VERIFICATION OF VYNPS LICENSE RENEWAL PROJECT REPORT

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This project report documents evaluations related to the VYNPS license renewal project. Signatures certify that the report was prepared, checked and reviewed by the License Renewal Project Team in accordance with the VYNPS license renewal project guidelines and that it was approved by the ENI License Renewal Project Manger and the VYNPS Manager, Engineering Projects.

License Renewal Project Team signatures also certify that a review for determining potential impact to other license renewal documents (based on previous revisions) was conducted for this revision.

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REVISION DESCRIPTION SHEET

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1.0 Introduction

This report supports the license renewal of Vermont Yankee Nuclear Power Station (VYNPS). The purpose of this report is to evaluate time-limited aging analyses (TLAA) related to mechanical fatigue for VYNPS components. In addition, the report discusses the VYNPS plant-specific responses to industry issues related to fatigue. Information on the overall license renewal project methodology and associated documentation can be found in LRPG-01, License Renewal Project Plan (Ref. 1).

Fatigue analyses are potential TLAA for Class 1 and selected non-Class 1 mechanical components. Fatigue is an age-related degradation mechanism caused by cyclic stressing of a component by either mechanical or thermal stresses that becomes evident by cracking of the component. Fatigue analyses are TLAA if they are based on a set of design transients that are based on the life of the plant.

When TLAA-metal fatigue is identified in the aging management program column, the TLAA associated with that fatigue is applicable. Review of the TLAA, per 10 CFR 54.21 (c)(1), determines whether:

(i) the TLAA remains valid for the period of extended operation,

(ii) the TLAA can be extrapolated to the end of the period of extend operation, or

(iii) effects of aging on the intended function(s) will be adequately managed for the period of extended operation.

For fatigue, if the TLAA remains valid (i) or is extrapolated to cover the period of extended operation (ii), then cracking due to fatigue is not an aging effect requiring management. If the TLAA does not remain valid for the period of extended operation, then cracking due to fatigue is an aging effect requiring management under 10 CFR 54.21(c)(1)(iii). Cracking due to fatigue can be managed by a variety of plant programs including ISI and BWRVIP.

Class 1 components (reactor vessel and recirculation system piping) received a fatigue analysis in accordance with ASME Section III, Subsection NB. ASME Section III requires evaluation of fatigue by considering design thermal and loading cycles. The design cycles for VYNPS are listed in VYNPS calculation VYC-378 (**Ref. 55**). VYNPS monitors transient cycles that contribute to fatigue usage in accordance with requirements of VYNPS Administrative Procedure AP-0145 (**Ref. 8**). Reactor coolant system pressure boundary piping (with the exception of reactor recirculation piping) was designed to ANSI B31.1 and secondary stresses (e.g., stress due to thermal expansion and anchor movements) are analyzed for fatigue using stress intensification factors (SIFs) and stress range allowables. The stress range allowables are a function of thermal design cycles.

The non-Class 1 aging management reviews for VYNPS identify non-Class 1 mechanical components that are within the scope of license renewal and are subject to aging management review. Based on exposure to mechanical and thermal cycling, specific components are subject to cracking by fatigue as identified in the non-Class 1 aging management reviews. Non-Class 1 component types subject to fatigue include pipe, tubing, fittings, tanks, vessels, heat exchangers, valve bodies and bonnets, pump casings, and miscellaneous process components.

Fatigue evaluations that meet the definition of TLAA for Class 1 and non-Class 1 mechanical components at VYNPS are described and evaluated below. Cumulative usage factors have been documented and the actual numbers of design transient cycles have been projected to 60 years. Although some transients are projected to exceed the cycle limits before the end of 60 years, an adequate program is in place to track cycles and to provide corrective actions if limits are approached. The maximum cumulative usage factors (CUF) identified for VYNPS components are summarized in Table 2.1-1.

In addition to metal fatigue, fracture mechanics analyses of flaws discovered during in-service inspection are TLAA for those analyses based on time-limited assumptions defined by the current operating term. When a flaw is detected during in-service inspections, either the flaw must be repaired or the component that contains the flaw can be evaluated for continued service in accordance with ASME Section XI. These evaluations may show that the component is acceptable to the end of the license term based on projected in-service flaw growth. Flaw growth is typically predicted based on the design thermal and loading cycles.

2.0 VYNPS Evaluation of Metal Fatigue Time-Limited Aging Analyses

The design basis for Class 1 nuclear power plant components subjected to cyclic service is in ASME Section III. Transient events that the plant might credibly experience are evaluated to establish a design basis for plant equipment. The fatigue analyses rely on the definition of design basis transients that envelope the expected cyclic service and the calculation of a cumulative usage factor (CUF). In accordance with ASME Section III, Subsection NB, the cumulative usage factor must be less than 1.0 **(Ref. 17)**.

10CFR54.21(c) **(Ref. 25)** requires an evaluation of time-limited aging analyses to demonstrate that either the analyses remain valid for the period of extended operation, the analyses have been projected to the end of the period of extended operation, or the effects of aging on the intended function(s) will be adequately managed for the period of extended operation. This section will review the VYNPS specific methods to meet the identified requirements and to ensure that the TLAA associated with fatigue are properly dispositioned for the period of extended operation. This review consists of the following sections.

- Section 2.1 reviews the Class 1 fatigue analysis documentation. The fatigue cumulative usage factors (CUFs) for Class 1 components are TLAA that are calculated by analyzing a number of transient cycles. The VYNPS transient monitoring program tracks the actual transient cycles that the plant experiences to ensure they are maintained below the analyzed number of cycles.

- Section 2.2 reviews the non-Class 1 fatigue analysis documentation. The design documentation is maintained to document the stress analysis determination of allowable cycles.

- Section 2.3 summarizes the fatigue analyses associated with the VYNPS containment.

- Section 2.4 addresses specific analyses associated with flaws identified by inservice inspection. Any crack growth analyses justifying continued operation have been dispositioned for the period of extended operation.

- Section 2.5 reviews the VYNPS responses to industry experience. Appropriate actions are taken based on industry experience for significant fatigue concerns that were not considered during the original design. This includes environmental-assisted fatigue concerns as expressed in NUREG/CR-6260.

2.1 <u>VYNPS Class 1 Fatigue</u>

2.1.1 ASME Code Requirements for Class 1 Fatigue

VYNPS Class 1 components evaluated for fatigue and flaw growth include the reactor pressure vessel (RPV) and appurtenances, certain reactor vessel internals, the reactor recirculation system (RRS), and the reactor coolant system (RCS) pressure boundary. The VYNPS Class 1 systems include components within the ASME Section XI, Subsection IWB inspection boundary and are described in aging management review reports AMRM-31, AMRM-32, and AMRM-33 (Refs. 5, 6 and 7).

Fatigue evaluations were performed in the design of the VYNPS Class 1 components designed in accordance with the requirements specified in ASME Section III (see Table 2.1-1). The fatigue evaluations are contained in analyses and stress reports, and because they are based on a number of transient cycles assumed for a 40-year plant life, these evaluations are TLAA.

Design cyclic loadings and thermal conditions for the Class 1 components are defined by the applicable design specifications for each component. The original design specifications provided the initial set of transients that were used in the design of the components and are included as part of each component analysis and stress reports, and because they are based on a number of transient cycles assumed for a 40-year plant life, these evaluations are TLAA.

Design cyclic loadings and thermal conditions for the Class 1 components are defined by the applicable design specifications for each component. The original design specifications provided the initial set of transients that were used in the design of the components and are included as part of each component analysis and/or stress report. The component analyses and stress reports contain the fatigue evaluations, which support the fatigue design basis for each component.

2.1.2 Cumulative Usage Factors

A review of the fatigue evaluations reveals the maximum cumulative usage factors (CUFs) for applicable VYNPS Class 1 components. The documents reviewed are current design basis fatigue evaluations that do not consider the effects of reactor water environment on fatigue life. The maximum cumulative usage factors (CUF) for Class 1 components are summarized in Table 2.1-1

CUFs were found for the following Class 1 components.

- Reactor pressure vessel
- Reactor vessel internals

The CUF for each component was determined by the following method.

1. Design documents (analytical reports, stress reports, design reports, evaluations, etc.) were searched for documented usage factors.

2. The main source document for the reactor pressure vessel was VYNPS calculation VYC-378 (**Ref. 9 and 55**). This report was completed to replace the varied transients in the original analysis with transients that represented actual plant events and would make tracking of cycles more realistic. Secondary purposes were to remove unnecessary conservatism, and produce a more accurate calculation of vessel fatigue life using current analytical methods. This calculation was based on a licensed power level of 1593 MWt.

3. A search was performed to find relevant documentation that post-dated VYC-0378 to determine if the usage factors documented in this analysis had been subsequently revised. A General Electric report (Ref. 61) prepared in support of the extended power uprate, was found. This report reviewed the existing CUFs, but did not refer to VYC-

378. It then revised these CUFs to include the power uprate, and "extended" the CUFs to 60 years by multiplying them by 1.5 (60 years / 40 years). The feedwater nozzles and RR outlet nozzles exceeded CUFs of 1.0 when extended by this method. However, unless the number of plant operational transients exceeds the analyzed numbers, these CUFs will not increase as predicted by this calculation.

No plant-specific CUFs were found for the core spray safe end, the feedwater piping, the RHR return piping, or the RR piping tee. As these locations are reviewed for environmentally assisted fatigue in Section 2.5.2, the generic CUFs calculated in NUREG-6260 were used.

Table 2.1-1
Cumulative Usage Factors

Location	CUF
Bottom Head and Support Skirt	0.40
Closure Flange	0.57
Closure Studs	0.62
Core Spray Nozzle	0.63
Core Spray Safe End (1)	0.18
Core Support Structure	0.06
CRD Penetration	0.13
CRD Return Nozzle	0.39
Feedwater Nozzle	0.75
Feedwater Piping (1)	0.43
Refueling Bellows	0.67
RHR Return Piping (1)	0.03
RR inlet nozzle	0.61
RR outlet nozzle	0.81
RR Piping Tee (1)	0.40
Shroud Repair Rod Threaded Ends	0.12
Shroud Support Plate Slotted Holes	0.23
Steam outlet nozzle	0.17

(1) Plant-specific CUFs were not found. Generic CUFs from NUREG-6260 were used.

Current design basis fatigue evaluations, including the CUFs, are based on design transients. The design transients are listed in Table 2.1-2.

The VYNPS fatigue monitoring program tracks and evaluates the cycles and requires corrective actions if limits are approached. The VYNPS fatigue monitoring program (administrative procedure AP 0145, Ref. 8) ensures that the numbers of transient cycles experienced by the plant remain within the allowable numbers of cycles, and hence the component cumulative usage factors (CUFs) remain below the code allowable value of 1.0.

AP 0145 (Ref. 8) provides background information on the program and gives instructions for the acquisition, review, recording and maintenance of transient cycle data. The transient events to be monitored are listed in form 1 (APF0145.01) of the procedure and are taken from the revised reactor vessel cycle calculation (Ref. 55). The reporting frequency for cycle count data is once per fuel cycle. The most recent cycle monitoring program report (Ref. 57) provides the number of transients logged as of May 4, 2004. This report formed the basis for the projected number of cycles at sixty (60) years, i.e., at the end of the license renewal period.

Through a review of Ref. 55, the transients currently being tracked at VYNPS have been identified. In Revision 1 to VYC-0378, VYNPS reduced the number of transients monitored from the original 18 to 6. AP 0145 counts five transients and compares their actual number of cycles to the design allowed numbers of cycles. The other 13 of the original 18 transients are covered by the sixth "transient" labeled "reactor startup/shutdown cycles", which consists of an engineering evaluation of plant data each fuel cycle. While this gives a more accurate evaluation of the fatigue to the plant from operation, there is no design allowable number of cycles for this transient. Actual events are analyzed by VYNPS engineers to determine how many cycles need to be credited for these Startup/Shutdown events.

To ensure that cyclic fatigue limits will not be exceeded during vessel design life, as well as into the period of extended operation, it is necessary to count, evaluate and track the six cyclic fatigue inducing events.

Completion of the VYNPS Equipment Cycle Record Keeping Procedure (Ref. 8) following each refueling alerts management if any transient is approaching its limiting number of cycles. Therefore, the VYNPS fatigue monitoring program provides an acceptable means for ensuring that TLAAs associated with fatigue for the RPV and associated Class 1 components will remain valid through the period of extended operation in accordance with 10 CFR 54.21(c)(i). The fatigue monitoring program, is discussed more detail in LRPD-02.

The number of cycles accrued to date have been extrapolated to determine the numbers of cycles expected at the end of 60 years of operation. The results of the 60-year projections show that for the five VYNPS transients with design allowable limits, the numbers will remain below the design allowable numbers during the period of extended operation. However, the projection for the sixth "transient" (engineering analysis of plant data for each fuel cycle) has no design allowable number against which to compare the projection.

First a projection factor for 60-years was calculated as the ratio of 60 years to the operating time through the last cycle update. For each transient, the 60-year projection is then calculated as the projection factor times the May 4, 2004, cycle count. The results are shown in Table 2.1-2. The results of the 60-year projections show that for the five VYNPS transients with design allowable limits, the numbers will remain below the design allowable numbers during the period of extended operation.

The VYNPS fatigue monitoring program is adequate for monitoring plant transients and will assure that the allowed number of transients is not exceeded. Consequently, the TLAA (fatigue analyses and CUFs) based on those transients will remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i). The fatigue monitoring program is discussed in more detail in LRPD-02, Aging Management Program Evaluation Results.

Table 2.1-2
Allowable and Projected Number of Thermal Cycles

	Design Transient	Design Basis Cycles (Ref. 8)	Current Cycles Logged as of 05/04/04 (Ref. 57)	Projection Factor(1)	Projected Cycles at 60 Years of Operation	% used in 60 years
1	Closure Flange Bolting	200	32	1.908	61	31%
2	Closure Flange Unbolting	200	32	1.908	61	31%
3	System Pressure Tests	120	32	1.908	61	31%
4	Heatup	300	90	1.908	172	57%
5	Cooldown	300	88	1.908	168	56%
6	Reactor Startup/Shutdown Cycles		32	1.908	61	

(1) The projection factor for 60-years was calculated as the ratio of 60 years to the operating time through the last cycle update.

Date of commercial operation for VYNPS = November 20, 1972
Date after 60 years of operation = November 20, 2032
Date of latest program report = May 04, 2004 (Ref. 57)
Projection factor = (November 20, 2032 – November 20, 1972) / (May 04, 2004 – November 20, 1972
= 1.908

2.1.3 Reactor Pressure Vessel

The reactor pressure vessel (and appurtenances) fatigue analyses were performed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III, 1965 Edition, 1966 and 1967 addenda. (A complete listing of applicable codes is given in table 4.1-1 of the UFSAR.) The fatigue analyses based on a number of transient cycles assumed for a 40-year plant life are considered TLAA. The design transients are listed in Table 2.1-2.

Design cyclic loadings and thermal conditions for the reactor pressure vessel were originally defined in the design specifications for the vessel. The original design specifications provided the set of transients that were used in the design of the components. Subsequent evaluations by VYNPS modified the list of transients to one which more closely reflected actual plant transients that were easier to track, while still bounding the original design transients.

The VYNPS Fatigue Monitoring program will assure that the allowed number of transient cycles is not exceeded. The program requires corrective action if transient cycle limits are approached. Consequently, the TLAA (fatigue analyses) based on those transients will remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i) or the effects of aging on the intended function(s) will be adequately managed for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(iii). Further details on cycle projections and cycle monitoring were provided in Section 2.1.2.

2.1.4 Reactor Internals

Although not mandatory, the design of the reactor vessel internals is in accordance with the intent of ASME Section III (Ref. 3, Section 3.3.4).

2.1.4.1 Internals Fatigue

UFSAR, Appendix C, section C.2.5.3 states that a fatigue analysis for the Dresden plant was performed that is a good approximation for VYNPS, the implication being that there is no site specific fatigue analysis. UFSAR Section 3.3.6 states "A vibration analysis of reactor vessel internals was performed in the design to reduce failures due to vibration. When necessary, vibration measurements were made during startup tests to determine the vibration characteristics of the reactor vessel internals and the recirculation loops under forced recirculation flow. Vibratory responses were recorded at various recirculation flow rates using strain gages on fuel channels and control rod guide tubes, accelerometers on the shroud support plate and recirculation loops, and linear differential transducers on the upper shroud and shroud head-steam separator assembly. The vibration analyses and tests were designed to determine any potential, hydraulically-induced equipment vibrations and to check that the structures should not fail due to fatigue. The structures were analyzed for natural frequencies, mode shapes, and vibrational magnitudes that could lead to fatigue at these frequencies. With this analysis as a guide, the reactor internals were instrumented and tested to ascertain that there are no gross instabilities. The cyclic loadings were evaluated using as a guide the cyclic stress criteria of the ASME Code, Section III. These field tests were only performed on reactor vessel internals that represent a significant departure from design configurations previously tested and found to be acceptable. Field test data were correlated with the analyses to ensure validity of the analytical techniques on a continuing basis.(3)" Reference (3) is Reference 83 of this document. This analysis is not a TLAA as it is not based on any time-limited assumptions; vibration levels were analyzed and confirmed to be acceptable.

Section 4.3.2.2 of the Dresden License Renewal Application (Ref. 85) states that this analysis does not contain any time-limited assumptions. The NRC SER for the Dresden Application (Ref. 86) does not dispute this statement but notes that the analysis has been redone for the Extended Power Uprate at Dresden. Section 2.2.3.2 of the NRC draft SER for the VYNPS extended power uprate (Ref. 87) states

> For components other than the steam separators and dryers, the evaluation of FIV for the reactor internal components was performed based on the vibration data recorded during startup testing at the GE prototype BWR/4 plant (Monticello) and VYNPS. The vibration levels were calculated by extrapolating the recorded vibration data to EPU conditions and compared to the plant allowable limits. The stresses at critical locations were calculated based on the extrapolated vibration peak response displacements and found to be within the

GE allowable design criteria of 10 ksi (where 1 ksi = 1000 pounds per square inch). Stress values less than 10 ksi for stainless steel are within the endurance limit under which sustained operation is allowed without incurring any cumulative fatigue usage. The vibration evaluation methodology, as described in Section 3.4.2 of the PUSAR, is conservative based upon the absolute sum combination of the various modes of vibration, including the absolute sum of the maximum vibration amplitude occurring in each mode. The licensee concluded that vibration levels of all safety-related reactor internal components are within the acceptance criteria. The NRC staff finds the licensee's specified stress limit of 10 ksi for the reactor internal components to be reasonably conservative in comparison to the ASME Code limit of 13.6 ksi for the peak vibration stress and is, therefore, acceptable.

Again, the described analysis is not based on any time-limited assumptions and is thus not a TLAA.

2.1.4.2 Shroud Repair Fatigue

UFSAR Section K.3.1 states that the core shroud repair was designed for a 40 year life. Refs. 14 and 15, the shroud repair stress reports, provide the fatigue design basis and were the source documents for the core shroud stabilizer CUFs.

In response (BVY 96-48 Ref. 14) to the NRC's Request for Additional Information on the core shroud repair, VYNPS stated that the fatigue analysis had been performed for the shroud repair hardware in calculation 2499502-601 (Ref. 15). This calculation included a fatigue analysis of the slotted hole in the shroud support plate where the shroud repair ligaments attach. This analysis is a TLAA. The resulting CUF was 0.23 (Table 5-6 of **Ref.** 15). This CUF is based on the design transients in the original reactor vessel design report. As such, the VYNPS fatigue monitoring program will assure that those transients are not exceeded and the TLAA will remain valid for the period of extended operation in accordance with 10CFR54.21(c)(1)(i). The fatigue monitoring program is discussed in LRPD-02.

The shroud and shroud repair was re-evaluated for the constant pressure power uprate (CPPU) (Ref. 28) as discussed above. The results of the CPPU evaluations showed that the loads and stresses for all shroud repair components remained within design limits, and thus the results of calculation 2499502-601 remain valid. No new fatigue analysis was performed.

The VYNPS Fatigue Monitoring program will assure that the allowed number of transient cycles is not exceeded. The program requires corrective action if transient cycle limits are approached. Consequently, the TLAA (fatigue analyses) based on those transients will remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i) or the effects of aging on the intended function(s) will be adequately managed for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(iii).

2.1.5 Class 1 Piping and Component Fatigue

The VYNPS Class 1 boundary corresponds to all reactor coolant system (RCS) pressure boundary components within the ASME Section XI, IWB inspection boundary and is described in aging management review reports AMRM-31, AMRM-32 and AMRM-33 (Refs. 5, 6, and 7). VYNPS Class 1 RCS pressure boundary piping was designed and analyzed in accordance with ANSI B31.1. (UFSAR Table 4.1-1 gives a complete listing of applicable codes.) As such, fatigue analyses that calculate cumulative usage factors are not required. Rather stress range reduction factors are used to account for anticipated transients (normally 7000 cycles). Applicable design specifications define the design cyclic loadings and thermal conditions for the Class 1 components.

Portions of certain systems have been replaced or modified over the course of operation of VYNPS. Those modifications may be done to more recent code requirements. Review of Current Licensing Basis documentation has found the following additional Class 1 fatigue topics.

2.1.5.1 Reactor Recirculation System

VYNPS replaced the reactor recirculation (RR) system piping in 1986. (See Section 4.3.6 of the UFSAR). Also replaced were connecting portions of the residual heat removal (RHR) system piping. The new piping was designed and analyzed to ANSI B31.1, but was inspected and tested to ASME Section III requirements. Stress analyses for the reactor recirculation system were performed to B31.1 requirements in Refs. 10 and 11. Even though B31.1 does not require a fatigue analysis, such an analysis was done for the highest anticipated usage factor location – the RHR to RR tee. These analyses were based on a number of cycles not expected to be exceeded in 40 years and as such are treated as TLAA.

The VYNPS Fatigue Monitoring program will assure that the allowable number of transient is not exceeded. The program requires corrective action if transient cycle limits are approached. Consequently, the TLAA (fatigue analyses) based on those transients will remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i) or the effects of aging on the intended function(s) will be adequately managed for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(iii).

Section 4.3 of Ref. 10 makes the following two points about this calculation.

1. The initiation of RHR has the highest delta-temperature (up to 200 degrees F) between RHR and RR. This relatively short transient is permissible for 4000 cycles. As it occurs only during plant cooldown, there will be far less than 4000 cycles in 60 years (300 cooldowns per Table 2.1-2 of this report). Consequently this portion of the analysis remains valid for the period of extended operation per 10 CFR 54.21(c)(1)(i).

2. "A detailed ASME Class 1 Section III 1983 edition fatigue analysis for the Tee has been performed. The duty cycles used consisted of 27 load sets. Each of the load sets includes pressure, thermal expansion effect, earthquake and the temperature gradient through wall at the Tee. The total number of cycles for each load set is based on 40 years of plant operation. The results of this study indicate that the RHR Tee meets the Class 1 fatigue criteria." Again, as noted in Section 2.1.2 VYNPS will not exceed the allowable number of cycles for 40 years even after 60 years of operation, this portion of the calculation will also remain valid for the period of extended operation per 10 CFR 54.21(c)(1)(i).

2.1.5.2 Main Steam Isolation Valve Cycles

UFSAR Section 4.6.3 states that the main steam isolation valves (MSIV) are designed for 40 years based on 100 cycles during the first year and 50 cycles per year thereafter. This statement may be interpreted to imply a TLAA. The UFSAR statement refers to mechanical cycles of the valve (in the UFSAR, 2,050 cycles are assumed for 40 years).

Cycling of these valves will lead to wear of active subcomponents (disc and seat) with no license renewal function and fatigue of the passive components (body and bonnet) that have a license renewal intended function (pressure boundary).

Fatigue of the valve body is not an issue due to the large allowable number of cycles on the valves. Projected cycles of the MSIVs are far below the 50 cycles per year allowed. This TLAA will remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i). The MSIVs will not exceed 2050 cycles in 60 years (34 cycles per year).

The MSIVs are monitored for cracking by the ASME Inservice Inspection program, which would also detect fatigue cracking if it were to occur.

2.1.5.3 Flow Induced Vibration (FIV) of the Main Steam (MS) and Feedwater (FW) Piping

The constant pressure power uprate (CPPU) increases the main steam and feedwater flowrates by approximately 20%. The GE CPPU report (Ref. 28) evaluated this increase in flow as it affects FIV of the MS and FW piping. By reference 28, VYNPS committed to perform a piping vibration startup test program, at the uprated power level, consistent with the ASME code and regulatory requirements. This testing is expected to confirm that FIV of this piping is not a concern for the period of extended operation. No TLAA is associated with these components.

2.2 VYNPS Non-Class 1 Fatigue

The non-Class 1 aging management reviews (AMRs) for VYNPS identify the non-Class 1 mechanical components susceptible to cracking by fatigue including pipe, tubing, fittings, tanks, vessels, heat exchangers, valve bodies and bonnets, pump casings, and miscellaneous process components. These components may experience thermal cycles as a result of either flow transients or cyclic thermal stratification.. These thermal cycles are not tracked as part of the fatigue monitoring program. The impact of thermal cycles on non-Class 1 components is reflected in the calculation of the allowable stress range. The allowable stress range is reduced by the stress range reduction factor if the number of thermal cycles exceeds 7000. (1995 ASME Boiler and Pressure Vessel Code, Division 1, Subsection NC, Class 2 Components, Page 158.)

Only those systems that may experience a high cycle frequency are of concern. 7000 cycles equates to approximately one cycle every 2 days for forty (40) years of operation, or approximately one cycle every 3 days for 60 years of operation.

The non-Class 1 fatigue screening document in Appendix H of the Mechanical Tools **(Ref. 18)** was used to determine locations susceptible to fatigue cracking in non-Class 1 systems at VYNPS. The first step in the screening process was to identify non-Class 1 components that may have normal/upset condition operating temperature in excess of 220°F for carbon steel or 270°F for stainless steel. These values are based on recommendations in the EPRI Fatigue Management Handbook (TR-104534), as summarized in the Mechanical Tools. Although most VYNPS non-Class 1 components do not exceed the temperature thresholds, some components, identified in the appropriate AMRs are further evaluated for fatigue below.

2.2.1 Non-Class 1 Piping and In-Line Components

The design of ASME III Code Class 2 and 3 piping systems incorporates the Code stress reduction factor for determining acceptability of piping design with respect to thermal stresses. The design of ASME B31.1 Code components also incorporates stress reduction factors based upon an assumed number of thermal cycles. In general, 7000 thermal cycles are assumed, leading to a stress reduction factor of 1.0 in the stress analyses. VYNPS evaluated the validity of this assumption for 60 years of plant operation. The results of this evaluation indicate that the 7000 thermal cycle assumption is valid and bounding for 60 years of operation. Therefore, the pipe stress calculations are valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

The design code for most non-Class 1 piping and in-line components (e.g., fittings and valves) is ANSI B31.1 or ASME III Subsections NC and ND. These Codes specify evaluation of cyclic secondary stresses (i.e., stresses due to thermal expansion and anchor movements) using stress intensification factors (SIFs) and allowable stresses (S_A). The allowable secondary stress range is 1.0 S_A for 7000 cycles or less and is reduced in steps to 0.5 S_A for greater than 100,000 cycles. No increase is allowed for less than 7000 cycles.

For all those non-Class 1 components identified in the AMR reports described above as subject to cracking due to fatigue, a review of system operating characteristics was conducted to determine the approximate frequency of significant thermal cycling. If the number of equivalent full temperature cycles for 60 years of operation is below the limit used for the original design (usually 7000 cycles, as described in Section 2.2 above), the component is suitable for the period of extended operation. If the number of equivalent full temperature cycles exceeds the limit, evaluation of the individual stress calculations will be required.

The following non-Class 1 systems include piping and in-line components subject to fatigue. The specific component types for each system are identified in the aging management review results table for the associated AMR..

- AMRM-02: The residual heat removal system (RHR) system contains filters, orifices, piping, thermowells, and valve bodies subject to fatigue. RHR is used during plant shutdowns to cold conditions. Even though cycling of the RHR system may occur during outages, significant thermal transients occur only early in the shutdown when reactor coolant is still at temperatures above 220 °F. Thus significant cycles of the RHR system are coincident with plant cooldowns, which are limited to 300 per Table 2.1-2. The RHR system fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-04: The automatic depressurization system (ADS) contains piping, tubing, and valve bodies subject to fatigue. ADS relieves pressure following a plant upset, not during normal plant operation. The number of cycles is expected to be orders of magnitude below 7000. The safety/relief valves are tested when removed, consequently testing does not fatigue the discharge piping. The ADS fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i). Relief valve discharge piping and torus penetrations have unique fatigue analyses based on a much lower number of cycles. These components are discussed in Section 2.3 of this report.

- AMRM-05: The high pressure coolant injection (HPCI) system contains drain pots, orifices, piping, steam traps, strainer housings, thermowells, tubing, and valve bodies subject to fatigue. The steam supply to the HPCI pump turbine is exercised during testing and is used to mitigate design basis events. The pump is tested quarterly (when steam pressure is available), so the number of tests in sixty years will be no more than 240. The plant is restricted to less than 400 reactor trips which limits the number of HPCI actuations. The number of total cycles is expected to be significantly below 7,000 equivalent full temperature cycles (less than 640 cycles) during the period of extended operation. The HPCI piping fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-06: The reactor core isolation cooling (RCIC) system contains drain pots, orifices, piping, steam traps, strainers, tubing, and valve bodies subject to fatigue. The steam supply to the RCIC pump turbine and turbine exhaust are exercised during testing and to mitigate design basis events. The pump is tested quarterly (when steam pressure is available), so the number of tests in sixty years will be no more than 240. The plant is restricted to less than 400 reactor trips which limits the number of RCIC actuations. The number of total cycles is expected to be significantly below 7,000 equivalent full temperature cycles (less than 640 cycles) during the period of extended operation. The RCIC pump turbine piping fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-13: The emergency diesel generators (EDG) contain expansion joints, piping, silencers, and turbocharger housings subject to fatigue. The diesels are tested monthly giving 720 full temperature cycles in 60 years. EDG actuations occur less frequently than the testing. Thus the total equivalent full-temperature cycles in 60 years will not exceed 7000. The EDG fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-17: The fire protection system (FP) contains diesel exhaust lines and lube oil return lines subject to fatigue. As these components are only thermally cycled when the fire protection diesel is loaded, they are expected to experience far less than 7000 cycles in 60 years similar to the emergency diesels above. The fire protection system fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-21: The John Deere Diesel contains a silencer, turbocharger, and exhaust piping subject to fatigue. As these components are only thermally cycled when the John Deere diesel is loaded, they are expected to experience far less than 7000 cycles in 60 years, as explained for the emergency diesels above. The John Deere diesel fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-26: The main condenser and MSIV leakage pathway contain orifices, heat exchanger tubes, piping, strainer housings, thermowells, steam traps, tubing, and valve bodies subject to fatigue. The main condenser and MSIV leakage pathway are normally in service during plant operation. However, they only see significant temperature transients during plant startup and shutdown. Again, the number of cycles expected on these systems is well below the 7000 cycles allowable. The main condenser and MSIV leakage pathway fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

- AMRM-30: Non-safety systems affecting safety related systems contain filter housing, flow elements, rupture disks, piping, and valve bodies subject to fatigue. The bulk of the components that experience temperatures above 220°F are in the steam/feedwater cycle. As such these systems are limited to the number of transients discussed above for the main condenser and main steam isolation valve leakage pathway and will not exceed 7000 cycles during the period of extended operation.

  The heating boiler (HB) system piping and valves carry steam to local space heaters, and HB piping and valves are in several rooms with safety related equipment. This system is designed to B31.1 and is thus inherently acceptable for 7000 cycles of operation. As the system is normally started and stopped (thermally cycled) several times per year based on prevailing weather, the total cycles for 60 years are expected to be in the hundreds of cycles, not thousands of cycles. The heating boiler fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

  The post accident sampling system (PASS) system contains tubing and valve bodies subject to fatigue. PASS is an accident mitigation systems that is not used during normal plant operation. The number of cycles to the PASS system is expected to be orders of magnitude below 7000. The PASS system fatigue analysis remains valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

  Some applicants for license renewal have estimated that piping in the primary sampling system will have more than 7000 thermal cycles before the end of the period of extended operation. At VYNPS, the sampling system is used to take reactor coolant samples every 96 hours during normal operation. However, the normal samples are taken from the RWCU filter influent, where the water has already been cooled. Thus normal sampling does not cause a thermal cycle. Alternate samples may be taken directly from the B discharge header of the reactor recirculation system via containment penetration X-41; however, this is an infrequently performed procedure and this piping, designed to ASME B31.1, will not exceed 7000 cycles prior to 60 years of operation.

  The non-safety systems affecting safety related systems fatigue analyses remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(1)(i).

Thus, the TLAA for the all non-Class 1 piping and piping components remain valid for the period of extended operation in accordance with 10 CFR 54.21(c)(i).

2.2.2 Non-Class 1 Pressure Vessels, Heat Exchangers, Storage Tanks, Pumps and Turbine Casings

Non-Class 1 pressure vessels, heat exchangers, storage tanks and pumps are designed in accordance with ASME VIII or ASME III Subsection NC or ND (e.g., Class 2 or 3). Some tanks and pumps are designed to other industry codes and standards, reactor designer specifications, and architect engineer specifications. ASME Section VIII Division 2 and ASME Section III Subsection NC-3200 include fatigue design requirements. Due to conservatism in ASME Section VIII Division 1 and ASME Section III NC-3100/ND-3000, detailed fatigue analysis is not required. Fatigue analyses are also not required for NC/ND pumps and storage tanks (< 15 psig). Also, the component designer should have specified ASME Section VIII Division 2 or NC-3200 if cyclic loading and fatigue usage could be significant. The design specification identifies the applicable design code for each component.

Both ASME Section VIII Division 2 and ASME Section III NC-3200 include provisions for "exemption from fatigue", which is actually a simplified fatigue evaluation based on materials, configuration, temperature and cycles.

Fatigue analysis is not required for other design codes (e.g. ASME Section VIII Division 1, AWWA, MSS, NEMA), and components designed and fabricated with these codes are suitable for the period of extended operation without further evaluation.

The non-Class 1 system heat exchangers, pumps and turbine casings identified in the aging management review reports as subject to fatigue are evaluated below.

AMRM-02 The residual heat removal system (RHR) system contains heat exchangers and pump casings subject to fatigue. The RHR pumps are designed to ASME Section III, Class C. The heat exchanger shell side is designed to ASME Section III, Class C while the heat exchanger tube side is designed to ASME Section VIII/TEMA Class 2. (Section 2.2.5.2 of Design Basis Document RHR, Revision 1, January, 1999) These codes do not require a fatigue analysis. As such, there is no TLAA associated with fatigue of the RHR components. The RHR pump and heat exchanger are acceptable for the period of extended operation.

AMRM-05: The HPCI system contains a turbine casing subject to fatigue. This turbine is designed to the NEMA code. This code does not require a fatigue analysis. As such, there is no TLAA associated with fatigue of the HPCI turbine. The HPCI turbine is acceptable for the period of extended operation.

AMRM-06: The RCIC system contains a turbine casing subject to fatigue. This turbine is designed to the NEMA code. This code does not require a fatigue analysis. As such, there is no TLAA associated with fatigue of the HPCI turbine. The HPCI turbine is acceptable for the period of extended operation.

2.3 VYNPS Containment Liner Plate, Metal Containment, and Penetrations Fatigue Analyses

The torus and torus attached piping systems were analyzed as part of the Mark 1 containment long-term program, using methods and assumptions consistent with NUREG-0661 (Ref. 80). The fatigue analyses performed included the torus, SRV piping and penetrations, and other torus attached piping.

The VYNPS torus analysis is Technical Report TR-5319-1 (Ref. 77), which was transmitted to the NRC via Ref. 78. The VYNPS torus attached piping analysis is Technical Report TR-5319-2 (Ref. 79). The piping analysis in turn references GE report MPR-751 (Ref. 16).

2.3.1 Fatigue Analysis of the Torus

The fatigue analyses of the torus looked at both the torus shell and attached piping systems.

The VYNPS plant specific fatigue usage factor (TR-5319-1, Section 3.3.1, **Ref. 77**) for the torus shell is 0.001 for normal operation and 0.011 for upset conditions. These values are so small that when multiplied by 1.5 to account for 60 years rather than 40 years, they are still insignificant usage factors. The fatigue analysis of the torus during normal operation and upset conditions has thus been projected through the period of extended operation in accordance with 10CFR54.21(c)(1)(ii).

The VYNPS fatigue usage factor (TR-5319-1, Section 3.3.1, **Ref. 77**) for the torus shell is 0.078 for the design basis accident. As there will still be only one design basis LOCA for the life of the plant, including the period of extended operation, this analysis is not based on a time-limited assumption and is not a TLAA.

The vent system was conservatively analyzed by assuming that all maximum stresses occur simultaneously, and that all cycles reach these maximum values. This produced a conservative CUF for the vent system of 0.76. The significant contributor to this CUFs is post-LOCA chugging, a once in plant-life event. As there will still be only one design basis LOCA for the life of the plant, including the period of extended operation, this analysis is not based on a time-limited assumption and is not a TLAA.

2.3.2 Fatigue Analysis of the Safety Relief Valve (SRV) Discharge Piping

TR-5319-2 (**Ref. 79**) documents stress evaluations for the SRV piping for various load combinations, but does not include a fatigue analysis. The fatigue analysis of the SRV piping, along with all the other torus attached piping (TAP) is bounded by MPR-751, the GE Mark 1 containment program (Ref. 16). MPR-751 was designed to bound all BWR plants which utilize the Mark I containment design. The analysis concluded that for all plants and piping systems considered, in all cases the fatigue usage factors for an assumed 40-year plant life was less than 0.5. In a worst-case scenario, extending plant life by an additional 20 years would produce usage factors below 0.75. Since this is less than 1.0, the fatigue criteria are satisfied. The MPR-751 generic fatigue analysis is thus projected for the period of extended operation in accordance with 10CFR54.21(c)(1)(ii).

A VYNPS plant specific analysis (TR-3519-2) addresses the torus SRV penetration sleeves and bellows. This analysis states that the SRV penetrations are qualified for 7500 cycles of maximum load while the SRVs are expected to see less than 50 cycles at maximum load and less than 4500 cycles a partial load. The report concludes "Since the 7500 cycles of maximum load bounds both of these by such a large margin and since no other significant loads are imposed on the line, the penetration was assumed acceptable for fatigue without further evaluation." (Section 2.4.5 of Ref. **79**) Increasing the 40 year cycles by 1.5 for the period of extended operation would still be only 75 maximum load cycles and 6750 low load cycles for a total of 6850 mixed load cycles, less than the 7500 maximum load cycles permitted. The fatigue analysis for torus penetrations thus remains valid for the period of extended operation in accordance with 10CFR54.21(c)(1)(i).

2.3.3 Fatigue Analysis of Other Torus Attached Piping (TAP)

The VYNPS plant-specific analysis (TR-5319-2) references the generic GE Mark 1 containment program (Ref. 16), for other torus attached piping. The results of the generic GE Mark 1 containment program (based on 40 years of operation) were that 92% of the TAP would have cumulative usage factors of less than 0.3, and that 100% would have usage factors less than 0.5. Conservatively multiplying the CUFs by 1.5 shows that for 60 years of operation, 92% of the TAP would have CUFs below 0.45, and 100% would have CUFs below 0.75. These calculations have thus been projected through the period of extended operation in accordance with 10 CFR 50.21(c)(ii).

2.4 VYNPS In-Service Inspection (ISI) - Fracture Mechanics Analyses

Flaws in Class 1, 2, or 3 components discovered during inservice inspections (ISI) must be evaluated in accordance with ASME Section XI, Subsections IWB, IWC, or IWD, respectively. One option is to show the indication is acceptable without repair based on a fracture mechanics analyses (FMA). FMA evaluation requires a prediction of flaw growth considering a chosen evaluation period, usually either the time until the next inspection or the remaining licensed life of the plant. FMA evaluations performed for the licensed life of the plant may be TLAA that must be addressed for license renewal.

Plant Technical Specifications (Ref. 4, Section 4.6.E) require an in-service inspection/testing program to verify the integrity of the reactor coolant pressure boundary, Specifically, 10 CFR 50.55a(g) (Ref. 22) requires ISI per ASME Section XI, and 10 CFR 50.36(c)(3) (Ref.23) provides general surveillance requirements. In accordance with 10 CFR 50.55a, the ISI Program Plan is reviewed every 120 months and revised, as necessary, to meet the latest NRC authorized edition of ASME Section XI. This revision is submitted to the NRC for approval.

The examination categories defined in Table IWB-2500-1 require the use of nondestructive examination (NDE) techniques to detect and characterize flaws. The flaws may be service-induced (e.g., fatigue) or may be fabrication flaws that have grown due to service loads. T able IWB-2500-1 specifies the extent and frequency of inspection . The inspection intervals are valid for any period of extended operation.

Flaws detected during examination are evaluated by comparing the examination results to acceptance standards established in ASME Section XI. Unacceptable indications require detailed analysis (e.g., ASME Section XI, Appendix A), repair, or replacement.

This section reviews analyses of flaws discovered during inservice inspections (ISI) at VYNPS. Class 1, 2, or 3 components require evaluation in accordance with ASME Section XI, Subsections IWB, IWC, or IWD, respectively. For any indication discovered during ISI that exceeds acceptance standards, Section XI requires that (1) repairs be made, (2) affected portions of the item be replaced, or (3) the indication be shown acceptable through fracture mechanics analysis (FMA).

Acceptance through FMA requires a prediction of flaw growth considering either a chosen evaluation period (i.e., no shorter than the time until the next inspection following discovery of the flaw), or the remaining service life of the component. Flaw indications that are determined not to grow beyond acceptance limits during the evaluation period are justified for continued operation. FMA evaluations performed for the current operating term may be TLAA. This review of the VYNPS inservice inspection records found six fracture mechanics analysis that were evaluated as potential TLAA; it was determined that none of them were actual TLAA. Results of the review are given below.

2.4.1 Recirculation (Jet Pump) Risers

Indications on four jet pump riser welds were found in the spring of 1998. These welds were originally evaluated for one fuel cycle (Ref. 70). However, Ref 71 was submitted in 1999 to justify extending the time between inspections to two fuel cycles, and this was accepted by the NRC in Reference 72.

The follow up inspection in 2001, and reanalysis of the 1998 data, showed that two of the 1998 indications were false. Indications on jet pump risers N2H and N2K were confirmed and are documented on IR# 01-10 (Ref. 26). The indications were analyzed by General Electric in Report JXOAL (Ref. 73) and determined to be acceptable for two cycles of operation. Additional evaluations performed by Entergy (Ref. 88) determined that these welds are acceptable until the refueling outage in 2007. The analysis in Reference 73 is still valid and the welds were scheduled for re-inspection in RFO 24 (2004).

The fatigue growth analysis does not justify leaving the flaws in service for the design life of the plant, rather it justifies leaving them in service for four cycles of operation (until RFO 26) after which they are inspected and sized. If the flaws are still below the size analyzed, they may stay in service two additional cycles and then be inspected again. This analysis is not a TLAA since it is not based on a time-limited assumption defined by the current operating term.

2.4.2 Core Spray Piping in the Reactor Vessel.

Indications were identified in core spray piping welds in 1996. Results and evaluations were submitted to the USNRC by Ref. 27. The flaw growth calculations (Ref. 76) for these indications are acceptable for 2 cycles of operation. Additional evaluations performed by Entergy (Ref. 89) determined that these indications are acceptable until RFO 26 (2007).VYNPS is continuing to inspect the core spray piping in accordance with the guidelines of BWRVIP-18. This analysis is not a TLAA since it is not based on a time-limited assumption defined by the current operating term.

2.4.3 Reactor Vessel Plate 1-15

Reactor vessel plate 1-15 had one indication in the 1995 inspection. The indication is located in the plate below weld EF which joins plates 1-12 and 1-15. The weld is outside the core region. The indication is acceptable for continued service per calculation package YAEC-25Q-301, which was submitted to the NRC by VYNPS letter BVY 96-119 (Ref. 74), and approved by the NRC in their letter of 11 Oct 96 (Ref. 75).

The analysis is not a TLAA since it does not involve a time-limited assumption defined by the current operating term. Allowable flaw size was calculated based on flaw growth, assuming a fixed number of cycles and worst case stresses. The predicted flaw size after the assumed number of cycles is significantly less than the allowable flaw size.

The flaw growth projection assumed 105 cycles (heatups). The flaw was re-inspected in 2004 (Ref. 94) and no flaw growth was observed. Conservatively assuming two heatups per year from 2004 through the period of extended operation (2004-2032, inclusive) results in only 58 cycles. Since the projected number of cycles is much less than the analyzed value, the analysis remains valid well beyond the period of extended operation. Note that the plant is expected to periodically re-inspect this weld each 10 year interval, thereby verifying there is no crack growth and essentially zeroing the count on allowable cycles.

2.4.4 Core Spray Nozzle to Safe End Weld Overlay

In 1986 cracks were found on the core spray nozzle to safe end welds. The repair, described to the NRC in FVY 86-036 (Ref. 67), was accomplished using a weld overlay, leaving the cracks in service. The original intent was to use the weld overlay for up to 5 years before doing a replacement of the nozzle safe ends. An analysis of the overlay acceptability for 5 years was provided in Appendix C to FVY 86-036. Subsequently, due primarily to the high radiation exposure that would be required for the repair, VYNPS decided to use the weld overlay as a permanent repair. This was presented to the NRC in VYNPS letter FVY 88-19 (Ref. 68). That letter included a report that reviewed the expected flaw growth for the as-found cracks. The conclusion was that flaw growth would be arrested by the compressive stress in the component and no growth above 75% thru-wall was expected. The NRC accepted use of the weld overlay as a permanent repair in letter NVY 88-080 (Ref. 69). The acceptance was based on the analysis provided and VYNPS's commitment to continue periodic inspection of these weld overlays in accordance with NUREG-0313 and Generic Letter 88-01. This analysis is not a TLAA as it is not based on time-limited assumptions for the current operating term.

2.4.5 Containment corrosion

In 2001, the Inspection of the containment structure (per ASME Section XI – IWE) found corrosion of the vent header and vent pipe bowls in the VY primary containment. This corrosion was analyzed by VYNPS Technical Evaluation TE 2001-25 (**Ref. 90**) and found to be acceptable for use as is. TE 2001-25 is a comparison of as-found wall thickness to minimum required wall thickness. This analysis does not include any time limited assumptions and is not based on any time period. As such this analysis is not a TLAA.

2.4.6 Primary Containment Localized Thinning

In 1999, corrosion was found on approximately 20 square inches of the containment. The condition was evaluated by VYNPS calculation VYC-2043 (**Ref. 91**) and found acceptable for the life of the plant. This analysis is not a TLAA since it does not involve a time-limited assumption defined by the current operating term. The calculation is based on 100 test cycles (design basis accident cycles) of containment pressure. At an expected test frequency of less than once every two years, the analysis remains valid for over 200 years, which is well beyond the period of extended operation.

2.5 <u>VYNPS Response to Industry Issues on Fatigue</u>

Industry experience and research efforts have revealed fatigue issues not considered as part of the original design basis. Some of these issues impact fatigue analyses and resulted in the issuance of NRC generic communications. The following subsections discuss concerns directly related to fatigue.

Although aging management review reports AMRM-31, AMRM-32 and AMRM-33 **(Refs. 5, 6** and **7)** review the industry experience and NRC identified concerns for Class 1 components, the reports do not review all of the fatigue-related concerns and do not contain site-specific responses. Industry events have identified some specific fatigue situations that were not a part of the original design evaluations. This section provides the VYNPS specific responses for fatigue related issues.

This review has determined that VYNPS has properly evaluated the existing industry experience on fatigue. VYNPS will continue to evaluate any future industry experience in accordance with plant procedures.

2.5.1 VYNPS Response to NRC Bulletin 88-08

NRC Bulletin 88-08 (Ref. 21), its supplements and associated information notices identified concerns with thermal stresses due to unanalyzed temperature distributions in piping connected to the reactor coolant system (RCS). The bulletin required a review of the systems connected to the RCS and a reporting of the results and necessary corrective actions. The supplements provided additional information on events and examinations to detect crack locations.

VYNPS provided responses to the NRC for NRC Bulletin 88-08 and its supplements. Based on these responses, the NRC staff found that VYNPS met the requirements of NRC Bulletin 88-08 (Ref. 66).

Subsequently, commitments regarding inspections in response to NRC Bulletin 88-08 have been superseded by the VYNPS risk-informed in-service inspection (RI-ISI) of ASME Class 1 piping as approved by the NRC (Ref. 64). Technical Specification 4.6.E.1 allows this alternate method as approved by the NRC staff (Ref. 65). Aging effects due to thermal stratification as described in Bulletin 88-08 will be managed by augmented inspections (as part of the ISI program) through the period of extended operation. There is no TLAA associated with Bulletin 88-08 as there are no analyses based on time-limited assumptions.

2.5.2 Effects of Reactor Water Environment on Fatigue Life

Test data indicate that certain environmental effects (such as temperature, oxygen content, and strain rate) in the primary systems of light water reactors could result in greater susceptibility to fatigue than would be predicted by fatigue analyses based on the ASME Section III design fatigue curves. The ASME design fatigue curves were based on laboratory tests in air and at low temperatures. Although the failure curves derived from laboratory tests were adjusted to account for effects such as data scatter, size effect, and surface finish, these adjustments may not be sufficient to account for actual plant operating environments (Ref. 19).

As reported in SECY-95-245, the NRC believes that no immediate staff or licensee action is necessary to deal with the environmentally assisted fatigue issue. In addition, the staff concluded that it could not justify requiring a back fit of the environmental fatigue data to operating plants. However, the NRC concluded that, because metal fatigue effects increase with service life, environmentally assisted fatigue should be evaluated for any proposed extended period of operation for license renewal.

NUREG/CR-6260 **(Ref. 50),** applied the fatigue design curves that incorporated environmental effects to several plants and identified locations of interest for consideration of environmental effects. Section 5.7 of NUREG/CR-6260 identified the following component locations to be most sensitive to environmental effects for VYNPS vintage General Electric plants. These locations and the subsequent calculations are directly relevant to VYNPS.

1. Reactor vessel shell and lower head
2. Reactor vessel feedwater nozzle
3. Reactor recirculation piping (including inlet and outlet nozzles)
4. Core spray line reactor vessel nozzle and associated Class 1 piping
5. Residual heat removal (RHR) return line Class 1 piping
6. Feedwater line Class 1 piping

Entergy evaluated the limiting locations (a total of nine components corresponding with the above six locations) using the guidance provided in NUREG-1801 **(Ref. 51**, Volume 2, Section X.M.1). Seven of the nine components reviewed have an environmentally adjusted CUF of greater than 1.0 (see Table 2.5-1). The ASME Code does not require environmental adjustment to fatigue analyses, let alone the extremely conservative evaluations done in this report. (The method used in this report essentially applies the worst case temperature and worst case strain rate to the full range of all transients. More refined finite element analyses could analyze each transient in sections, using realistic values for temperature and strain, and greatly reduce the predicted CUFs.)

However, there is an increased potential for fatigue cracking during the period of extended operation at locations having CUFs exceeding 1.0. Prior to entering the period of extended operation, for each location that may exceed a CUF of 1.0 when considering environmental effects, VYNPS will implement one or more of the following:

(1) further refinement of the fatigue analyses to lower the predicted CUFs to less than 1.0. Such analyses would include calculation of site specific environmentally adjusted CUFs for all of the NUREG-6260 locations. (Projection of the TLAA per 10CFR54.21(c)(1)(ii).)

(2) management of fatigue at the affected locations by an inspection program that has been reviewed and approved by the NRC (e.g., periodic non-destructive examination of the affected locations at inspection intervals to be determined by a method accepted by the NRC). (Aging effects managed per 10CFR54.21(c)(1)(iii).)

(3) Repair or replacement of the affected locations. (Aging effects managed per 10CFR54.21(c)(1)(iii).)

Should VYNPS select the option to manage environmental-assisted fatigue during the period of extended operation, details of the program to be implemented such as scope, qualification, method, and frequency will be provided to the NRC prior to the period of extended operation.

The effects of environmental-assisted thermal fatigue for the limiting locations identified in

NUREG-6260 have been evaluated. Cracking by environmentally-assisted fatigue of these locations is addressed using one of the above three approaches in accordance with 10 CFR 54.21(c)(1).

Table 2.5-1 VYNPS Cumulative Usage Factors for NUREG/CR-6260 Limiting Locations

	NUREG-6260 Location	CUF of Record	Material Type	F_{en}	Environmentally Adjusted CUF
1	Vessel shell and bottom head	0.400	LAS	2.45	0.98
2	Feedwater Nozzle	0.750	LAS	3.81	2.86
3	RR Inlet Nozzle	0.608	LAS	2.45	1.50
3	RR Outlet Nozzle	0.807	LAS	2.45	1.99
3	RR Piping Tee	0.397[1]	SS	15.35	6.09
4	Core Spray Nozzles	0.625	LAS	2.45	1.55
4	Core Spray Safe End	0.182[1]	SS	15.35	2.79
5	RHR Return Piping	0.032[1]	SS	15.35	0.49
6	Feedwater Piping	0.427[1]	CS	3.01	1.29

1 No VYNPS specific CUF is available; used value documented in NUREG/CR-6260.

Carbon Steel

The environmentally assisted fatigue correction factor (F_{en}) for carbon steel is calculated as follows.

$F_{en} = \exp(0.585-0.00124T-0.101\ S^*T^*O^*\varepsilon^*)$ (NUREG/CR-6583, Equation 6.5a)

$T = 25$ °C Ambient Temperature (Ref. 82)

$S^* = S$ $(0 < S \text{ (Sulfur)} \leq 0.015 \text{ wt\%})$
$S^* = 0.015$ $(S \geq 0.015 \text{ wt\%})$

$T^* = 0$ (Temperature (T) < 150°C)
$T^* = T-150$ (T = 150-350°C)

$O^* = 0$ (DO ≤ 0.05 ppm)

$O^* = \ln(DO/0.04)$	$(0.05\ ppm < DO \leq 0.5\ ppm)$
$O^* = \ln(12.5) = 2.53$	$(DO > 0.5\ ppm)$
$\varepsilon^* = 0$	(strain rate (ε) > 1%/s)
$\varepsilon^* = \ln(\varepsilon)$	$(0.001 \leq \varepsilon \leq 1\%/s)$
$\varepsilon^* = \ln(0.001)$	$\varepsilon < 0.001\%/s)$

For VYNPS, the only carbon steel location in NUREG/CR-6260 is the feedwater piping. Therefore the carbon steel correction factor is calculated using FW temperature and dissolved oxygen. Sulfur content and strain rate are assumed at the values that yield the highest F_{en}.

$S^* = 0.015$	– Assume bounding Sulfur > 0.015 wt%
$T^* = 49.72$	– FW Temp 391.5°F(Ref., 28)
$O^* = 1.056$	– 0.03 ppm <FW DO < 0.2 ppm (Ref. 59)
$\varepsilon^* = -6.91$	– Assume bounding strain rate (0.001%/s)

$$F_{en}\ (\text{Feedwater}) = \exp(0.55-(0.00124)(25)-(0.101)(0.015)(49.72)(1.056)(-6.91)) = 3.01$$

The adjusted CUF for the VYNPS feedwater piping is shown in Table 2.5-1.

The feedwater line has an environmentally adjusted CUF greater than 1.0 and requires a more rigorous management strategy as discussed above. Conservative assumptions were made regarding the sulfur content and strain rate of the carbon steel feedwater line. If less conservative values can be justified for these parameters, or if more detailed calculations are performed, the adjusted CUF for the feedwater line could be less than 1.0.

Low Alloy Steel

The environmentally assisted fatigue correction factor (F_{en}) for low alloy steel is calculated as follows:

$$F_{en} = \exp(0.929-0.00124T-0.101\ S^*T^*O^*\varepsilon^*) \quad \text{(NUREG/6583, Eq. 6.5b)}$$

$T = 25$	°C Ambient Temperature	(Ref. 82)
$S^* = S$	$(0 < S\ (\text{Sulfur}) \leq 0.015\ wt\%)$	
$S^* = 0.015$	$(S \geq 0.015\ wt\%)$	
$T^* = 0$	(Temperature (T) < 150°C)	
$T^* = T-150$	(T = 150-350°C)	
$O^* = 0$	$(DO \leq 0.05\ ppm)$	
$O^* = \ln(DO/0.04)$	$0.05\ ppm < DO \leq 0.5\ ppm)$	
$O^* = \ln(12.5) = 2.53$	$(DO > 0.5\ ppm)$	
$\varepsilon^* = 0$	(strain (ε) > 1%/s)	
$\varepsilon^* = \ln(\varepsilon)$	$(0.001 \leq \varepsilon \leq 1\%/s)$	
$\varepsilon^* = \ln(0.001)$	$\varepsilon < 0.001\%/s)$	

There are five subcomponents of low alloy steel in the 6 limiting locations at VYNPS. A separate F_{en} will be calculated for each location to account for material/environment differences.

$S^*_{(lower\ head)}$ =	0.015	RV material certs for shell plates typically > 0.015 ppm Sulfur
$S^*_{(FW\ nozzle)}$ =	0.012	RV material certifications (Ref. 60)
$S^*_{(RR\ in\ nozzle)}$ =	0.011	RV material certifications (Ref. 60)
$S^*_{(RR\ out\ nozzle)}$ =	0.015	RV material certifications (Ref. 60)
$S^*_{(CS\ nozzle)}$ =	0.012	RV material certifications (Ref. 60)
$T^*_{(lower\ head)}$ =	93.17	Averaged FW inlet temp and saturation temp.
$T^*_{(FW\ nozzle)}$ =	49.72	FW Temp 391.5°F (Ref., 28)
$T^*_{(RR\ in\ nozzle)}$ =	93.17	Averaged FW inlet temp and saturation temp.
$T^*_{(RR\ out\ nozzle)}$ =	93.17	Averaged FW inlet temp and saturation temp.
$T^*_{(CS\ nozzle)}$ =	136.61	Saturation temp = 547.9 °F.
$O^*_{(FW\ nozzle)}$ =	1.056	– 0.03 ppm < FW DO <0.2 ppm (Ref. 59)[1]
$O^*_{(other)}$ =	0	Oxygen target value is 0.015 ppm (Ref. 92)
ε^* =	-6.91	– Assume bounding strain rate (0.001%)

$F_{en\ (lower\ head)}$ = exp(0.929-(0.00124)(25)-(0.101)(0.015)(93.17)(0.000)(-6.91)) = 2.45

$F_{en\ (FW\ nozzles)}$ = exp(0.929-(0.00124)(25)-(0.101)(0.012)(49.72)(1.056)(-6.91)) = 3.81

$F_{en\ (RR\ in\ nozzles)}$ = exp(0.929-(0.00124)(25)-(0.101)(0.011)(93.17)(0.000)(-6.91)) = 2.45

$F_{en\ (RR\ out\ nozzles)}$ = exp(0.929-(0.00124)(25)-(0.101)(0.015)(93.17)(0.000)(-6.91)) = 2.45

$F_{en\ (CS\ nozzles)}$ = exp(0.929-(0.00124)(25)-(0.101)(0.012)(93.17)(0.000)(-6.91)) = 2.45

The adjusted CUFs for the VYNPS low alloy steel locations when considering environmental effects are shown in Table 2.5-1. Four of the five low alloy steel locations have environmentally adjusted CUFs greater than 1.0 and require a more rigorous management strategy as discussed above. Conservative assumptions were made regarding the strain rate of the low alloy steel components. If a less conservative value can be justified, or if more detailed calculations are performed, the adjusted CUF for these components could be less than 1.0.

Austenitic Stainless Steel

The environmentally assisted fatigue correction factor (F_{en}) for stainless steel is calculated as follows:

$F_{en} = \exp(0.935 - T'O'\varepsilon')$ (NUREG/CR-5704, Equation 13)

$T' = 0$	($T < 200°C$)
$T' = 1$	($T > 200°C$)
$O' = 0.26$	($DO < 0.05$ ppm)
$O' = 0.172$	($DO \geq 0.05$ ppm)
$\varepsilon' = 0$	($\varepsilon > 0.4\%/s$)
$\varepsilon' = \ln(\varepsilon/0.4)$	($0.0004 \leq \varepsilon \leq 0.4\%/s$)
$\varepsilon' = \ln(0.0004/0.4)$	($\varepsilon < 0.0004\%/s$)

For VYNPS there are three stainless steel components in the locations of interest, the RR piping tee, the RHR return piping, and the core spray nozzle safe ends. F_{en} is calculated for all three locations as follows.

$T'_{(all)}$ =	1	Temp = 547.9 °F or 469.7°F (Ref. 28)
$O'_{(all)}$ =	0.26	Oxygen target value is 0.015 ppm (Ref. 92)
$\varepsilon'_{(all)}$=	-6.91	Assume bounding strain rate

$F_{en} = \exp(0.935-(1.0)(0.172)(-6.91)) = 15.35$

The target DO of 15 ppb was used for all components. The fatigue factor for stainless steel actually goes up as DO decreases, so justifying a lower DO would make these factors larger.

The adjusted CUFs for the limiting VYNPS stainless steel locations when considering environmental effects are shown in Table 2.5-1. All stainless steel locations (the RHR tee, the RHR piping and the Core Spray safe end) have environmentally adjusted CUFs greater than 1.0 and require a more rigorous management strategy as discussed above. Conservative assumptions were made regarding the strain rate of the stainless steel components. If a less conservative value can be justified, or if more detailed calculations are performed, the adjusted CUF for these components could be less than 1.0.

3.0 Summary and Conclusions

This report reviewed the time-limited aging analyses associated with metal fatigue of Class 1 and non-Class 1 components and fracture mechanics evaluations for flaws discovered in mechanical components. This report documents that VYNPS time-limited aging analyses related to fatigue on Class 1 and non-Class 1 components have been appropriately evaluated for the period of extended operation in accordance with the requirements of 10CFR54.21(c).

Two specific items of interest are noted below.

None of the monitored transients are projected to exceed the allowable cycle limits before the end of 60 years. The Fatigue Monitoring Program, once enhanced as discussed in LRPD-02 (Ref. 24), will provide an adequate program to count, evaluate, track and trend cycles and to provide corrective actions if limits are approached. For a more detailed discussion of this program see LRPD-02.

The effects of reactor water environment on fatigue life were identified and adjusted CUFs were calculated. Several components will exceed a CUF of 1.0 when environmental effects are considered. This requires enhanced fatigue management that must be resolved before the period of extended operation.

The time-limited aging analyses that are associated with fatigue have been reviewed to ensure acceptability for the period of extended operation. All three of the methods listed in 10 CFR 54.21(c)(1)(i) through (iii) for demonstrating acceptability of TLAA for license renewal have been utilized for different fatigue evaluations. The combination of these efforts show that all fatigue related TLAA are adequately addressed for the period of extended operation. A summary of the results is provided in Table 3-1.

Table 3-1: Summary of Fatigue TLAA

Section of this Report	Component(s)	Result
2.1.2	Cumulative Usage Factors (CUFs)	10 CFR 54.21(c)(i)
2.1.3	Reactor pressure vessel	10 CFR 54.21(c)(i)
2.1.4.1	Reactor vessel internals	No TLAA
2.1.4.2	Shroud Repair	10 CFR 54.21(c)(i)
2.1.5.1	Reactor recirculation system	10 CFR 54.21(c)(i)
2.1.5.2	MSIV cycles	10 CFR 54.21(c)(i)
2.1.5.3	FIV for MS and FW components	No TLAA
2.2.1	Non-Class 1 piping and in line components	10 CFR 54.21(c)(i)
2.2.2	Non-Class 1 vessels, heat exchangers, tanks and pumps	No TLAA

2.3.1	Torus	10 CFR 54.21(c)(ii) and No TLAA
2.3.2	SRV discharge lines	10 CFR 54.21(c)(i) and 10 CFR 54.21(c)(ii)
2.3.3	Torus Attached Piping (TAP)	10 CFR 54.21(c)(ii)
2.4.1	Jet Pump Riser flaws	No TLAA
2.4.2	Core Spray piping	No TLAA
2.4.3	RPV plate 1-15 flaw	10 CFR 54.21(c)(i)
2.4.4	Core Spray weld overlay	No TLAA
2.4.5	Containment Corrosion	Not a TLAA
2.4.6	Containment Localized Thinning	10 CFR 54.21(c)(i)
2.5.1	Bulletin 88-08 response	No TLAA
2.5.2	Environmentally Assisted Fatigue	10CFR 54.21(c)(ii) or 10CFR 54.21(c)(iii)

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