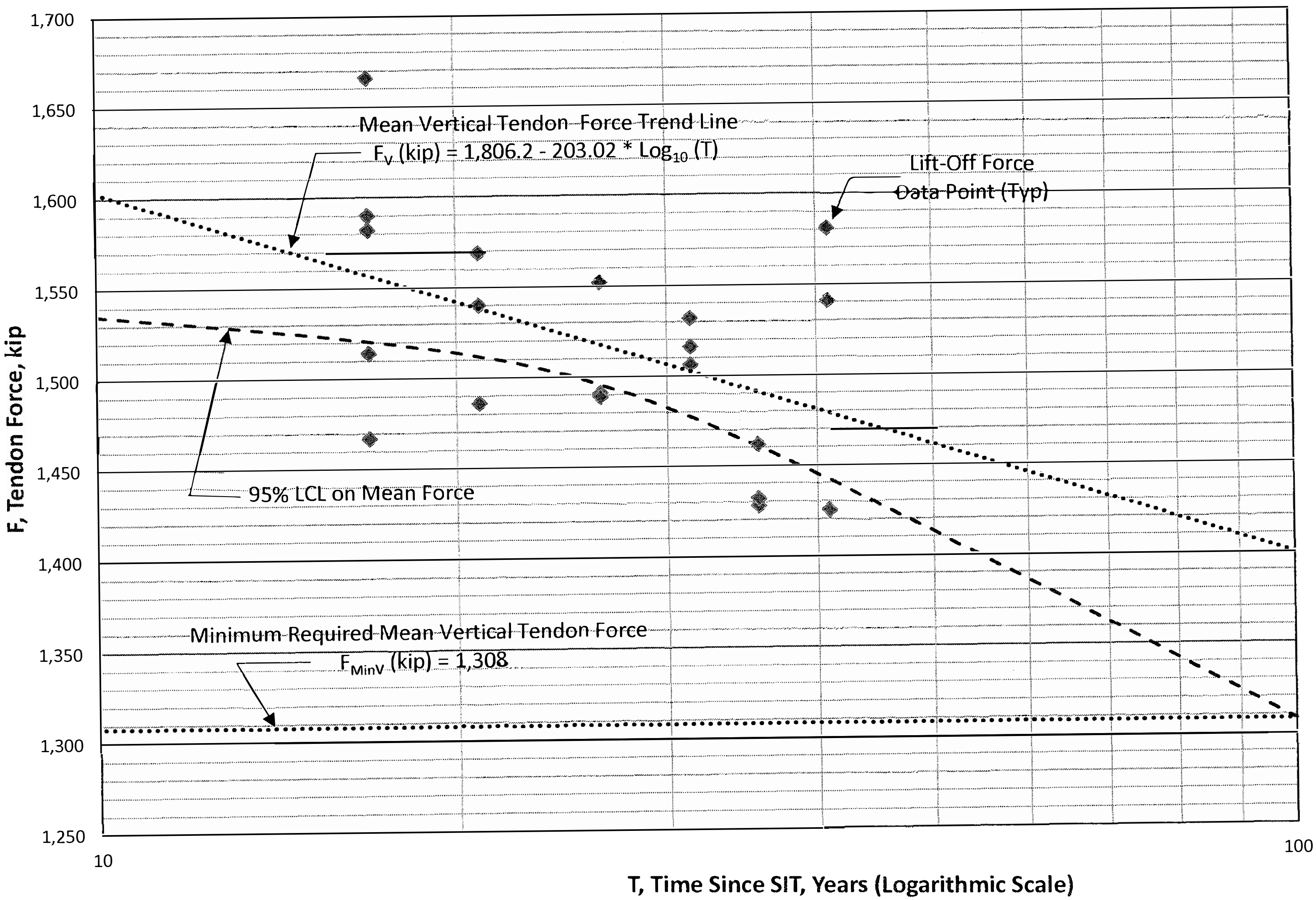


Figure 6 - Common Vertical Tendon Force Trend

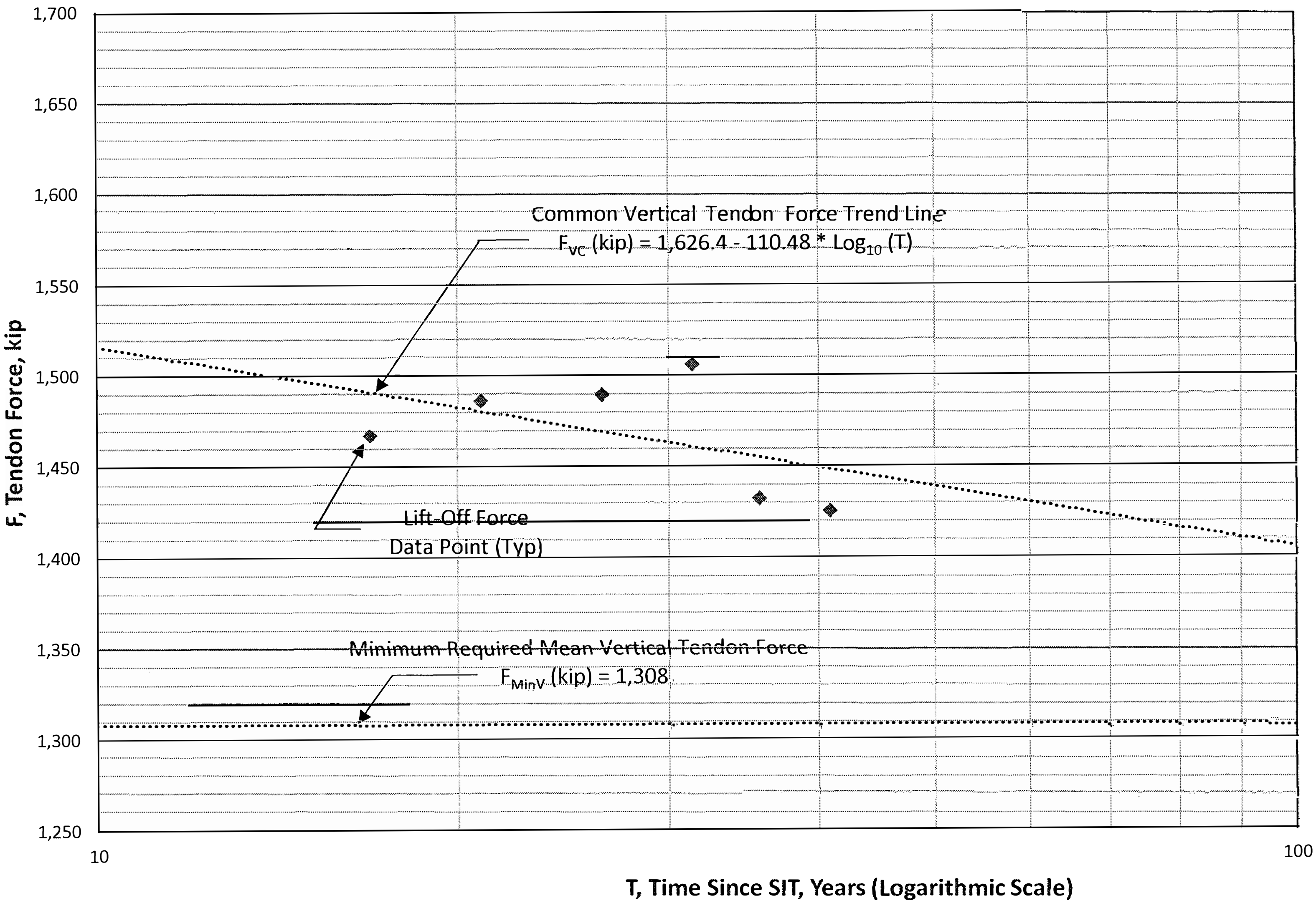


Figure 7 - Dome Tendon Force Trend & LCL

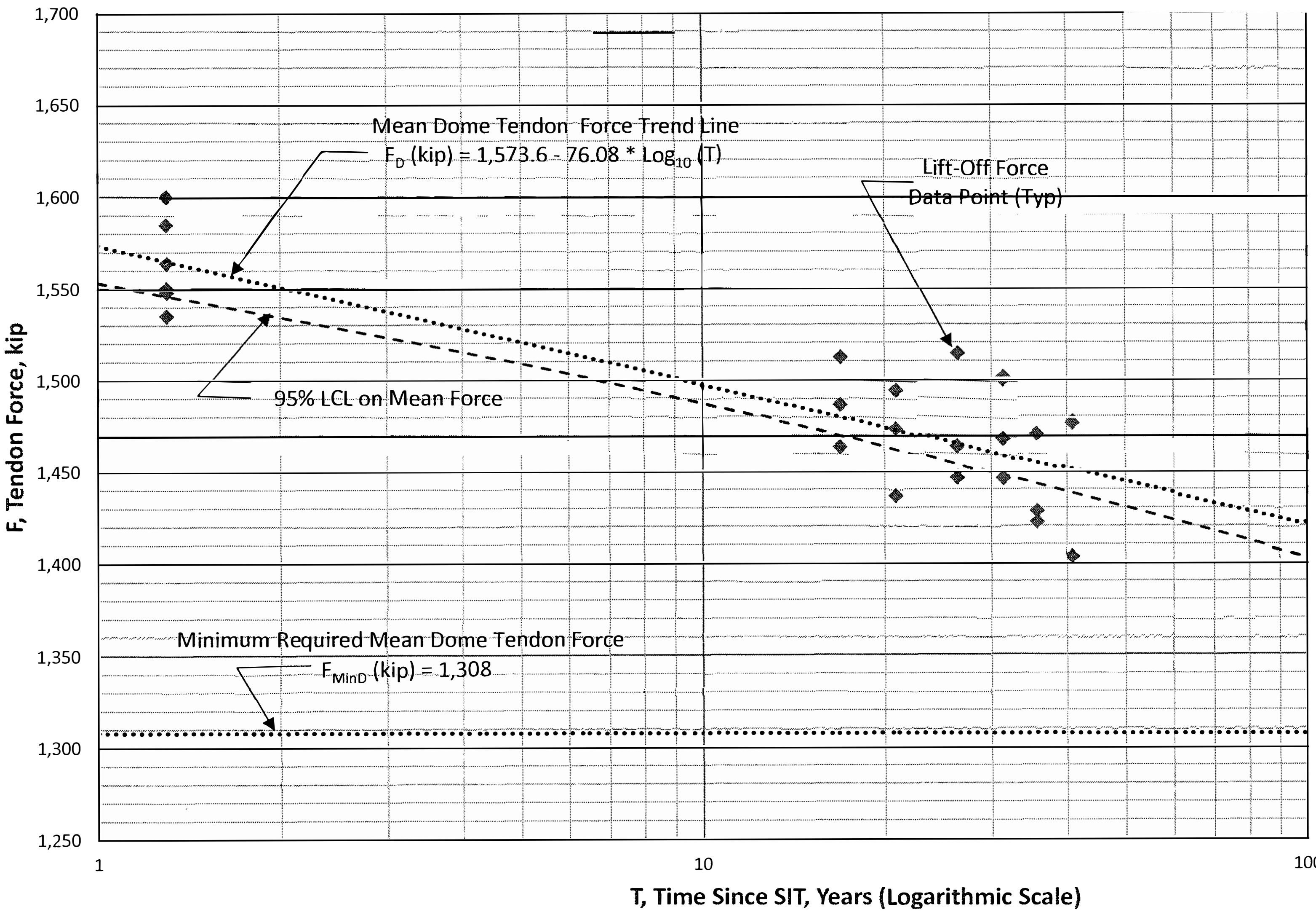


Figure 8 - Dome Tendon Force Trend & LCL / 15 - 40 Year Surveillance Results

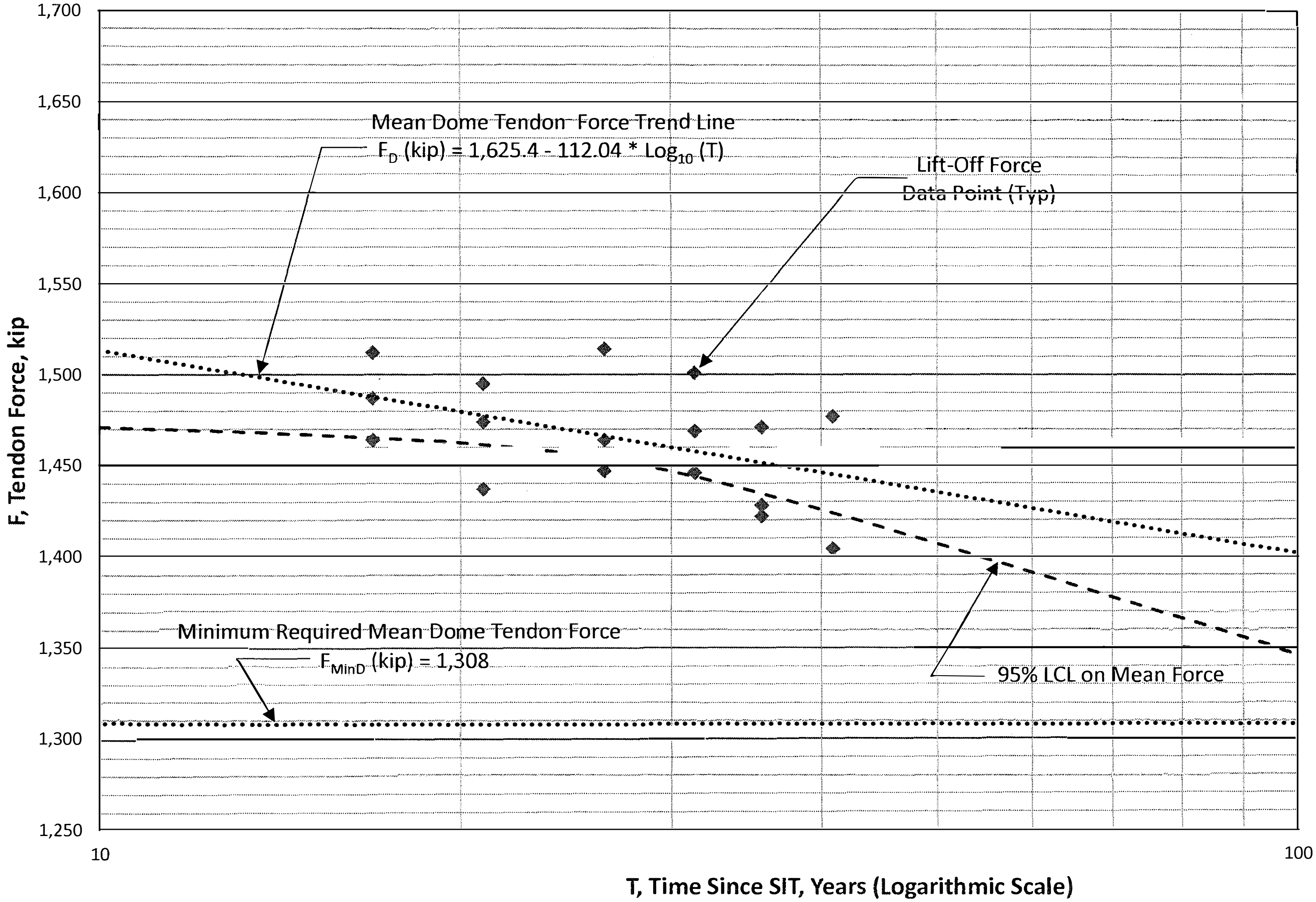
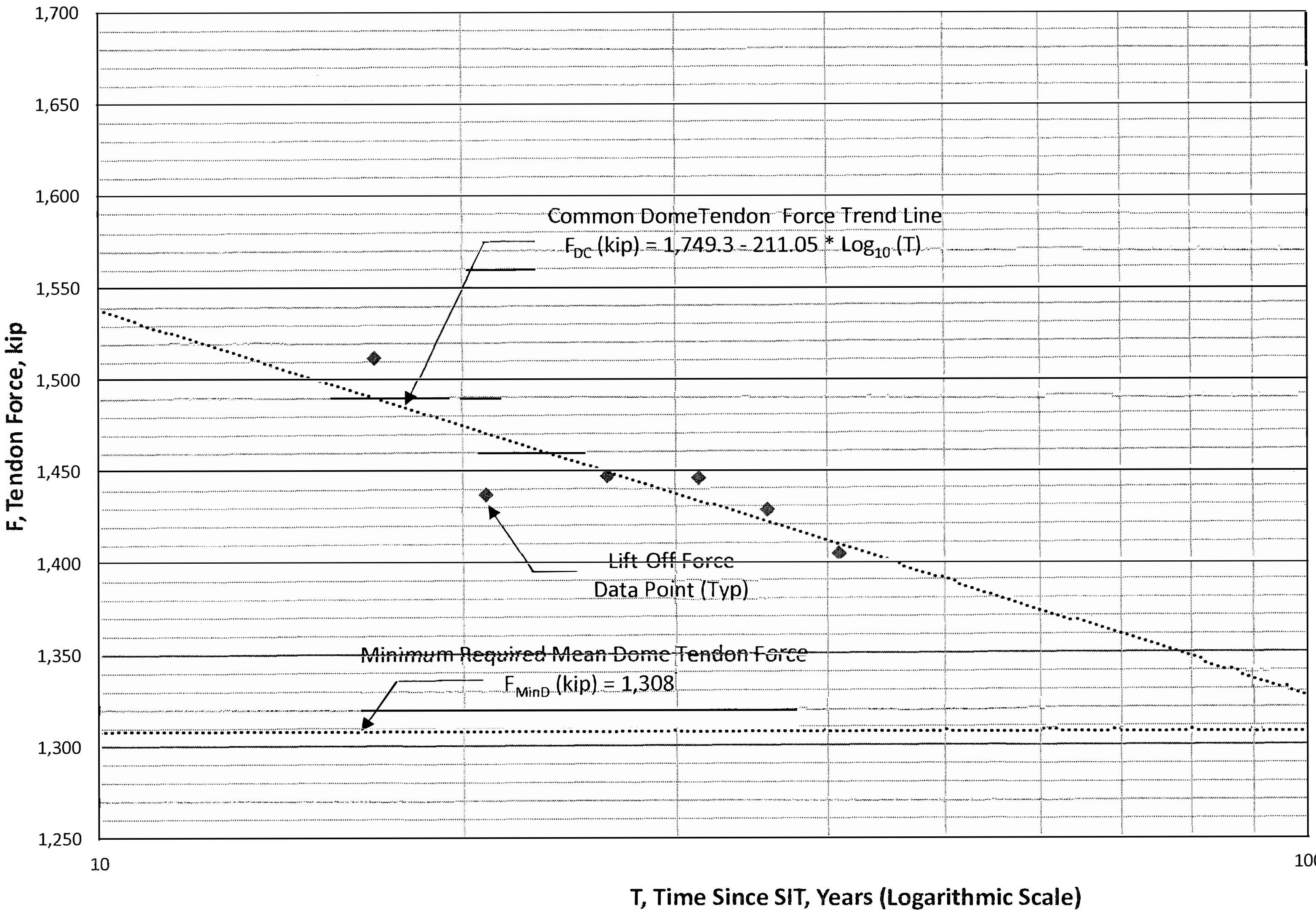


Figure 9 - Common Dome Tendon Force Trend



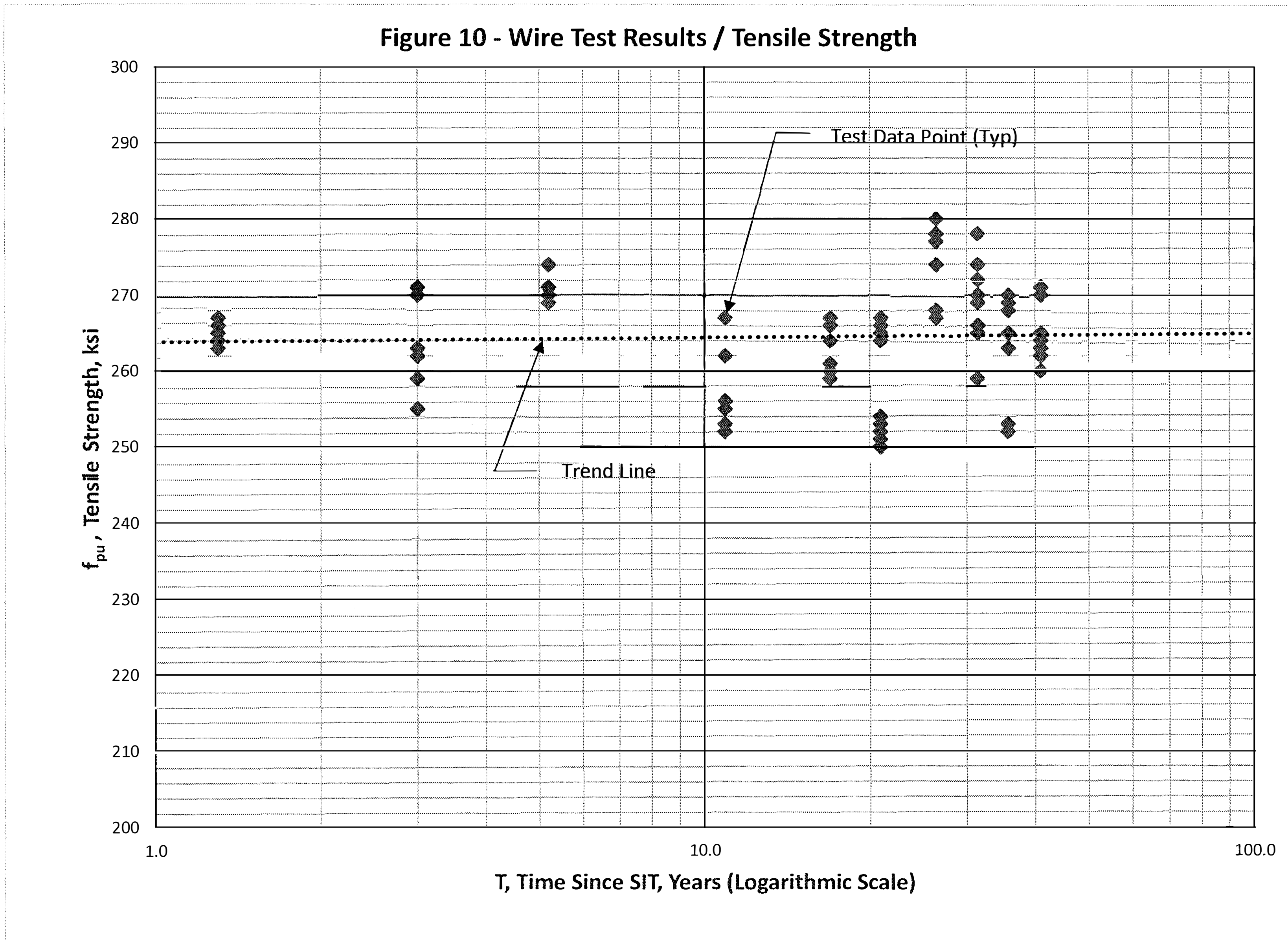


Figure 10 - Wire Test Results / Tensile Strength
300
290
280
270
260
250
240
230
220
210
200
f_{pu}, Tensile Strength, ksi
Test Data Point (Typ)
Trend Line
1.0
10.0
100.0
T, Time Since SIT, Years (Logarithmic Scale)

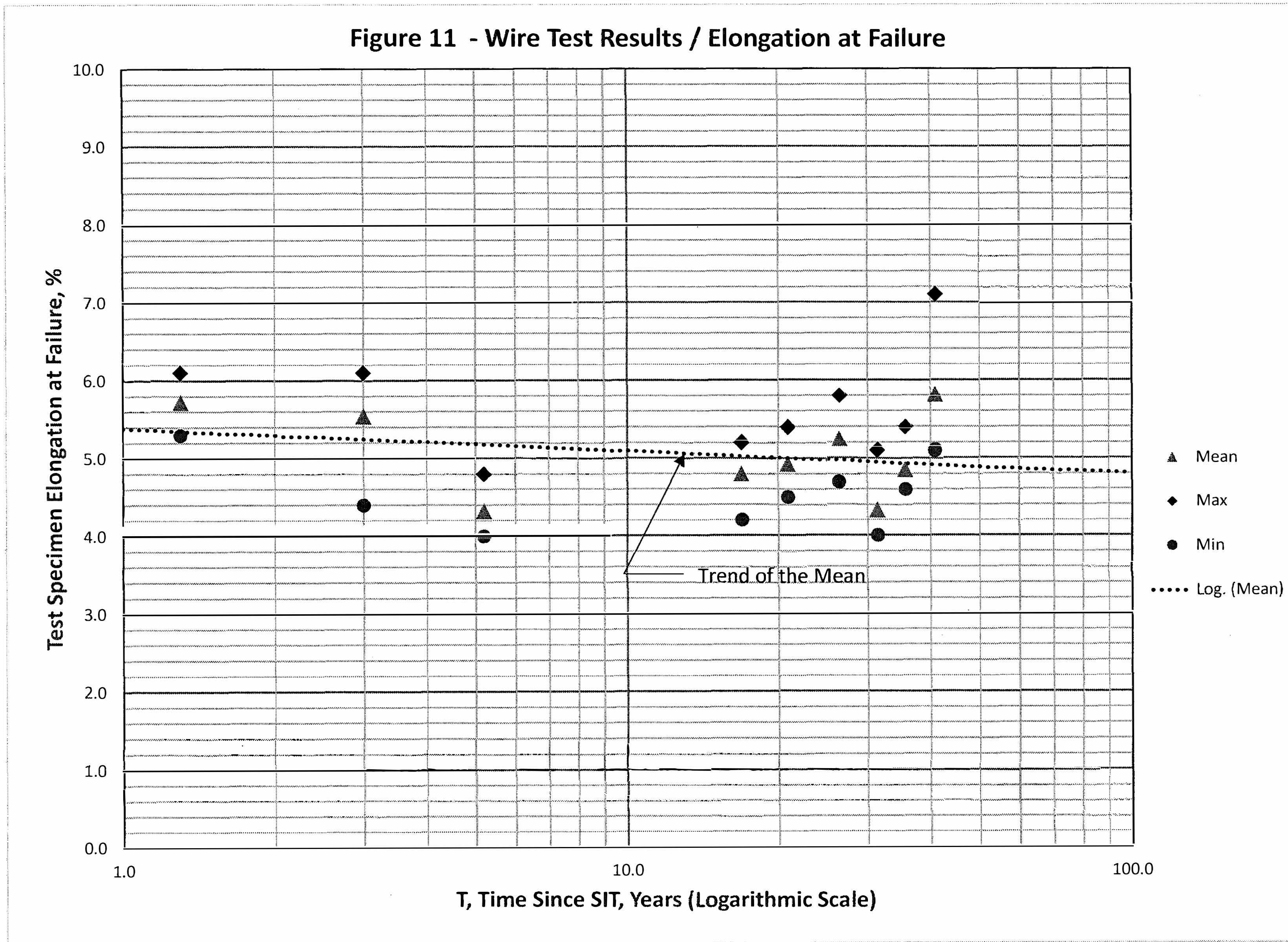


Figure 11 - Wire Test Results / Elongation at Failure
Test Specimen Elongation at Failure, %
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1.0
10.0
100.0
T, Time Since SIT, Years (Logarithmic Scale)
Trend of the Mean
Mean
Max
Min
Log. (Mean)