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10 CFR 50.55a

TMI-18-094

October 16, 2018

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Three Mile Island Nuclear Station, Unit 1
Renewed Facility Operating License No. DPR-50
NRC Docket No. 50-289

Subject: Submittal of Relief Request RR-18-01 Concerning Containment Unbonded Post-Tensioning System Inservice Inspection Requirements

Attached for your review is a relief request associated with the fourth Inservice Inspection (ISI) interval for the Three Mile Island Nuclear Station (TMI), Unit 1. RR-18-01 concerns requirements associated with the containment inservice inspection program. The fourth interval program complies with the 2004 Edition, no Addenda of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code. The fourth ISI interval began on April 20, 2011 and is currently scheduled to end April 19, 2022. We request your approval by August 31, 2019.

There are no regulatory commitments in this letter.

If you have any questions concerning this letter, please contact Tom Loomis at (610) 765-5510.

Respectfully,

D. P. Helker

David P. Helker
Manager - Licensing & Regulatory Affairs
Exelon Generation Company, LLC

Attachment: Relief Request RR-18-01

cc: Regional Administrator, Region I, USNRC
USNRC Senior Resident Inspector, TMI
USNRC Project Manager, [TMI] USNRC

Attachment

Relief Request RR-18-01

Request for Relief RR-18-01 for Containment Unbonded Post-Tensioning System Inservice Inspection Requirements in Accordance with 10 CFR 50.55a(z)(1)

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:	Three Mile Island (TMI), Unit 1 Reactor Building

2. Applicable Code Edition and Addenda

The ISI program is based on the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, 2004 Edition, no Addenda. The fourth ISI interval began on April 20, 2011 and is currently scheduled to end April 19, 2022.

3. Applicable Code Requirement

Subsubarticle IWL-2420 requires that 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. Three Mile Island (TMI), Unit 1 is currently required to examine the post-tensioning system every 5 years.

Subarticle 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 at failure 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 that drains from the tendon during examination shall be documented.

Table IWL-2500-1, Item Numbers 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 Section XI requires periodic visual examination and physical testing of Reactor Building concrete as well as physical testing of post-tensioning systems. The examination and testing to date has indicated that the post-tensioning system is expected to maintain its safety-related function through the period of extended operation. This relief request proposes to perform visual examination only of the concrete containment and accessible steel hardware visible without tendon cover removal during the 45th year surveillance. Physical testing would be performed only if visual examination results indicate a need for such testing as determined by the Responsible Engineer (IWL-2320). The 45th year surveillance is required to be completed no later than March 8, 2020. The 50th year surveillance would be due at any time from March 9, 2023 to March 8, 2025 and would be completed during the subsequent 5th inservice inspection interval. This one-time deferral 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.

While this relief request is based on maintaining an acceptable level of quality and safety, there are additional benefits to deferring physical testing one surveillance cycle. Physical testing requires exposing the involved personnel to industrial safety hazards. Removing the tendon end caps and load testing or detensioning/tensioning the tendons also unnecessarily cycles the tendons and exposes the system to an unsealed environment during testing. Below are specific hazards and undesirable conditions that would be eliminated for one surveillance cycle by this proposed relief request:

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

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

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

4. Requires working with high pressure hydraulics.

5. Requires working in the vicinity of high energy plant systems.

6. Requires working with solvents and hot petroleum products and associated fumes.

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

8. Requires working in the vicinity of high levels of stored elastic energy (>1 million foot-pounds) in the tendons. Sudden rotation during force measurement has resulted in high speed shim ejection.

9. Handling of heavy loads (test equipment) that also exposes plant equipment to hazards as well as the involved personnel 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.

11. Performing examination/testing on a reduced frequency reduces the repetitive loading required for force measurement or detensioning and retensioning.

12. Eliminating tendon end cap removal would prevent exposing the tendon hardware to environmental conditions.

13. Elimination of tendon end cap removal will reduce environmental waste (e.g., solvents, used grease, other consumables).

5. Proposed Alternative and Basis for Use

Proposed Alternative

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

TMI, Unit 1 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 L1.11 and L1.12, 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 evidenced 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 gross leakage of corrosion protection medium will be evaluated and a plan developed for corrective actions as defined in an engineering evaluation documented by the Responsible Engineer.

TMI, Unit 1 will report the results of the completed examinations and any required testing within 3 months of completion of the surveillance as required by Technical Specification 4.4.2.1.6 ("Reports").

Containment General Design Description

The Reactor Building is a reinforced concrete structure with a cylindrical wall, a flat foundation mat, and a shallow dome roof. The foundation slab is conventionally reinforced with mild steel reinforcing. The cylindrical wall is prestressed with a post-tensioning system in the vertical and horizontal directions. The dome roof is prestressed using a three-way post-tensioning system. There are a total of 166 vertical, 330 horizontal, and 147 dome tendons. The inside surface of the

Reactor Building is lined with a carbon steel liner to ensure a high degree of leak tightness during operating and accident conditions. Nominal liner plate thickness is 3/8 inch for the cylinder and dome and 1/4 inch for the base.

The prestressing system used for the Reactor Building is the BBRV system using a maximum of 169 1/4 inch diameter wires per tendon for a maximum total of 108,667 wires. The wires consist of high tensile steel, bright, cold drawn, and stress relieved conforming to ASTM A421-65T, Type BA. The BBRV system uses parallel wires with cold-formed buttonheads at the ends which bear upon a perforated steel anchor head, thus providing a positive mechanical means for transferring the prestress force. The anchorage hardware is designed and fabricated for the use of 170 wires. However, one hole located on the outer perimeter of the holes in the anchor head was used to accommodate a removable unstressed surveillance wire.

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

Enclosure 1 provides a detailed discussion of the historical basis for examination and testing of containment post-tensioning systems. The Enclosure also includes the TMI, Unit 1 specific observations that provide a basis for deviation from the Section XI examination and testing requirements included in Table IWL2500-1, Examination Category L-B. The Enclosure observations are summarized below.

Tendon Force Trends and Forecasts (Item Number L2.10)

The trend of the mean force was analyzed separately for the hoop, vertical, and dome tendon groups not affected by steam generator replacement. Each analysis included 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 all 10 of the originally scheduled surveillances (the 'all data' case).
- Trend based on measured forces recorded during the 10th year and subsequent surveillances.
- Trend based on normalized values of the forces recorded during the 10th year and subsequent surveillances.
- 95% lower confidence limit (LCL) on the trend of measured forces recorded during the 10th year and subsequent surveillances.
- Trend using the slope of the common tendon trend.

Of the 15 trends/LCLs evaluated, all but two show the trend line or LCL curve remaining above the group lower limit through T = 100 (years after the Structural Integrity Test (SIT)), a time that extends well beyond the range of interest but used because it represents a major gridline on a logarithmic plot. The SIT was performed on March 9, 1974 and the 50th year surveillance must be completed no later than March 8, 2025 when including a one-year float allowed by IWL-2420(c). The remaining two, the hoop tendon all data case trend line and the dome tendon LCL curve, cross the lower limit after T = 70 years which is 10 years after the April 2034 expiration of the extended operating license and 19 years after the latest date for completion of the 50th year surveillance.

The trends of common tendon forces were separately evaluated. Common tendon forces exhibit little scatter about the log-linear trends. And the slopes of the 3 trend lines fall within a narrow range, as these should, given that the mean force in each group is affected by the same time dependent material properties (steel relaxation, concrete shrinkage and concrete creep). This suggests that common tendon rate of loss is probably the best proxy for group mean force rate of loss.

Based on the above summary, it is concluded that:

- There is essentially nothing to be gained by continuing to monitor pre-stressing forces at the 5-year intervals specified by subsection IWL; the tendon pre-stress loads are predicted to remain acceptable well past the proposed 50th year surveillance latest completion date.

- The proposed extension of the interval to 10 years is fully supported by the analysis of tendon mean force trends.

End Anchorage Condition (Item Number L2.30)

Tendon end anchorage hardware and adjacent concrete have performed well throughout the life of the plant (through the most recent surveillance in 2013) and show no trends of deteriorating condition.

There have been no findings of active corrosion on anchor heads, shims and wire. Minor active corrosion found on bearing plates is in exposed areas that are regularly examined in accordance with IWL-2510 and is addressed through maintenance procedures. Inactive corrosion is, with one exception, limited to minor light rust. The single exception, inactive medium rust found on the button heads at the upper end of a vertical tendon during the year 5 surveillance and re-examined during the 10-year surveillance, is considered unique and not indicative of a more widespread condition.

No free water has been found in end caps, on anchor heads, on shims or on wires with the unique exception of tendon V-86 which was discovered with a gap between the end cap and bearing plate during the 25th year surveillance. No corrosion was found on V-86 hardware items exposed to the water within the end caps and ductwork.

Only 6 discontinuous wires not previously reported have been found. These represent only a minor fraction of the ~108,000 wires comprising the TMI, Unit 1 tendons.

No hardware damage, cracking or distortion has been found during visual examinations of end anchorages.

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

Considering the above, it can be concluded that the end anchorage conditions are stable and unlikely to change significantly before the March 2034 expiration of the extended operating license. Therefore, it can be concluded that the end anchorage examination interval can be extended to 10 years without compromising the safety of the plant.

Wire Examination and Test Results (Item Number L2.20)

Review of wire testing data shows that tendon wire strength and ductility are essentially invariant with time. In addition, visual examination of 33 wires extracted from test sample designated hoop, vertical, and dome tendons between 1975 and 2013 has uncovered no evidence of damage, active corrosion, or an unacceptable level of pre-existing (prior to tendon duct filling) corrosion. Wires examined/tested include the one extracted from tendon V-86 in 1999. This tendon was added to the originally designated sample when a gap between the upper end cap flange and the bearing plate was observed. As the gap would allow water to enter the tendon duct, the decision was made to de-tension the tendon and remove a wire for examination and testing.

Examinations and tests conducted over almost 4 decades have shown that wire condition, strength, and ductility are not changing over time. Based on these observations it is concluded that there is no merit to retaining the current requirement for wire examination/testing and for the associated de-tensioning of tendons to extract test wires. Testing could be specified by the Responsible Engineer if conditions indicative of wire degradation are found during future end anchorage visual examinations and/or force measurements.

Corrosion Protection Medium and Free Water Testing (Item Numbers L2.40 and L2.50)

Corrosion protection medium collected during the 11 surveillances conducted between 1975 and 2013 have been tested for the presence of corrosive ions (all surveillances), absorbed water (since 1977), and reserve alkalinity (since 1995). The results of these examinations and tests are summarized below:

- Corrosive ion (chlorides, nitrates, sulfides) concentration is well below the 10 ppm limit and shows no trend of increasing over time.

- Absorbed water content is well below the 10% (of dry weight) limit and shows no trend of increasing over time; with 2 exceptions (one at 4.1% and one at 3.7%), all tested samples had water contents below 1%.

- Neutralization numbers (base numbers) vary over a wide range depending on the product formulation and the degree of mixing of different formulations. All but 3 of the samples tested met the acceptance criteria and the three exceptions were accepted by evaluation. Test data show no trend indicating that the corrosion protection characteristics of the CPM are degrading over time.

Only one instance of tendon free water has been identified at TMI, Unit 1 during the 40 years of containment surveillances. Water collected at the lower end of V-86 was analyzed to determine pH. The pH of the water was determined to be 11.67.

An evaluation of the CPM test results and free water, 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 is 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 continue to be collected and analyzed to determine pH.

Examination and Testing of Tendons Affected by Repair/Replacement Activities

The 2009 refueling outage included replacement of the steam generators which required a temporary opening in the side wall of the Reactor Building. This work required detensioning of 30 hoop and 45 vertical tendons. Of this population, 22 hoop and 10 vertical tendons were replaced with new tendons while the remainder of the population was retensioned. Since the refueling outage, these tendons are treated as a separate population as required by IWL-2521.2 and examined/tested during an Augmented Examination surveillance in 2010 as well as during the 2013 40th year surveillance.

Based on evaluations of visual examinations, tendon force measurements, wire tests, and CPM analyses performed in conjunction with the augmented and year 40 surveillances, it is concluded that the steam generator replacement tendons are performing well and that the corrosion protection system is functioning as intended. Two broken wires found during the augmented surveillance were determined to be the result of a singular event and do not affect this conclusion. The results of examinations and tests support the recommendation to extend the surveillance interval to 10 years and to conduct the next post-tensioning system examinations/tests in the 2024 time frame (50th year surveillance).

License Renewal and Additional Supporting Actions

On March 7, 2014 the U.S. Nuclear Regulatory Commission completed a license renewal commitments inspection at TMI, Unit 1 (Reference 2). The inspection included Commitment 25 which included the ASME Section XI, Subsection IWL Program. The program was an existing program at the time of license extension application and approval and is in compliance with ASME Code and 10 CFR 50.55a. No findings were identified. The inspectors concluded the commitment is being implemented and there is reasonable assurance that the effects of aging will be managed during the extended period of operation.

The Subsection IWL program at TMI, Unit 1 is credited for managing Reactor Building degradation. The Examination Category L-A visual examinations being performed are expected to be capable of identifying conditions that would allow water intrusion into the tendons and gross 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 TMI, Unit 1 mean prestresses are predicted to be acceptable well beyond the 50-year surveillance based on acceptable performance over 40 years; therefore, extending the surveillance an additional 5 years will continue to provide an acceptable level of quality and safety.

TMI, Unit 1 implements other inspections of the Reactor Building concrete and exposed exterior metal components. The tendon end caps are monitored for leakage annually. External visual inspection of the Reactor Building exterior is performed by a qualified design engineer on a one refueling outage cycle frequency and structural monitoring inspections of the Reactor Building are performed at least every five years but are generally performed on an every second outage basis to allow access to areas not accessible during operation. These examinations provide an additional defense in depth that supports the proposed relief request to perform Table IWL-2500-1 Examination Category L-B examinations on a less frequent basis and offer additional assurance that performing the L-B examinations/tests on a less frequent basis will continue to provide an acceptable level of quality and safety.

Summary and Conclusions

The results of the 11 post-tensioning system inservice examinations conducted at TMI, Unit 1 between 1975 and 2013 show that the system is continuing to perform its intended function and that it can be expected to do so until well past the April 2034 expiration of the extended operating period license. Visual examination planned for the 45th year surveillance (2019) will be adequate to determine when physical testing and examination per Examination Category L-B is required. Reporting of examination results per Technical Specification 4.4.2.1.6 will be completed and submitted to the NRC within three months of completion of the 45th year surveillance.

6. Duration of Proposed Alternative

This relief request will remain in effect for the 45th year surveillance through the remainder of the current 4th inservice inspection interval which is scheduled to be end on April 19, 2022. The subsequent 50th year IWL surveillance is projected to occur at any time from March 9, 2023 to March 8, 2025 at which time a complete Section XI IWL examination will be performed.

7. Precedents

None

8. References

1. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, 2004 Edition, No Addenda.

2. Letter from, M. Gray (U.S. Nuclear Regulatory Commission) to M. Pacilio (Exelon Nuclear), "Three Mile Island Nuclear Station, Unit - NRC License Renewal Commitments Inspection Report 05000289/2014008," dated April 11, 2014, Accession Number ML14101A286.

Enclosure 1

Three Mile Island Nuclear Station Unit 1 Containment Post-Tensioning System Inservice Inspection Document Number 5971-2018-011
Technical Report
Basis for Proposed Extension of Examination Interval

THREE MILE ISLAND NUCLEAR STATION
UNIT 1 CONTAINMENT POST-TENSIONING SYSTEM INSERVICE INSPECTION
DOCUMENT NUMBER 5971-2018-011
TECHNICAL REPORT
BASIS FOR PROPOSED EXTENSION OF EXAMINATION INTERVAL

Report Prepared by:
Howard T. Hill, PhD, P.E. (California Civil Certificate C 22265)
04 October 2018

1. PURPOSE, CONTAINMENT / ISI PROGRAM DESCRIPTION AND ORGANIZATION

This report provides the technical evaluation / justification supporting a request for relief to allow deviation from certain containment inservice inspection (ISI) requirements specified in USNRC Regulation 10CFR50.55a (Reference 7.21) and, by reference therein, ASME Section XI, Subsection IWL (Reference 7.18). The current TMI Unit 1 containment ISI program conforms to these regulatory and code requirements.

1.1 CONTAINMENT DESCRIPTION

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

The containment is a reinforced and post-tensioned concrete structure with cylindrical wall, a shallow dome roof and a flat foundation mat. A massive ring girder serves as a transition between the dome and the cylinder. The cylindrical wall is prestressed with a post-tensioning system in the vertical and circumferential (hoop) directions. The dome roof is prestressed using a three way post-tensioning system. The foundation mat is conventionally reinforced (not post-tensioned). The inside surface of the containment is lined with a carbon steel liner to ensure a high degree of leak tightness during operating and accident conditions. Nominal liner plate thickness is 3/8 inch for the cylinder and dome and 1/4 inch for the base.

The cylinder has an inside diameter of 130 ft, wall thickness of 3 ft 6 inches, and a height of 157 ft from top of foundation slab to the dome spring line. The cylinder has 6 external buttresses that provide anchorage for the circumferential pre-stressing elements (tendons). The foundation mat is 9 ft thick with a 2 ft thick concrete slab above the bottom liner plate. The shallow dome roof has a large radius of 110 ft, a transition radius of 20 ft 6 inches, and a thickness of 3 ft.

The containment wall and dome are pre-stressed using 169 wire BBRV (wires anchored by cold formed button heads) tendons. The ASTM A421 (Reference 7.22) wires have a diameter of 0.250 inches.

Dome pre-stressing consists of 3 layered sub-groups each having 49 tendons and intersecting at 60 degrees. Dome tendons anchor at the face of the ring girder.

Wall circumferential (hoop) pre-stressing consists of 6 sub-groups each having 55 tendons and spanning 120 degrees. Sub-groups are offset by 60 deg to provide continuous overlap of pre-stressing force. Circumferential tendons anchor at the buttress faces.

Wall vertical pre-stressing consists of 166 vertical 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.

Containment tendons were initially tensioned to a nominal 1,400 kips. Current forces are less due to elastic shortening, concrete shrinkage, concrete creep and pre-stressing wire relaxation losses. After tendons are tensioned, the duct and end anchorage caps are filled with a micro-crystalline wax for corrosion protection.

1.2 CONTAINMENT ISI PROGRAM SUMMARY DESCRIPTION

Continuing containment structural[1] integrity is verified through regular examinations and tests performed in accordance with the requirements of USNRC Regulation 10CFR50.55a (Reference 7.21) and, by reference therein, ASME Section XI, Subsection IWL (Reference 7.18). The ISI program requires visual examination of the entire containment concrete surface and examination and testing of random samples selected from the tendon population. Surface visual examinations follow the applicable guidelines given in the ACI reports referenced in IWL.

Tendon examinations / tests consist of the following.

- Visual examination to detect corrosion / damage at tendon end anchorages and along the length of the wires extracted for strength / ductility testing;
- Measurement of tendon force applied at the end anchorage;

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

- Measurement of the strength and ductility of sample wires extracted from designated tendons.
- Laboratory analysis of corrosion protection medium samples to determine absorbed water content, concentration of corrosive ions and reserve alkalinity.
- Laboratory analysis to determine the pH of free water found in tendon end caps and ductwork.

1.3 REPORT ORGANIZATION

The remainder of this report consists of the following 7 parts.

Part 2 – Summary of Proposed Deviations, Visual Examination Program Enhancements and Conclusions

Part 3 - Background of Current ISI Requirements and Basis for Proposed Deviations

Part 4 – TMI-1 Examination History and Results Analysis / Evaluation

Part 5 – Overall Summary, Conclusions and Recommendations

Part 6 - Future Examinations, Testing Enhancements and Year 40 Report Commitments

Part 7 – References

Part 8 – Tables and Figures

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

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

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

- Where possible, direct visual examination (IWL-2310) of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and corrosion protection medium leakage. Direct visual examination will be performed where access to anchorage areas is available (e.g., top of ring girder, tendon gallery and buttress areas accessible from floors, platforms or ladders). Where direct visual examination is not possible, remote examination (IWL-2310) techniques (high power optics and / or drone mounted cameras) will be used.
- 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 by the Responsible Engineer (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. Corrective action 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 corrective action taken as specified by the RE.

- Examinations will be performed to detect gross leakage of CPM. If gross CPM leakage is detected, a corrective action plan (e.g., end cap gasket replacement and duct refilling / top-off) plan will be prepared by the RE and implemented.

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 Examination Category L-B. Containment liner and penetration assembly inservice inspection requirements specified in Subsection IWE will continue to be implemented in accordance with the current ISI plan.

The results of tests on corrosion protection medium (CPM) samples collected at the Buttress 1 end of H13-08, the Buttress 3 end of H35-02 and the bottom end of V-32 during the year 40 surveillance showed acid numbers greater than the TMI administrative limit of 1. For this reason, the topical report (Reference 7.13) covering that surveillance includes a follow-up action to reexamine the associated anchorage assemblies during the next surveillance, then expected to be performed in 2018. As no corrosion or free water was found at these anchorages during the year 40 surveillance, it is concluded that the CPM is continuing to perform its protective function and that delaying the next examination to 2024 will not compromise plant safety. The examinations and associated pump through of CPM cited for follow-up action will be done at that time. This is discussed further in Part 6 of this technical report.

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 7.20) 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 prior to the completion of the first pre-stressed concrete containment structures 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 & 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 represent consensus opinions reached 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 RG 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.

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[2], 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 RG 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 RG 1.35, Rev. 3.

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

3.3 USNRC Regulation 10CFR50.55a

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

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

[Note: This section of the technical report includes a generalized summary of post-tensioning system performance observed during 4 decades of periodic examinations conducted at 24 U. S. nuclear plant sites with 41 pre-stressed concrete containments. It

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[2] 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.

is intended to show that most containment post-tensioning systems are continuing to perform well and that, in general, system examination intervals could be significantly increased without compromising safe operation of the plant

This summary, intended to be qualitative, is based on the author's experience as described below. As the summary is qualitative, specific references are not cited as the bases for generalized statements regarding post-tensioning system performance.

- 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 noted in 3.1, 3.2 and 3.3 above, the examination intervals and wire testing addressed in the 1973 original issue of RG 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 24 domestic sites with a total of 41 pre-stressed containments (listed in Table 1) 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 Examination Category L-B examinations during the 50 year surveillance rather than the 45 year surveillance. Containment ISI programs should be based on individual plant performance and not bound by requirements that were established without the benefit of the accumulated operating experience available today.

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

- It reduces personnel radiation exposure.
- It reduces personnel and equipment safety hazards associated with working at heights, handling of heavy loads, working with high pressure hydraulic equipment, working close to tendon end anchorages that can suddenly release stored mechanical energy 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 operating experience accumulated over the past 4 decades at the 24 domestic plants with containments having unbonded post-tensioning systems and, in particular, the operating experience documented during the post-tensioning system examinations performed at TMI. The general conclusions regarding post-tensioning system performance are listed below. Conclusions specific to TMI Unit 1 are addressed in detail in subsequent sections 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[3] (~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[4]. 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 exceed 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[5].
- 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 4, 8, 12 & 13), adjusted up or down, as applicable, to current group mean force levels, indicate that group means will remain above required minima with acceptable margins through the deadline for completion of the subsequent examination.

3.4.2 System Hardware Condition History

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[3] TMI steam generator replacement project documentation turned over by SGT includes reports on shrinkage, creep and relaxation tests; test durations noted in these reports is typical.

[4] 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.

[5] 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.

There have been relatively few significant issues associated with post-tensioning system hardware (tendon wire / strand[6], anchor heads, wedges, shims and bearing plates). Active corrosion is typically found only on the exposed parts of bearing plates. Free water is not often found in end caps and / or on hardware.

Instances of deformation / damage / 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 wires (e.g., the 643 TMI containment tendons have an aggregate of over 108,000 wires).

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 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 entered the caps through these holes and submerged the short lengths of uncoated wire just below the anchor heads. A number of wires were severely corroded and found to be no longer effective as pre-stressing elements.

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

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

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

3.4.3 Wire Test Results

Wire sample tests, performed by certified laboratories using appropriate equipment and procedures as specified in the applicable ASTM standards, show that strength and elongation at failure do not degrade with time. While past industry data often show reported strength and elongation to vary significantly from examination to examination,

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[6] 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 Vogtle is currently operating.

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 (see test setup description in Reference 7.4).
- Testing equipment was often vendor fabricated and did not meet ASTM specifications (see wire test procedure included in Reference 7.4).
- Personnel assigned to the testing work did not always have the necessary experience.

In general, tests that conform to ASTM specifications and that are performed by experienced technicians show that both strength and elongation are close to, but exceed, the minima (240 ksi and 4%, respectively) specified for ASTM A421 (Reference 7.22) 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 for 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 7.18) 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 absorbed water.

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).

3.4.5 Condition of Tendons Affected by Steam Generator Replacement

There is no evidence of significant degradation / deterioration associated with tendons, whether new or de-tensioned / re-tensioned, affected by steam generator replacement work.

- Force in the tendons has been found to decrease slowly, as expected, since concrete compressive strain resulting from ongoing creep and shrinkage is small relative to that occurring during the early period following initial tensioning at the time of construction.
- Little or no active corrosion on end anchorage hardware and extracted wires has been reported.
- New and re-tensioned wire strength and elongation do not degrade with time.
- The protective characteristics of corrosion protection medium show no unusual rate of decrease in protection properties over time.

4. TMI-1 EXAMINATION HISTORY AND RESULTS ANALYSIS / EVALUATION

The visual examination results and test data used in the development of Sections 4.1 through 4.5 are those documented in TMI inservice inspection reports, References 7.1, 7.2, 7.4 and 7.6 through 7.13.

TMI-1 has completed 10 originally planned pre-stressing system examinations as well as the mandated augmented examination of the tendons replaced or de-tensioned / re-tensioned to support steam generator replacement. These examinations were conducted in accordance with Regulatory Guide 1.35 or ASME Section XI Subsection IWL as shown below.

Examination No.	Type[1]	Year Performed	Years[2] after March 1974 SIT	Governing Document(s)
1	Originally planned	1975	1.2	Reg Guide 1.35
2	Originally planned	1977	3.6	Reg Guide 1.35
3	Originally planned	1980	6.2	Reg Guide 1.35
4	Originally planned	1985	11.2	Reg Guide 1.35
5	Originally planned	1989	15.6	Reg Guide 1.35
6	Originally planned	1994	20.6	Reg Guide 1.35
7	Originally planned	1999	25.5	Reg Guide 1.35 and 10CFR50.55a / IWL
8	Originally planned	2004	30.6	10CFR50.55a / IWL
9	Originally planned	2009[3]	35.6	10CFR50.55a / IWL
9a	Augmented	2010	Note 4	10CFR50.55a / IWL
10	Originally planned	2013	39.6	10CFR50.55a / IWL

Note 1: Originally planned examinations are those following the Reg Guide 1.35 and IWL schedule of 1, 3 and 5 years after the SIT and every 5 years thereafter.

Note 2: Years listed represent the time from the SIT to the approximate mid-point of the surveillance.

Note 3: The examination scope included replacement of leaking end cap gaskets. Replacement of CPM in the ductwork of one or more vertical tendons that required lower end cap gasket replacement was deferred to early 2010 for scheduling efficiency. Examinations specified in 10CFR50.55a / IWL were completed in 2009.

Note 4: The augmented examination was performed approximately 1 year after the steam generator replacement outage as required by IWL.

The following subsections, 4.1 through 4.5, of this report provide a comprehensive evaluation of TMI post-tensioning examination results documented in the 1, 3, 5, 10, 15, 20, 25, 30, 35, and 40 year examination reports as well as the augmented examination report. These address the following aspects of examination results acquired over the 40 year period. Tendon force trends and forecasts are, as noted below, addressed separately for hoop tendons, vertical tendons, dome tendons and common tendons.

Subsection 4.1 – Tendon force trends and forecasts

- Hoop tendon force trends and forecasts
- Vertical tendon force trends and forecasts
- Dome tendon force trends and forecasts
- Common tendon force trends

Subsection 4.2 – Post-tensioning system hardware condition

Subsection 4.3 – Tendon wire mechanical properties

Subsection 4.4 – Corrosion protection medium chemical properties and free water analysis

Subsection 4.5 – Consolidated performance of SGR tendons

The proposed extension of the tendon examination interval to 10 years is justified if the extension can be separately justified for each of the 8 (Subsection 4.1 addresses 4 categories) post-tensioning system performance categories listed above.

4.1 Tendon Force Trends and Forecasts

Forces in designated sample[7] tendons, and additional tendons as mandated by procedure or specified by the Responsible Engineer, were 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 UFSAR (Reference 7.16) Par. 5.7.5.2.3.a until well after the April 2034 expiration of the extended period operating license. Hoop, vertical and dome tendon

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[7] Sample tendons designated for the first nine examinations were those randomly selected by the Designer (Gilbert Associates) prior to the year 1 examination. The predesignated sample tendons are listed in Enclosure 2 of TMI Surveillance Procedure 1301-9.1 which is included as Appendix E of the year 35 surveillance report (Reference 7.11).

Tendons pre-selected for the year 40 examination and de-tensioned / re-tensioned or replaced during the steam generator work were no longer valid undisturbed samples. New sample tendons were randomly selected from a population that excluded those affected by the SGR work as well as all others that had been previously examined. SGR tendons are treated as a separate population and are subject to the separate sampling requirements of IWL-2521.2.

force trends and forecasts are presented and discussed in 4.1.1, 4.1.2 and 4.1.3 below. The trends of the 3 common (or control) tendons[8] merit additional discussion which is included in 4.1.4. SGR tendon trends are addressed separately in 4.1.5.

Tendon force trends and forecasts are determined for both measured and normalized forces to ensure completeness of the presentation. Normalizing is a process, applied in the year 10 and later surveillances, when determining the means of the hoop, vertical and dome forces measured during each consecutive examination. It consists of adjusting measured force to account for variations in initial lock-off and for the elastic shortening losses that result from sequential tensioning. Normalized forces are generally used only to make group means computed for small samples more representative of population means. In theory, normalizing should greatly reduce the scatter of tendon force data. But, as is subsequently shown, reduction, if any, is modest.

Most of the normalizing adjustments (commonly referred to as factors but, as these are adders and not multipliers, this report uses the more correct term, adjustment) used in this report are as listed in TMI calculation C-1101-153-E410-046 (Reference 7.19). That calculation was prepared to provide a comprehensive listing of individual tendon force predictions and weighting factors for tendons that might be included in a future (at the time of its preparation) examination sample; it does not include tendons that had been previously examined. Normalizing adjustments not included in C-1101-153-E410-046 are as listed in the individual examination topical reports (References 7.1, 7.2, 7.4 and 7.6 through 7.13).

Measured and normalized forces documented for each examination are listed in Tables 2through 4 and plotted in Figures 1 through 13. Four separate plots, as discussed below, are provided for each of the three tendon groups (hoop, vertical and dome). Figure 13 plots measured forces in each of the common tendons.

The first of the four plots shows forces measured during each of the 10 consecutive 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 7.24, and extrapolated to T (years since the SIT) = 100.

The second shows both measured and normalized forces for tendons examined in surveillance years 10 through 40 and the (extrapolated) log-linear trend lines determined for both sets of forces. In all three cases (hoop, vertical, dome) the measured force trends are flatter (hoop and dome trends are slightly positive, a consequence of scatter) than those computed using forces measured during each of the 10 surveillances. This confirms the general industry finding that the rate of decrease in mean force with the logarithm of time is not linear but, in fact, falls off with time. Normalization should greatly

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[8] One tendon in each group that is included in consecutive examination samples.

reduce scatter. But considerable scatter is evident in the normalized force plots. This is a common phenomenon, probably due to variations in initial force (at the completion of tensioning operations) resulting from the greatly simplified normalizing process as well as thermal and other effects not accounted for in the computation of normalizing factors.

The third plot shows the forces measured in surveillance years 10 through 40 with both the (extrapolated) log-linear trend line and a curve (also extrapolated) showing the 95% lower confidence limit on the mean.

The fourth plot shows only common tendon measured forces with a log-linear trend line. In all cases (hoop, vertical, dome) common tendon plots exhibit relatively little scatter. Such scatter as there is can be attributed to limitations on measurement accuracy and the effect of end anchorage temperature on lift-off force.

4.1.1 Hoop Tendon Trends and Forecast

Hoop tendon forces measured during each of the 10 surveillances are listed in Table 2, which also includes normalization adjustments and normalized forces for tendons included in the year 10 through year 40 examinations. As previously noted, forces measured during the first 3 surveillances were not normalized because adjustments for these are not listed in the applicable surveillance reports (References 7.1, 7.2 and 7.4) and because adjustments for these and other tendons de-tensioned / re-tensioned prior to its issuance were not computed and included in Reference 7.19.

4.1.1.1 Hoop Tendon Mean Force Trend / All Data

The measured force data listed in Table 2 are shown in the Figure 1 plot which also includes the extrapolated log-linear trend of the mean and a line indicating the 1,108 kip minimum acceptable mean hoop tendon force. As the force data are scattered, it is difficult to visualize an actual trend. However, the plot does show that forces probably decrease less with Log (T) as T increases.

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 7.24, suggests that mean hoop tendon force is defined by the equation $F_H = 1{,}263.7 - 83.03 * \text{Log}_{10}(T)$, where T is, as earlier noted, years since the March 1974 SIT.

The trend line, which is based on the previously stated postulate, crosses the minimum line at T = 75.0 ($T = 10^{\alpha}$ where $\alpha = [1{,}263.7 - 1{,}108] / 83.03$) or, in March 2049, 15 years after the 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 (SIT anniversary date plus the one year tolerance allowed by IWL). The extrapolated trend line ordinate at T = 51 is 1,121.9 kip which is above the 1,108 kip minimum. This shows that even a very conservative trend, which incorporates the more rapid force decrease associated with the first few years following the end of tensioning operations, supports extension of the examination interval to 10 years. This is one of several factors that, considered together, provide justification for the proposed extension.

4.1.1.2 Hoop Tendon Mean Force Trend / From Surveillance Year 10

Figure 2 is a plot of both measured and normalized hoop tendon forces over the time period T = 10 to T = 100; the plot includes the associated trend lines as well as a line representing the lower limit on mean hoop tendon force.

Both sets of data exhibit scatter. This is expected for the measured force data since it includes the effects of both lock-off force and elastic shortening loss[9]. In theory, normalizing should greatly reduce scatter. But, as normalizing procedures are always simplified to facilitate the computations, these neglect significant factors such as increase in concrete modulus with time during the tensioning period, thermal effects and the inherent limitations associated with using only tensioning sequence to determine the response of a complex structure. Nonetheless, the neglected factors tend to average out over large data sets as is evidenced by the closely matched trend lines.

As noted above, the measured and normalized force trend lines are relatively close together. This suggests that either set of data can be used to compute a mean force trend. The difference in calculated mean values is about 15 kip at T = 1 and 10 kip at T = 100. The measured and normalized force trend lines cross T = 100 at 1,150.9 kip and 1,140.8 kip, respectively; both numbers are well above the lower limit of 1,108 kip.

One noticeable feature of the plot is the positive slope of the measured force trend. As it is not possible for mean force to increase with time over the long term (thermal effects can impact short term trends), the positive slope is concluded to be a consequence of data scatter. But, as the absolute values of both trend line slopes are small (between T = 10 and T = 100, the measured force trend increases by 6.09 kip and the normalized force trend decreases by 6.53 kip) it can also be concluded that the true trend is small. While the true trend is unknown, it can be bounded by confidence limits as is done in 4.1.1.3 below.

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[9] Elastic shortening loss is the loss of force in an already tensioned tendon as containment concrete is further compressed by tensioning of the remaining tendons. Tendons tensioned early in the sequence have the largest losses while those tensioned at the end of the sequence see little or no (the last tendon tensioned) loss. In some cases, the loss may be negative (force increase) due to the Poisson effect of subsequently tensioning tendons in another group; e.g., tensioning hoop tendons will increase force in previously tensioned vertical tendons.

The trend lines computed for the force data acquired after T = 10 are both much flatter than that the Figure 1 trendline constructed using all data. This confirms the observation, discussed in the first paragraph of 4.1.1.1, that the rate of change in mean force with the logarithm of time decreases with time. This also supports the conclusion that treating mean force as a log-linear function of time is conservative; i.e., the log-linear model significantly underestimates the level of mean force in the later years of plant operation.

Both the measured force and normalized force trend lines remain above the lower limit at T = 100. This provides further justification that the post-tensioning system examination interval can be extended to 10 years (with the next examination to be completed no later than March 2025 (T = 51) without compromising post-accident safety.

4.1.1.3 Hoop Tendon Mean Force Trend & LCL / From Surveillance Year 10

Figure 3 is a plot of measured hoop tendon forces over the time period T = 10 to T = 100; the plot includes the associated trend line and the 95% lower confidence limit (LCL) curve as well as a line representing the lower limit on mean hoop tendon force.

The 95% LCL, computed using the procedure developed in Reference 7.24, represents a statistically derived lower bound on true mean tendon force. Subject to the postulates that the force-time relationship is log-linear and that scatter is normally distributed about the trend line, the following can be concluded regarding the true mean hoop tendon force.

- There is a 95% probability that the true mean lies above the LCL curve.

In the present case, the LCL curve crosses the T = 100 ordinate line at about 1,114.9 kips, somewhat above the 1,108 kip lower limit, and is everywhere else greater than 1,114.9 kips.

The above statistical analysis, which shows that, at T = 100 years, the 95% LCL on hoop tendon mean force exceeds the 1,108 kip lower limit provides one more justification for the proposed extension of the post-tensioning system examination interval to 10 years.

4.1.1.4 Hoop Tendon Common Tendon Force Trend

Prior to the completion of the TMI year 15 surveillance in 1989 there was no requirement to designate and monitor common tendons. Regulatory Guide 1.35, Revision 2, issued in 1976, states that one tendon in each group sample 'may' be common across consecutive surveillances but provides no further guidance in this regard. Subsection IWL, incorporated into Section XI in 1992 requires one tendon in each group to be common across consecutive surveillances. TMI included requirements for common tendon monitoring in the year 20 surveillance[10] (performed in 1994) procedure.

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 and 5 TMI examinations 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. Therefore, common tendons were selected from the year 10 examination (the earliest examination that did not include a requirement to de-tension / re-tension all sample tendons) sample. This retains the IWL intent to ensure that common tendons are undisturbed.

Figures 1, 2 and 3 show that both measured and normalized forces exhibit a considerable degree of scatter which obscures meaningful trends. As a result, statistical analyses are needed to develop conclusions regarding future values of hoop tendon mean force. It is expected that the trend of measured forces in a single tendon will have significantly less scatter since these are affected only by the limitations of measurement accuracy and temperature variations. This expectation is confirmed by the forces recorded for common hoop tendon H62-26 as well as forces recorded for the common vertical and dome tendons as discussed in 4.1.2, 4.1.3 and 4.1.4 below.

Figure 4 is a plot of H62-26 measured forces and includes the log linear trend line. Scatter is seen to be small relative to that illustrated in Figures 1, 2 and 3.

Due to the limited scatter and the similarity between Figure 4 and the vertical and dome common tendon plots shown in Figures 8 and 12, the slope of the Figure 4 plot trend line, -25.77 kip per unit logarithmic interval, is considered to be a reasonable proxy for the slope of the hoop tendon true mean force trend. Using this slope as a proxy provides one more basis for a forecast of hoop tendon mean force.

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

$$F_{HM}(T) = F_{HM}(T_o) + b * [\mathrm{Log}_{10}(T) - \mathrm{Log}_{10}(T_o)]$$

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

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[10] Common hoop tendon H62-26 was examined during the year 15 surveillance. The vertical and dome common tendons were not examined at that time.

The force values plotted on Figure 3 cover a time range of 11.2 years to 39.6 years. The logarithmic mid-point of this range is at 21.1 years. Of the 39 force values plotted, 19, or effectively half, were measured prior to T = 21.1 years and the remainder after that time. Since Figures 1, 2 and 3 all indicate a slow decrease in mean force or relatively flat trend, it is reasonable to postulate that the true mean at T = 21.1 is quite close to the numerical average of all 39 (a relatively large sample) measured and / or normalized forces plotted on Figure 2. These averages, computed using the values listed in Table 2, are:

Measured force average, F_{MMean} = 1,146.9 kip

Normalized force average, F_{NMean} = 1,145.1 kip

The two averages are almost equal, differing by only 1.8 kip out of 1,146. Using the smaller of the two averages (rounded down to 1,145 kip) for the value of $F_{HM}(T_o)$, the common tendon force trend slope of -25.77 and T_o = 21.1 gives the following equation for true mean hoop tendon force.

$$F_{HM}(T) = 1{,}145.1 - 25.77 * [\mathrm{Log}_{10}(T) - \mathrm{Log}_{10}(21.1)]$$

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

$$F_{HM}(100) = 1{,}145.1 - 25.77 * [\mathrm{Log}_{10}(100) - \mathrm{Log}_{10}(21.1)] = 1{,}127.7 \text{ kip}$$

The above forecast mean exceeds the 1,108 kip lower limit by 19.7 kip. The forecast mean at T = 51 years, the latest date for completion of the next surveillance if the examination period is extended to 10 years, is:

$$F_{HM}(51) = 1{,}145.1 - 25.77 * [\mathrm{Log}_{10}(51) - \mathrm{Log}_{10}(21.1)] = 1{,}135.2 \text{ kip}$$

The above analysis provides further confirmation that the hoop tendon mean force will remain above the lower limit not only beyond the deadline for completion of the next surveillance but also well beyond T = 100 years.

4.1.1.5 Hoop Tendon Force Evaluation Summary and Conclusions (Non-SGR)

It is concluded, based on the statistical analyses and other evaluations discussed above, that mean hoop tendon force will remain above the 1,108 kip lower limit well beyond the expiration of the extended operating license. This conclusion is supported by the following.

a) The hoop tendon mean force trend, computed using all measured force data acquired during the 10 examinations conducted at TMI, does not cross the lower limit line until T (years since the March 1974 structural integrity test) = 75, or, almost 15 years after license expiration in April of 2034.

b) The hoop tendon mean force trend, computed using measured force data acquired during the year 10 and subsequent examinations, has a slight positive slope (+6.09 kips per unit logarithmic interval), a clear indication that the true slope of the trend is small and that the trend will remain above the lower limit until well beyond T = 100.

c) The hoop tendon mean force trend, computed using force data acquired during the year 10 and subsequent examinations and normalized to adjust for both original seating forces and the effect of stressing sequence, has a slight negative slope (-6.53 kips per unit logarithmic interval) but remains above the lower limit until well beyond T = 100.

d) The trend line slopes listed in a), b) and c) support the conclusion, based on visual assessment of the Figure 1 plot, that the rate of loss of mean force with the logarithm of time decreased with time.

e) The 95% lower confidence limit on hoop tendon mean force, computed using measured force data acquired during the year 10 and subsequent examinations, remains above the 1,108 kip minimum beyond T = 100.

f) Hoop tendon mean force, computed using the slope of the common tendon (H62-26) measured force trend and the average of all forces (measured and normalized force averages) recorded for the year 10 and later surveillances, remains above the lower limit until well beyond T = 100. Forecast mean force, conservatively determined using the smaller normalized force average, at T = 100 is 1,127.7 kip or 19.7 kip above the 1,108 kip minimum.

The results of the analyses and evaluations summarized in a) through f) above provide evidence that hoop tendon mean force will remain above the lower limit until at least March 2049 and, with a high degree of probability, until well after March 2074, 100 years after the SIT.

Therefore, the results of these analyses and evaluations justify the proposed extension of the interval between hoop tendon force measurements (hoop tendon force trends and forecasts are, as listed at the beginning of Part 4, one of the 8 examination categories considered in this report) to 10 years.

4.1.2 Vertical Tendon Trends and Forecast

Vertical tendon forces measured during each of the 10 surveillances are listed in Table 3, which also includes normalization adjustments and normalized forces for tendons included in the year 10 through year 40 examinations. As previously noted, forces measured during the first 3 surveillances were not normalized.

4.1.2.1 Vertical Tendon Mean Force Trend / All Data

The measured force data listed in Table 3 are shown in the Figure 5 plot which also includes the extrapolated log-linear trend of the mean and a line indicating the 1,033 kip minimum acceptable vertical tendon mean force. As the force data are scattered, it is difficult to visualize an actual trend. However, the plot does show that forces probably decrease less with Log (T) as T increases.

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 suggests that mean vertical tendon force is defined by the equation $F_V = 1{,}294.8 - 72.11 * \mathrm{Log}_{10}(T)$, where T is, as earlier noted, years since the March 1974 SIT.

Mean force shown by the trend line at T = 100 is 1,150.6 kip, 117.6 kip above the 1,033 kip lower limit. This provides evidence that vertical tendon mean force will be acceptable throughout the period of the extended license and, that the trend supports the proposed extension of examination interval to 10 years.

4.1.2.2 Vertical Tendon Mean Force Trend / From Surveillance Year 10

Figure 6 is a plot of both measured and normalized vertical tendon forces over the time period T = 10 to T = 100; the plot includes the associated trend lines as well as a line representing the lower limit on vertical tendon mean force.

Both sets of data exhibit scatter. This is expected for the measured force data since it includes the effects of both lock-off force and elastic shortening loss. In theory, normalizing should greatly reduce scatter. But, as normalizing procedures are always simplified to facilitate the computations, these neglect significant factors such as increase in concrete modulus with time during the tensioning period, thermal effects and the inherent limitations associated with using only tensioning sequence to determine the response of a complex structure. Nonetheless, the neglected factors tend to average out over large data sets as is evidenced by the closely matched trend lines.

As noted above, the measured and normalized force trend lines are relatively close together. This suggests that either set of data can be used to compute a mean force trend. The measured and normalized force trend lines cross T = 100 at 1,188.3 kip and 1,193.7 kip, respectively; both numbers more than 150 kip above the lower limit of 1,033 kip.

One noticeable feature of the plot is the positive slope of the normalized force trend. As it is not possible for mean force to increase with time over the long term (thermal effects can impact short term trends), the positive slope is concluded to be a consequence of data scatter. But, as the absolute values of both trend line slopes are small (between T = 10 and T = 100, the measured force trend decreases 14.35 kip and the normalized force trend increases by 6.70 kip) it can also be concluded that the true trend is small. While the true trend is unknown, it can be bounded by confidence limits as is done in 4.1.2.3 below.

The trend lines computed for the force data acquired after T = 10 are both much flatter than that computed for all data and shown in Figure 5. This confirms the observation, discussed in the first paragraph of 4.1.2.1, that the rate of change in mean force with the logarithm of time decreases with time. This also supports the conclusion that treating mean force as a log-linear function of time is conservative; i.e., the log-linear model significantly underestimates the level of mean force in the later years of plant operation.

Both the measured force and normalized force trend lines remain more than 150 kip above the lower limit at T = 100. This provides further justification for extension of the post-tensioning system examination interval to 10 years (with the next examination to be completed no later than March 2025 (T = 51) without compromising post-accident safety.

4.1.2.3 Vertical Tendon Mean Force Trend & LCL / From Surveillance Year 10

Figure 7 is a plot of measured vertical tendon forces over the time period T = 10 to T = 100; the plot includes the associated trend line and the 95% lower confidence limit (LCL) curve as well as a line representing the lower limit on mean vertical tendon force.

The LCL curve crosses the T = 100 ordinate line at 1,156.9 kips, well above the 1,033 kip lower limit.

The above statistical analysis, which shows that, at T = 100 years, the 95% LCL on vertical tendon mean force exceeds the 1,033 kip lower limit by a wide margin, provides one more justification for the proposed extension of the post-tensioning system examination interval to 10 years.

4.1.2.4 Vertical Tendon Common Tendon Force Trend

Figures 5, 6 and 7 show that both measured and normalized forces exhibit a considerable degree of scatter which obscures meaningful trends. As a result, statistical analyses are needed to develop conclusions regarding future values of vertical tendon mean force. As noted in the above hoop tendon performance discussion, it is expected that the trend of measured forces in a single tendon will have significantly less scatter since these are affected only by the limitations of measurement accuracy and temperature variations. This expectation is confirmed by the forces recorded for common vertical tendon V-32 as well as forces recorded for the common hoop and dome tendons as discussed in 4.1.1, 4.1.3 and 4.1.4.

Figure 8 is a plot of V-32 measured forces and includes the log linear trend line. Scatter is seen to be small relative to that illustrated in Figures 5, 6 and 7.

Due to the limited scatter and the similarity between Figure 8 and the hoop and dome common tendon plots shown in Figures 4 and 12, the slope of the Figure 8 plot trend line, -39.34 kip per unit logarithmic interval, is considered to be a reasonable proxy for the slope of the vertical tendon true mean force trend. Using this slope as a proxy provides one more basis for a forecast of vertical tendon mean force.

If vertical tendon mean force is conservatively postulated to follow a log-linear trend rather than a flattening 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 force values plotted on Figures 8 cover a time range of 11.2 years to 39.6 years. The logarithmic mid-point of this range is at 21.1 years. Of the 33 force values plotted, 16, or effectively half, were measured prior to T = 21.1 years and the remainder after that time. Since Figures 5, 6 and 7 all indicate a slow decrease or relatively flat trend in mean force, it is reasonable to postulate that the true mean at T = 21.1 is quite close to the numerical average of all 33 (a relatively large sample) measured and / or normalized forces plotted on Figure 6. These averages, computed using the values listed in Table 3, are:

Measured force average, F_{MMean} = 1,197.7 kip

Normalized force average, F_{NMean} = 1,189.3 kip

The two averages are quite close, differing by only 8.4 kip out of a nominal 1,200. Using the smaller of the two averages for the value of $F_{VM}(T_o)$, the common tendon force trend slope of –39.34 and T_o = 21.1 gives the following equation for true mean vertical tendon force.

$$F_{VM}(T) = 1.189.3 – 39.34 * [Log_{10} (T) – Log_{10} (21.1]$$

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

$$F_{VM}(100) = 1{,}189.3 - 39.34 * [\text{Log}_{10}(100) - \text{Log}_{10}(21.1)] = 1{,}162.7 \text{ kip}$$

The 1,162.7 kip forecast mean exceeds the 1,033 kip lower limit by 129.7 kip.

The above analysis provides further confirmation that the vertical tendon mean force will remain above the lower limit not only beyond the deadline for completion of the next surveillance but also well beyond T = 100 years.

4.1.2.5 Vertical Tendon Force Evaluation Summary and Conclusions (Non-SGR)

It is concluded, based on the statistical analyses and other evaluations discussed above, that mean vertical tendon force will remain above the 1,033 kip lower limit well beyond the April 2034 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 10 examinations conducted at TMI, remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,150.6 kip or 114 kip above the 1,033 kip lower limit. Slope of the trend line, see discussion in c), is -72.11 kip per unit logarithmic interval.

b) The vertical tendon mean force trend, computed using measured force data acquired during the year 10 and subsequent examinations, also remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,188.3 kip or 155.3 kip above the 1,033 kip lower limit. Slope of the trend line, see discussion in c), is –14.35 kip per unit logarithmic interval.

c) The slopes of the trend lines shown in a) and b) confirm the conclusion, based on visual assessment of the Figure 5 plot, that the rate of loss of mean force with the logarithm of time decreases with time.

d) The vertical tendon mean force trend, computed using force data acquired during the year 10 and subsequent examinations and normalized to adjust for both original seating forces and the effect of stressing sequence, has a small positive slope (6.70 kips per unit logarithmic interval). Mean force cannot increase over the long term so the positive slope is concluded to be the result of scatter. However, the slope is relatively small, which provides added confirmation that decrease in true mean force with time is also small.

e) The 95% lower confidence limit on vertical tendon mean force, computed using measured force data acquired during the year 10 and subsequent examinations, remains above the 1,033 kip minimum beyond T = 100. The forecast LCL at T = 100 is 1,156.9 kip or 123.9 kip above the 1,033 kip lower limit.

f) Vertical tendon mean force, computed using the slope of the common tendon (V-32) measured force trend and the average of all forces (measured and normalized force averages) recorded for the year 10 and later surveillances, remains above the lower limit until well beyond T = 100. The forecast mean force, conservatively determined using the lower normalized force mean, at T = 100 is 1,162.7 kip or 129.7 kip above the 1,033 kip lower limit.

The results of the analyses and evaluations summarized in a) through f) above provide evidence that vertical tendon mean force will remain above the lower limit until well after T = 100 (100 years after the SIT) or, for more than 40 years beyond the April 2034 expiration of the extended operating license.

Therefore, the results of these analyses and evaluations justify the proposed extension of the interval between vertical tendon force measurements to 10 years.

4.1.3 Dome Tendon Trends and Forecast

Dome tendon forces measured during each of the 10 surveillances are listed in Table 4, which also includes normalization adjustments and normalized forces for tendons included in the year 10 through year 40 examinations. As previously noted, forces measured during the first 3 surveillances were not normalized.

4.1.3.1 Dome Tendon Mean Force Trend / All Data

The measured force data listed in Table 4 are shown in the Figure 9 plot which also includes the extrapolated log-linear trend of the mean and a line indicating the 1,064 kip minimum acceptable dome tendon mean force. As the force data are quite scattered, it is difficult to visualize an actual trend. However, the plot does show that forces probably decrease less with Log (T) as T increases.

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 suggests that mean dome tendon force is defined by the equation $F_D = 1,267.6 - 81.63 * \text{Log}_{10}(T)$, where T is, as earlier noted, years since the March 1974 SIT.

Mean force shown by the trend line at T = 100 is 1,104.3 kip, 40.3 kip above the 1,064 kip lower limit. This provides clear evidence that dome tendon mean force will be acceptable throughout the period of the extended license and, that the trend supports the proposed extension of examination interval to 10 years.

4.1.3.2 Dome Tendon Mean Force Trend / From Surveillance Year 10

Figure 10 is a plot of both measured and normalized dome tendon forces over the time period T = 10 to T = 100; the plot includes the associated trend lines as well as a line representing the lower limit on dome tendon mean force.

While both sets of data exhibit scatter, the normalized forces are in contrast with the hoop and vertical normalized forces, noticeably less scattered. This may result from the normalizing procedure working better on the doubly curved surface.

The measured and normalized force trend lines are relatively close together. This suggests that either set of data can be used to compute a mean force trend. The measured and normalized force trend lines cross T = 100 at 1,106.1 kip and 1,131.9 kip, respectively; both numbers are well above the lower limit of 1,064 kip.

The trend lines computed for the force data acquired after T = 10 are not greatly different from that computed for all data and shown in Figure 9. This is in contrast to the hoop and vertical tendon cases, discussed above, which exhibit a significant decrease in trend line slope when the 1, 3 and 5 year data are excluded. However, this does not alter the conclusion that dome tendon mean force will remain above the required minimum of 1,064 kip through the end of the current operating license.

Both the measured force and normalized force trend lines remain well above (42.1 and 67.9 kip respectively) the lower limit at T = 100. This provides further justification for extension of the post-tensioning system examination interval to 10 years (with the next examination to be completed no later than March 2025 (T = 51) without compromising post-accident safety.

4.1.3.3 Dome Tendon Mean Force Trend & LCL / From Surveillance Year 10

Figure 11 is a plot of measured dome tendon forces over the time period T = 10 to T = 100; the plot includes the associated trend line and the 95% lower confidence limit (LCL) curve as well as a line representing the lower limit on dome tendon mean force.

The LCL curve crosses the 1,064 kip lower limit at T > 70 (years after the SIT) and is more than 10 kip above the lower limit at T = 60 when the current operating license expires.

As the LCL remains above the dome tendon mean force lower limit throughout the period of extended operation, the above statistical analysis provides one more justification for the proposed extension of the post-tensioning system examination interval to 10 years.

4.1.3.4 Dome Tendon Common Tendon Force Trend

Figures 9, 10 & 11 show that both measured and normalized forces exhibit a considerable degree of scatter which tends to obscure meaningful trends. As a result, statistical analyses are needed to develop conclusions regarding future values of dome tendon mean force. As previously discussed, it is expected that the trend of measured forces in a single tendon will have significantly less scatter since these are affected only by the limitations of measurement accuracy and temperature variations. This expectation is confirmed by the forces recorded for common dome tendon D-225 as well as forces recorded for the common hoop and vertical tendons as discussed in 4.1.1, 4.1.2 and 4.1.4.

Figure 12 is a plot of D-225 measured forces and includes the log linear trend line. Scatter is seen to be quite small relative to that illustrated in Figures 9, 10 & 11.

Due to the limited scatter and the similarity between Figure 12 and the hoop and vertical common tendon plots shown in Figures 4 and 8, the slope of the Figure 12 plot trend line, -47.18 kip per unit logarithmic interval, is considered to be a reasonable proxy for the slope of the dome tendon true mean force trend. Using this slope as a proxy provides one more basis for a forecast of dome tendon mean force.

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

$$F_{DM}(T) = F_{DM}(T_o) + b * [\text{Log}_{10}(T) - \text{Log}_{10}(T_o)]$$

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

As 14 of the 23 dome force measurements were recorded between T = 25.5 and T = 39.6, the numerical average of all 23 should be less than that at T = 21.1, the value of T_o used in 4.1.1.4 and 4.1.2.4 to forecast hoop and vertical common tendon mean forces. Therefore, using T_o = 21.1 in the dome tendon mean force forecast, as is done below, is conservative.

The numerical averages of the measured and normalized dome tendon forces listed for the year 10 through year 40 surveillances in Table 4, and plotted in Figure 10, are:

Measured force average, F_{MMean} = 1,155.8 kip

Normalized force average, F_{NMean} = 1,172.7 kip

The two averages are reasonably close as expected. Using the smaller of the two averages (that computed for measured forces) for the value of $F_{DM}(T_o)$, the common tendon force trend slope of –47.18 and $T_o = 21.1$ gives the following equation for true mean vertical tendon force.

$$F_{DM}(T) = 1{,}155.8 - 47.18 * [\text{Log}_{10}(T) - \text{Log}_{10}(21.1)]$$

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

$$F_{DM}(100) = 1{,}155.8 - 47.18 * [\text{Log}_{10}(100) - \text{Log}_{10}(21.1)] = 1{,}123.9 \text{ kip}$$

The 1,123.9 kip forecast mean exceeds the 1,064 kip lower limit by 59.9 kip.

The above analysis provides further confirmation that the dome tendon mean force will remain above the lower limit not only beyond the deadline for completion of the next surveillance but also well 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 1,064 kip lower limit well beyond the April 2034 expiration of the extended operating license. This conclusion is supported by the following.

a) The dome mean force trend, computed using all measured force data acquired during the 10 examinations conducted at TMI, remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,104.3 kip or 40.3 kip above the 1,064 kip lower limit. Slope of the trend line, see discussion in d), is -81.63 kip per unit logarithmic interval.

b) The dome tendon mean force trend, computed using measured force data acquired during the year 10 and subsequent examinations, also remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,106.1 kip or 42.1 kip above the 1,064 kip lower limit. Slope of the trend line, see discussion in d), is –82.40 kip per unit logarithmic interval.

c) The dome tendon mean force trend, computed using force data acquired during the year 10 and subsequent examinations and normalized to adjust for both original seating forces and the effect of stressing sequence remains above the lower limit until well beyond T = 100. The forecast mean force at T = 100 is 1,131.9 kip or 67.9 kip above the 1,064 kip lower limit. Slope of the trend line, see discussion in d), is –67.71 kip per unit logarithmic interval.

d) The slopes of the trend lines shown in a), b) and c) are, in contrast to the hoop and vertical tendon trend lines, not significantly different. However, this does not alter the conclusion that dome tendon mean force will remain above the 1,064 kip minimum until the expiration of the current operating license.

e) The 95% lower confidence limit on dome tendon mean force, computed using measured force data acquired during the year 10 and subsequent examinations, remains above the 1,064 kip minimum until T > 70 or, more than 10 years following the expiration of the extended operating license and >19 years beyond the next scheduled examination.

f) Dome tendon mean force, computed using the slope of the common tendon (D-225) measured force trend and the average of all forces (measured and normalized force averages) recorded for the year 10 and later surveillances, remains above the lower limit until well beyond T = 100. The forecast mean force, conservatively determined using measured, rather than normalized forces, at T = 100 is 1,123.9 kip or 59.9 kip above the 1,064 kip lower limit.

The results of the analyses and evaluations summarized in a) through f) above provide evidence that dome tendon mean force will remain above the lower limit at least until T = 70 (years after the SIT) and, for 10 years beyond the April 2034 expiration of the extended operating license.

Therefore, the results of these analyses and evaluations justify the proposed extension of the interval between dome tendon force measurements to 10 years.

4.1.4 Common Tendon Trend Pattern

Figure 13 is a plot of hoop, vertical and dome common tendon forces with trend lines. As previously discussed, forces plotted for each of the common tendons exhibit relatively little scatter about the trend lines. In addition, the slopes of the 3 trend lines fall within a narrow band of -25.77 to -47.18 kip per unit logarithmic interval which is expected since the rates of loss for the hoop, vertical and dome tendons are determined by the same material behaviors (steel stress relaxation, concrete shrinkage and concrete creep).

Given the low scatter and the narrow band into which the trend line slopes fall, it is reasonable to postulate that time dependent loss of common tendon force can be used to represent the time dependent loss of the associated group mean over time. This suggests that the mean forces computed using this postulate may represent the best estimate of the true means.

Common tendon trends are determined using data that has minimal scatter about the computed trend lines. As scatter is minimal, computed trends are expected to be quite close to the true trends which supports the use of common tendon trends as one of several bases for assessing the state of containment pre-stress.

4.1.5 Tendon Mean Force Trend Summary and Conclusions

The trend of the mean force was analyzed separately for the hoop, vertical and dome tendon groups. Each analysis included the following 5 computations, all based on the postulate that mean force varies linearly with the logarithm of time. SGR tendons were excluded from the analyses as these are covered in a separate subsection of this report.

- Trend based on measured forces recorded during all 10 of the originally scheduled surveillances (the 'all data' case).
- Trend based on measured forces recorded during the 10th year and subsequent surveillances.
- Trend based on normalized values of the forces recorded during the 10th year and subsequent surveillances.
- 95% lower confidence limit (LCL) on the trend of measured forces recorded during the year 10 and subsequent surveillances.
- Trend using the slope of the common tendon trend.

Of the 15 trends / LCL's evaluated, all but two show the trend line or LCL curve remaining above the group lower limit through T = 100 (years after the SIT), a time that extends well beyond the range of interest but used because it represents a major gridline on a logarithmic plot. The remaining two, the hoop tendon all data case trend line and the dome tendon LCL curve, cross the lower limit after T = 70 years which is, itself, 10 years after the April 2034 expiration of the extended operating license.

The trends of common tendon forces were separately evaluated. Common tendon forces exhibit relatively little scatter about the log-linear trends. And the slopes of the 3 trend lines fall within a relatively narrow range, as these should since the mean force in each group is affected by the same time dependent material properties (steel relaxation, concrete shrinkage and concrete creep). This suggests that common tendon rate of loss is probably the best proxy for group mean force rate of loss.

Based on the above summary, it is concluded that:

- There is essentially nothing to be gained by continuing to monitor pre-stressing forces at the 5 year intervals specified by Subsection IWL; performing pre-stressing measurements no later than March, 2025 will maintain and acceptable level of quality and safety.

- The proposed extension of the interval to 10 years is fully supported by the analysis of tendon mean force trends.

4.2 End Anchorage Condition

During each of the surveillances, end anchorage areas were visually examined for evidence of corrosion, presence of free water, discontinuous wires, damage to / distortion of load bearing components and cracks in concrete adjacent to bearing plates. Results of these examinations are summarized in 4.2.1 through 4.2.5.

4.2.1 Corrosion

No active corrosion was observed on anchor heads, shims or wires. With the exception noted below, observed corrosion was limited to light rust identified as category 2 or, alternatively, category B.

During the year 5 surveillance, 20% of the button heads at the upper end of V-138 were observed to have category 4 corrosion (heavy rust; 10 – 20 passes of 100 grit sand paper to remove down to bright metal) and the remaining button heads found to have category 2. The surveillance report does not include an evaluation of the condition. Re-examination during the year 10 surveillance downgraded the category 4 corrosion to category 3 but also included no evaluation. As nothing similar has been observed at other anchorages, this is considered a singular event, cause unknown, and not indicative of a more widespread condition.

Active corrosion was noted on the exposed areas of some bearing plates. Some bearing plate corrosion involved light pitting but none resulted in significant loss of metal. Bearing plate corrosion results from loss of coating and is one focus of the containment exterior visual examination. As such, it will continue to be monitored at 5 year intervals. Cleaning and recoating of bearing plates will be done at the direction of the Responsible Engineer.

4.2.2 Free Water

Except as discussed below, no free water was found in tendon end caps, on tendon end anchorage hardware or on extracted wires during any of the 11 (including the augmented examination of SGR tendons in 2010) surveillances.

The sole reported instance of free water was the consequence of a gap between the end cap and bearing plate at the top of V-86. The gap, which was concluded to be the result of incorrect cap replacement during the 1975 (year 1) surveillance and found during the year 25 surveillance, allowed entry of water into the top end of this vertical tendon. Water travelled down the tendon duct, accumulating at the bottom end; approximately 2.5 gallons accumulated in the bottom cap. The condition was corrected when found and the tendon refilled with new P-4 formulation CPM. The presence of water caused no observable corrosion on tendon end anchorage hardware or on the wire removed from the tendon for visual examination and testing. Reference 7.9 includes a detailed description of the findings and corrective action taken.

Water collected at the lower end of V-86 was analyzed to determine pH. The pH determined by this analysis was 11.67 as reported in Reference 7.9

Water accumulation at V-86 is considered a singular event and not indicative of a more widespread condition.

4.2.3 Discontinuous Wires

Only 6 discontinuous wires (broken wires and those missing button heads) not documented at the time of time of initial tensioning or re-tensioning have been reported. These are listed below.

- Year 1 Surveillance – One broken wire was found in vertical tendon V-27. The wire was removed in two pieces. No evaluation of the break, other than a brief statement that it appeared to be the result of a fabrication defect, was provided in the surveillance report.
- Year 1 Surveillance – One button head was found to be missing at the Buttress 3 end of hoop tendon H13-46. The affected wire could not be identified at the Buttress 1 end. No evaluation of the condition was provided.
- Year 10 Surveillance - One button head was found to be missing at one end of hoop tendon H13-46. The affected wire was not identified at the opposite end. No evaluation of the condition was provided.
- Augmented (2010) Surveillance - Re-tensioned SGR vertical tendon V-118 was found to have 2 broken wires. These were concluded to have been damaged by a singular event during re-tensioning. This is discussed in more detail in 4.5.2 below. Reference 7.25 provides a comprehensive evaluation of the breaks.
- Year 40 Surveillance – The bottom end of new SGR V-136 was found to have one missing button head. CPM in the bottom end cap was heated / strained in an effort to find the button head; it was not found. The opposite end of the wire was not identified. AR 01567224, attached to the year 40 surveillance report (Reference 7.13) provides

a comprehensive evaluation of the condition which is considered to be singular and not indicative of a more widespread pattern of missing button heads.

4.2.4 Load Bearing Components Damage / Distortion

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

4.2.5 Concrete Cracking Adjacent to Bearing Plates

Surface shrinkage cracks radiating out from the corners of bearing plates are common and normally not documented if crack width is <0.010 inches. Other than in ring girder pocket areas, as discussed in the ensuing paragraph, only one surveillance sample tendon anchorage area crack having a width greater than 0.01 inches has been reported. The year 25 surveillance report (Reference 7.9) identified a 2.5 foot long by 0.013 inch wide crack radiating out from a hoop tendon H46-30 bearing plate. The crack was re-measured during the year 30 surveillance and found to be unchanged.

Dome pocket areas contain numerous stress risers and thin sections of concrete that induce shrinkage cracking. Many 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 have no structural significance.

4.2.6 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 2013) and show no trends of deteriorating condition.

There have been no findings of active corrosion on anchor heads, shims and wire. Minor active corrosion on bearing plates is in exposed areas that are regularly examined in accordance with IWL-2510 and is addressed through maintenance procedures. Inactive corrosion is, with the one exception noted in 4.2.1, limited to category 2 (minor light rust). The single exception is considered unique and not indicative of a more widespread condition.

No free water has been found in end caps, on anchor heads, on shims or on wires with the unique exception of V-86 as discussed in 4.2.2 above. No corrosion was found on V-86 hardware items exposed to the water within the end caps and ductwork.

Only 6 discontinuous wires not previously reported have been found. These represent only a miniscule fraction of the ~108,000 wires (643 tendons @ 169 wires) comprising the TMI tendons.

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

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

Considering the above, it can be concluded that the end anchorage conditions are stable and unlikely to change significantly before the March 2034 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.

4.3 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.

Table 5 with Figure 14 and Table 6 with Figure 15 summarize the results of the tests. These include the results of tests on specimens from the re-tensioned (but, not new) SGR tendons that were de-tensioned during the 2010 augmented surveillance (at T = 36.6 years) and the year 40 surveillance. Re-tensioned tendons V-118 and H51-40 were de-tensioned for wire removal during the augmented and year 40, respectively, surveillances.

4.3.1 Wire Visual Examination and Condition

The entire length of each extracted wire was visually examined for signs of damage and / or corrosion. None of the 33 wires had signs of damage and, with few exceptions, no corrosion. Such corrosion as was observed consisted of Category B, or 2, defined in the examination procedures as small areas of light, tightly adhering rust. As none of the surveillance reports indicated the presence of water along the length of the extracted wires, it is concluded that the Category B (or 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, in all likelihood, before the completed tendons were dipped in a protective coating bath at the fabrication facility.

As no damage and neither active nor unacceptable levels of early corrosion have been found on the wires extracted during the 11 surveillances completed to date, it is concluded that TMI tendon wire damage / corrosion should not be a concern over the remaining life of the plant.

4.3.2 Wire Tensile Strength

Table 5 lists the ultimate tensile strength found for the three test specimens cut from each extracted wire, the mean of the 3 UTS values (Group Mean) and the mean of all UTS values listed for the examination year (Exam Mean). Figure 14 is a log-time based plot showing, for each examination year, the examination mean UTS and the maximum & minimum UTS values. The tabulated and plotted data have the following characteristics.

- Each of the 99 specimens has an ultimate tensile strength greater than the specified 240 ksi minimum.
- 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.
- Group means shown for a given exam year tend to have a greater variation which probably results from minor variations in wire properties. Such variations could be the result of small differences in heat chemistry, minor wear of drawing line equipment (dies, etc.) and fabrication conditions / procedures.
- 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 99 UTS values exceed the 240 ksi lower limit, as there is no trend to the data plotted on Figure 14 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.

4.3.3 Wire Elongation at Failure

Table 6 lists the elongation at failure, EF, documented for the three test specimens cut from each extracted wire, the mean of the 3 EF values (Group Mean) and the mean of all EF values listed for the examination year (Exam Mean). Figure 15 is a log-time based plot showing, for each examination year, the examination mean EF and the maximum & minimum EF values. The tabulated and plotted data have the following characteristics.

- With 5 exceptions (discussed below), the specimens had an elongation at failure greater than the 4% lower limit.
- All elongations documented during the year 1 and year 10 through year surveillance 40 reports are in the 4.0% to 6.0% range. The 14 values outside this range were found during the year 3 (5 < 4.0%) and year 5 (all 9 > 6.0%) surveillances.
- Group means computed for the year 1 and year 10 through year 40 surveillance results range from 4.3% to 5.9%, with 23 of the 27 computed means falling between 5.0% and 5.9%.
- Exam means computed for the year 10 through year 40 surveillances fell in the range of 5.0% to 5.6%
- As shown by Figure 15, there is no apparent trend to the elongations. The year 1 and year 40 surveillance exam means, 4.9% and 5.4% respectively, differ by only 0.5%. The year 3 surveillance elongations have the lowest mean, 4.4%, and the year 5 surveillance elongations have the highest, 6.9%.

The only elongations falling below the 4% lower limit are the 5 documented for tests done during the year 3 surveillance. Two hoop tendon wire specimens, two vertical tendon wire specimens and one dome tendon wire specimen are documented as failing at elongations below 4%. Given that the low values are distributed across the three tendons from different groups, that the spread of elongations documented for each wire is quite large (refer to Table 6) and that recorded elongations can be misleading if measurements are not done according to appropriate and definitive procedures, it is deemed likely that the elongations documented for the year 3 surveillance tests are not meaningful.

As there is no pattern, i.e., no trend for elongation at failure to increase or decrease over time, it is concluded that much of the variation can be attributed to variations in testing procedures / equipment from examination to examination. Several of the early tests were done using field-built assemblies (as shown in the year 10 surveillance report, Reference 7.6) and 100 inch specimens while the later tests were done by laboratories that followed ASTM requirements for testing machines, rates of loading, measurement procedures and 10 inch gage length specimens. This alone can account for significant differences. Other differences can be due to variations in heat chemistry, minor wear of drawing line equipment (dies, etc.) and fabrication conditions / procedures.

Given the differences in testing equipment and procedures, it is reasonable to discount the results of the year 3 and year 5 surveillances. If this is done, the remaining elongations fall into a reasonably tight grouping with no discernible trend.

Based on the above discussion, it is concluded that wire ductility does not change over time and that it continues to meet 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 ongoing ductility.

4.3.4 Wire Visual Examination / 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 33 wires extracted from designated hoop, vertical and dome tendons between 1975 and 2013 has uncovered no evidence of damage, active corrosion or an unacceptable level of pre-existing (prior to tendon duct filling) corrosion. Wires examined / tested include the one extracted from tendon V-86 in 1999. This tendon was added to the originally designated sample when a gap between the upper end cap flange and the bearing plate was observed. As the gap allowed water to enter the tendon duct, the decision was made to de-tension the tendon and remove a wire for examination and testing.

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

4.4 Corrosion Protection Medium Testing

Corrosion protection medium (CPM) was collected at the ends[11] of sample tendons during each of the 10 surveillances addressed in this section of the report; testing of CPM collected during the augmented surveillance in 2010 is covered in 4.5 below. Each CPM sample was tested for the presence of three corrosive ions (chlorides, nitrates and

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[11] During the year 3 surveillance, samples of vertical tendon CPM were taken from the drums of material drained from the ducts rather than the tendon end anchorage areas.

sulfides) and, except in the case of the year 1 surveillance, for absorbed water content. A test for neutralization number was added beginning with the year 20 surveillance. 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 below. Conclusions and recommendations for future testing are included in 4.4.4.

- All tested samples met the Table IWL-2525-1 10 ppm upper limit on chloride, nitrate and sulfide ion concentration.
- All tested samples met the Table IWL-2525-1 10% upper limit on water content.
- With 3 exceptions, 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 below).

4.4.1 Corrosive Ion Concentrations

Laboratory reports listing corrosive ion concentrations determined for CPM samples do not show consistent trends. Typical reports show concentrations of one or more ions to be less than (what are presumed to be) threshold of resolution values applicable to the analytical procedures used by the laboratory at the time. In these cases, actual concentrations are not known but are below the threshold values listed.

Table 7 lists the following summary data applicable to the ion concentrations documented in the reports covering each of the originally scheduled surveillances (augmented surveillance results are discussed in subsection 4.5). All table entries are rounded to the nearest 0.1 ppm for consistency[12].

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[12] The tables in the various surveillance reports show concentrations / thresholds to the nearest 1 ppm, 0.1 ppm, 0.01 ppm or 0.001 ppm depending on the year and type of ion. As the upper

- 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 30 surveillance year / ion type groupings, 17[13] list ion concentrations as less than (what is presumed to be) the threshold of resolution; actual concentrations are unknown but below the thresholds shown. Only 3 of the maximum values shown in the table are close to the 10 ppm upper limit; 9.2 ppm and 8.9 ppm chlorides as shown on the year 10 and year 20, respectively, surveillance lines and 9.8 ppm nitrates as shown on the year 25 surveillance line.

During a surveillance, CPM is collected for samples and packaged under field conditions; as a result, it is possible for samples to become contaminated, e.g., with drops of sweat, before being sealed for shipment to the laboratory. Chloride contamination is, considering the field environment, probably more likely than nitrate or sulfide contamination. Therefore, it is possible that the higher chloride concentrations reported represent the presence of some contamination. And, considering the environment of the CPM prior to being sampled, it is difficult to postulate a reasonable scenario for contaminants entering the bulk medium during original manufacture, shipping, injection or after it is in place in the tendon ducting. This leads to the conclusion that reported chloride concentrations probably do not represent a characteristic of the bulk medium.

The nitrate tests are noted in the laboratory reports as difficult to perform and 2 (one each for year 5 and year 25 samples) have been repeated with significant reductions in the concentrations found. Therefore, many of the higher nitrate values reported by the laboratories may err on the high side.

Sulfide concentrations listed in Table 7 are relatively low; the largest surveillance year maximum value listed is 3.2 ppm or 32% of the Table IWL-2525-1 limit and largest mean is 1.5 ppm.

None of the Table 7 columns indicate a trend. The pattern of maxima, means and minima suggests that the fluctuations are more a function of laboratory practice than variations in ion concentrations. For example, both nitrate and sulfide concentrations are uniformly higher in surveillance year 5, uniformly lower in years 10 and 15 and uniformly higher

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limit applicable to all 3 ions is 10 ppm, 0.1 ppm (1% of the limit) provides adequate resolution for analysis and evaluation of the ion concentration data.

[13] Includes year 40 chloride data which is listed as either 0.5 ppm (19 values) or <0.5 ppm (19 values).

again in year 25. This cannot be accounted for by any reasonable sampling or contamination scenario.

Considering the above discussion of ion concentration patterns, the fact that the values reported for the 91 samples tested in conjunction with the year 30, 35 and 40 surveillances are all very low (1 ppm max and 86 values at or below 0.5 ppm) and the lack of significant or active corrosion on end anchorage hardware and extracted wires, it is concluded that the presence of corrosive ions in CPM is not a concern.

In addition, it is concluded that ongoing improvements in laboratory practices have resulted in better testing controls and, as a result, that the recent (year 30 and later) test data, rather than that reported for earlier surveillance years, should be considered more representative of the true CPM condition.

4.4.2 Water Content

Beginning with the year 3 surveillance in 1977, CPM samples were checked for absorbed water content, reported as a percent of sample dry weight. Results are summarized below. All reported water contents are below the 10% upper limit.

- Year 3 – All 13 samples below the indicated detection threshold of 0.1%.
- Year 5 - All 23 samples below the indicated threshold of 0.5%.
- Year 10 – Actual values, shown for all 29 samples, ranged from 0.05% to 0.34%.
- Year 15 – 21 samples below the indicated 0.10% threshold; 11 between 0.09%[14] and 0.30%.
- Year 20 – 16 samples below the indicated 0.10% threshold; 5 at 0.10%; 1 at 0.19%.
- Year 25 - 32 samples below the indicated 0.10% threshold; 5 at 0.10%; 9 between 0.20% and 0.30%; 1 at 4.10%.
- Year 30 - 18 samples below the indicated 0.10% threshold; 7 between 0.14% and 0.31%; 1 at 0.64%; 1 at 3.7%.
- Year 35 - 19 samples below the indicated 0.10% threshold; 6 between 0.15% and 0.50%; 1 at 0.58%.
- Year 40 - 31 samples below the indicated 0.10% threshold; 2 at 0.10%; 5 between 0.19% and 0.31%.

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[14] Value below the indicated threshold; no explanation provided in the surveillance report.

Over the course of 9 surveillances, 257 samples were checked for absorbed water content. Only 4 contained more than 0.50% (the limit of resolution indicated for the year 5 surveillance) water. Of these, 2 contained less than 1% (0.58%, one 0.64%). Of the remaining two, discussed below, one contained 3.7% and the other, 4.10%.

During the year 25 surveillance a CPM sample was collected at the bottom end of tendon V-86[15] following the discovery of a gap under the upper end cap and approximately 2.5 gallons of water in the bottom end cap. The water content reported for this sample is <0.1%. Water collected at the bottom end of V-86 was analyzed to determine pH which was found to be 11.67 or well into the basic range.

Also, during the year 25 surveillance a CPM sample was collected from the bottom end of V-83. There is no report of free water having been found but the CPM sample water content is documented as 4.10

During the year 30 surveillance the bottom end of V-86 was checked for the presence of free water and a CPM sample was collected. No free water was observed but the CPM sample water content was found to be 3.7%.

The scenario described in the preceding 3 paragraphs is plausible if:

- As there was no prior evidence of water intrusion into V-83, the year 25 V-83 and V-86 samples may have been inadvertently interchanged in the laboratory (mislabeling in the field is unlikely due to the procedures followed) or the test data sheets mislabeled. This would result in the reported V-83 water content being that determined for V-86 and,
- V-86 was refilled with new CPM which has an effective water content of 0%. However, if the year 30 V-86 sample was collected from a part of the bottom end cap that was not thoroughly cleaned before being reinstalled during the prior surveillance, it would reflect the water content of the CPM that was removed after the water intrusion into the tendon ducting was found and before the new medium was injected.

If the above postulates are assumed to be correct (and are concluded to be in 4.4.3 below), the only 2 (of 257) samples with water contents exceeding 0.68% were collected at the bottom end of V-86 and, in both cases, the higher water contents can be explained by the intrusion of water at the top end of this tendon over a 24 year period.

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[15] V-86 was examined during the year 1 surveillance in 1975; at that time the end cap was not correctly reinstalled which allowed rain water / snow melt intrusion into the tendon duct over the succeeding 24 years. The condition was corrected during the year 25 surveillance in 1999.

Evaluating the above discussions leads to the conclusion that there is no trend of CPM water content increasing over time. And, the water content of all CPM samples analyzed during all past surveillances fell below the Table IWL-2525-1 limit of 10%.

4.4.3 Reserve Alkalinity / Neutralization Number

Later formulations of the Viscosity Oil CPM used at TMI incorporated an alkaline component that provides protection against strong acids. Beginning with the year 20 surveillance, CPM samples were tested to ensure the ongoing protective feature of the formulation. These tests determine the neutralizing ability of the CPM when it is subjected to a strong acid in accordance with the procedure detailed in ASME Section XI, Subsection IWL. Test results are reported as a neutralization, or base, number computed as described in Table IWL-2525-1.

The product used to fill the tendon ductwork during TMI-1 construction has a very low base number as verified by the results of tests on samples from tendons that have never been opened for addition or replacement of CPM. However, over time, later CPM formulations have been used to 'top off' the quantity of material in the ducting / end caps and to replace material drained from tendons or removed from end caps / end anchorage areas during examinations. As a result, samples from tendons that have been opened for CPM addition / replacement may contain a mixture of various formulations. The only tendons that contain a single formulation are those that have never been opened and those that were replaced during the steam generator outage[16].

There is often no reasonable way to know the expected characteristics of a sample that may be a mixture of formulations. Consequently, it is not possible to perform a comprehensive evaluation of test results for time dependent changes, if any, in the reserve alkalinity of mixed CPM samples. In addition, the manufacturer specifies a minimum number of 35 for new 2094P-4 material, (which has been used at TMI for refill since the year 1 surveillance), but does not provide data on how the actual number may vary above this value from batch to batch.

Also, as no neutralization number tests were performed on samples collected during the year 1 through year 15 surveillances, no data are available for trending, if any, of CPM characteristics prior to the year 20 surveillance.

While the testing procedure detailed in IWL appears straight forward, the quality of results may depend to a considerable degree on the exact manner in which a test is performed.

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[16] The ductwork was cleared of bulk CPM prior to installation of the new tendons. However, there was still some mixing of the newly injected material with the coating of original material adhering to the inner surface of the duct and trumpet.

Therefore, reported neutralization number values may vary somewhat from a presumed 'true value' depending on laboratory practices, skill / experience of the lab technicians, quality of equipment / reagents used and other factors. Considering the variations in results from surveillance to surveillance, as discussed below, it is reasonable to postulate that there may be reasonably large differences between reported numbers and 'true values'.

Results of neutralization number tests conducted during consecutive surveillances are summarized, with discussion, below.

- Year 20 Surveillance – Tests on 18 of 22 samples yielded neutralization numbers of <0.50, the presumed threshold of resolution. These values are consistent with those expected for the CPM originally used at TMI.

  The remaining 4 samples, taken at the ends of common tendons H62-26, D-225 and V-32 which are partially refilled or 'topped off' following each examination, yielded numbers of 30.9, 50.5, 51.6 and 52.2. These values indicate that 4 of the 6 common tendon samples consisted of new or mixed material.

- Year 25 Surveillance - Tests on 10 of 47 samples yielded neutralization numbers of <0.50. An additional 29 samples yielded numbers between 0.544 and 5.60. These results are not unreasonable for original material considering possible variations in test conditions as discussed above.

  The 6 common tendon samples yielded numbers of 8.32 (bottom of V-32), 33.6, 51.8, 53.2, 54.3 and 55.4. This is consistent with 4 new material samples and 2 mixed material samples.

  The number reported for the D-313 shop end sample is 49.3, a value expected when tendons are refilled / topped off with 2090P-4 material.

  The number reported for the V-83 bottom end sample is 36.4, while that reported for the V-86 bottom end sample is <0.50. As V-86 was refilled with the P-4 formulation during the year 1 surveillance, the sample number should have been closer to 35. As the V-83 and V-86 bottom end sample water contents appear to be reversed, it can be concluded that either samples or test documents were inadvertently interchanged. Therefore, the number for V-86 is concluded to be 36.4 and that for V-83 to be <0.50. Both values are consistent with expectations.

  The 10 samples with base numbers shown as <0.50 were retested to determine an acid number[17]. All acid numbers are reported as <0.18, the presumed threshold of resolution.

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[17] An acid number test is required, for TMI only, by Exelon Corporate Procedure ER-AA-330-006 (included in Appendix E of Reference 7.13) if the base number is reported as <0.50; the acid number test is not addressed in IWL.

- Year 30 Surveillance – No numbers <0.50 are reported for the 27 samples collected during the year 30 surveillance. The numbers shown for 14 samples range from 0.7 to 6.17 which is reasonable for original material.

  The 6 common tendon sample numbers are 25.8 (bottom end of V-32), 48.9, 56.6, 59.5, 65.2 and 68.1. These values indicate new or mixed (bottom end of V-32) material. Th larger numbers may reflect either differences in material batches or, as discussed above, variations in test conditions.

  The following 7 neutralization numbers are within the range expected when samples are collected after a maintenance 'top off' or pump through of new material to replace CPM lost through leakage.

  D-213 field end – 34.9

  D-230 field end – 52.0

  V-53 shop end – 42.6

  V-66 shop end – 55.7

  V-86 field end – 41.4

  V-140 shop end – 46.7

  V-164 field end – 45.2

  The number determined for the V-86 field end is greater (41.4 vs 36.4) than that found during the year 25 surveillance. The increase may be due to ongoing mixing or to the previously discussed variations in test conditions.

- Year 35 Surveillance - Tests on 4 of 26 samples yielded neutralization numbers of <0.50. An additional 13 samples yielded numbers between 0.57and 5.11. These results are not unreasonable for original material considering possible variations in test conditions as discussed above.

  The 6 common tendon sample numbers are 34.70, 37.30, 39.70 (bottom end of V-32), 44.60, 50.60 and 52.00. These numbers are generally less than those recorded for common tendon samples in the year 30 report but the number for the bottom end of V-32 is again up. The common tendons are 'topped off' during each surveillance so the variations over time may be due to differences in the materials used in the topping off process, variations in test conditions or ongoing mixing of CPM. There is no evidence that the differences are due to time dependent changes in the chemistry of the CPM.

  The following 3 neutralization numbers are, as previously noted, within the range expected when samples are collected after a maintenance 'top off' or pump through of new material to replace CPM lost through leakage.

V-11 shop (top) end – 31.90

V-132 shop end – 46.80

D-122 field end – 55.00

Three of the samples with base numbers reported as <0.5 were also tested to determine an acid number. All three acid numbers are reported as <0.50.

- Year 40 Surveillance - Tests on 9 (including the V-32 bottom end sample) of 38 samples yielded neutralization numbers of <0.50. An additional 13 samples yielded numbers between 0.52 and 3.70. These results are not unreasonable for original material considering possible variations in test conditions as discussed above.

  The 6 common tendon sample numbers are <0.50 (bottom end of V-32 as noted above), 38.1, 38.4, 42.1, 47.9 and 53.1. These numbers are, with the exception of the number for the V-32 bottom end sample, generally similar to those recorded for common tendon samples in the year 35 report. The reason for the large difference in the V-32 bottom end number is not addressed in the surveillance report. It could, again, be the result of an inadvertent sample interchange.

  The 38 samples include 8 collected at the ends of SGR tendons V-115, V-136, H46-34 and H51-40. The base numbers found for these samples ranged from 28.4 to 57.9 which is consistent with expectations for new material and mixtures that include small quantities of residual original material.

  The remaining 3 neutralization numbers, listed below, are, as previously noted, within the range expected when samples are collected after a maintenance ‘top off’ or pump through of new material to replace CPP lost through leakage.,

  V-108 shop (top) end – 26.9

  V-159 shop end – 26.3

  D-237 field end – 34.6

  The 9 samples with base numbers reported as <0.50 and one additional sample with a base number of 0.52 were tested to determine acid number[18]. In 3 cases,

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[18] When a 10 gram CPM sample in solvent solution is broken down by the addition of 20 cc of 1N sulfuric acid, the resulting compounds are, on balance, acidic. If more than 20 cc of 1N sodium hydroxide is needed to neutralize the sample, the calculated base number is negative and equivalent to a positive acid number. A positive acid number indicates that the CPM will be acidic when broken down by a strong acid. This is not a problem for a tendon assembly encased in CPM filled ductwork since there is no strong acid source in the vicinity of the tendons, either at the end anchorages or around the concrete encased ducting.

Additionally, if the CPM has little or no reserve alkalinity (the case for the material used during original construction), it cannot chemically protect tendon hardware from acid attack; it only provides protection by providing a thick coating and physically isolating the hardware from the

the reported acid number is <0.50. The acid number reported for an additional 3 is 0.53. The remaining three sample acid numbers are 1.06, 1.06 and 2.64, all of which exceeded the 1.00 acceptance limit specified for TMI CPM samples in Exelon Procedure ER-AA-330-006 (included in Appendix E of Reference 7.13). All were accepted by evaluation (Reference 7.13). There were no indications of active corrosion on associated tendon V-32, H13-08 or H35-02 anchorage hardware.

The sample with a base number of 0.52 was found to have an acid number of 0.53, a seeming contradiction. This may indicate the limitations of the testing procedure with its dependence on laboratory practice and technician skill / experience as well as the equipment and reagents used.

The data covered in the above summary do not show evidence of a time dependent degradation in the corrosion inhibiting properties of the CPM used at TMI. No active corrosion has been found on end anchorage hardware within the CPM coverage area; i.e., within the volume bounded by the tendon end caps. This supports the conclusion that the CPM is continuing to provide a high level of protection.

4.4.4 Summary and Conclusion - CPM Test Results

Post-tensioning system end anchorage hardware and extracted wires have been examined for damage and corrosion during 10 surveillances (the augmented surveillance of SGR tendons is addressed in Section 4.5) spanning a period of 38 years from 1975 to 2013. Corrosion protection medium samples collected during these surveillances have been tested for the presence of corrosive ions (all surveillances), absorbed water (since 1977) and reserve alkalinity (since 1995). The results of these examinations and tests are summarized below.

- There has been no evidence of active corrosion; observed corrosion consists of light rusting 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 is well below the 10 ppm limit and shows no trend of increasing over time.

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acid. Therefore, while reserve alkalinity is theoretically beneficial, it has little practical impact, particularly if the majority of the CPM used is from an early formulation with a minimal base number.

For the reasons discussed above, CPM sample tests that yield small (low single digit) acid numbers are not a cause for concern. Higher acid numbers could be indicative of CPM contamination and require an engineering evaluation.

- Absorbed water content is well below the 10% (of dry weight) limit and shows no trend of increasing over time; with the 2 exceptions discussed above, all tested samples had water contents below 1%.
- Neutralization numbers (base numbers) vary over a wide range depending on the product formulation and the degree of mixing of different formulations. All but 3 of the samples tested met the acceptance criteria and the three exceptions were accepted by evaluation. 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 continue to be collected and analyzed to determine pH.

4.5 SGR Tendon Examination and Test Results Evaluation

The temporary containment wall opening created for steam generator replacement (SGR) required de-tensioning 30 hoop and 45 vertical tendons. Of these, 8 hoop and 35 vertical tendons were re-tensioned. The remaining 22 hoops and 10 verticals were replaced with new tendons fabricated using low relaxation wire. Subsection IWL requires that examination samples include a specified percentage of these SGR tendons.

SGR tendons were examined during the 2010 augmented surveillance and again during the year 40 surveillance in 2013.

Evaluations of SGR tendon examination and test results are addressed in this section. These tendons are addressed separately for the following reasons.

- SGR tendons (re-tensioned and new) were seated at a nominal 1,400 kips (70% of the 240 ksi specified minimum ultimate strength) which is well above the then current mean force in the remaining tendons.
- SGR tendons will experience lower creep, shrinkage and relaxation losses than the originally installed tendons.

- New SGR tendons use a low relaxation wire that has somewhat higher strength than that used for the original tendons.
- The strength and elongation characteristics of re-tensioned tendons may have been affected by being cycled again to 80% of specified minimum ultimate strength (this so-called overstress cycle is a standard part of the tensioning sequence).
- The corrosion protection medium pumped into the SGR tendon ducts is Visconorust 2090P-4 which is formulated to have a higher base number than the product used during construction.

SGR tendon force trends, end anchorage examination results, wire test results and CPM test results are evaluated in 4.5.1 through 4.5.4 below.

4.5.1 Tendon Force Trends and Forecasts

The augmented and year 40 surveillance samples each included 2 hoop and 2 vertical SGR tendons. The sample for each group included one re-tensioned and one new tendon.

Measured and group mean (of 2 values) forces are shown in Table 8. The changes in group mean forces (both hoop and vertical means increased by 3 kips) are shown for information only since each group mean is based on only two measured forces. But, as the measured SGR tendon forces are much greater than those in non-SGR tendons and, as the changes in mean values over the 3 year period between surveillances are consistently small, it is concluded that the forces in SGR tendons will always be well above those in the remaining tendons. This is consistent with expectations since time dependent SGR tendon losses after tensioning should be minimal when compared with time dependent losses experienced by the tendons tensioned at the time of original construction.

Measured SGR tendon forces confirm expectations that these are decreasing at a slow rate and that these will remain well above the forces in the non-SGR tendons for the foreseeable future. Therefore, extending the interval between examination of these tendons to 10 years will not compromise safe operation of the plant.

4.5.2 End Anchorage Condition

Tendon end anchorages, including those of V-117 and V-119, which were added to the augmented surveillance visual examination scope, were free of active corrosion and, except as discussed below, free of damage. Minor inactive rust (acceptable) was found on a few anchor heads and shims. The rust observed probably formed prior to the time that the tendon ducts were filled with CPM as there was no evidence moisture or other conditions conducive to corrosion when the examinations were performed. No free water was found on any of the anchorages examined.

Augmented surveillance tendon V-118 was found to have 2 broken wires. Both wires were at a point four inches down from the top end button heads or, at the interface between the anchor head and shims. Both wires were on the outer periphery of the anchor head honeycomb pattern.

Metallurgical examinations (documented in Technical Evaluation 1129072-02, Reference 7.25) of the broken wires found that these had been bent, had been burnished by hard contact near the bend and had failed in shear. It was concluded that the two wires were subjected to a large side load, probably during tensioning. The metallurgical evaluation included testing 6 wire segments, 3 cut from each of the extracted broken wires, for ultimate tensile strength and elongation at failure. Results of these tests, tabulated below, show that the tensile strength and ductility of the broken wires are acceptable.

Sample ID	Ultimate Tensile Strength, ksi		Elongation at Failure, %	
	Measured	Acceptance Criterion	Measured	Acceptance Criterion
Wire 1 / 1	250.1	≥240 ksi	5.7	≥4%
Wire 1 / 23	250.1		5.5	
Wire 1 / 45	247.5		6.0	
Wire 2 / 1	248.5		5.25	
Wire 2 / 23	248.0		5.45	
Wire 2 / 45	247.5		5.0	

The V-118 wire breaks were concluded to have been the result of a singular event with the extent of condition limited to the breaks found. Nonetheless, it was decided to expand the scope of the surveillance and visually examine the anchorages of adjacent tendons V-117 and V-119. No further damage was found. Cause and impact of the broken wires are addressed in the cited Technical Evaluation.

During the year 40 surveillance the bottom anchor head of tendon V-136 was found to be missing one button head (not documented on the SGR re-tensioning data sheets), a condition that is occasionally observed during end anchorage visual examinations. The tendon was not de-tensioned for removal of the discontinuous wire so the cause of condition remains unknown. The condition was judged acceptable per IR 1567224 (cited in Reference 7.13) as it was not observed at any of the remaining SGR, or other, tendon anchorages (the broken wires discussed above are a separate issue) and therefore considered singular.

Overall it can be concluded that the visual examination results described above show that the SGR tendon anchorage areas are in good condition and not subject to time dependent degradation. Consequently, extending the examination interval to 10 years is unlikely to result in missing a safety significant condition at the ends of the SGR tendons.

4.5.3 Wire Examination and Test Results Evaluation

Wires extracted from a hoop tendon and a vertical tendon during each of the two surveillances were examined for damage / corrosion and tested to determine ultimate strength / elongation at failure.

None of the 4 extracted wires showed signs of either damage or corrosion. Tensile tests showed ultimate tensile strength (UTS) and elongation at failure to be in the expected ranges. New wire UTS was uniformly greater than that of the original wire, probably as a result of minor differences in chemistry and / or drawing equipment / technique. Test results are shown in Table 9 and summarized below.

- New wire UTS (mean of three samples tested) decreased by 5 ksi and original wire UTS increased by 2 ksi. On balance, overall changes shown were small and not considered to represent a trend. The changes in UTS could be due a combination of differences in wire lots, small differences in specimen diameter and the margin of error inherent in the test technique.
- New wire mean elongation at failure shows a small (0.3%) decrease but the spread (1.0% for the H46-39 samples and 1.2% for the V-136 samples) of individual sample values is such that the 'true' means[19] could easily differ from those computed by more than 0.3%. Therefore, the decrease is considered to be a consequence of data scatter rather than a trend.
- New wire UTS is uniformly greater than original wire UTS (see above discussion).
- New wire elongation is possibly lower (see above discussion on individual sample spread) than that of the original wire and, if so, could be a normal consequence of the higher strength.

4.5.4 Corrosion Protection Medium Test Results and Evaluation

Results reported for corrosive ion concentration and water content tests conducted on SGR tendon CPM samples collected during the augmented (8 samples) and year 40 (8

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[19] Standard deviation computed for the V-136 sample elongations is 0.6% and that for the H46-39 sample elongations is 0.5%.

samples) surveillances are summarized below. Neutralization number test results are discussed in the ensuing paragraph.

- All chloride ion concentrations are below the 0.50 ppm threshold.
- All nitrate ion concentrations are below the 0.50 ppm threshold.
- All sulfide ion concentrations are below the 0.50 ppm threshold.
- All but 3 water contents are below the 0.1% (of dry weight) threshold. The two exceptions are:
    - (Augmented surveillance) 0.19% at the top end of V-118;
    - (year 40 surveillance) 0.28% at the top end of V-115;
    - (year 40 surveillance) 0.22% at the bottom end of V-136;

Neutralization number (base number) test results are shown in Table 10. The numbers reported for the augmented surveillance (T = 36.6 years) samples appear unusually high (more protective) when compared to those shown for the year 40 surveillance SGR tendon samples. The numbers also appear high when compared to those found for other samples collected since the year 20 surveillance and that include the P-4 formulation of the Visconorust 2090 CPM added during prior maintenance or surveillance activities. It is possible that the large differences are the result of a procedural or other problem at the laboratory when the augmented surveillance samples were tested.

Regardless of the reason for the high values shown for the augmented surveillance samples, there is nothing in the neutralization number data to indicate that the product is degrading and that it will not continue to provide corrosion protection until the proposed 2024 time frame for the subsequent post-tensioning system examinations and tests.

4.5.5 Summary and Conclusions – SGR Tendons

Based on evaluations of visual examinations, tendon force measurements, wire tests and CPM analyses performed in conjunction with the augmented and year 40 surveillances it is concluded that the SGR tendons are performing well and that corrosion protection system is functioning as intended. The broken wires found during the augmented surveillance were determined to be the result of a singular event and do not affect this conclusion.

Therefore, the results of examinations and tests as discussed in 4.5.1 through 4.5.4 support the recommendation to extend the surveillance interval to 10 years and to conduct the next post-tensioning system examinations / tests in the 2024 time frame.

5. OVERALL SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The results of the 11 post-tensioning system inservice examinations conducted at TMI between 1975 and 2013 show that the system is continuing to perform its intended function and that it can be expected to do so until well past the March 2034 expiration of the extended operating license. Performance of the system, determined by evaluations of the visual examination findings / test results as detailed in Part 3 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 March 2034 license expiration. This projection is supported by the low scatter trend of common tendon force data.

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 minor (acceptable) rusting that has been observed is concluded to have occurred prior to filling of the tensioned tendon duct with corrosion protection medium.

The two broken wires documented in the 2010 augmented surveillance report were determined to have been the result of a singular event 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[20] tendons (wires anchored by cold formed button heads) and generally occurs during or shortly after tensioning. Nothing in the surveillance reports indicate that the number of missing button heads is increasing over time.

Only one instance of free water was reported. Free water was found in the lower end cap of V-86 during the year 25 surveillance and was the result of incorrect end cap installation (leaving a gap between the cap and bearing plate) at the top end of this tendon during the year 1 surveillance in 1975. Probable exposure of the tendon and end anchorage hardware to water over a 25 year period did not cause noticeable corrosion, leading to the conclusion that the corrosion protection medium is preforming as intended.

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

c) Tendon Wire Strength and Ductility

Tensile tests on samples cut from extracted wires show that ultimate tensile strength and elongation at failure are above specified minimum values 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 3 exceptions) have been met and that there are no discernible trends over time. In Particular:

- All reported absorbed water content values are below the 10% (of dry weight) upper limit and all but 2 are below 1%. The 2 values exceeding 1% were found for samples collected at the bottom of V-86[21] which had accumulated free water as discussed in b) above.
- All corrosive ion concentrations are below the 10 ppm upper limit and most are below the indicated limit of resolution applicable to the ion.
- Neutralization numbers are acceptable with 3 exceptions, all accepted by evaluation. The patterns of the numbers reported by the laboratories tend to fluctuate over a relatively wide range from surveillance to surveillance. For this reason, it was concluded that the documented values may reflect variations in testing procedures, technician skill / experience and other laboratory dependent factors as much as actual differences in neutralization number. But, 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.

e) SGR Tendon Performance

Much of the expected eventual concrete creep and shrinkage strain had already occurred by the time that the SGR tendons were tensioned. In addition, the new SGR tendons were fabricated using low relaxation wire and the de-tensioned / re-tensioned tendons showed no sign of significant relaxation recovery. Therefore, losses in SGR tendons are expected to be much less than those in the other tendons. For this reason, SGR tendons were considered as a separate category in this technical report.

Evaluation of SGR tendon examination and test results reported in the augmented and year 40 surveillances confirms that:

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[21] It was concluded in Section 4.4 above that the 4.1% water content shown on the V-83 bottom end line in the year 25 surveillance report (PSC report Table I) should have been on the V-86 bottom end line.

- SGR tendon forces are decreasing slowly and expected to remain well above those in the remaining tendons throughout the lifetime of the plant.
- Wire test results show that tensile strength and elongation at failure are not affected by de-tensioning / re-tensioning. The test results also show that wire used to fabricate the new tendons has a tensile strength greater than that of the original wire and, possibly, somewhat lower (but still above the 4% lower limit) elongation at failure. Neither the new nor re-tensioned tendons show any indication of time related degradation in either strength or ductility.
- CPM test results show corrosive ion concentrations below threshold levels, a maximum absorbed water content of 0.28% (upper limit is 10%) and relatively high neutralization numbers that reflect refilling with 2090P-4 material.

Based on the evaluations detailed in Part 4 of this technical report and summarized above, it is concluded that the TMI-1 post-tensioning system will continue to perform its design function until well after the 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 been observed on only one occasion, was due to a unique mistake made during the year 1 surveillance, did not result in corrosion and will not be a concern.

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 on open platforms with no ready means of egress in the event of sudden changes in weather;
  - Working in a de facto confined space (the tendon gallery).

  - Working with high pressure hydraulic systems;
  - Working around high energy plant systems;
  - Working around solvent and hot petroleum product fumes.
  - Working around containers and 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.
- Reducing end anchorage exposure to the elements during periods when end caps are removed for examination, force measurement and wire extraction.

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, TESTING ENHANCEMENTS AND YEAR 40 REPORT COMMITMENTS

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 examinations of tendon end caps, bearing plates and anchorage area concrete for evidence of damage / deformation, corrosion, cracking and CPM leakage. Direct visual examination (IWL-2310) will be performed where possible (e.g., top of ring girder, tendon gallery and buttress areas accessible from floors, platforms or ladders). If direct visual examination is not possible, remote examination (IWL-2310) techniques (high power optics and / or drone mounted cameras) will be used.

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). Additional actions will be taken as specified by the RE following the evaluation.

If an end anchorage area examination uncovers active corrosion on a bearing plate or end cap, the condition will be evaluated by the RE and corrective measures implemented if and 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, the RE will perform a detailed examination (IWL-2310) and evaluation of the condition and specify corrective measures as deemed appropriate.

Visual examinations will also focus on gross leakage of CPM. If gross leakage is detected, a corrective action (e.g., end cap gasket replacement and duct refilling / top-off) plan will be prepared by the RE. The corrective action plan will be implemented in accordance with RE requirements.

The results of tests on corrosion protection medium (CPM) samples collected at the Buttress 1 end of H13-08, the Buttress 3 end of H35-02 and the bottom end of V-32 during the year 40 surveillance showed acid numbers greater than the limit of 1. For this reason, the topical report (Reference 7.13) covering that surveillance includes a requirement to reexamine the associated anchorage assemblies during the next surveillance, then expected to be performed in 2018. As no corrosion or free water was found at these anchorages during the year 40 surveillance, it is concluded that the CPM is continuing to perform its protective function and that delaying the next examination to 2024 will not compromise plant safety. The examinations and associated pump through of CPM cited in those recommendations will be completed at that time.

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.

7. REFERENCES

Note: Reference documents 7.1 through 7.17 were transmitted to the author under TODI ID# 5971-2018-004.

7.1 GAI Report Number 1880, September 29,1975, *Reactor Containment Building First Tendon Surveillance One Year After S.I.T.*

7.2 GQL 0204, *Three Mile Island Generating Station Unit No. 1 Second Surveillance Test of Reactor Containment Building Three Years After S.I.T.*

7.3 TM-PBD-AMP-2.1.25, Revision 1, *Program Basis Document, ASME Section XI, Subsection IWL, GALL Program XI.S2-ASME Section XI, Subsection IWL.*

7.4 TDR No. 229, Revision 0, *Containment Building Tendon Surveillance Test Report for Third Period (5 years after S.I.T.).*

7.5 TMI04.G03, Revision 5, *Three Mile Island Nuclear Station Unit 1 ISI Program Fourth Ten-Year Inspection Interval.*

7.6 Topical Report No. 025, Revision 1, *Three Mile Island Unit 1 Reactor Building Tendon Surveillance Inspection Period 4 (10 Years).*

7.7 Topical Report No. 069, Revision 1, *Three Mile Island Unit 1 Reactor Building Tendon Surveillance Inspection Period 5.*

7.8 Topical Report No. 093, Revision 1, *Three Mile Island Unit 1 Reactor Building Tendon Surveillance Inspection Period 6.*

7.9 Topical Report No. 136, Revision 1, *Three Mile Island Unit No. 1 25th Year Reactor Building Tendon Surveillance (Period 7).*

7.10 Topical Report No. 183, Revision 0, *Three Mile Island Unit No. 1 30th Year Reactor Building Tendon Surveillance (Period 8).*

7.11 Topical Report No. 203, Revision 0, *35th Year Reactor Building Tendon Surveillance (Period 9).*

7.12 Topical Report No. 204, Revision 1, *Augmented Reactor Building (IWL) Inservice Inspection (Following the 1R18 Steam Generator Replacement).*

7.13 Topical Report No. 213, Revision 0, *40th Year Reactor Building Tendon Surveillance (Period 10).*

7.14 Technical Specification 3.19, *Containment Systems.*

7.15 Technical Specification 4.4, *Reactor Building.*

7.16 TMI-1 UFSAR, Revision 24, Section 5, *Containment System and Other Special Structures.*

7.17 TMI-1 UFSAR, Revision 24, Appendix A, *Final Safety Analysis Report Supplement (License Renewal).*

7.18 ASME Boiler and Pressure Vessel Code, Section XI, Subsection IWL, 2004 Edition w / No Addenda.

7.19 C-1101-153-E410-046, Revision 0, *TMI Reactor Building / Post-Tensioning System Inservice Inspection / Tendon Force Prediction.* (Transmitted Under TODI ID# 5971-2018-008)

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

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

7.22 ASTM A421 *Specification for Uncoated Stress Relieved Wire for Prestressed Concrete.*

7.23 Transmittal of Design Information (TODI) ID # 5971-2018-004, Approved 18 July 2018, *TMI Reactor Building Tendon Design (UFSAR), Program Bases, and Surveillance History for Technical Report to Support IWL Relief Request.*

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

7.25 TMI Technical Evaluation 1129072-02, *Evaluation of Two Broken Wires on Tendon V118 as Found During the 2010 Augmented Reactor Building (IWL) In-Service Inspection.* (Transmitted under TODI ID# 5971-2018-008)

7.26 Transmittal of Design Information (TODI) ID # 5971-2018-008, Approved 07 September 2018, *TMI Reactor Building Tendon Design (UFSAR), Program Bases, and Surveillance History for Technical Report to Support IWL Relief Request.*

8. TABLES AND FIGURES

Tables and figures cited in the above text follow.

Note: Tables 2, 3 and 4 normalization adjustments shown in shaded cells are those listed in the applicable surveillance reports. All others are as computed and listed in Reference 7.19.

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 (Non-SGR) Hoop Tendon Forces					
Surveillance Year	**T, Time Since SIT, Years**	**Tendon**	**F_M, Measured Force, kip**	**A_N, Normalization Adjustment, kip**	**F_N, Normalized Force, kip**
1	1.2	H13-46	1,260	N/A	N/A
		H13-34	1,273	N/A	N/A
		H62-16	1,253	N/A	N/A
		H62-10	1,272	N/A	N/A
		H35-10	1,259	N/A	N/A
		H35-28	1,282	N/A	N/A
		H13-28	1,261	N/A	N/A
		H51-12	1,293	N/A	N/A
		H24-21	1,267	N/A	N/A
		H24-47	1,280	N/A	N/A
3	3.6	H62-47	1,113	N/A	N/A
		H24-48	1,194	N/A	N/A
		H24-19	1,105	N/A	N/A
		H35-11	1,242	N/A	N/A
		H35-29	1,219	N/A	N/A
		H46-28	1,206	N/A	N/A
		H46-24	1,225	N/A	N/A
		H51-13	1,217	N/A	N/A
		H62-53	1,177	N/A	N/A
		H62-11	1,163	N/A	N/A
5	6.2	H62-51	1,222	N/A	N/A
		H24-49	1,191	N/A	N/A
		H46-32	1,253	N/A	N/A
		H46-30	1,243	N/A	N/A
		H24-20	1,253	N/A	N/A
		H24-28	1,243	N/A	N/A
		H62-28	1,243	N/A	N/A
		H35-16	1,221	N/A	N/A
		H62-10	1,253	N/A	N/A
		H51-11	1,243	N/A	N/A

Table 2 - Summary of (Non-SGR) Hoop Tendon Forces

Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip	A_N, Normalization Adjustment, kip	F_N, Normalized Force, kip
10	11.2	H13-35	1,191	-59	1,132
		H13-36	1,066	15	1,081
		H13-37	1,182	-44	1,138
		H24-26	1,173	-24	1,149
		H35-26	1,156	17	1,173
		H62-26	1,145	2	1,147
		H62-30	1,152	4	1,156
15	15.6	H24-29	1,072	41	1,113
		H24-30	1,139	-36	1,103
		H24-31	1,114	31	1,145
		H24-51	1,142	73	1,215
		H46-34	1,177	-27	1,150
		H62-13	1,088	58	1,146
		H62-26	1,128	2	1,130
20	20.6	H24-40	1,132	-5	1,127
		H35-23	1,200	-34	1,166
		H35-47	1,192	-39	1,153
		H62-26	1,161	2	1,163
		H62-49	1,163	47	1,210
25	25.5	H13-50	1,159	25	1,184
		H35-33	1,169	-15	1,154
		H46-37	1,129	46	1,175
		H51-43	1,170	-52	1,118
		H62-26	1,136	2	1,138
30	30.6	H13-11	1,218	-54	1,164
		H35-49	1,201	-7	1,194
		H46-25	1,121	51	1,172
		H62-18	1,105	10	1,115
		H62-26	1,120	2	1,122

Table 2 - Summary of (Non-SGR) Hoop Tendon Forces

Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip	A_N, Normalization Adjustment, kip	F_N, Normalized Force, kip
35	35.6	H13-41	1,151	-47	1,104
		H24-33	1,123	38	1,161
		H46-50	1,131	-9	1,122
		H51-49	1,154	-25	1,129
		H62-26	1,141	2	1,143
40	39.6	H13-03	1,076	-40	1,036
		H13-10	1,150	4	1,154
		H24-22	1,161	-37	1,124
		H35-02	1,216	8	1,224
		H62-26	1,126	2	1,128

Table 3 - Summary of (Non-SGR) Vertical Tendon Forces					
Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip	A_N, Normalization Adjustment, kip	F_N, Normalized Force, kip
1	1.2	V-16	1,348	N/A	N/A
		V-27	1,285	N/A	N/A
		V-61	1,306	N/A	N/A
		V-86	1,285	N/A	N/A
		V-158	1,306	N/A	N/A
3	3.6	V-24	1,283	N/A	N/A
		V-48	1,275	N/A	N/A
		V-72	1,258	N/A	N/A
		V-97	1,258	N/A	N/A
		V-119	1,209	N/A	N/A
5	6.2	V-13	1,274	N/A	N/A
		V-31	1,147	N/A	N/A
		V-55	1,211	N/A	N/A
		V-105	1,253	N/A	N/A
		V-138	1,211	N/A	N/A
10	11.2	V-14	1,243	-28	1,215
		V-30	1,193	-10	1,183
		V-32	1,196	-7	1,189
		V-84	1,189	-22	1,167
		V-160	1,192	-6	1,186
15	15.6	V-22	1,171	-7	1,164
		V-50	1,213	-31	1,182
		V-21	1,196	-40	1,156
		V-23	1,175	17	1,192
		V-83	1,196	-11	1,185
		V-85	1,179	4	1,183
		V-19	1,187	-9	1,178

Table 3 - Summary of (Non-SGR) Vertical Tendon Forces

Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip	A_N, Normalization Adjustment, kip	F_N, Normalized Force, kip
20	20.6	V-32	1,210	-7	1,203
		V-78	1,306	-35	1,271
		V-126	1,209	19	1,228
25	25.5	V-32	1,193	-7	1,186
		V-40	1,202	-1	1,201
		V-114	1,189	27	1,216
		V-164	1,181	-42	1,139
30	30.6	V-32	1,190	-7	1,183
		V-53	1,222	-27	1,195
		V-66	1,178	25	1,203
		V-137	1,218	-7	1,211
		V-140	1,144	4	1,148
		V-141	1,207	-46	1,161
35	35.6	V-11	1,206	26	1,232
		V-32	1,175	-7	1,168
		V-90	1,200	-30	1,170
		V-132	1,206	-30	1,176
40	39.6	V-32	1,181	-7	1,174
		V-108	1,225	14	1,239
		V-159	1,154	20	1,174

Table 4 - Summary of Dome Tendon Forces

Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip	A_N, Normalization Adjustment, kip	F_N, Normalized Force, kip
1	1.2	D-101	1,252	N/A	N/A
		D-201	1,278	N/A	N/A
		D-301	1,269	N/A	N/A
		D-220	1,253	N/A	N/A
		D-316	1,259	N/A	N/A
		D-116	1,259	N/A	N/A
3	3.6	D-130	1,252	N/A	N/A
		D-148	1,226	N/A	N/A
		D-202	1,273	N/A	N/A
		D-219	1,226	N/A	N/A
		D-334	1,247	N/A	N/A
		D-348	1,226	N/A	N/A
5	6.2	D-131	1,180	N/A	N/A
		D-147	1,180	N/A	N/A
		D-218	1,137	N/A	N/A
		D-203	1,159	N/A	N/A
		D-346	1,169	N/A	N/A
		D-336	1,221	N/A	N/A
10	11.2	D-133	1,107	69	1,176
		D-225	1,125	45	1,170
		D-314	1,290	-54	1,236
15	15.6	D-145	1,220	-34	1,186
		D-347	1,183	-40	1,143
20	20.6	D-141	1,164	47	1,211
		D-225	1,120	45	1,165
		D-248	1,202	9	1,211
25	25.5	D-102	1,280	18	1,298
		D-225	1,104	45	1,149
		D-313	1,120	19	1,139

Table 4 - Summary of Dome Tendon Forces

Surveillance Year	T, Time Since SIT, Years	Tendon	F_M, Measured Force, kip	A_N, Normalization Adjustment, kip	F_N, Normalized Force, kip
30	30.6	D-213	1,094	67	1,161
		D-225	1,120	45	1,165
		D-230	1,149	8	1,157
35	35.6	D-122	1,119	31	1,150
		D-225	1,088	45	1,133
		D-322	1,135	-15	1,120
		D-342	1,150	-3	1,147
40	39.6	D-146	1,184	-4	1,180
		D-225	1,106	45	1,151
		D-237	1,167	19	1,186
		D-303	1,200	-35	1,165

Table 5 - Wire Test Results / Ultimate Tensile Strength

Exam Year	Group	Ultimate Tensile Strength, ksi			Group Mean	Exam Mean
		Specimen 1	Specimen 2	Specimen 3		
1	Hoop	252.55	255.61	253.57	254	254
	Vertical	255.10	254.59	255.61	255	
	Dome	254.08	252.55	251.02	253	
3	Hoop	246.10	245.30	243.70	245	244
	Vertical	242.00	241.20	242.90	242	
	Dome	242.90	243.30	244.70	244	
5	Hoop	267.00	265.00	267.00	266	264
	Vertical	269.00	268.00	268.00	268	
	Dome	256.00	257.00	255.00	256	
10	Hoop	240.29	241.24	244.79	242	247
	Vertical	252.22	253.78	253.14	253	
	Dome	248.00	248.64	242.22	246	
15	Hoop	261.17	258.02	260.23	260	264
	Vertical	269.68	270.62	272.82	271	
	Dome	261.49	261.80	261.49	262	
20	Hoop	249.96	251.47	251.47	251	251
	Vertical	245.73	248.75	249.36	248	
	Dome	254.58	252.79	252.19	253	
25	Hoop	250.30	255.34	254.71	253	258
	Vertical[1]	263.54	261.01	263.54	263	
	Vertical	266.66	261.62	262.88	264	
	Dome	250.87	250.87	250.87	251	
30	Hoop	260.60	259.00	258.30	259	258
	Vertical	259.20	256.30	257.60	258	
	Dome	256.00	257.30	261.40	258	
35	Hoop	287.00	287.00	287.00	287	283
	Vertical	282.00	280.00	278.00	280	
	Dome	282.00	280.00	281.00	281	
Aug-mented	Hoop	N/A				247
	Vertical[2]	247.30	246.20	246.60	247	
	Dome	N/A				
40	Hoop	258.90	258.50	257.80	258	254
	Hoop[2]	248.20	249.70	248.80	249	
	Vertical	249.40	251.60	253.50	252	
	Dome	259.60	254.70	253.50	256	

Note 1: V-86, found to have unseated upper end cap, added to original sample

Note 2: Re-tensioned (not new) SGR tendon

Table 6 - Wire Test Results / Elongation at Failure

Exam Year	Group	Elongation at Failue, %			Group Mean, %	Exam Mean, %
		Specimen 1	Specimen 2	Specimen 3		
1	Hoop	5.10	5.10	5.10	5.1	4.9
	Vertical	5.00	5.00	5.00	5.0	
	Dome	4.50	4.50	5.10	4.7	
3	Hoop	3.42	5.23	3.59	4.1	4.4
	Vertical	3.71	3.87	5.35	4.3	
	Dome	3.78	6.55	4.42	4.9	
5	Hoop	5.63	7.50	6.88	6.7	6.8
	Vertical	6.88	6.88	6.88	6.9	
	Dome	6.25	6.88	7.50	6.9	
10	Hoop	4.20	4.40	4.40	4.3	5.0
	Vertical	5.20	5.50	5.50	5.4	
	Dome	5.40	5.50	5.30	5.4	
15	Hoop	5.80	5.30	5.60	5.6	5.5
	Vertical	5.50	6.00	5.40	5.6	
	Dome	5.20	5.50	5.20	5.3	
20	Hoop	6.35	5.60	5.80	5.9	5.6
	Vertical	5.05	5.75	5.95	5.6	
	Dome	5.25	5.40	4.80	5.2	
25	Hoop	4.80	5.20	4.80	4.9	5.0
	Vertical	5.30	4.90	4.95	5.1	
	Vertical[1]	5.00	4.85	5.50	5.1	
	Dome	4.80	5.20	5.00	5.0	
30	Hoop	5.65	5.30	5.35	5.4	5.1
	Vertical	5.40	5.25	5.20	5.3	
	Dome	4.65	4.05	4.75	4.5	
35	Hoop	5.30	5.30	5.30	5.3	5.3
	Vertical	5.40	5.20	5.10	5.2	
	Dome	5.30	5.30	5.60	5.4	
Aug-mented	Hoop	N/A				5.3
	Vertical[2]	4.50	5.90	5.40	5.3	
	Dome	N/A				
40	Hoop	5.80	6.20	5.80	5.9	5.4
	Hoop[2]	5.20	5.80	5.00	5.3	
	Vertical	5.70	5.00	4.80	5.2	
	Dome	5.20	5.20	5.10	5.2	

Note 1: V-86, found to have unseated upper end cap, added to original sample

Note 2: Re-tensioned (not new) SGR tendon

Table 7 – 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 / 6	<1.0	<1.0	<1.0	<4.0	<4.0	<4.0	<1.0	<1.0	<1.0
3 / 13	<1.0	<1.0	<1.0	<5.0	<5.0	<5.0	<1.0	<1.0	<1.0
5 / 23	2.3	1.7	0.6	9.0[1]	2.8[1]	0.1	0.3	0.1	0.0
10 / 29	9.2	4.6	0.6	1.3	0.6	0.1	0.2	0.0	0.0
15[2] / 32	1.2	0.4	0.0	1.2	0.5	0.0	0.1	0.0	0.0
20 / 22	8.9	4.5	2.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
25 / 47	<0.5	<0.5	<0.5	9.8	3.4	<0.5[3]	3.2	1.5	0.9
30 / 27	1.0	0.6[4]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
35 / 26	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
40 / 38	0.5[5]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Note 1: Initial laboratory report showed one sample with a 14 ppm nitrate concentration. Follow-up letter from testing laboratory states that a retest of the sample yielded a concentration of <1 ppm. Letter also states that there were difficulties implementing the analysis procedure and that all nitrate concentrations are probably <1 ppm.

Note 2: Calculated means exclude 1 chloride reported as <0.044 ppm, 1 nitrate reported as <0.05 ppm and 14 sulfides reported as <0.025 ppm.

Note 3: Test result for backup sample replaced 10.3 ppm primary sample result. Mean excludes the single nitrate result reported as <0.5 ppm. Also, during this surveillance, the V-164 bottom end sample nitrate concentration was recorded as 8.57 ppm; nitrate concentration recorded for a confirmatory sample taken during the 30 year surveillance is <0.5 ppm.

Note 4: 22 of 26 chloride results reported as <0.5 ppm. The mean concentration shown is computed using the following values – 22 @ 0.5 ppm, 4 @ 0.6 ppm & 1 @ 1.0 ppm.

Note 5: 19 of 38 sample chloride concentrations reported as the threshold value of 0.5 ppm; the remaining 19 as <0.5 ppm.

Table 8 – SGR Tendon Forces						
T, Years Since SIT	**Tendon (N) New**	**Force, kip**	**Group Mean, kip**	**Tendon (N) New**	**Force, kip**	**Group Mean, kip**
36.6	H46-39 (N)	1,373	1,365.0	V-118	1,365	1,353.5
	H46-41	1,357		V-134 (N)	1,342	
39.6	H46-34 (N)	1,397	1,368.0	V-115	1,378	1,356.5
	H51-40	1,341		V-136 (N)	1,335	
	Change		+3			+3

Table 9 – SGR Tendon Wire Tests						
T, Years Since SIT	**Test Results**					
	Tendon	**Sample**	**UTS, ksi**	**Mean[1], ksi**	**Elongation, %**	**Mean, %**
36.6	H46-39 New	1	267.0	268	5.1	5.1
		2	269.9		5.6	
		3	267.4		4.6	
	V-118	1	247.3	247	4.5	5.3
		2	246.2		5.9	
		3	246.6		5.4	
39.6	H51-40	1	248.2	249	5.2	5.3
		2	249.7		5.8	
		3	248.8		5.0	
	V-136 New	1	262.8	263	4.2	4.8
		2	262.0		5.4	
		3	263.4		4.7	

Note 1: UTS mean values rounded to the nearest ksi for added clarity of presentation.

Table 10 – SGR Tendons / CPM Sample Neutralization Number

T, Years Since SIT	Tendon	End	Neutralization Number
36.6	H46-39 (New)	Shop	73.6
		Field	71.2
	H46-41	Shop	74
		Field	71.3
	V-118	Shop (Top)	68.1
		Field (Bottom)	65.1
	V-134 (New)	Shop (Top)	70.8
		Field (Bottom)	63.3
39.6	H46-34 (New)	Shop	56.4
		Field	50.4
	H51-40	Shop	46.6
		Field	48.2
	V-115	Shop (Top)	57.9
		Field (Bottom)	28.4
	V-136 (New)	Shop (Top)	45.9
		Field (Bottom)	35.2

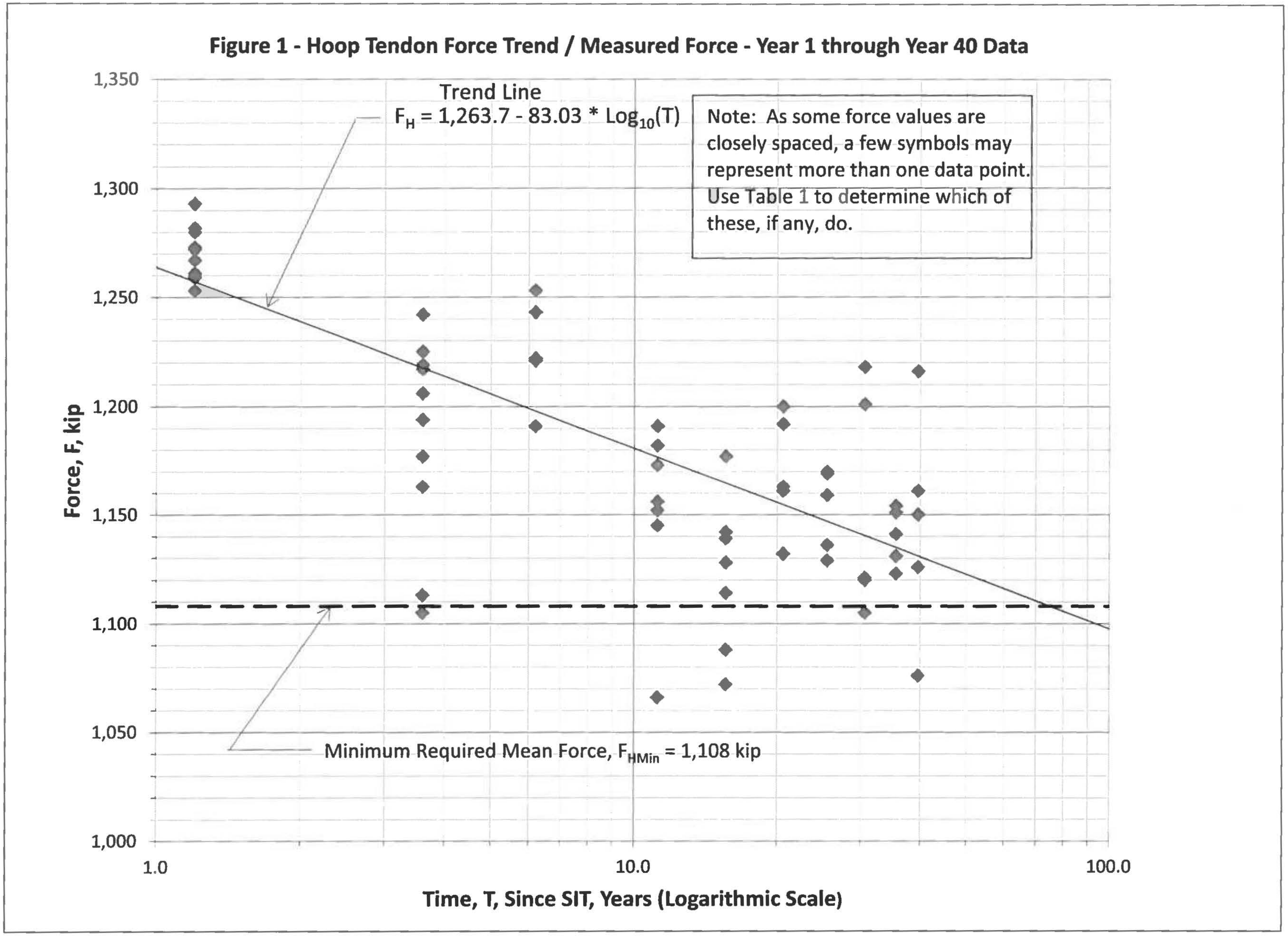


Figure 1 - Hoop Tendon Force Trend / Measured Force - Year 1 through Year 40 Data
Trend Line
F_H = 1,263.7 - 83.03 * Log10(T)
Note: As some force values are closely spaced, a few symbols may represent more than one data point. Use Table 1 to determine which of these, if any, do.
Minimum Required Mean Force, F_HMin = 1,108 kip
Force, F, kip
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
1.0
10.0
100.0
Time, T, Since SIT, Years (Logarithmic Scale)

Figure 2 - Hoop Tendon Force Trend / Measured & Normalized Force - Year 10 through Year 40 Data

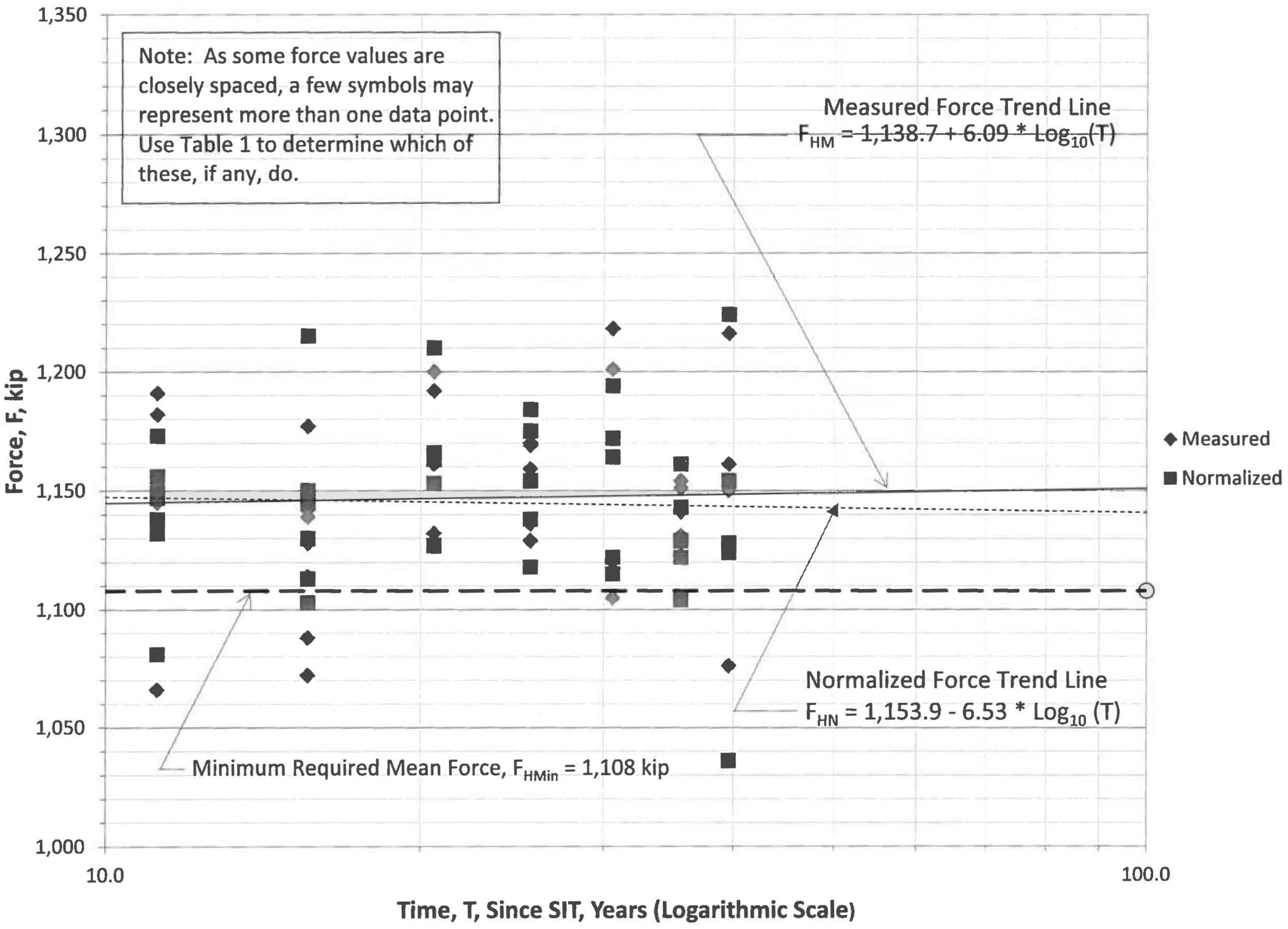


Figure 3- Hoop Tendon Force Trend / Measured Force & UCL - Year 10 through Year 40 Data

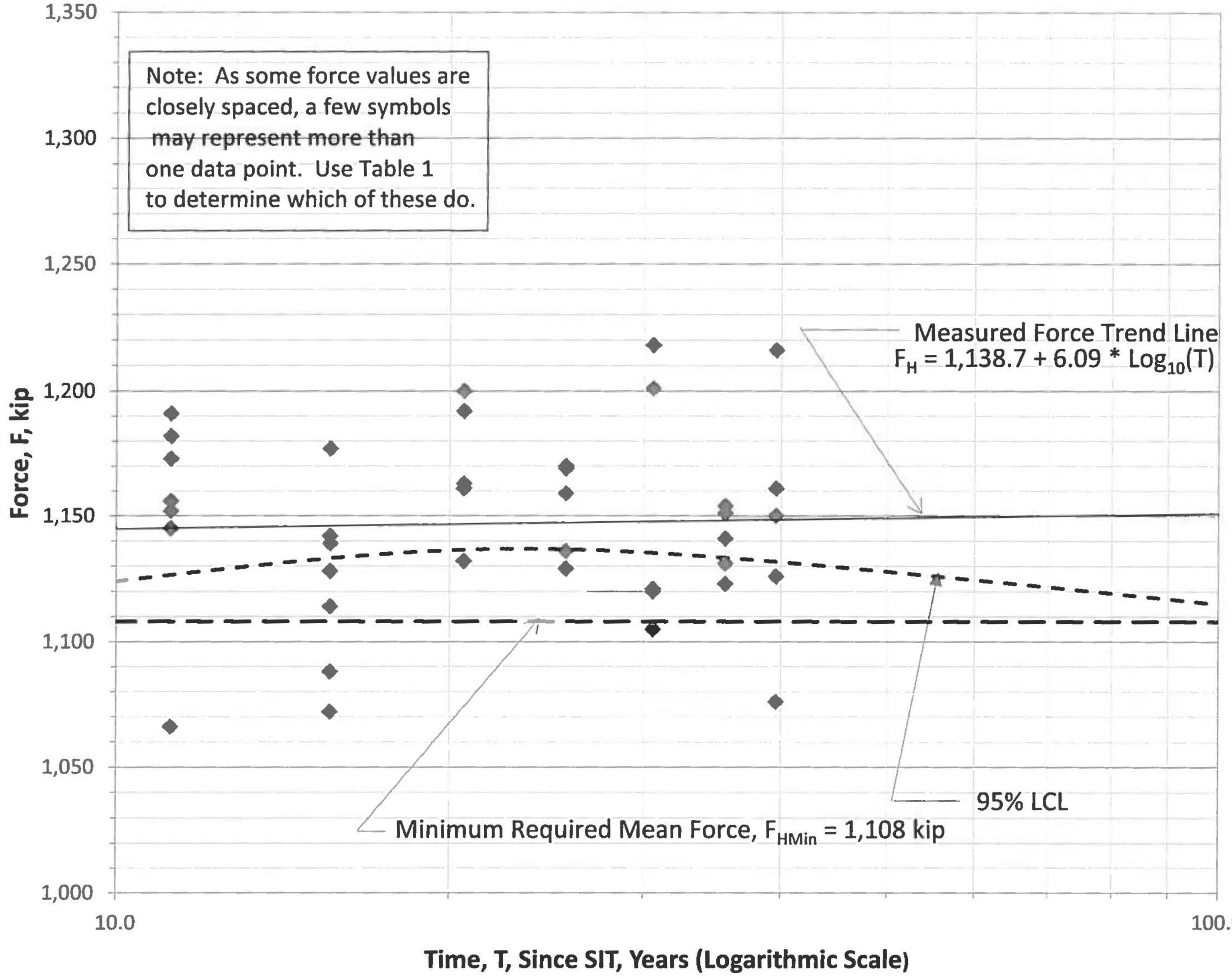


Figure 4 - Hoop Common Tendon H62-26 Force Trend / Measured Force - Year 10 through Year 40 Data

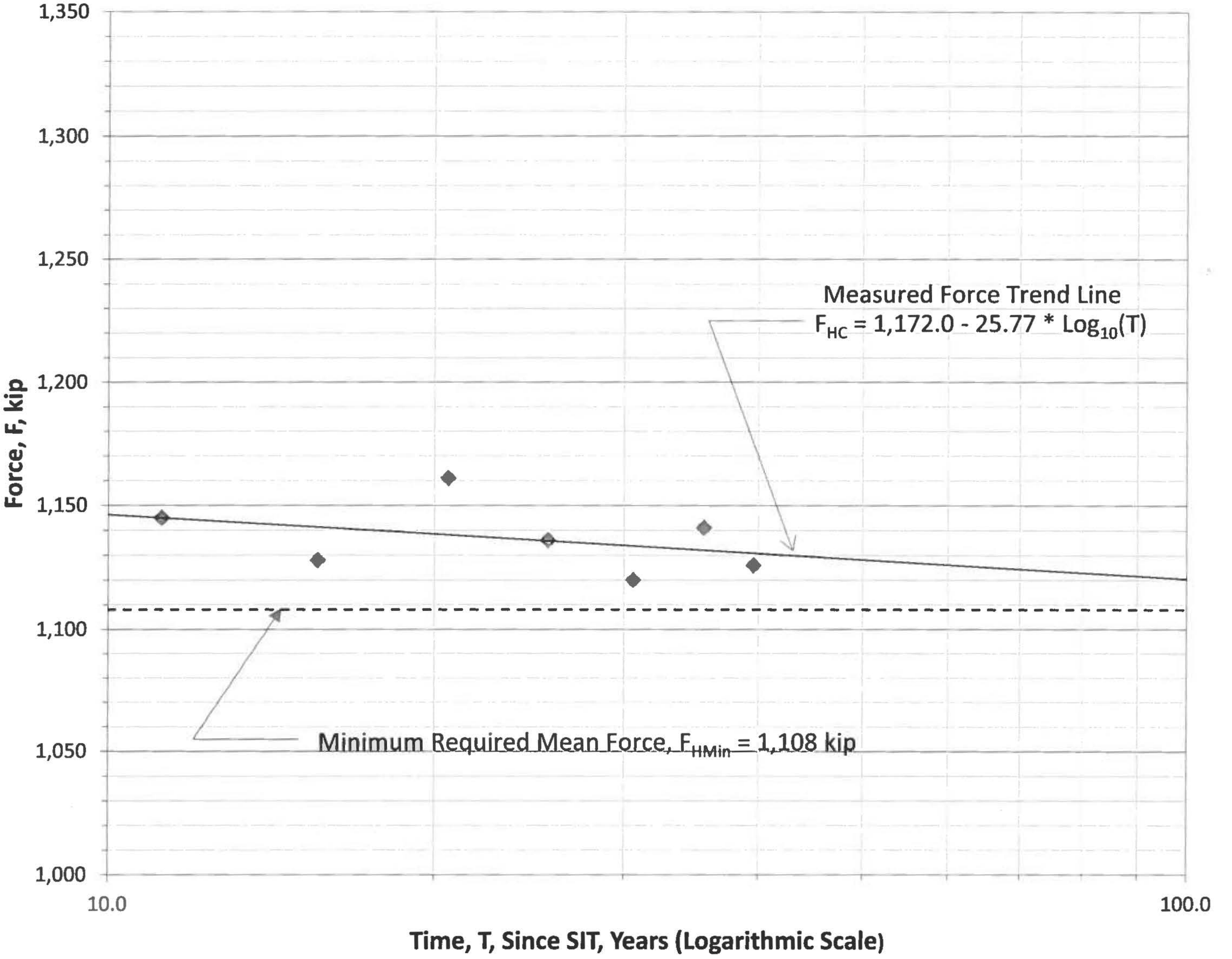
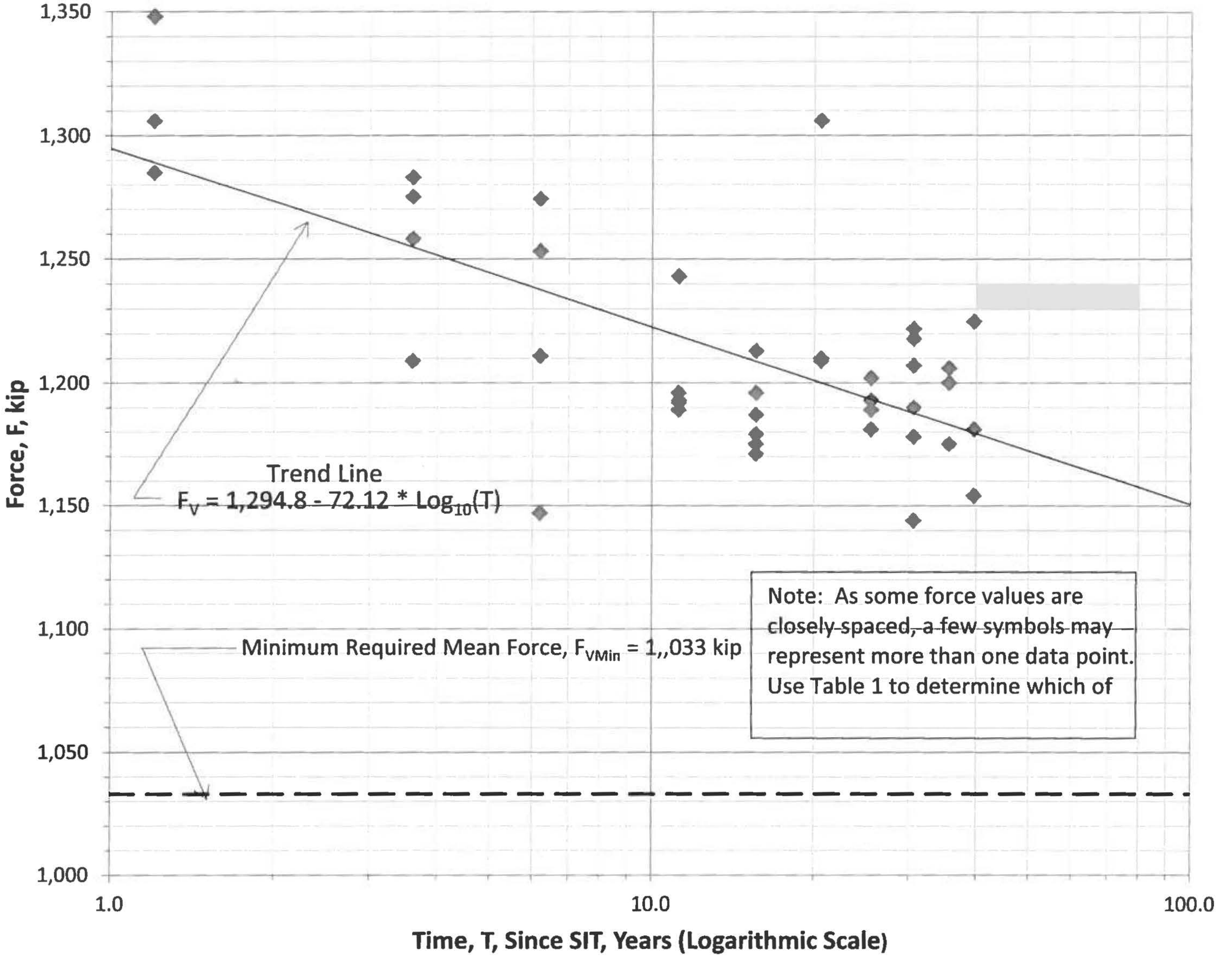


Figure 5 - Vertical Tendon Force Trend / Measured Force - Year 1 through Year 40 Data



Note: As some force values are closely spaced, a few symbols may represent more than one data point. Use Table 1 to determine which of

Figure 6 - Vertical Tendon Force Trend / Measured & Normalized Forces - Year 10 through Year 40 Data

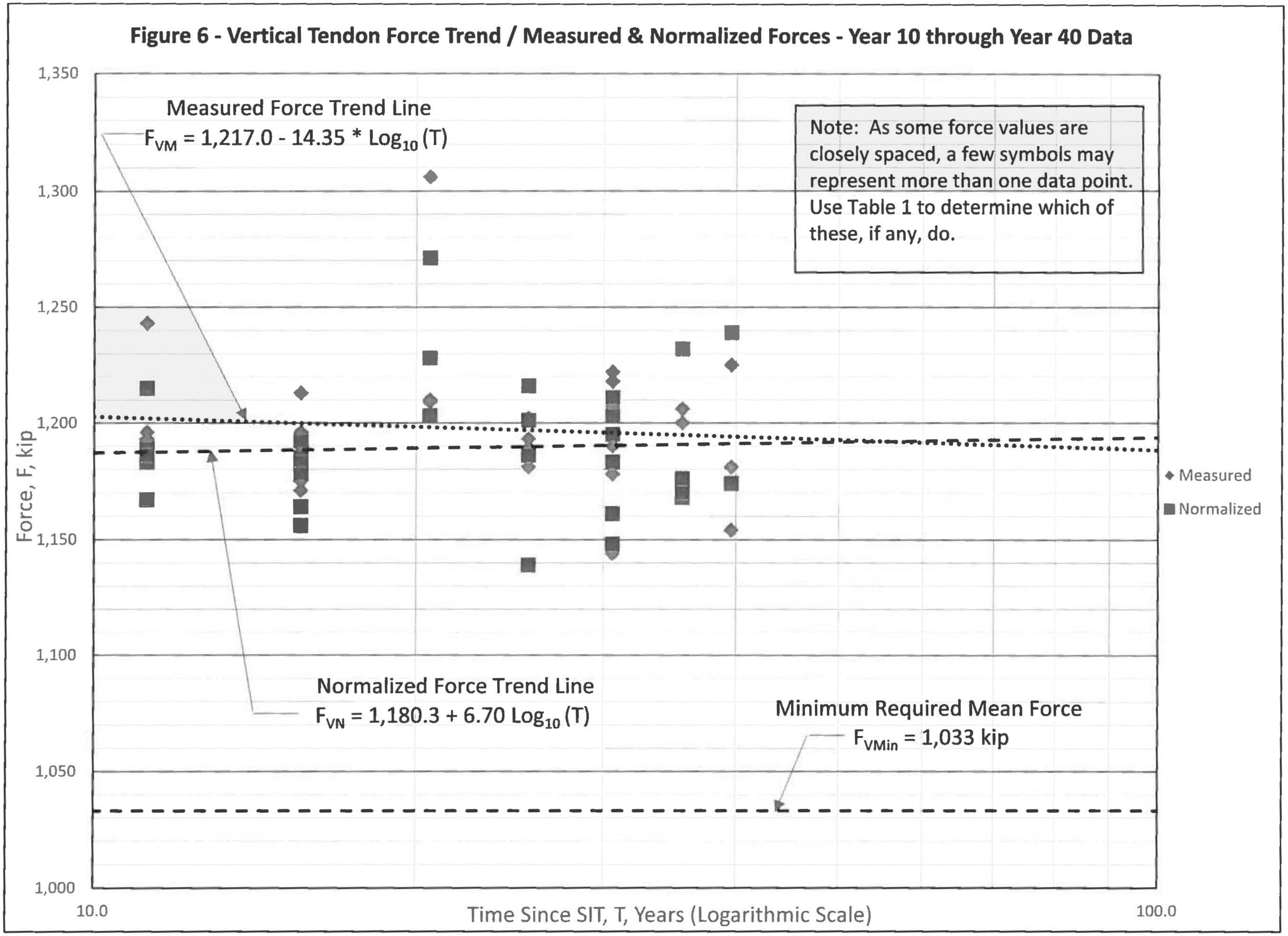
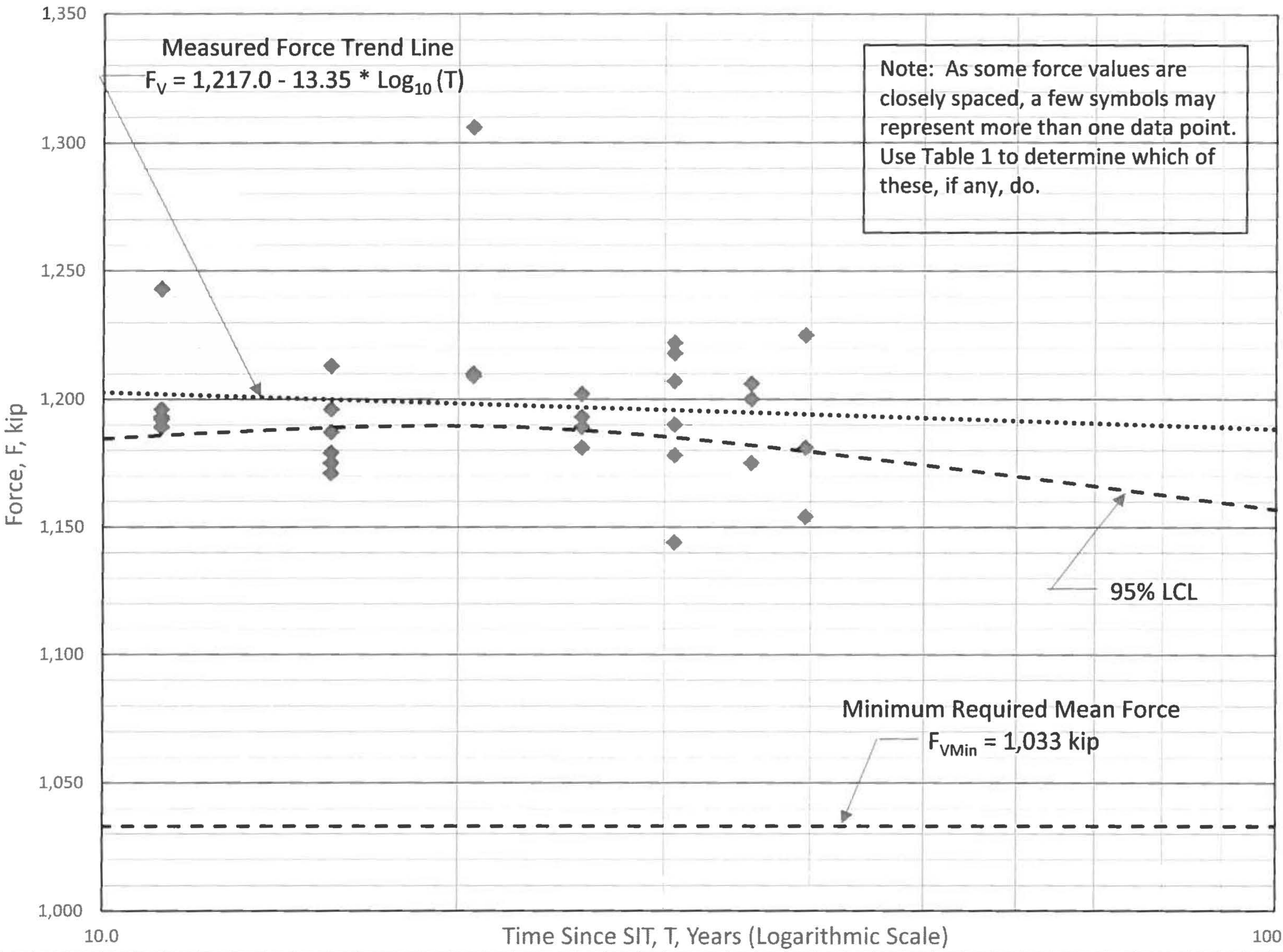


Figure 7 - Vertical Tendon Force Trend / Measured Force & UCL - Year 10 through Year 40 Data



Note: As some force values are closely spaced, a few symbols may represent more than one data point. Use Table 1 to determine which of these, if any, do.

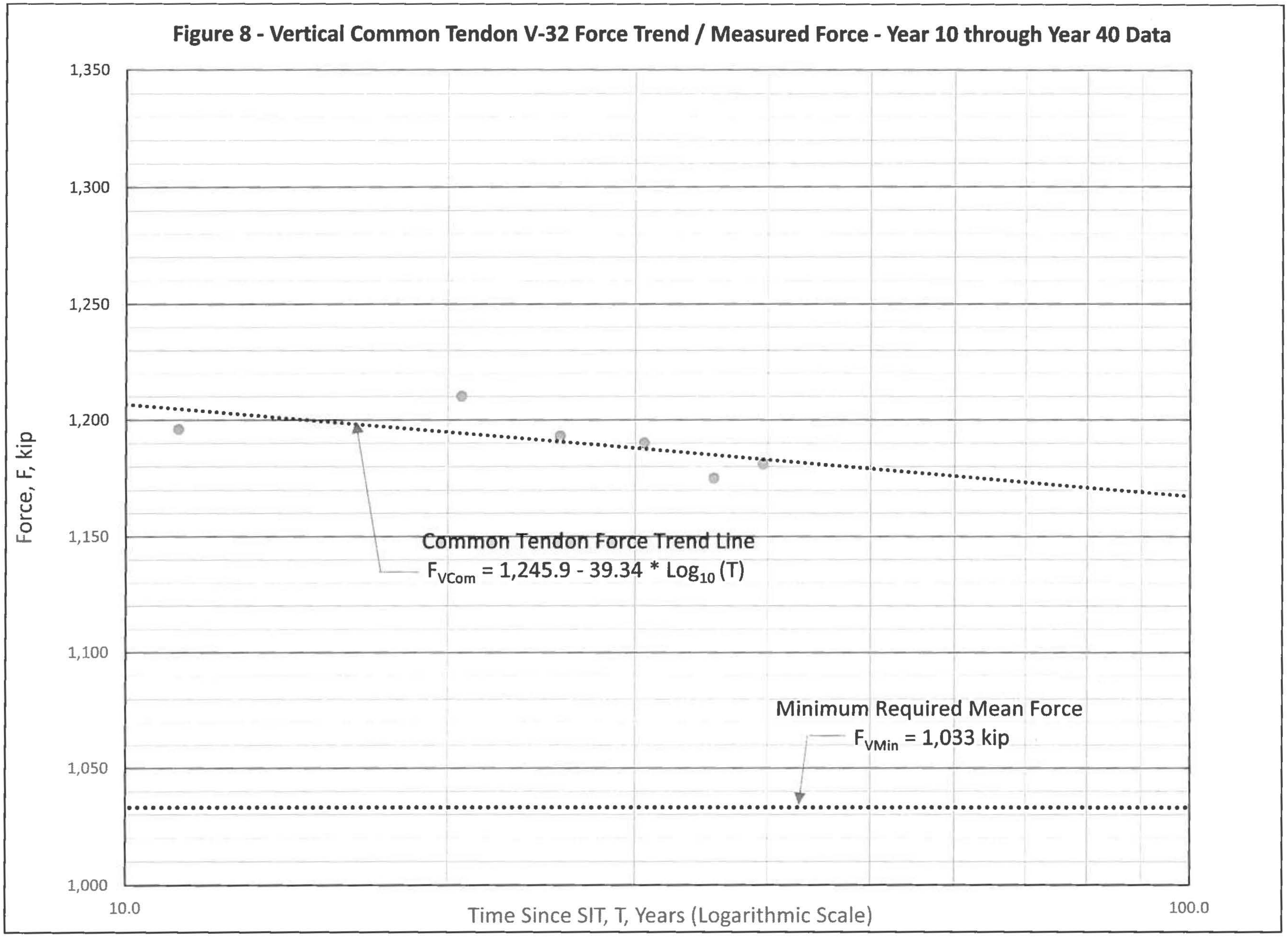
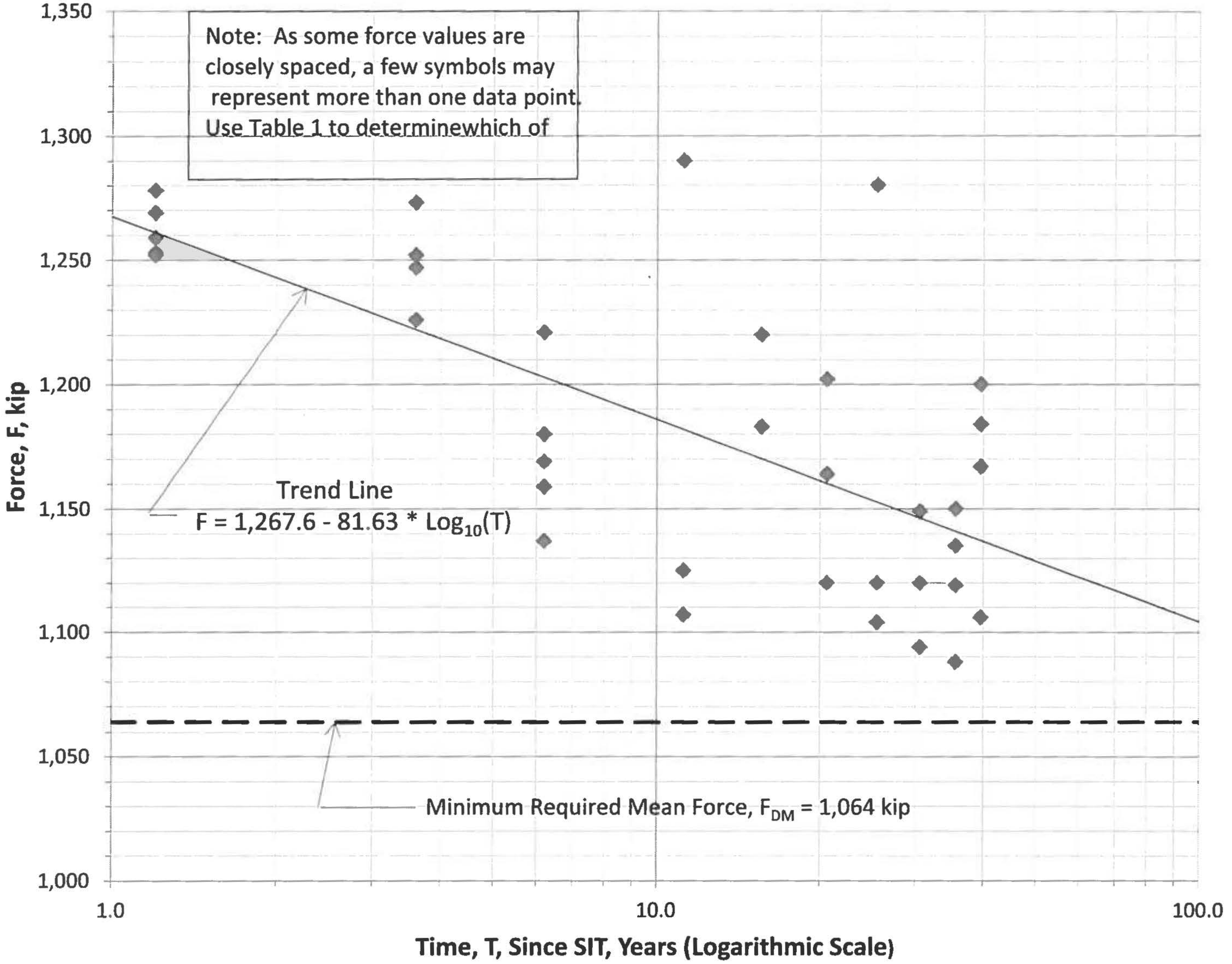


Figure 8 - Vertical Common Tendon V-32 Force Trend / Measured Force - Year 10 through Year 40 Data
Force, F, kip
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
10.0
100.0
Time Since SIT, T, Years (Logarithmic Scale)
Common Tendon Force Trend Line
$F_{VCom} = 1,245.9 - 39.34 * Log_{10}(T)$
Minimum Required Mean Force
$F_{VMin} = 1,033$ kip

Figure 9 - Dome Tendon Force Trend / Measured Force - Year 1 through Year 40 Data



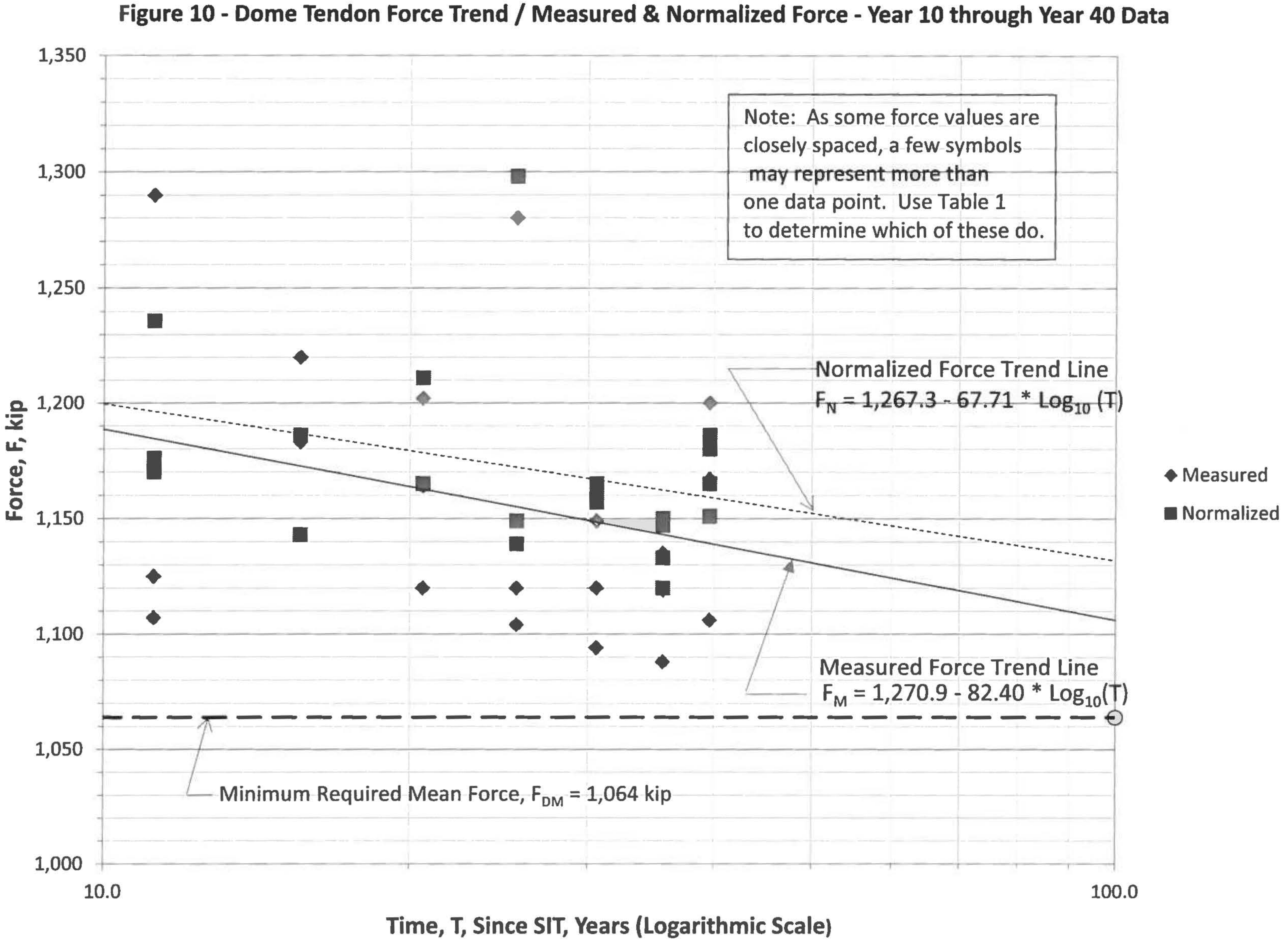


Figure 10 - Dome Tendon Force Trend / Measured & Normalized Force - Year 10 through Year 40 Data
Force, F, kip
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
10.0
100.0
Time, T, Since SIT, Years (Logarithmic Scale)
Note: As some force values are closely spaced, a few symbols may represent more than one data point. Use Table 1 to determine which of these do.
Normalized Force Trend Line
F_N = 1,267.3 - 67.71 * Log10 (T)
Measured Force Trend Line
F_M = 1,270.9 - 82.40 * Log10(T)
Minimum Required Mean Force, F_DM = 1,064 kip
◆ Measured
■ Normalized

Figure 11 - Dome Tendon Force Trend / Measured Force & UCL - Year 10 through Year 40 Data

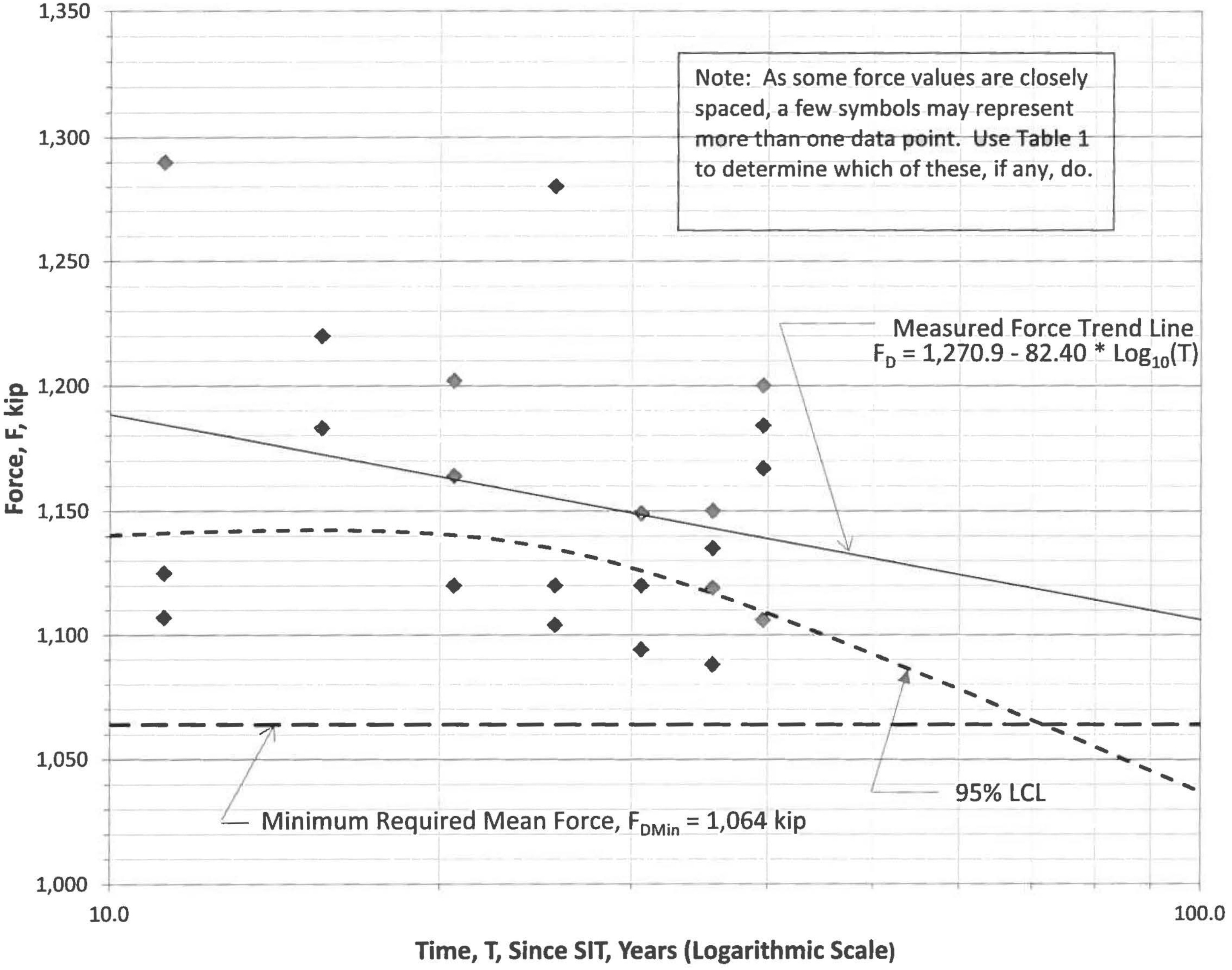


Figure 12 - Dome Common Tendon D-225 Force Trend / Measured Force - Year 10 through Year 40 Data

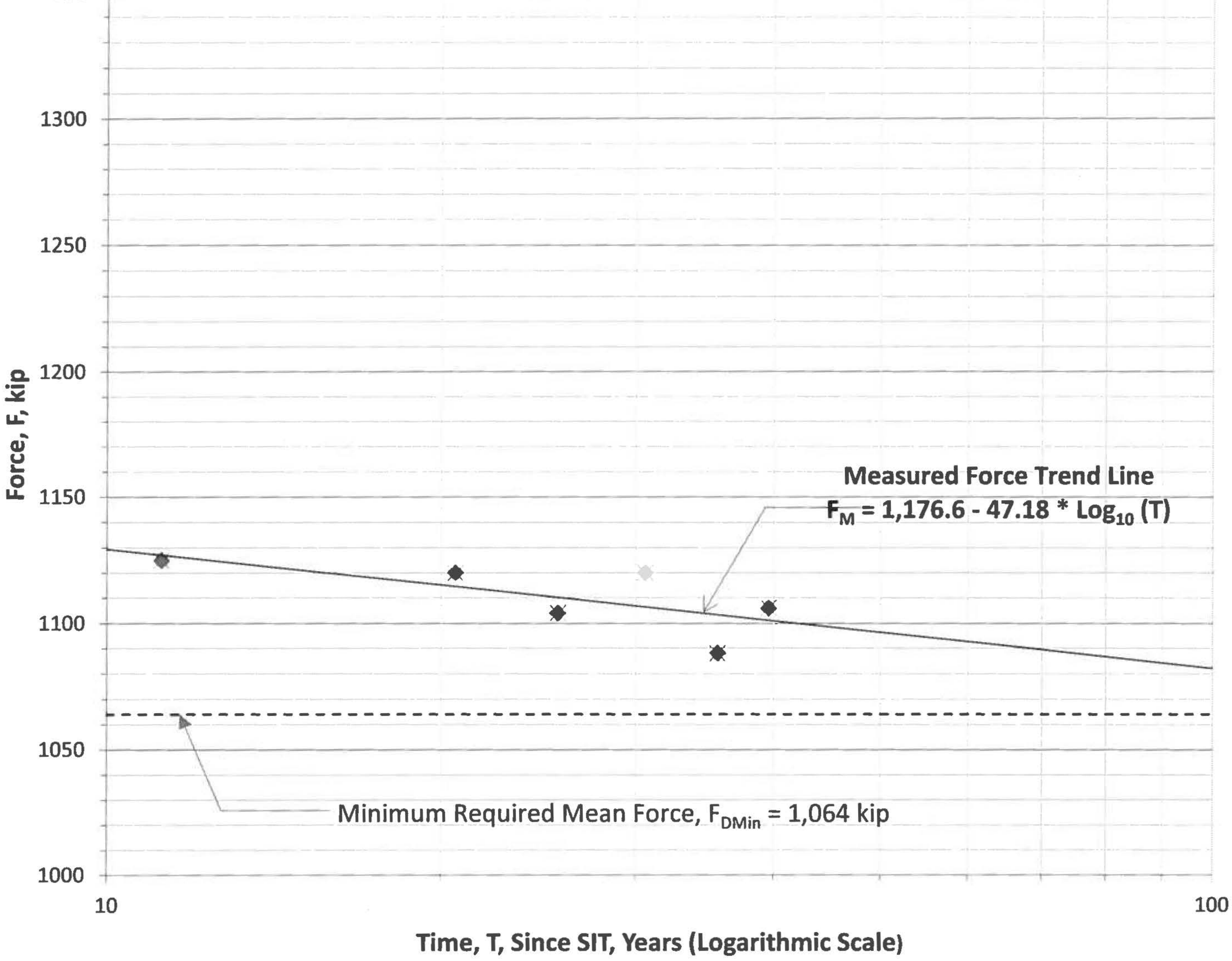
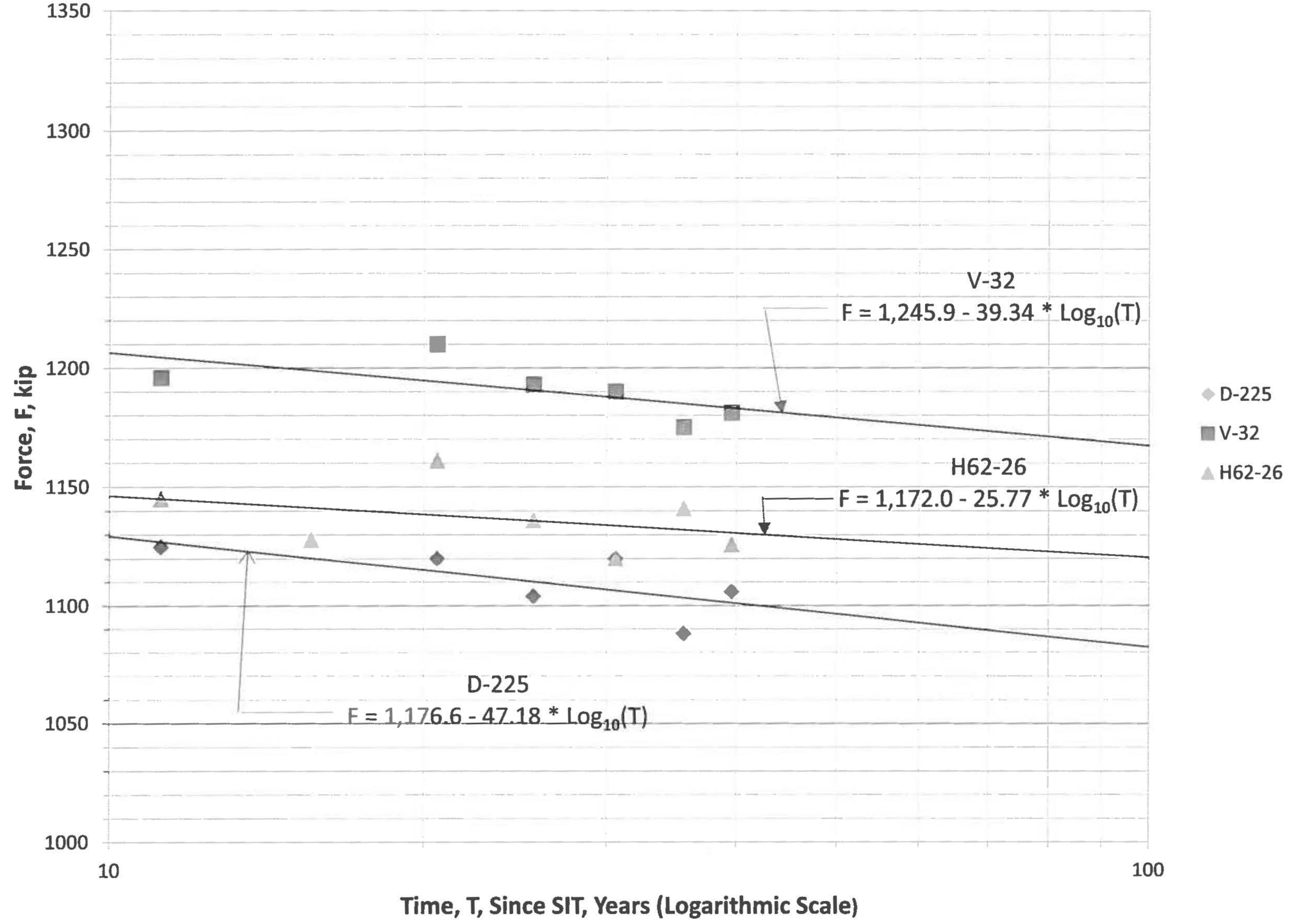


Figure 13 - Common Tendon Force Trends - All Groups



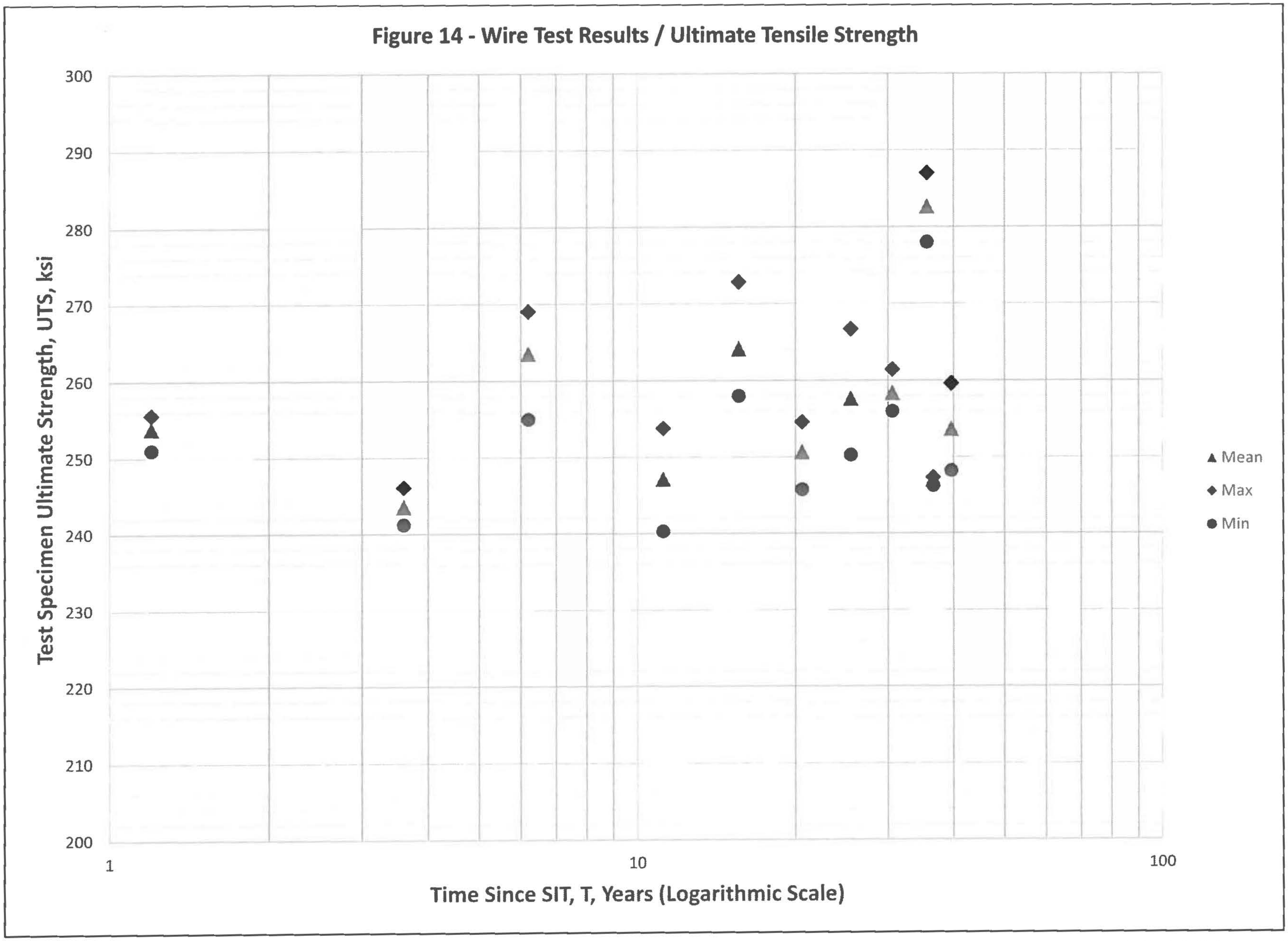


Figure 14 - Wire Test Results / Ultimate Tensile Strength
Test Specimen Ultimate Strength, UTS, ksi
300
290
280
270
260
250
240
230
220
210
200
1
10
100
Time Since SIT, T, Years (Logarithmic Scale)
▲ Mean
◆ Max
● Min

Figure 15 - Wire Test Results / Elongation at Failure