UNITED STATES
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

**Before Administrative Judges:**

**Alex S. Karlin, Chairman**
**Dr. Richard E. Wardwell**
**Dr. William H. Reed**

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| **In the Matter of** | ) | |
| | ) | |
| **ENTERGY NUCLEAR VERMONT YANKEE, LLC** | ) | **Docket No. 50-271-LR** |
| **and ENTERGY NUCLEAR OPERATIONS, INC.** | ) | **ASLBP No. 06-849-03-LR** |
| | ) | |
| **(Vermont Yankee Nuclear Power Station)** | ) | |

**NEW ENGLAND COALITION, INC.**

**CONTENTIONS 2A and 2B**

**PREFILED EXHIBITS**

**NEC-JH_03 – NEC-JH_ 24**

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**Volume 1**

NEC-JH_03

# Review of Entergy Nuclear Vermont Yankee, LLC and Entergy Nuclear Operations, Inc. ("Entergy") Analyses of the Effects of Reactor Water Environment on Fatigue Life of Risk-significant Components During the Period of Extended Operation

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## TABLE OF CONTENTS

# I. BACKGROUND

## A. Basic Technical Principles

Fatigue is an age-related degradation mechanism caused by cyclic stressing of a component by either mechanical or thermal stresses that eventually cause the component to crack. Under such cyclic loading, a crack will be initiated and the component will fail under stresses that are substantially lower than those that cause failure under static loadings. During each loading cycle, some fraction of the component's fatigue life is exhausted, its size depending on the magnitude of the applied stress. Eventually, after N cycles, the component's allowable fatigue life is fully expended. The number of cycles n at any given stress amplitude divided by the corresponding N is called the usage fatigue factor. The cumulative usage fatigue factor, CUF, is simply a summation of the individual usage factors. ASME Code Section III requires that CUF must not exceed unity. The CUF is expressed as

$$CUF = \sum n_k / N_k$$

The basic equation that describes the crack growth rate for a given stress intensity includes two empirical constants, C and x. A large data base exists on the empirical constants C and x, which was derived from laboratory tests mostly in air under controlled conditions. This equation can predict crack growth reliably as long as it is used under the conditions that were used to calibrate C and x. This principle is very important in assessing how Entergy used laboratory data to calculate fatigue life of selected components at the VY plant.

To account for the fact that crack propagation in water is different than in air, the individual usage factor in air is multiplied by a corresponding correction factor Fen. Fen is simply the ratio of the fatigue life in air at room temperature to the fatigue life in water at the local temperature. The environmentally corrected CUF is defined as,

$$\text{CUFen} = \text{Fen (CUF)}$$

Fen is derived from laboratory data on the effect of strain on fatigue life, i.e. the number of cycles to failure. NUREG/CR-6909 describes such laboratory tests in detail.

The procedures to analyze components for fatigue are specified in Section III of the ASME Code. The Code provides fatigue curves for various materials, which specify the allowable number of cycles for a given stress intensity. The code requires that the CUF at any given location be maintained below one. Since the Code used data from laboratory tests with smooth specimens, the code made allowances (2 on stress and 20 on cycles) in recognition that a test specimen in air may have a longer fatigue life than actual components in a reactor. The most current ASME code also provides a simplified set of rules in Subparagraph NB-3600, and a more rigorous rule in Subparagraph NB- 3200, which is based on using a finite element analysis to calculate CUF values. Replacing the simplified analysis with a more detailed analysis has the advantage of removing unwanted conservatism from the results of the simplified analysis. Since the detailed analysis may require a larger data base than the simplified analysis, the user must ascertain that the necessary data base exists. When such information is not available, and the user instead makes arbitrary assumptions, the benefit of the detailed analysis is completely negated.

## B. Regulatory Requirements

NRC regulation 10 CFR § 54.21(c) requires that each license renewal application must include "an evaluation of time-limited aging analyses" ("TLAA") for components covered by the license renewal regulations.[1] If

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1 TLAAs are defined as:

Those licensee calculations and analyses that:

(1) Involve systems, structures, and components within the scope of license renewal, as delineated in § 54.4(a);
(2) Consider the effects of aging;
(3) Involve time-limited assumptions defined by the current operating term, for example, 40 years;
(4) Were determined to be relevant by the licensee in making a safety determination;
(5) Involve conclusions or provide the basis for conclusions related to the capability of the system, structure and component to perform its intended functions, as delineated in § 54.4(b); and

the applicant is unable to demonstrate that TLAAs "remain valid for the period of extended operation" or that they "have been projected to the end of the period of extended operation," it must demonstrate that "the effects of aging on the intended function(s) will be adequately managed for the period of extended operation." 10 C.F.R. 54.21(c)(1)(i)-(iii).

NUREG-1801, Rev. 1, Generic Aging Lessons Learned (GALL) Report (2005) ("NUREG-1801") also provides guidance for the preparation of TLAAs.[2] NUREG-1801 advises that a license renewal applicant may address "the effects of the coolant environment on component fatigue life by assessing the impacts of the reactor coolant environment on a sample of critical components for the plant." Id., Vol. 2 at X M-1. Examples of critical components are identified in NUREG/CR-6260, Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components (1995). The sample of critical components "can be evaluated by applying environmental life correction factors to the existing ASME Code fatigue analyses." NUREG-1801, Vol. 2 at X M-1. If these components are found not to comply with the acceptance criteria (i.e., CUF less than one), "corrective actions" must be taken that "include a review of additional affected reactor coolant pressure boundary locations." Id. at X M-2. As explained further in industry guidance document MRP-47:

> The locations evaluated in NUREG/CR-6260 [2] for the appropriate vendor/vintage plant should be evaluated on a plant-unique basis. For cases where acceptable fatigue results are demonstrated for these locations for 60 years of plant operation including environmental effects, additional evaluation or locations need not be considered. However, plant-unique evaluations may show that some of the NUREG/CR-6260 [2] locations do not remain within allowable limits for 60 years of plant operation when environmental effects are considered. In this situation, plant specific evaluations should expand

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(6) Are contained or incorporated by reference in the CLB [current licensing basis].

2 NUREG-1801 is referenced with approval in Regulatory Guide 1.188, Rev. 1, *Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses* (2005) ("Reg. Guide 1.188").

the sampling of locations accordingly to include other locations where high usage factors might be a concern.[3]

## II. ENTERGY'S CUFen ANALYSES

### A. Brief History

The VYNPS License Renewal Application (LRA) Table 4.3-3 summarizes Entergy's evaluation of effects of reactor water environment on the fatigue life of nine components for the period of extended operations. The components selected correspond to the limiting locations identified in NUREG/CR-6260.[4] LRA Table 4.3-3 states that the environmentally corrected Cumulative Usage Factor (CUFen) of the following risk-significant reactor components will exceed unity: feedwater nozzle, RR inlet nozzle, RR outlet nozzle, RR piping tee, core spray nozzles, core spray safe end, and feedwater piping.

To address this problem, Entergy chose to "refin[e] the fatigue analyses to lower the predicted CUFs to less than 1.0."[5] Entergy's refinement of its CUFen analysis proceeded in two steps: (1) an initial reanalysis involving, in part, the use of a simplified Green's function method to calculate stress loads during plant transient operations; and (2) a "confirmatory" reanalysis of only the feedwater nozzle that did not involve use of the simplified Green's function method. I have reviewed the reports of both Entergy's initial CUFen reanalysis, and its "confirmatory" reanalysis of the feedwater nozzle that Entergy produced to NEC.[6]

The five elements of Entergy's initial reanalysis included:

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[3] MRP-47, Revision 1, Electric Power Research Institute, *Materials Reliability Program: Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application* at 3-4 (2005).

[4] Safety Evaluation Report Related to the License Renewal of Vermont Yankee Nuclear Power Station (February 2008)("FSER"), NRC Staff_Exh_01 at 4-32.

[5] LRA at 4.3-7.

[6] These reports are submitted in this proceeding as Exhibits NEC-JH_04 – NEC-JH_21.

1. Development of a finite element model
2. Development of heat transfer coefficients
3. Development of Green Functions
4. Development of thermal transient definitions
5. Performance of Stress and Fatigue Analysis.

Entergy reported the results of its initial reanalysis in the Table 1, reproduced below:

**TABLE 1**
**VYNPS Cumulative Usage Factors for NUREG/CR-6260 Limiting Locations**[7]

| | NUREG-6260 Location | Material | Overall* Environmental Multiplier ($F_{en}$) | Environmentally Adjusted CUF |
|---|---|---|---|---|
| 1 | RPV vessel shell/ bottom head | Low alloy steel | 9.51 | 0.08 |
| 2 | RPV shell at shroud support | Low alloy steel | 9.51 | 0.74 |
| 3 | Feedwater nozzle forging blend radius | Low alloy steel | 10.05 | 0.64 |
| 4 | RR Class 1 piping (return tee) | Stainless steel | 12.62 | 0.74 |
| 5 | RR inlet nozzle forging | Low alloy steel | 7.74 | 0.50 |
| 6 | RR inlet nozzle safe end | Stainless steel | 11.64 | 0.02 |
| 7 | RR outlet nozzle forging | Low alloy steel | 7.74 | 0.08 |
| 8 | Core spray nozzle forging blend radius | Low alloy steel | 10.05 | ~~0.0432~~ 0.1668 |
| 9 | Feedwater piping riser to RPV nozzle | Carbon steel | 1.74 | 0.29 |

* Effective multiplier for past and projected operating history, power level, and water chemistry.

The NRC Staff rejected Entergy's initial CUFen reanalysis. As reported in the FSER, Entergy and the NRC Staff "were unable to resolve the issues raised [with respect to Entergy's use of Green's functions to calculate stress loads]."[8] The NRC Staff therefore requested that Entergy perform, and Entergy did perform, the additional "confirmatory" CUFen analysis of the feedwater nozzle, using the ASME Code Section III, Subsection NB-3200 methodology to calculate the stress intensities "without referencing Green's function."[9]

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[7] Exhibit NEC-JH_35 at Attachment 2.

[8] FSER, NRC Staff Exhibit 01 at 4-40.

[9] FSER, NRC Staff Exhibit 01at 4-41; *See also,* Exhibit NEC-JH_22 (Summary of Meeting Held on January 8, 2008, Between the U.S. Nuclear Regulatory Commission Staff and Entergy Nuclear Operations, Inc. Representatives to Discuss the Response to a Request for Additional Information Pertaining to the Vermont Yankee Nuclear Power Station License Renewal Application).

At the February 7, 2008 meeting of the ACRS, which I attended, the NRC Staff informed the ACRS that it was satisfied with the CUFen calculations based on Entergy's then-reported "confirmatory" results for the feedwater nozzle. As reported in the FSER, however, during a subsequent February 14, 2008 audit of Entergy's confirmatory analysis, the NRC Staff requested that Entergy recalculate the feedwater nozzle CUFen yet again, substituting a different Fen value. Specifically, NRC Staff requested use of "the maximum Fen value used in [Entergy's] previous analyses," rather than "different, but appropriate" Fen values Entergy had used in its "confirmatory" analysis.[10]

The following Table 2 summarizes how Entergy's reported CUFen values for the feedwater nozzle have changed with each iteration of its analysis.

**Table 2- CUFen Calculations For the Feedwater Nozzle**

| REFERENCE | CUF | Fen | CUFen |
|---|---|---|---|
| License Renewal Application Table 4.3-3 | 0.750 | 3.81 | 2.86 |
| Entergy Initial CUFen Reanalysis Using Simplified Green's Function. NEC Exhibit JH_18 at 3-18, Table 3-10. | 0.0636 | 10.05 | 0.6392 |
| Entergy "Confirmatory" CUFen Reanalysis. NEC Exhibit JH_21 at 7, Table 1. | 0.0889 | 3.97 | 0.3531 |
| Adjusted "Confirmatory" Reanalysis result verbally provided during February 14, 2008 NRC Staff audit of Entergy's "Confirmatory" Reanalysis. FSER, NRC Staff Exhibit 1 at 4-42. | | | 0.8930 |

A comparison of Entergy's result using the simplified Green's function method, 0.639, with its "confirmatory" result, ultimately 0.8930 as recalculated February 14, 2008, demonstrates that the simplified Green's

[10] FSER, NRC Staff Exhibit 01 at 4-42.

function method underestimates CUF by about 40%. As reported in the FSER, the NRC Staff therefore concluded that "the results of the Green's function application using the specific software could underestimate CUF, and therefore cannot be the analysis of record."[11]

The NRC Staff has designated Entergy's "confirmatory" analysis the "analysis of record" for the feedwater nozzle.[12] The NRC Staff has also recommended a license condition that would require Entergy to perform the "confirmatory" analysis for the spray (CS) and recirculation (RR) nozzles no later than two years before the start of the life extension period.[13]

The NRC Staff is now revisiting the sufficiency of environmentally-assisted fatigue analyses based on the simplified Green's function method, which the NRC had previously accepted in support of license renewal for plants other than Vermont Yankee. On April 18, 2008, the NRC Staff issued a Regulatory Issue Summary ("RIS"), requesting that "license renewal applicants that have used this simplified Green's function methodology perform confirmatory analyses to demonstrate that the simplified Green's function analyses provide acceptable results."[14] This RIS also states: "For plants with renewed licenses, the staff is considering additional regulatory actions if the simplified Green's function methodology was used."[15] On April 3, 2008, the NRC Staff issued a Notification of Information in Docket No. 50-219-LR (License Renewal for Oyster Creek Nuclear Generating Station), stating that it will require "confirmatory" fatigue analyses due to Oyster Creek's reliance on the simplified Green's function method.[16]

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[11] Id. at 4-43.

[12] Id. at 4-43.

[13] Id.

[14] Exhibit NEC-JH-23 at 2.

[15] Id.

[16] Exhibit NEC-JH_24.

## III. ASSESSMENT OF ENTERGY's CUFen REANALYSES

The following discussion explains my assessment of both Entergy's initial and "confirmatory" CUFen reanalyses. Part A explains that Entergy failed to produce information necessary to validate both analyses. Part B lists key assumptions underlying both analyses. Part C explains why, as a results of Entergy's key assumptions, both analyses underestimated CUFen, and overestimated expected fatigue life. Part D discusses the significance of Entergy's failure to perform an error analysis. Part E explains why the "confirmatory" analysis of the feedwater nozzle does not bound the analysis for other components.

### A. Incomplete Information

The materials Entergy has produced to NEC in the ASLB proceeding do not include all the information necessary to establish the validity of Entergy's CUFen reanalyses, initial or "confirmatory." Specifically, Entergy has not provided:

1. Adequate layout drawings of the plant piping. Based on the information provided, I cannot determine how the connecting pipes are oriented with respect to the nozzles; how many diameters the pipe is straight upstream of each nozzle; or whether there are any discontinuities, such as welds, upstream of the nozzle.[17] This information is necessary to validate the assumption of uniform heat transfer distribution.

2. A complete description of the methods or models used to determine velocities and temperatures during transients. For example, the following discussion appears in the Structural Integrity Associates, Inc. ("SIA") report of Entergy's initial CUFen reanalysis, VY-16Q-307:

> The internal heat transfer coefficient h for the transients with flow occurring in the pipe is calculated based on the following relation for forced convection:

[17] Exhibit NEC-JH_25 is illustrative of the layout drawings Entergy produced to NEC.

$h = 0.023\ Re^{0.8}\ Pr^{0.4}\ k/D$

Where Re = Reynolds number
Pr = Prandtl number
k = Thermal conductivity
D = Pipe diameter

The heat transfer coefficients were calculated by PIPESTRESS using the above relation. The flow rates described for each transient in Section 3 were used. For the transients where flow is stopped, the natural convection heat transfer coefficient was used. The formula for h is:

$h=0.55\ (Gr\ Pr)^{0.25}\ k/L$

Where Gr = Grashof Number
L = Pipe diameter

PIPESTRESS only has the forced convection heat transfer formula built in, so an equivalent flow rate was determined that would give the same heat transfer coefficient as the free convection coefficient.[18]

I cannot determine, based on this discussion, how this was done when the flow goes to zero. I discuss this issue in more detail in Part III(C)(2) of this report.

## B. Entergy's Assumptions

Both Entergy's Initial and "Confirmatory" CUFen Reanalyses incorporated the following assumptions:

1. The environmental correction factor, Fen, depends only on the temperature, the dissolved oxygen, the sulphur content and the strain rate.

[18] Exhibit NEC-JH_10 at 12-13 (emphasis added).

2. With respect to determination of the heat transfer coefficients in all three nozzles:

    a. Nozzle entrance and exit effects can be neglected
    b. Water properties do not change with temperature
    c. Uniform circumferentially.

3. The base metal under the cladding at the feedwater blend radius has no cracks.

4. The number of transients will increase linearly with time during the life extension period.[19] It was assumed that the 40-year CUFs can be multiplied by 1.5 to project those values to the end of the 60 year extended period.

5. The oxygen at the surface of any component can be evaluated based on plant records, using the EPRI –BWRVIA computer code.

. Entergy's Initial CUFen Reanalysis also included the following additional assumption:

6. Green's functions can be used as a substitute for the ASME Code Section III, Subsection NB-3200 method.

**C. Assessment of Assumptions**

Entergy's above-stated assumptions resulted in the underestimation of CUFen, and the overestimation of expected fatigue life, for the following reasons.

**1. Environmental Correction Factor, Fen**

Entergy calculated the Fen parameters based on outdated Argonne National Laboratory (ANL) statistical equations stated in NUREG/CR 6583 and NUREG/CR 5704 ("the NUREG equations"), which were derived more

[19] Exhibit NEC-JH_18 at 3-18, note 2 (CUF results based on "actual cycles accumulated to-date and projected to 60 years.").

than nine years ago.[20] In February 2007, ANL updated the previous data and published its results in NUREG/CR-6909.[21] The revised ANL equations are based on a much larger database and the limits of their applicability is more clearly stated.

The developer of the revised ANL equations, O. Chopra, stated to the ACRS:

> To apply the laboratory data to actual reactor components, we need to adjust these results to account for parameters or variables which we know affect fatigue life but are not included in this data. And these variables are **mean stress, surface finish, size, and loading history.**[22]

This same caveat is repeated in NUREG/CR-6909. To account for uncertainties, the NUREG report states:

> **"Under certain environmental and loading conditions, fatigue lives in water relative to those in air can be a factor of ≈12 lower for austenitic stainless steels, ≈3 lower for Ni-Cr-Fe alloys, and ≈17 lower for carbon and low-alloy steels."**

NUREG/CR-6909 at 62.[23]

Entergy did not provide any data on the surface roughness of the components it evaluated. The ANL equations were developed using a crack free, smooth specimen. In comparison to a smooth surface, a rough surface would reduce the fatigue life by a factor of 3.[24] Since most of the components Entergy evaluated were fabricated from carbon or low alloy steel, they are susceptible to flow accelerated corrosion, FAC, which characteristically increases surface roughness. In the case of the VY

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[20] Exhibit NEC-JH_18 at 3-1.

[21] Exhibit NEC-JH_26.

[22] Exhibit NEC-JH_27 at 22.

[23] Exhibit NEC-JH_26 at 62.

[24] Exhibit NEC-JH_26 at 14.

feedwater nozzle, the existence of surface cracks at the blend radius both in the clad and the base metal is another factor that must be considered (see Comment 3 below).

Because of the above uncertainties, I believe that it is appropriate to use a factor of 17, at a minimum, to correct the CUFs for environmental effects.

At the February 7, 2008 ACRS meeting, which I attended, in response to an ACRS member question as to why Entergy is allowed to use old fatigue data, the NRC staff stated only that it has traditionally used the old data in approving LRAs and did not want to change the procedures at this time.[25] The Staff stated that the new data will apply to new reactor applications.[26] It would appear that it would be equally important, if not more important, to apply the new data to a 40 year reactor.

**2. Heat Transfer**

Entergy used the following heat transfer equations to calculate the thermal stress for each transient:

1. $h = 0.023\,(Re)^{.8}\ (Pr)^{.4}\ k/D$[27]

2. $h = 0.55\,(GrPr)^{.25}\,k/L$[28]

3. $h = 0.555\,(\,R\,(R-Rs)gk^3 h_{fg} / (\,ud\ \ del\ T\,)\,)^{.25}$ (R=rho, u =mu)[29]

Equation 1 is applicable only to a fully developed turbulent flow, constant fluid properties in pipes. The flow in all three nozzles is not the same as in a straight pipe because the nozzle is relatively short and it

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25 Exhibit NEC-JH_28 at 96-97.

26 Id.

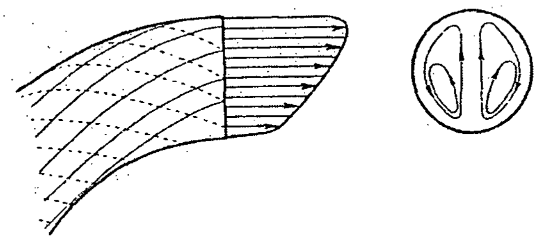
27 Exhibit NEC-JH_04 at 11, Table 4.

28 Exhibit NEC-JH_14 at 14.

29 Exhibit NEC-JH_19 at 7.

contains discontinuities. It is difficult to see how the flow could be fully developed, especially at the exit from the nozzle at the blend radius area (Region 6).[30] Nevertheless, depending on the Reynolds number and the distance from the inlet to the nozzle, the heat transfer can be either above or below the value specified by Equation 1. Plots for calculating the heat transfer at the entrance section of pipes can be found on page 212 of Reference 2.[31] Equation 1 also must be corrected by the ratio of the viscosities evaluated at the bulk and wall temperatures during each transient. Page 212 of Reference 2 also provides such a correction.[32]

To justify the use of the axixsymetrical model, Entergy must first show that the flow upstream of each nozzle is fully developed at the entrance to the nozzle and its main axis coincides with the axis of



the nozzle. As shown in Reference 3 and the above sketch, the velocity distribution in the nozzle will vary circumferentially.[33] Such flow distribution would lead to circumferentially varying wall temperature and different stress distribution than would be predicted by an axixsymetrical model.

To my knowledge, Entergy has not provided to NEC the complete piping layout as it exists now in the plant. Unless special precautions were

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[30] See, Exhibit NEC-JH_04 at 16.

[31] Exhibit NEC-JH_29.

[32] Id.

[33] Exhibit NEC-JH_30.

taken during installation, one must assume that the connecting pipe is at some angle with respect to the nozzle and therefore the axixsymetrical assumption is not valid.

Equation 2 is used to calculate average heat transfer coefficients when the flow is driven by gravitational forces. This equation is not appropriate for applications where one is required to determine local stress distributions along the pipe and not average stress distributions.

Equation 2 does not apply because, for some transients, the forced convection internal flow in pipes stops, and the flow becomes driven by gravity forces.[34] Based on physical considerations, the flow does not just suddenly go from forced convection to natural convection, but it rather goes through a mixed forced/free convection region. In the free convection region, the flow is driven by gravity forces and its fundamental characteristic is commonly described by a flow down a vertical plate where both the velocity and the heat transfer coefficient vary with the height of the plate. The natural convection flow inside a pipe is more complex and is based on empirical correlations of the average heat transfer coefficient such as given in Equation 2 for laminar flow. This equation does not describe the variation in the heat transfer coefficient, and the stresses, along the pipe.

The following statement quoted from one report of Entergy's initial CUFen reanalysis demonstrates that Entergy ignored the inherently local feature of natural convection:

> PIPESTRESS only has the forced convection heat transfer formula built in, so an equivalent flow rate was determined that would give the same forced convection heat transfer coefficient as the free convection heat transfer coefficient.[35]

Such a procedure is appropriate for the determination of overall heat balances but not for the determination of stress distributions.
In my opinion, the stress analysis should not be dictated by what is available in a given computer program; it should be driven by the nature of the problem.

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[34] Exhibit NEC-JH_14 at 14.

[35] Id.

Equation 3 is an empirical equation for the average heat transfer coefficient during condensation of refrigerants at low laminar velocities. For higher flow rates, a different equation must be used. Entergy did not specify that the flow in the nozzle was laminar. More importantly, to calculate the temperature distribution in the nozzle, one must use local heat transfer coefficients, not average values. Average heat transfer coefficients can only be used to calculate overall heat balances, not local temperatures.

Entergy's CUFen results are based on the assumption that the stresses are axixsymetric in all nozzles. As shown on page 26 of SIA report VY-16Q-310, the stress in a given nozzle is very sensitive to the heat transfer coefficient.[36] Throughout its analyses, Entergy used location-independent heat transfer coefficients, which is inappropriate, as I have explained in the above discussion.

**3. Base Metal Cracks**

In the late 1970s, the feedwater nozzles of most BWR plants developed cracks due to high cycle fatigue because of differences in the thermal properties of the cladding and the base metal. The cladding was removed from most BWR plants, with the exception of Vermont Yankee and a few others. NUREG-O609. In the Millstone 1 plant, some cracks penetrated to 1/3' at the blend radius area. Because the cladding is 5/16" thick and high cycle fatigue cracks propagate to depths of about ¼" or more, the base metal may contain cracks, especially after 40 years of service. Id. In RAI 4.3-H-02, VY admitted that the cladding may contain cracks,[37] but has not provided any data to indicate that these cracks did not penetrate the base metal. They did, however, admit to the possibility that such cracks will penetrate the base metal. The 2001 inspection of the feedwater nozzles only indicates that the results were "acceptable".[38] Since Ultrasonic Inspection, UT, measures only the total length of a crack and, based on the VY drawings Entergy has produced, the exact thickness of the clad is not known,[39]

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[36] Exhibit NEC-JH_13 at 26.

[37] Exhibit NEC-JH_32.

[38] Exhibit NEC-JH_33 at 4.

[39] Exhibit NEC-JH_25.

Entergy has not provided any proof that the base metal is not cracked. One therefore must assume that the base metal is cracked and account for these cracks in the ASME Code analysis. The ASME Section III, NB 3122.3 does not require Entergy to include the cladding in the structural analysis because the cladding is less than 10% of wall thickness. When, however, subsurface cracks are known to exist, they can not be ignored in the ASME Code analysis, and must be included together with the cladding.

## 4. Number of Transients

Entergy's apparent assumption that the number of transients the plant would experience varies linearly with time must be challenged. The failure frequency of pressure vessels (and mechanical and electrical components) is statistically very high later in life due to aging of the plant. The recent VYNPS 20% power uprate introduced new stresses on already aging components, and will likely increase the number of unanticipated transients, as demonstrated by the August, 2007 collapse of the VYNPS cooling tower and plant shutdown due to a steam valve failure. VYNPS experienced two unanticipated transients within 10 days in late August 2007. Based on this experience and the assumption of linearity, one could predict 912 transients during the next 25 years. The above extreme case illustrates that Entergy must consider a more conservative number of transients than predicted by the linear formula to project the number of transients during the extended period of operation.

Entergy provided no justification for selecting a non-conservative factor for projecting the number of transients. In my opinion, the number of transients proposed by Entergy should be at a minimum multiplied by 1.2 to account for the probability of an increase in unanticipated failures due to the 20% power uprate.

## 5. Oxygen

Even though the Fen varies exponentially with oxygen concentration, Entergy did not discuss the reasons for not including unanticipated changes in water chemistry (oxygen excursions) during the extended period. Nor did they explain how the chemistry data from the feedwater line or the electrochemical potential measurements relate to the oxygen concentration at the component surface during transients.

Only in February 2008, in response to an NRC Staff request for information concerning how Entergy's CUFen analysis accounted for water chemistry effects, Energy stated for the first time that the EPRI –BWRVIA computer code was used at VY to assess the oxygen concentration at the surface of a given component.[40]

NRC requires that analytical codes be assessed and benchmarked against measured plant data. Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 229 to Facility Operating License No. DPR-28, Entergy Nuclear Vermont Yankee, LLC and Entergy Nuclear Operations, Inc., Vermont Yankee Nuclear Power Station, Docket No. 50-271 § 2.8.7.1.[41] A code is only considered valid within the range in which the data was provided.[42] Entergy did not describe how the BWRVIA code was benchmarked.

The oxygen concentration at the surface of any given component can only be estimated by considering the kinetics of oxide buildup and dissolution throughout the plant. Since Entergy has not described the algorithm in the BWRVIA code, one must assume that the oxygen concentrations that were used by Entergy to calculate the Fens contain unknown errors.

## 6. Green's Function

In its initial analysis, Entergy applied a simplified Green's function method to calculate stresses for each transient, instead of using the ASME Code, Section III, Subsection NB-3200 approach.[43] The Green's function is a powerful tool that, when properly applied, can considerably reduce the cost of the ASME code analysis, especially when the number of transients is

[40] Exhibit NEC-JH_34 at Attachment 2.

[41] Exhibit NEC-JH_ 35.

[42] Id.

[43] See, e.g., Exhibit NEC-JH_04.

very large. The Green's function is also, however, an approximate technique in comparison to the NB-3200 methodology, which may introduce errors in the final calculations of the CUF.

As discussed in Part II(A) of this report, a comparison of Entergy's results using the simplified Green's function method with the results of its "confirmatory" analysis for the feedwater nozzle demonstrate that the Green's function method underestimated CUF by about forty percent. For this reason, also as discussed in Part II(A) of this report, the NRC Staff rejected Entergy's initial CUFen analysis.

## D. Lack of Error Analysis

To validate its analytical techniques, Entergy should have performed an error analysis to show the admissible range for each variable. Based on the reports of Entergy's CUFen reanalyses produced to NEC,[44] it has not done so. The lack of error analysis is troubling. For example, Entergy reported a CUFen of 0.74 for the RHR Class 1 piping (Table 1, above). In light of the fact that data scatter in fatigue studies often exceeds an order of magnitude, the value of 0.74 without an error band has little significance and imparts little confidence that fatigue failure will not occur.

## E. "Confirmatory" Analysis of Feedwater Nozzle

I have reviewed the reports produced to NEC of the additional "confirmatory" CUFen analysis of the feedwater nozzle that Entergy conducted at the request of the NRC Staff.[45] This analysis contains all of the errors in calculation of both CUF and Fen values that I have discussed in Part III(C) above, except that the simplified Green's function method was not used.

Even if it were valid, I do not agree that the "confirmatory" analysis would bound the analysis for components other than the feedwater nozzle. There are considerable differences in geometry, heat transfer characteristics, and loadings between the feedwater and the other two nozzles. These differences could result in different stress distributions which would affect

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[44] Exhibits NEC-JH_04 – NEC-JH_21.

[45] Exhibits NEC-JH_19 – NEC-JH_21.

the CUFs. Entergy did not discuss these differences; instead it only provided the following vague and unscientific statement:

> The analysis of the feedwater nozzle is bounding for the core spray and recirculation outlet nozzles since the calculated usage factors are at least 70% less than those for the feedwater nozzle and the number and severity of thermal transients are less.[46]

The statement that the feedwater nozzle results are bounding could only be justified if Entergy had demonstrated an understanding of the reasons for the differences in the CUFs obtained by the simplified Green's function analysis and those that were obtained by the more exact classical ASME analysis. **Entergy was not able to do so.**

## IV. HOPENFELD CUFen RECALCULATION

The CUFens calculated by Entergy, with and without the simplified Green's function method, contain error and they are unreliable. An alternative to these calculations is to use the conservative CUFs as were originally provided in LRA and multiply them by the bounding values given in NUREG/CR-6909. The results of this procedure are given below in Table 3.

[46] Exhibit NEC-JH_35 at Attachment 1.

**TABLE 3 - Recalculated Cumulative Usage Factors for Sample Locations at VYNPS**

| No. | NUREG/CR-6260 Sample Location (License Renewal Application, Table 4.3-3) | CUF (VYNPS License Renewal Application, Table 4.3-3) | Fen (Ref. 1) | **Recalculated CUFen** |
|---|---|---|---|---|
| 1 | Vessel shell & bottom head | 0.400 | 17 | 6.80 |
| 2 | Core spray safe end | 0.182 | 12 | 2.18 |
| 3 | Feed water nozzle | 0.750 | 17 | 12.75 |
| 4 | RHR return Piping | 0.032 | 12 | 0.38 |
| 5 | RR inlet nozzle | 0.610 | 17 | 10.37 |
| 6 | RR piping tee | 0.397 | 12 | 4.76 |
| 7 | RR outlet nozzle | 0.810 | 17 | 13.77 |
| 8 | Core spray nozzle | 0.625 | 17 | 10.62 |
| 9 | Feed water piping | 0.427 | 17 | 7.26 |

## V. SUMMARY

By introducing five key assumptions, excluding those connected with use of the Green's function methodology, Entergy purports to show that the CUFens for all NUREG/CR-6260 limiting locations are less than one. My assessment demonstrates that Entergy ignored critical factors in making its assumptions. When these assumptions are lifted and more appropriate and conservative assumptions are introduced, the CUFen for all but one of the components exceeds unity.

Entergy has not demonstrated that the predicted fatigue life of risk-significant components at VY will meet the ASME criteria for safe operation for the extended period of operation. Neither Entergy's initial analysis nor its "confirmatory" analysis demonstrate that CUFens for the components listed in License Renewal Application 4.3-3 or NUREG/CR-6260 limiting locations are less than one. It is my opinion that acceptance of Entergy's results will lead to an unjustified reduction in the scope of fatigue monitoring at the Vermont Yankee plant.

Entergy should be required to develop a valid methodology for calculating CUFen; expand its fatigue analysis to components in addition to the NUREG/CR-6260 locations if a valid CUFen analysis indicates that CUFen for any NUREG/CR-6260 location will exceed unity; and formulate a meaningful plan to properly inspect and maintain all components which are susceptible to fatigue.

## VI. REFERENCES


1. J. P. Holman, Heat Transfer, 1981 Ed.

2. E. R. G. Eckert and R. Drake, Heat and Mass Transfer 2nd, Ed 1959.

3. H. Schlichting, Boundary Layer Theory, 4th Ed. 1960.

4. NUREG/CR-6909, "Effect of LWR coolant Environment on Fatigue Life of Reactor Materials" (Final Report), ANL -06/08 U.S. NRC, Wash., D.C. Feb. 2007.

5. NUREG/CR-6583, "Effect of LWR Coolant Environment on Fatigue-Design Curves of Carbon and Low Alloy Steels," March 1998.

6. NUREG/CR 5704, "Effect of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steel," April 1999.

7. NUREG/CR-6936, "Probability of Failure and Uncertainty Estimate for Passive Components – A Literature Survey," May 2007.

## VII. GLOSSARY OF TERMS

Cumulative Usage Factor (CUF) – A summation of usage fatigue factors.

Fatigue -- An age-related degradation mechanism caused by cyclic stressing of a component by either mechanical or thermal stresses that eventually cause the component to crack

Feedwater Nozzle- A short pipe welded to the reactor vessel through which feedwater enters the vessel.

Fen – An environmental correction factor used to account for differences between fatigue in water and fatigue in air, defined as the ratio of the fatigue life in air at room temperature to that in water at the service temperature.

Green's Function – A simplified numerical technique for thermal stress calculations.

Laminar Flow – Sometimes known as streamline flow, it occurs when a fluid flows in parallel layers, with no disruption between layers.

Recirculation Nozzle - A short pipe welded to the reactor vessel through which water flow either in or out of the jet pump.

Spray Nozzle – A nozzle on top of the vessel used to cool the core in case of an accident.

Transient – Plant response to a change in power level.

Turbulent Flow – Fluid (gas or liquid) flow in which the fluid undergoes irregular fluctuations or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow, the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction.

Usage Fatigue Factor -- The number of cycles n at any given stress amplitude divided by the corresponding number of cycles to end of life, N.

| Structural Integrity Associates, Inc. CALCULATION PACKAGE | File No.: VY-16Q-301 **NEC-JH_04** |
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| | Project No.: VY-16Q |

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

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| **CLIENT:** | **PLANT:** |
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| Entergy Nuclear Operations, Inc | Vermont Yankee Nuclear Power Station |

**CALCULATION TITLE:**

Feedwater Nozzle Stress History Development for Green Functions

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## Table of Contents



## List of Tables

## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation is to compute the pressure stresses, thermal stresses, and the Green's Functions for high (100%), mid (40%), and low (25%) flow thermal loading of the Vermont Yankee Nuclear Power Station feedwater nozzle.

## 2.0 FEEDWATER NOZZLE MODEL

An axisymmetric finite element model of the feedwater nozzle was developed in Reference [1] using ANSYS [2]. The geometry used in Reference [1] was utilized in this calculation. The material properties are taken at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which will be applied to the FE model for Green's Function development. Table 1 listed the material properties at 300°F. The meshed model is shown in Figure 1.

## 3.0 APPLIED LOADS

Both pressure and thermal loads will be applied to the finite element model.

### 3.1 Pressure Load

A uniform pressure of 1000 psi was applied along the inside surface of the feedwater nozzle and the vessel wall. A pressure load of 1000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the nozzle. Since only nodes were modeled, the nodal forces shown in Table 2 are defined by the following equation:

$$F_{element} = \pi(IR)^2 P \cdot \frac{\pi\left(R_o^{\;2} - R_i^{\;2}\right)}{\pi\left(OR^2 - IR^2\right)}$$

where:

P = Pressure = 1,000 psi
IR = Inner Radius = 4.8345 in
OR = Outer Radius = 5.42 in
$R_i$ = Inside Radius of element that node is attached to
$R_o$ = Outside Radius of element that node is attached to
$F_{node}$ = The average of the element forces on either side of the node.
*Note: The force on the innermost and outermost nodes is calculated as one half of the force on the element that they are attached to.*

The calculated nodal forces were applied as positive values so they would exert tension on the end of the model. The ANSYS input file FWP_VY.INP, in the computer files, contains the feedwater nozzle geometry as well as the pressure loading. Figures 2, 3, and 4 show the internal pressure distribution, cap load, and symmetry condition applied to the vessel end of the model, respectively.

## 3.2 Thermal Load

Thermal loads are applied to the feedwater nozzle model. The heat transfer coefficients after power uprate were determined from Reference [1]. These values were determined for various regions of the finite element model for 100% (4,590 GPM), and 25% (1,148 GPM) [1]. The annulus leakage flow rate is assumed to be 25 GPM for non-EPU conditions and 31 GPM for EPU conditions. The 25 GPM value is calculated by scaling the 23 GPM [Page 6, 4] value up by approximately 9%. The 23 GPM value is scaled up to provide some conservatism and allow for inaccuracies in the determination of leakage flow. The 31 GPM value is calculated by multiplying the 25 GPM value by 1.25 [Page 6, 4]. Based on this, the annulus leakage flow rate is assumed to be 8 GPM for EPU conditions with 25% flow rate. The temperatures used are based upon a thermal shock from 500°F to 100°F. An additional 40% flow rate (1836 GPM and 13 GPM) was added in this calculation.

### 3.2.1 *Heat Transfer Coefficients*

Referring to Figure 5, heat transfer coefficients were applied as following:

Region 1

The heat transfer coefficient, h, for 100% flow is 3705 BTU/hr-ft$^2$-°F at 300°F. [1, Table 5]

The heat transfer coefficient, h, for 40% flow is 1780 BTU/hr-ft$^2$-°F at 300°F. [Table 4]

The heat transfer coefficient, h, for 25% flow is 1222.2 BTU/hr-ft$^2$-°F at 300°F. [1, Table 4]

Region 2

Per Reference [1], the heat transfer coefficient for Region 2 (safe end-to-thermal sleeve contact region) should be linearly transitioned from the value of the heat transfer coefficient used in Region 1 to the value used in Region 3.

Region 3

The heat transfer coefficient, h, for 100% flow is 1489 BTU/hr-ft$^2$-°F at 300°F. [1, Table 9]

The heat transfer coefficient, h, for 40% flow is 743 BTU/hr-ft$^2$-°F at 300°F. [1, Table 9]

The heat transfer coefficient, h, for 25% flow is 504 BTU/hr-ft$^2$-°F at 300°F. [1, Table 9]

Region 4

Per Reference [1], the he heat transfer coefficient for Region 4 (thermal sleeve transition in diameter) should be linearly transitioned from the value of the heat transfer coefficient used in Region 3 to the value used in Region 5.

Region 5

The heat transfer coefficient, h, for 100% flow is 177.4 BTU/hr-ft$^2$-°F at 300°F. [1, Table 16]

The heat transfer coefficient, h, for 40% flow is 88.5 BTU/hr-ft$^2$-°F at 300°F. [1, Table 16]

The heat transfer coefficient, h, for 25% flow is 60 BTU/hr-ft$^2$-°F at 300°F. [1, Table 16]

Region 6

Per Reference [1], the heat transfer coefficient for Region 6 (nozzle inner blend radius) should be linearly transitioned from the value of the heat transfer coefficient used in Region 5 to the value used in Region 7.

Region 7

Per Reference [1], the heat transfer coefficient for Region 7 (reactor vessel inside wall) is a constant of 864 BTU/hr-ft$^2$-°F. This value is consistent with the feedwater nozzle work performed in the past for VY and should be used for all reactor conditions.

Region 8

The heat transfer coefficient, h, is 0.2 BTU/hr-ft$^2$-°F [1].

### 3.2.2 *Boundary Fluid Temperatures*

For the Green's Functions, a 500°F – 100°F thermal shock is run to determine the stress response to a one-degree change in temperature. The following temperatures are valid when there is water flow. Values between defined points are linearly interpolated. For the 100%, 40%, and 25% flow cases, the thermal shock is run as follows:

Regions 1 to 5
T = 500°F – 100°F
Region 6
Linearly transitioned from the value of the temperature used in Region 5 to the value used in Region 7
Region 7
T = 500°F
Region 8
T = 120°F

## 4.0 THERMAL AND PRESSURE LOAD RESULTS

The three flow dependent thermal load cases outlined in Section 3.0 were run on the finite element model. Appendix A contains the thermal transient input files FWT_VY_100.INP, FWT_VY_40.INP, and FWT_VY_25.INP for 100%, 40%, and 25% full flow rate, respectively. The three flow dependent input files for the stress runs are also included in Appendix A. The stress filenames are FWS_VY_100.INP, FWS_VY_40.INP, and FWS_VY_25.INP for 100%, 40%, and 25% full flow rate, respectively.

The critical safe end location was chosen as node 192, which has the highest stress intensity due to thermal loading under high flow conditions. As shown in Figures 6 and 7, Node 192 is located on the inside diameter of the nozzle safe end of the model and the maximum stress occurs at 1.4 seconds.

The critical blend radius location was chosen, based upon the highest pressure stress. Conservatively assuming the cladding has cracked, the critical location is selected as node 657 at base metal of the nozzle, as shown in Figures 8 and 9.

The stress intensity for use in the Green's functions are calculated from the component stresses (X, Y, and Z) and compared to the stress intensity reported by ANSYS. As seen in Figure 10, the Z-X calculated total stress intensity best matches the ANSYS reported stress intensity for 100% flow at the safe end. Therefore, the Z-X stress will be used for the total and membrane plus bending Green's functions for all flow rates for the safe end. As seen in Figure 11, the Z-X calculated total stress intensity best matches the ANSYS reported stress intensity for 100% flow at the blend radius in very beginning. Therefore, the Z-X stress will be used for the total and membrane plus bending Green's functions for all flow rates for the blend radius.

The stress time history for the critical paths was extracted during the stress run for 100% flow rate. This produced two files, HFSE.OUT and HFBLEND.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the files HFSE_Inside.RED and HFBLEND_Inside.RED, where SE and BLEND corresponded to the safe end and blend radius locations, respectively.

The stress time history for the critical paths was extracted during the stress run for 40% flow rate. This produced two files, MFSE.OUT and MFBLEND.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the files MFSE_Inside.RED and MFBLEND_Inside.RED, where SE and BLEND corresponded to the safe end and blend radius locations, respectively.

The stress time history for the critical paths was extracted during the stress run for 25% flow rate. This produced two files, LFSE.OUT and LFBLEND.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the files LFSE_Inside.RED and LFBLEND_Inside.RED, where SE and BLEND corresponded to the safe end and blend radius locations, respectively.

As the models were run with a 400°F step change in temperature, and the Green's Functions are for a 1°F step change in temperature, all data values were divided by 400. The governing Green's Functions for the feedwater nozzle during 100% flow, 40% flow, and 25% flow are shown in Figures 12 to 23. The data for the Green's Functions is included in the files HFBR_M+B-Green.xls, HFBR_T-Green.xls, HFSE_M+B-Green.xls, HFSE_T-Green.xls, MFBR_M+B-Green.xls, MFBR_T-Green.xls, MFSE_M+B-Green.xls, MFSE_T-Green.xls, LFBR_M+B-Green.xls, LFBR_T-Green.xls,LFSE_M+B-Green.xls, and LFSE_T-Green.xls in the project Files. Where HF, MF, and LF corresponded to 100% flow, 40% flow, and 25% flow rate, respectively. M+B and T corresponded to membrane plus bending stress and total stress, respectively.

The pressure stress intensities for the path were extracted during the pressure run. The pressure stresses were extracted along the nodal paths as shown in Figures 7 and 9. This produced two files, PSE.OUT and PBLEND.OUT for the safe end and blend radius locations, respectively.

For the pressure loading specified (1,000 psig), the total stress intensity at Node 192 and Node 657 were determined to be 8,891 psi and 28,300 psi, respectively. The membrane plus bending stress intensity at Node 192 and Node 657 were determined to be 8,693 and 27,490 psi, respectively. Table 3 shows the pressure results.

Results were also extracted from the vessel portion of the model to verify the accuracy of the pressure results obtained from the ANSYS model, and to check the results due to the use of the 1.5 multiplier on the vessel radius. These results are contained in the file, PVESS.OUT. Based on earlier work [1], the radius of the finite element model (FEM) was multiplied by a factor of 1.5 to account for the fact that the vessel portion of the two-dimensional (2D) axisymmetric model is a sphere, but the true geometry is the intersection of two cylinders.

The equation for the membrane hoop stress for a sphere is:

$$\sigma = \frac{(pressure) \times (radius)}{2 \times thickness}$$

Considering a vessel base metal radius, R, of 105.90625 inches increased by a factor of 1.5, a vessel base metal thickness, t, of 5.4375 inches, and an applied pressure, P, of 1,000 psi, the calculated stress for a sphere is PR/(2t) = 14,608 psi. This compares very well with the remote vessel wall membrane hoop stress from the ANSYS result file, PVESS.OUT, of 13,410 psi. Thus, considering the peak total pressure stress of 28,300 psi reported above, the stress concentrating effect of the nozzle corner is 28,300/14,608 = 1.94. In other words, the peak nozzle corner stress is 1.94 times higher than nominal vessel wall stress for the 2D axisymmetric model.

The equation for the membrane hoop stress in a cylinder is:

$$\sigma = \frac{(pressure) \times (radius)}{thickness}$$

Based on the previous dimensions, the calculated stress for a cylinder without the 1.5 factor is 19,477 psi. Increasing this by a factor of 1.94 yields an expected peak nozzle corner stress of 37,785 psi, which would be expected from a cylindrical geometry that is representative of the nozzle configuration. Therefore, the result from the ANSYS file for the peak nozzle corner stress (28,300 psi) is lower than the peak nozzle corner stress for a cylindrical geometry because of the use of the 1.5 multiplier. This is consistent with SI's experience where a factor of two increase in radius is typical for representing the three-dimensional (3D) effect in a 2D axisymmetric model.

Based on the foregoing, the ANSYS pressure stresses for the vessel blend radius are increased for use in the subsequent fatigue analysis by 1.33 (2.0/1.5). Thus, the blend radius results presented in Table 3 were obtained by multiplying the ANSYS stresses for the pressure loading by a 1.33X multiplication factor.

## 5.0 REFERENCES


1. SI Calculation No. VY-10Q-301, Revision 0, "Feedwater Nozzle Finite Element Model and Heat Transfer Coefficients."
2. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.
3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
4. VY Calculation Change Notice (CCN), CCN Number 1 for Calculation VYC1005 Revision 2, "This CCN Provides a Basis for the Power Uprate Safety Analysis Report being submitted as part of the power uprate project. The 50.59 assessment will be handled by the EPU design change and NRC SER for this submittal." SI File Number VY-05Q-208.
5. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.
6. J. P. Holman, "Heat Transfer," 5th Edition, 1981.
7. GE Nuclear Energy Certified Design Specification, "Reactor Vessel – Extended Power Uprate," Revision 1, SI File No. VY-05Q-236.
8. N. P. Cheremisinoff, "Heat Transfer Pocket Handbook," Gulf Publishing Co, 1984.

## Table 1: Material Properties @ 300°F [(1)]

| Material Ident. | Young's Modulus, E x $10^6$ (psi) | Instantaneous Coefficient of Thermal Expansion, $\alpha$ x $10^{-6}$ (in/in-°F) | Density, $\rho$ (lb/in³) (assumed) | Conductivity, k (BTU/hr-ft-°F) | Diffusivity, d (ft²/hr) | Specific Heat, $c_p$ (BTU/lbm-°F) (see Note 5) | Poisson's Ratio (assumed) |
|---|---|---|---|---|---|---|---|
| SA533 Grade B, A508 Class II (see Note 2) | 26.7 | 7.3 | 0.283 | 23.4 | 0.401 | 0.119 | 0.3 |
| SS Clad (see Note 3) | 27.0 | 9.8 | 0.283 | 9.8 | 0.160 | 0.125 | 0.3 |
| A508 Class I (see Note 4) | 28.1 | 7.3 | 0.283 | 32.3 | 0.561 | 0.118 | 0.3 |
| A106 Grade B (see Note 4) | 28.3 | 7.3 | 0.283 | 32.3 | 0.561 | 0.118 | 0.3 |

Notes

1. The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, 2000 Addenda, Section II, Part D, except for density and Poisson's ratio, which are assumed typical values [3].
2. Properties of A508 Class II are used (3/4Ni-1/2Mo-1/3Cr-V).
3. Properties of 18Cr - 8Ni austenitic stainless steel are used.
4. Composition = C-Si.
5. Calculated as $[k/(\rho d)]/12^3$.

## Table 2: Nodal Force Calculation for End Cap Load

| Node Number | Element Number | Radius (in) | Δ Radius (in) | $R_o^2$-$Ri^2$ (in²) | $F_{element}$ (lb) | $F_{node}$ (lb) |
|---|---|---|---|---|---|---|
| 1 | | 5.42 | | | | 7678.0 |
| | 1022 | | 0.1171 | 1.25565 | 15356.1 | |
| 2 | | 5.3029 | | | | 15188.4 |
| | 1021 | | 0.1171 | 1.22823 | 15020.7 | |
| 3 | | 5.1858 | | | | 14853.0 |
| | 1020 | | 0.1171 | 1.20080 | 14685.3 | |
| 4 | | 5.0687 | | | | 14517.6 |
| | 1019 | | 0.1171 | 1.17338 | 14349.9 | |
| 5 | | 4.9516 | | | | 14182.2 |
| | 1018 | | 0.1171 | 1.14595 | 14014.5 | |
| 6 | | 4.8345 | | | | 7007.3 |

## Table 3: Pressure Results

| Location | Membrane Plus Bending Stress Intensity (psi) | Total Stress Intensity (psi) |
|---|---|---|
| Safe End | 8693 | 8891 |
| Blend Radius | 36653 | 37733 |

Note: The results for the Blend Radius have been increased by a factor of 1.33 (2.0/1.5) as discussed in Section 4.0.

## Table 4: Heat Transfer Coefficients for Region 1 (40% Flow)

### *Calculation of Heat Transfer Coefficients for Feedwater Nozzle Flow Path*

Pipe Inside Diameter, D = 9.669 inches = 0.806 ft = 0.246 m

Flow, % of rated = 40%

Fluid Velocity, V = 8.022 ft/sec = 1,836.0 gpm = 0.793742524 Mlb/hr

Characteristic Length, L = D = 0.806 ft = 0.246 m

100% rated flow = 4,590 gpm
@ T = 391.9 °F
Density, $\rho$ = 53.8997 lbm/ft$^3$

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $T_{fluid} - T_{surface}$, $\Delta T$ = assumed to be 12% of fluid temperature = | | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| *Note: The above assumption is based on experience with past RPV heat transfer analyses.* | = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [5] | Value at Fluid Temperature, T [8] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| $\rho$ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | kg/m$^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | lbm/ft$^3$ |
| $\beta$ | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | m$^3$/m$^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | ft$^3$/ft$^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | m/s$^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | ft/s$^2$ |
| $\mu$ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| ***Calculated Parameter*** | ***Formula*** | ***70*** | ***100*** | ***200*** | ***300*** | ***400*** | ***500*** | ***600*** | °F |
| Reynold's Number, Re | $\rho VD/\mu$ | 6.0147E+05 | 8.7645E+05 | 1.8859E+06 | 2.8491E+06 | 3.7255E+06 | 4.5248E+06 | 4.7336E+06 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 1.2852E+08 | 6.6834E+08 | 1.2721E+10 | 6.5918E+10 | 2.0931E+11 | 5.4429E+11 | 1.1372E+12 | --- |
| Rayleigh Number, Ra | GrPr | 8.9710E+08 | 3.0142E+09 | 2.4297E+10 | 8.0420E+10 | 1.9885E+11 | 4.6755E+11 | 1.2168E+12 | --- |
| *From [5]:* ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 5,132.76 | 6,119.10 | 8,626.61 | 10,107.53 | 10,960.57 | 11,236.63 | 10,678.39 | W/m$^2$-°C |
| | | 903.95 | 1,077.66 | 1,519.26 | 1,780.07 | 1,930.31 | 1,978.92 | 1,880.61 | Btu/hr-ft$^2$-°F |
| | | 1.744E-03 | 2.079E-03 | 2.931E-03 | 3.434E-03 | 3.724E-03 | 3.817E-03 | 3.628E-03 | Btu/sec-in$^2$-°F |
| *From [5]:* ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 289 of [6]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 232.43 | 330.57 | 599.85 | 815.28 | 988.69 | 1,118.54 | 1,192.73 | W/m$^2$-°C |
| | | 40.93 | 58.22 | 105.64 | 143.58 | 174.12 | 196.99 | 210.06 | Btu/hr-ft$^2$-°F |
| | | 7.896E-05 | 1.123E-04 | 2.038E-04 | 2.770E-04 | 3.359E-04 | 3.800E-04 | 4.052E-04 | Btu/sec-in$^2$-°F |

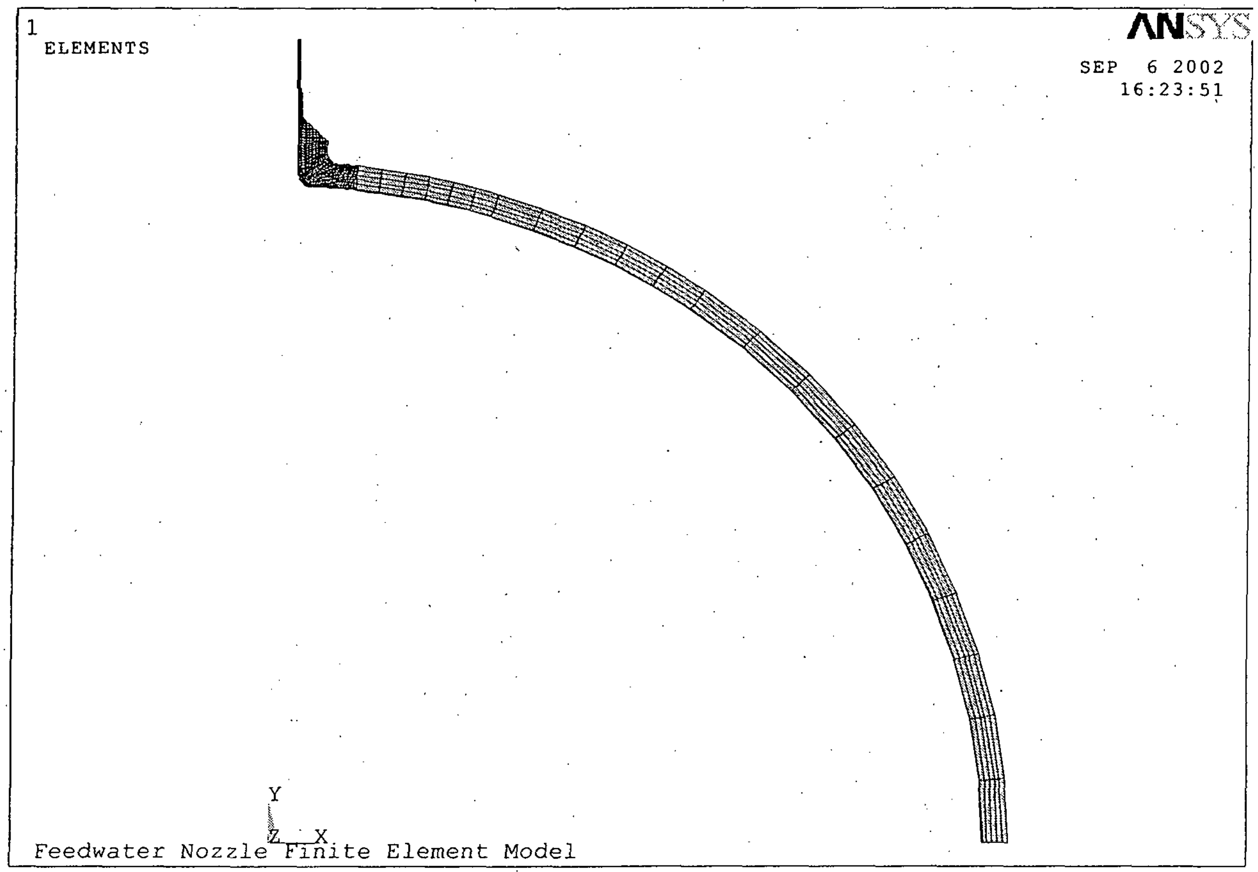



**Figure 1: ANSYS Finite Element Model**

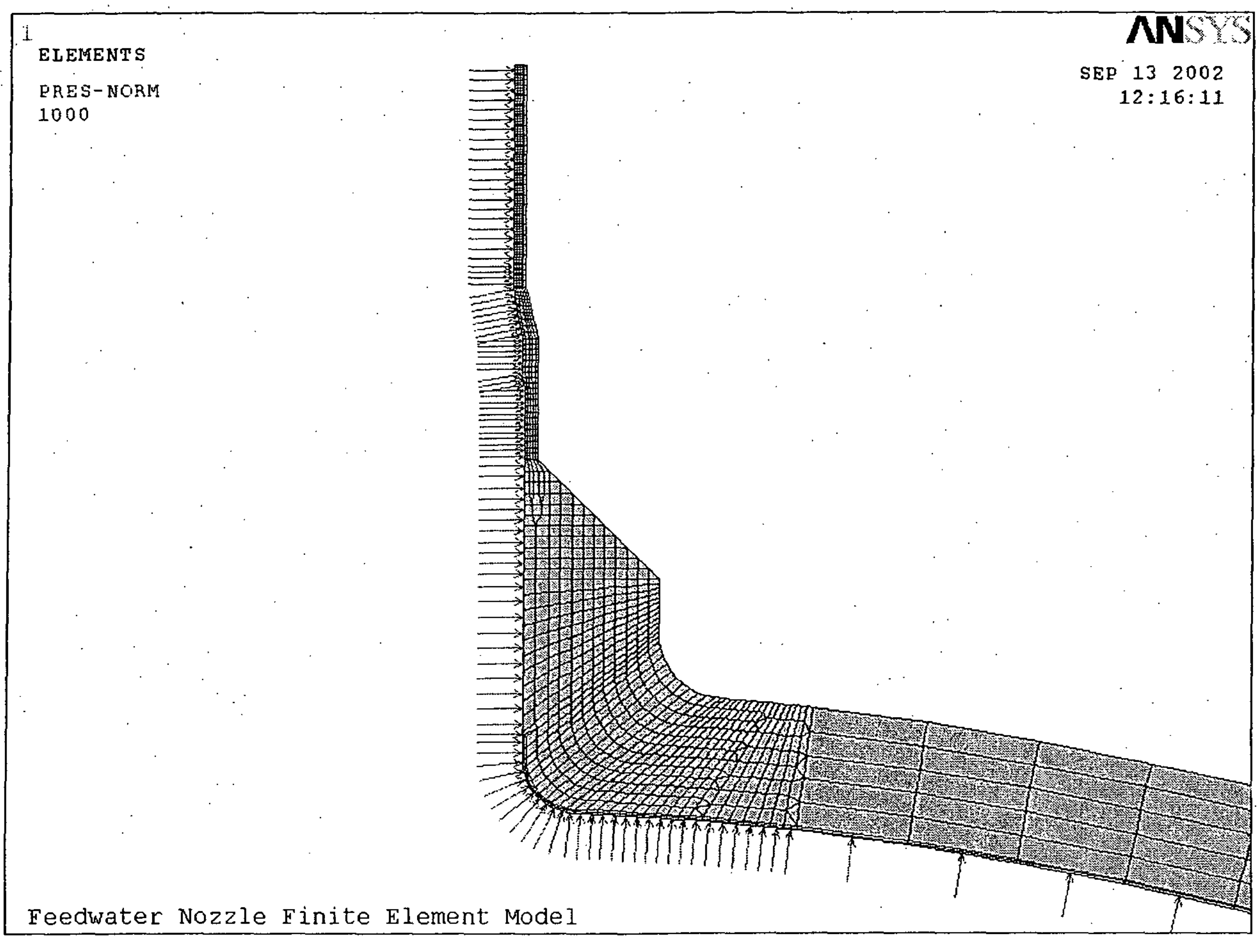



**Figure 2: Feedwater Nozzle Internal Pressure Distribution**

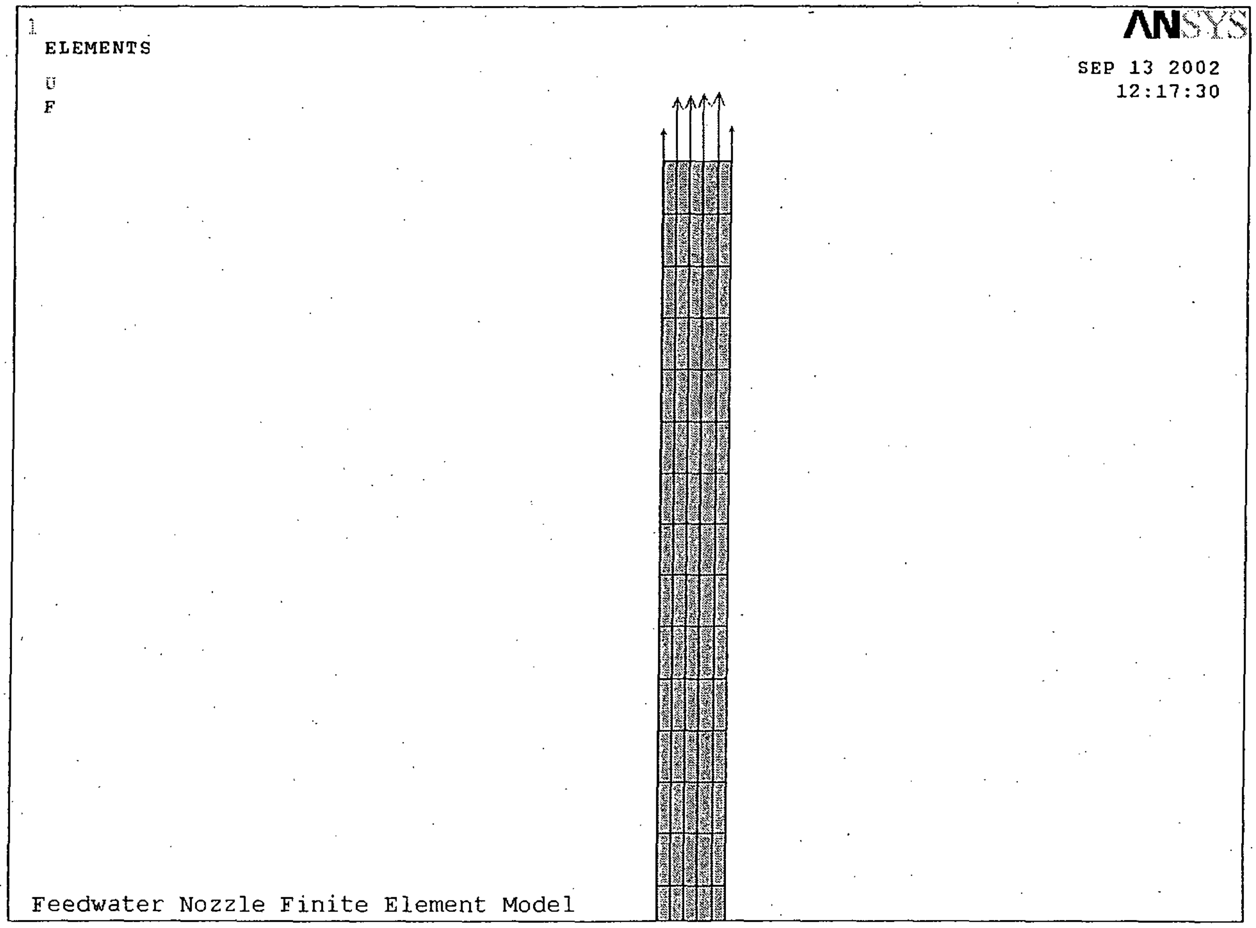



**Figure 3: Feedwater Nozzle Pressure Cap Load**

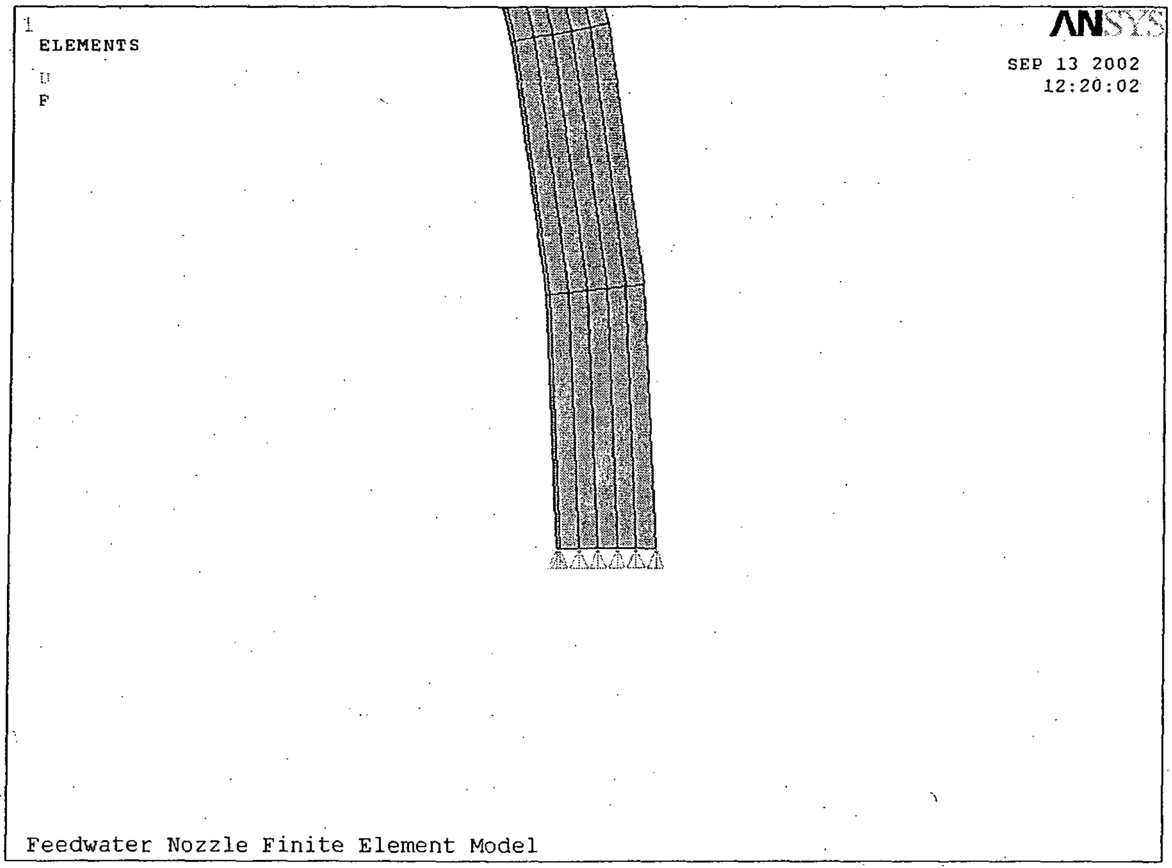
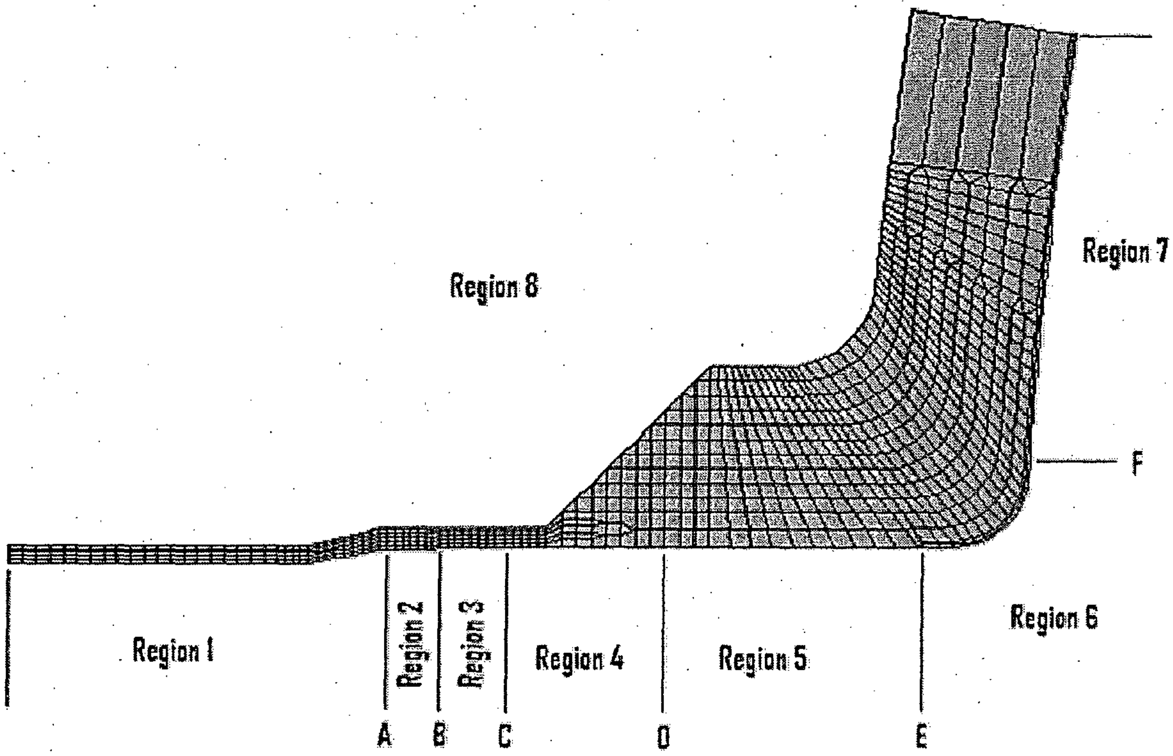



**Figure 4: Feedwater Nozzle Vessel Boundary Conditions**




Notes: Point A: End of thermal sleeve = Node 204 = 0.25" from feedwater inlet side of thermal sleeve flat.
Point B: Beginning of annulus = Node 252.
Point C: Beginning of thermal sleeve transition = approximately 4.0" from Point A = Node 294.
Point D: End of thermal sleeve transition = approximately 9.5" from Point A = Node 387.
Point E: End of inner blend radius (nozzle side) = Node 553.
Point F: End of inner blend radius (vessel wall side) = Node 779.

**Figure 5: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries [1]**

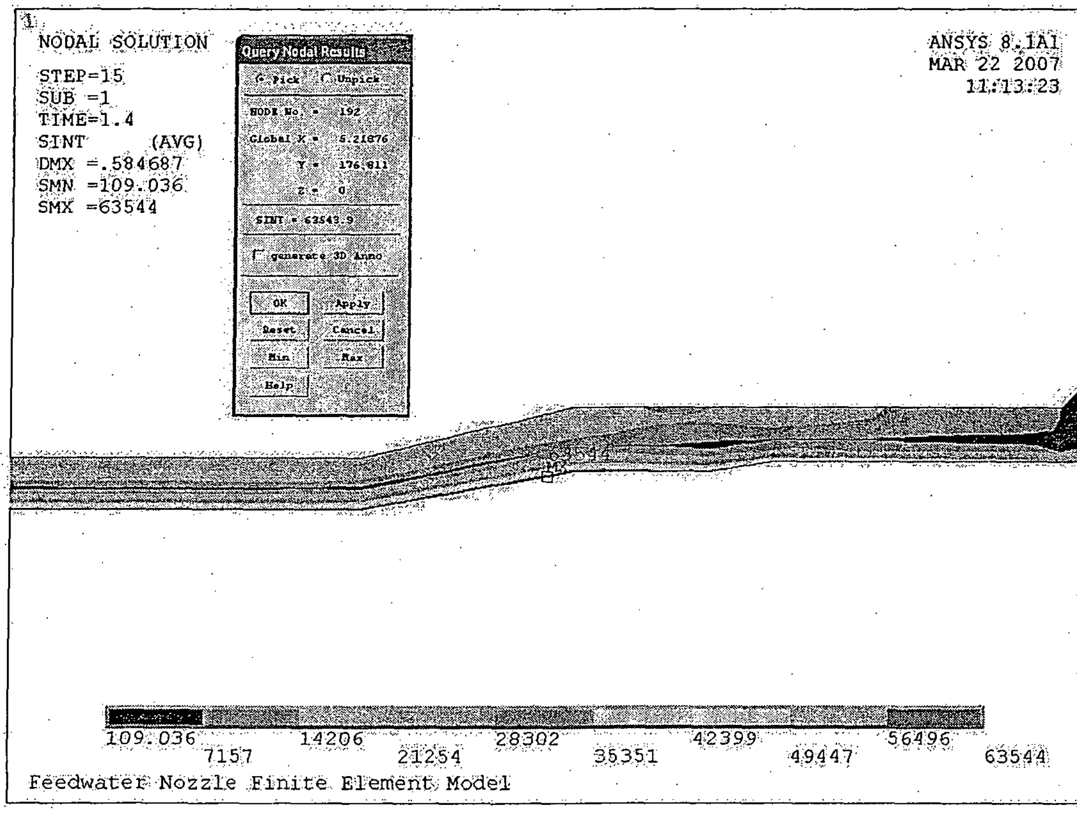



**Figure 6: Safe End Critical Thermal Stress Location**

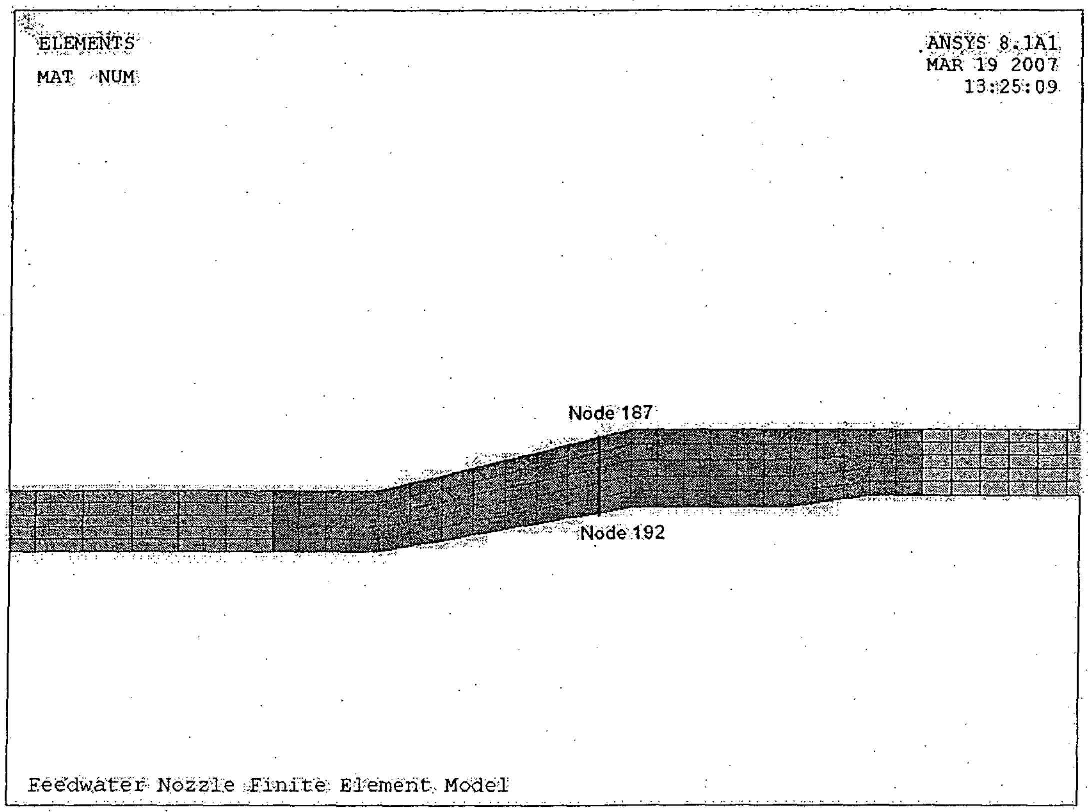



**Figure 7: Safe End Limiting Linearized Stress Paths**

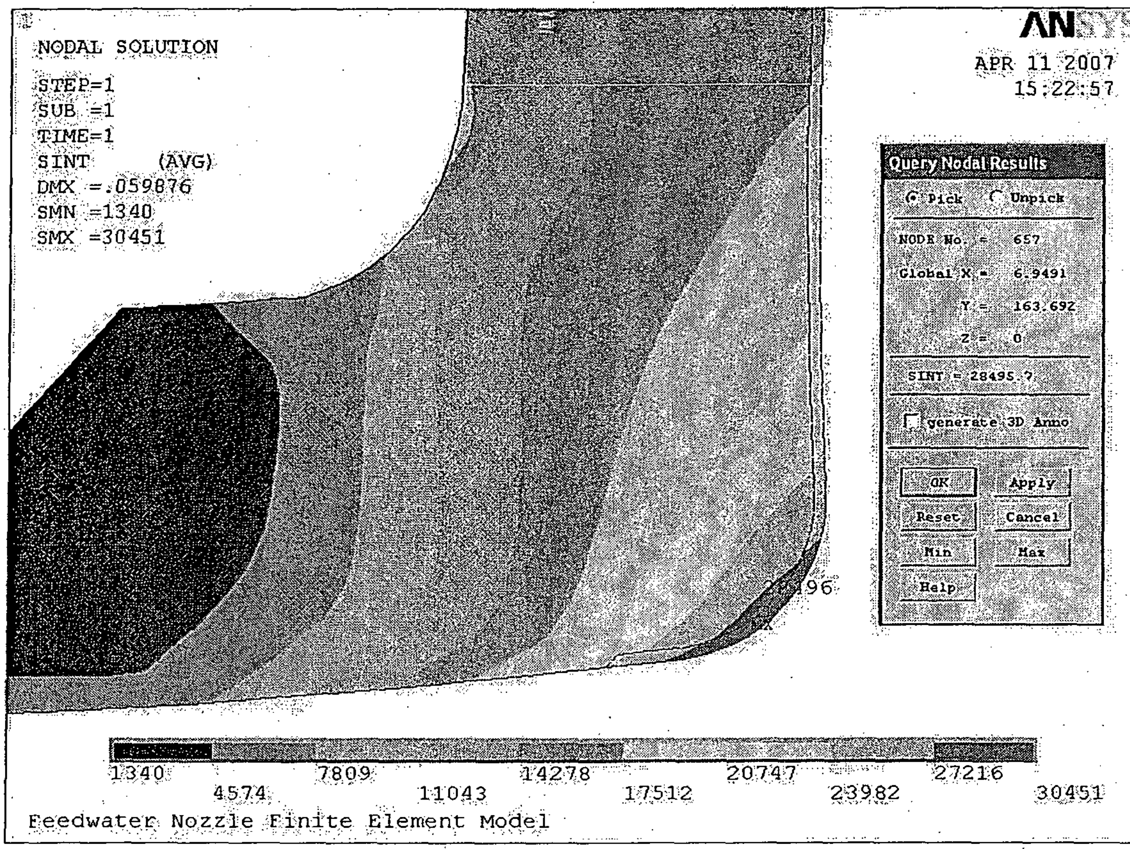



**Figure 8: Blend Radius Limiting Pressure Stress Location**

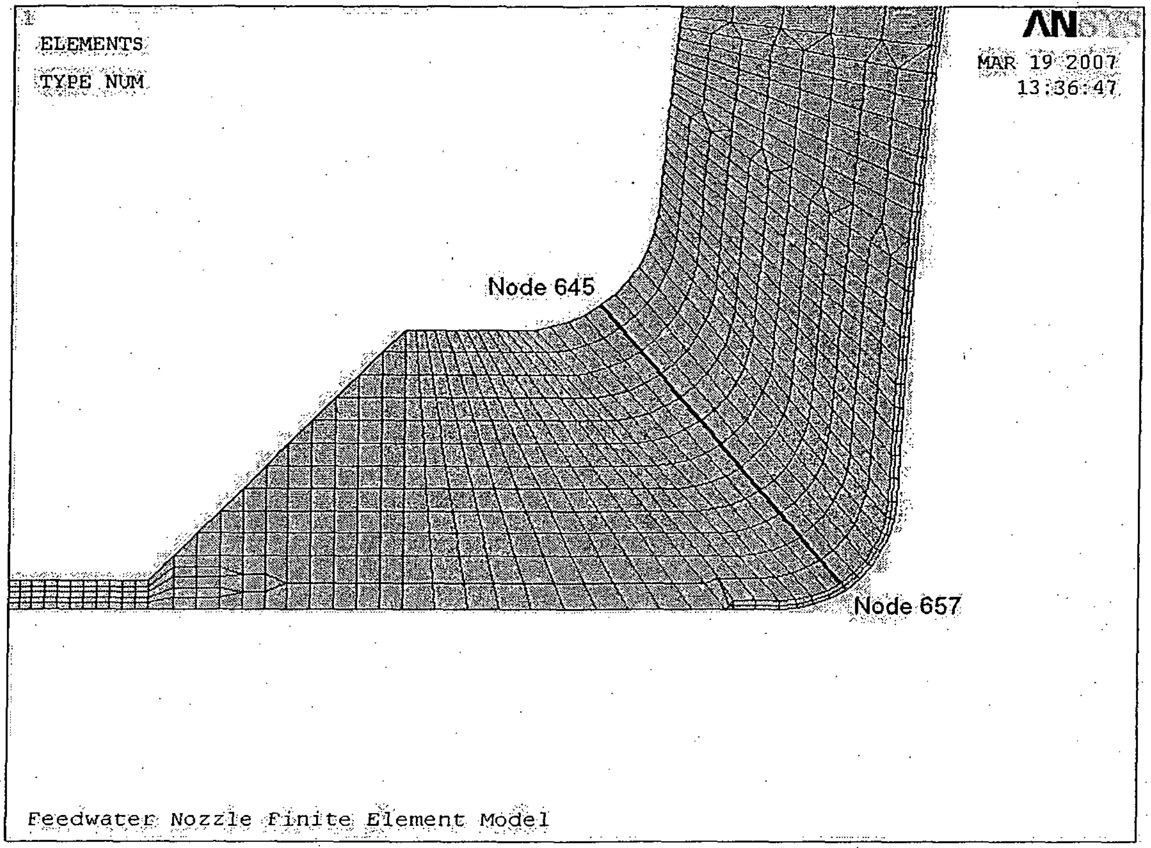



**Figure 9: Blend Radius Linearized Stress Path**

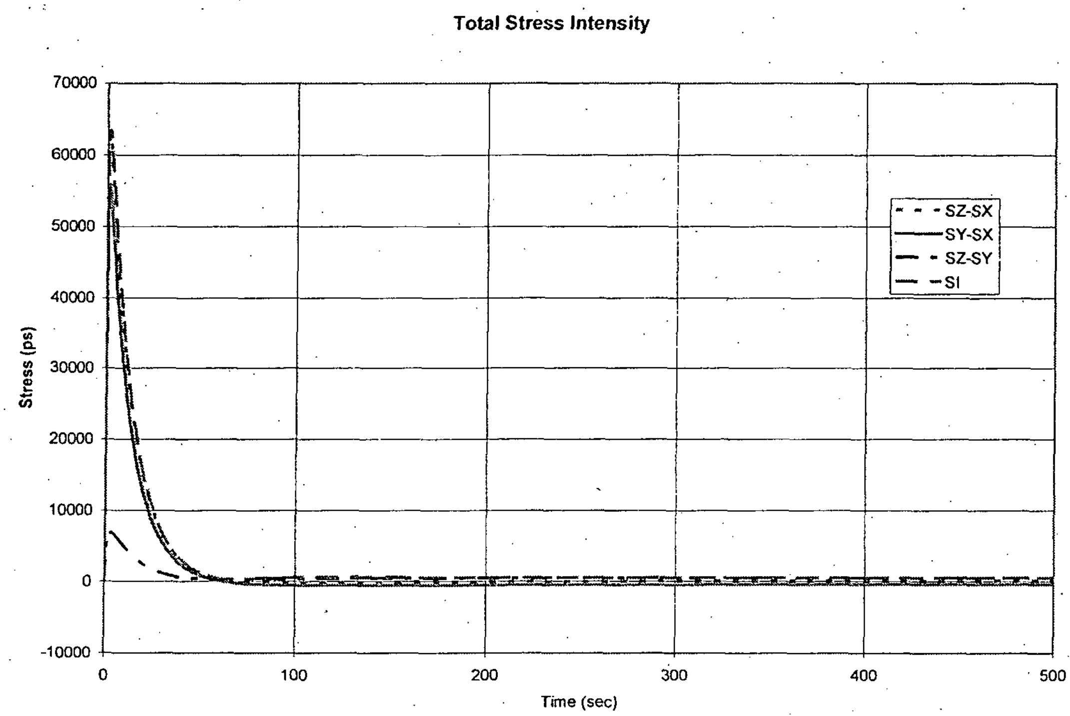



**Figure 10: Safe End 100% Flow Total Stress Intensity**

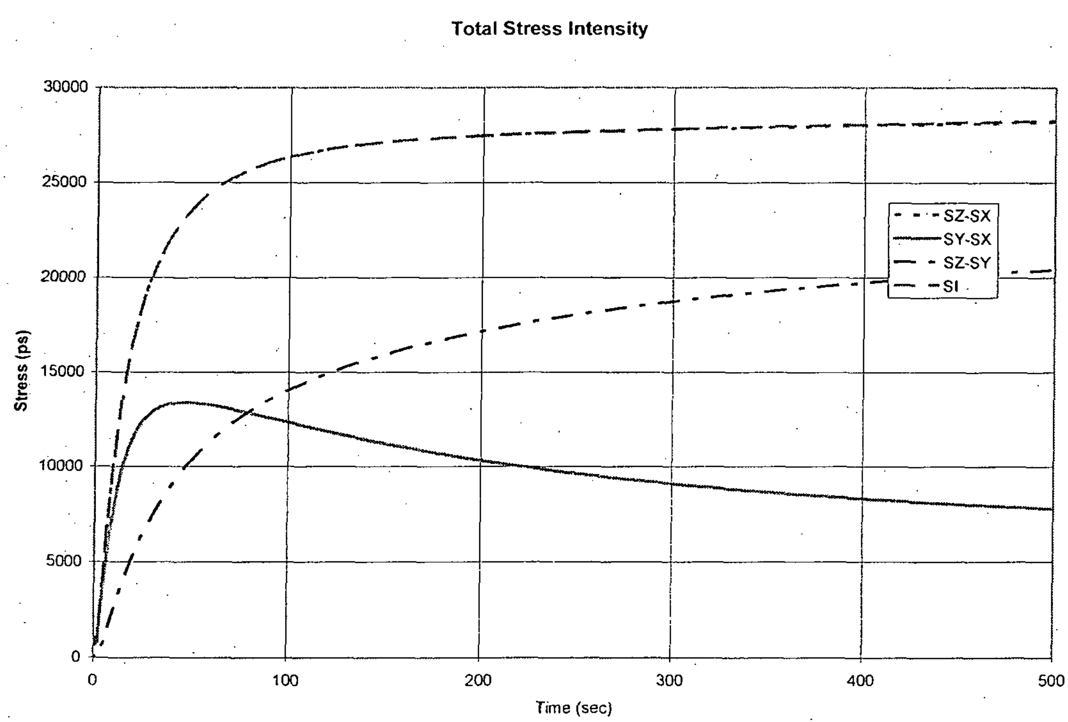



**Figure 11: Blend Radius 100% Flow Total Stress Intensity**

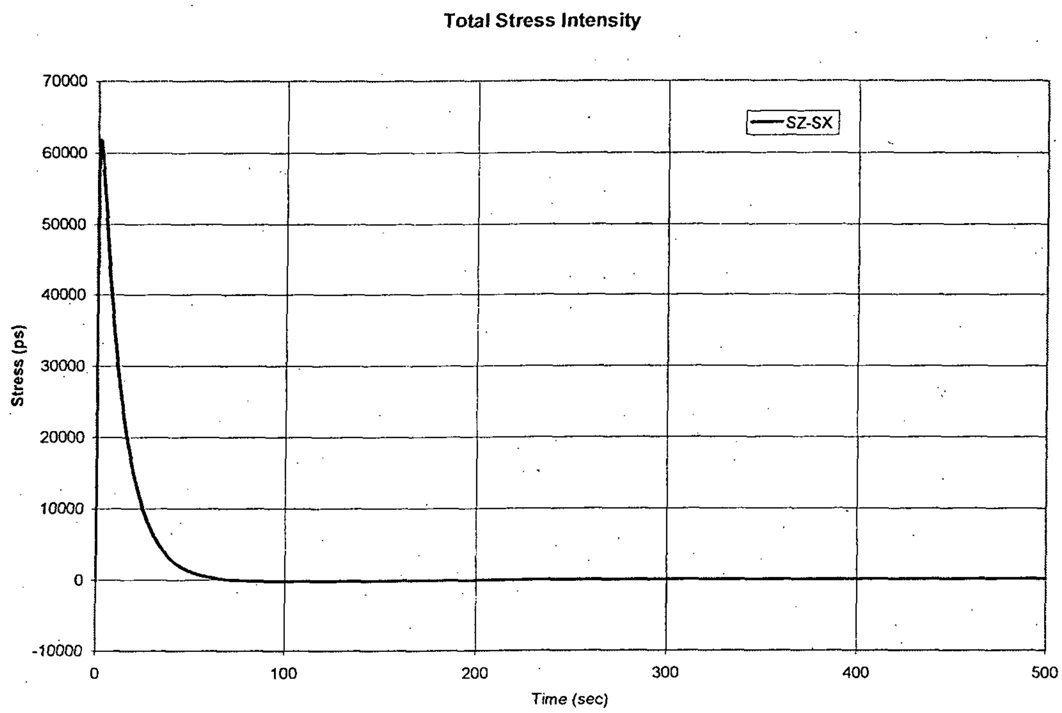



**Figure 12: Safe End Total Stress History for 100% Flow**

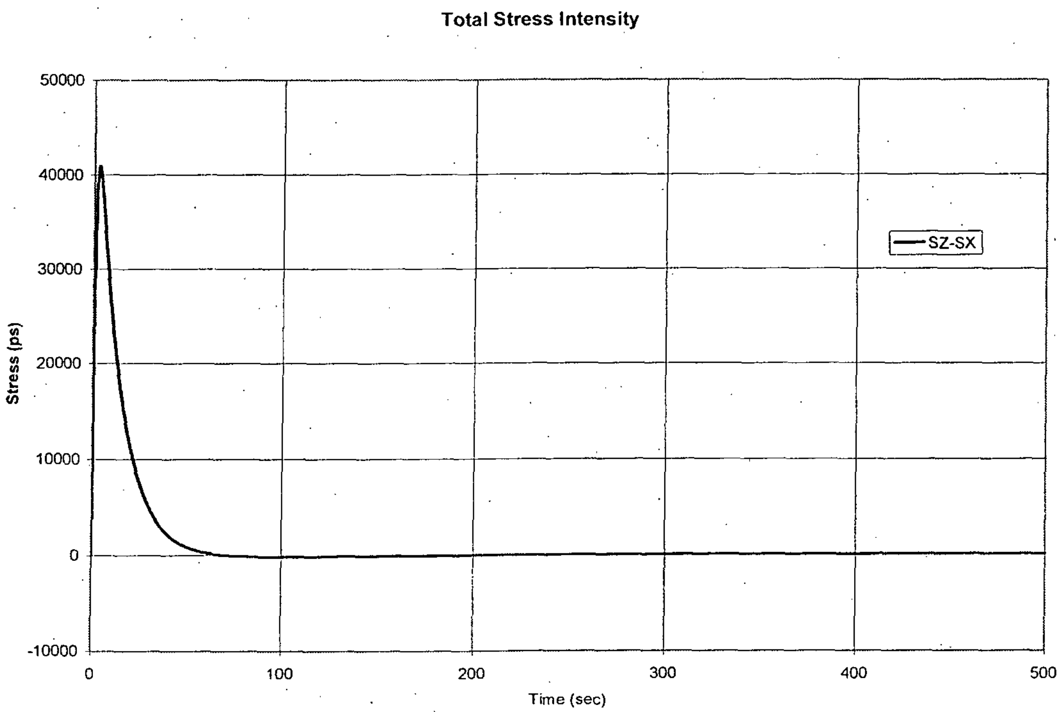



**Figure 13: Safe End Membrane Plus Bending Stress History for 100% Flow**

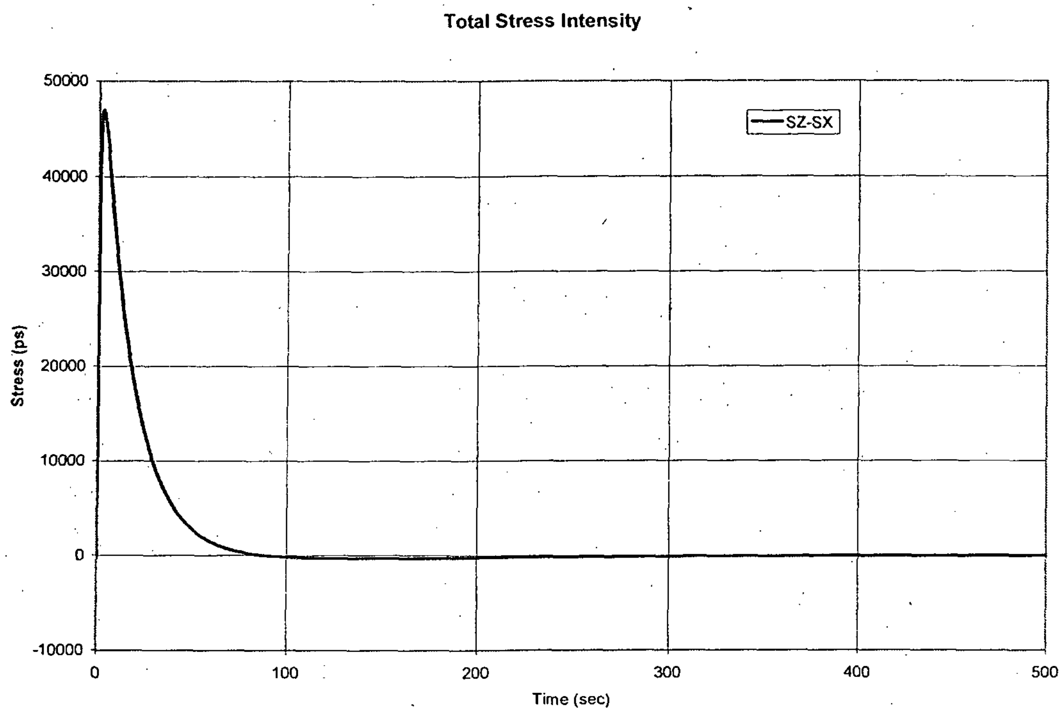



**Figure 14: Safe End Total Stress History for 40% Flow**

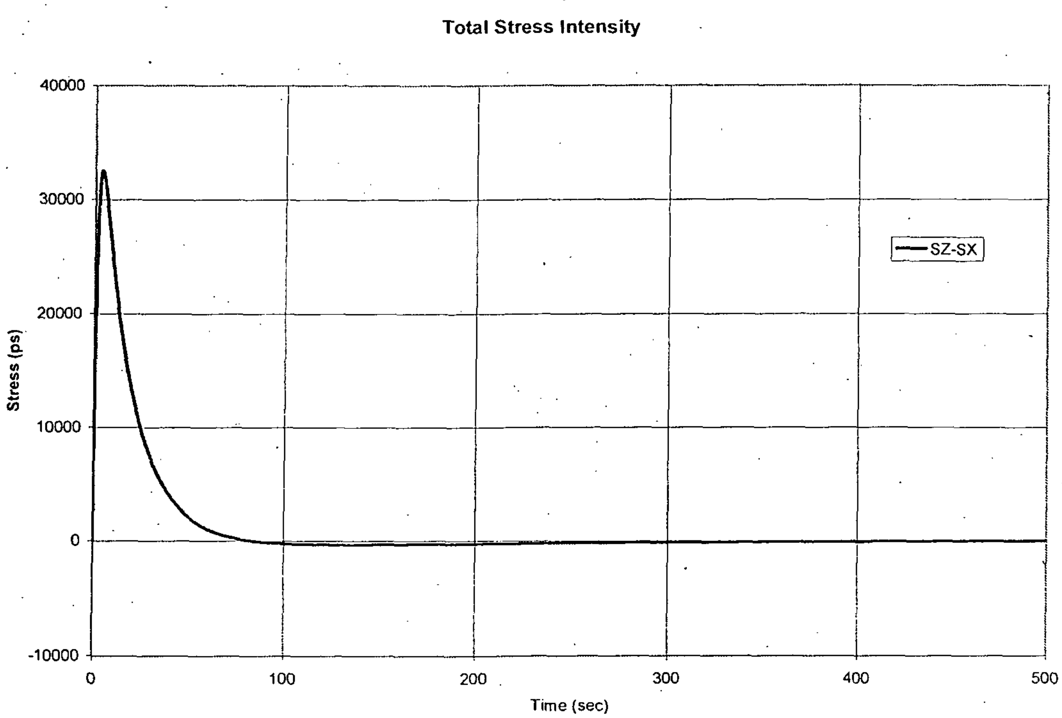



**Figure 15: Safe End Membrane Plus Bending Stress History for 40% Flow**

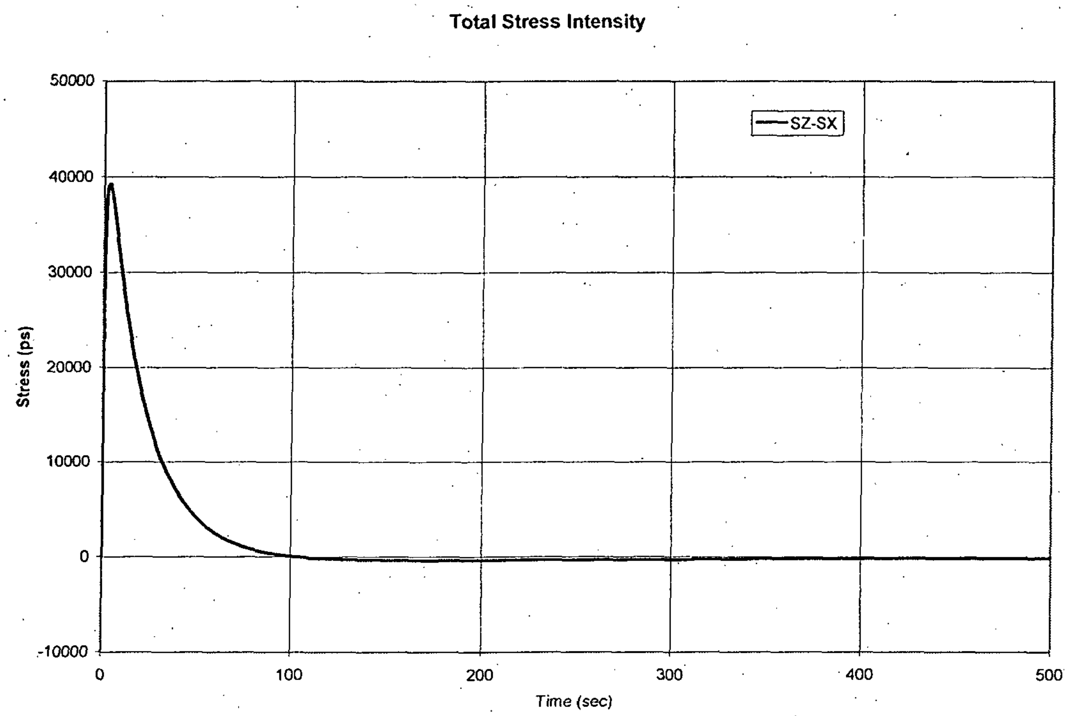



**Figure 16: Safe End Total Stress History for 25% Flow**

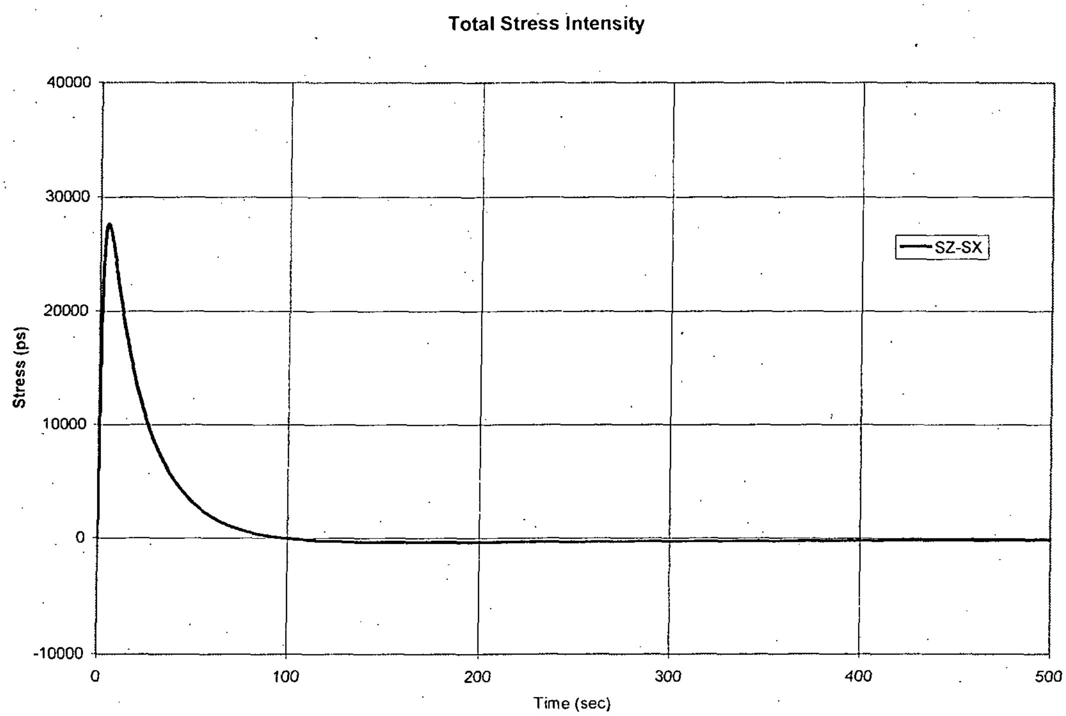



**Figure 17: Safe End Membrane Plus Bending Stress History for 25% Flow**

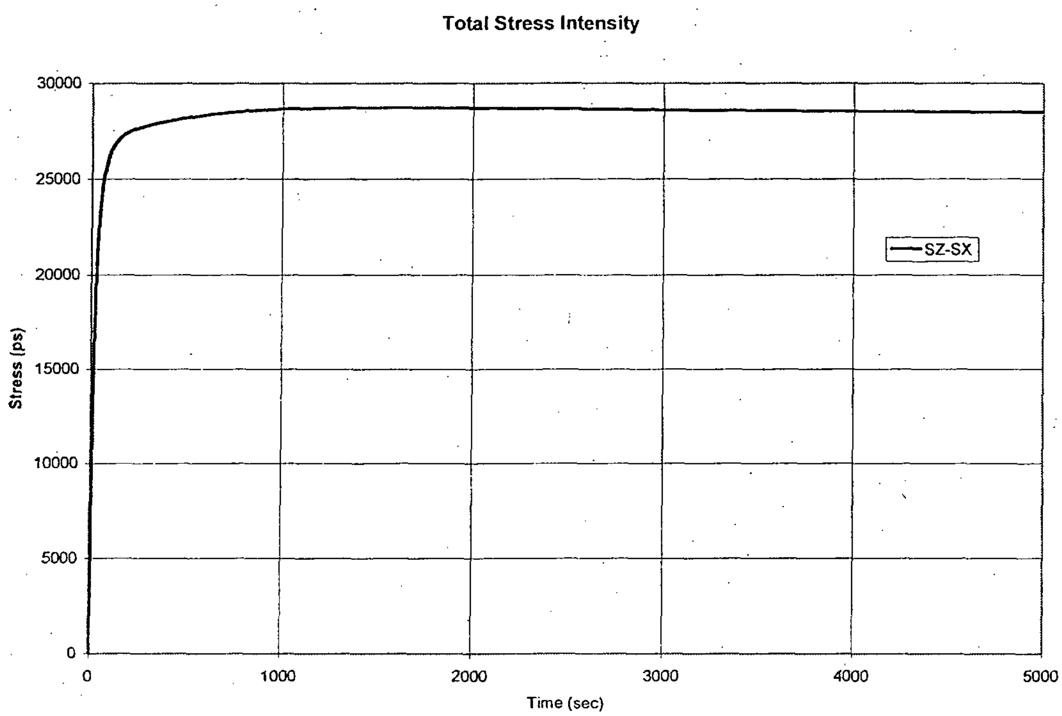



**Figure 18: Blend Radius Total Stress History for 100% Flow**

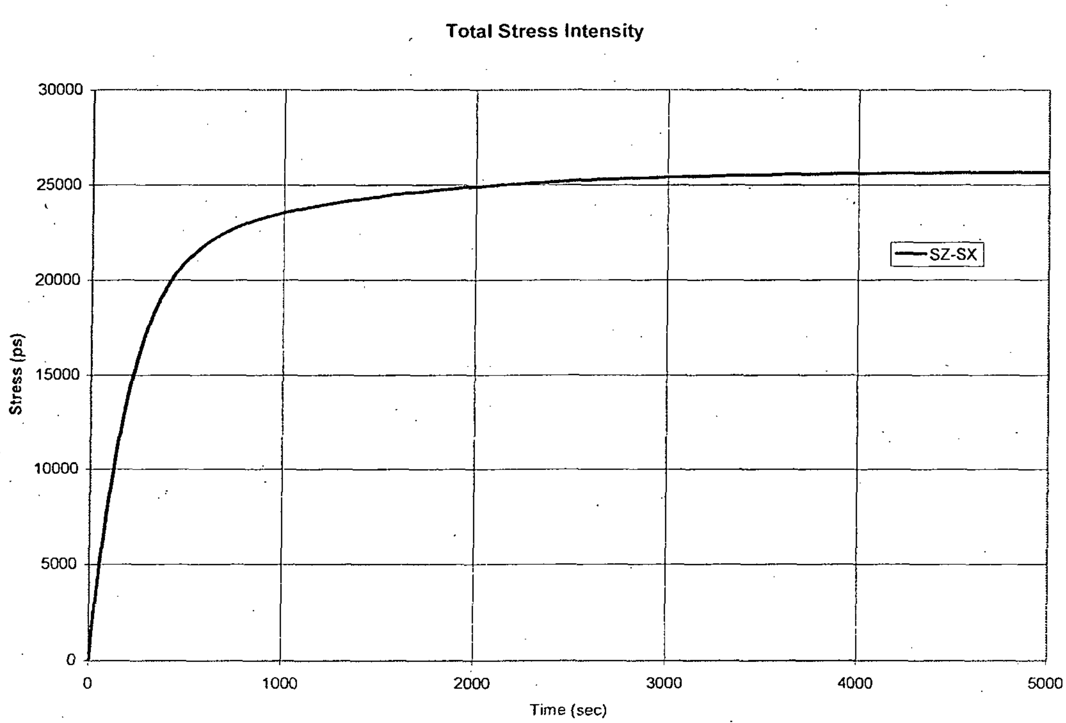



**Figure 19: Blend Radius Membrane Plus Bending Stress History for 100% Flow**

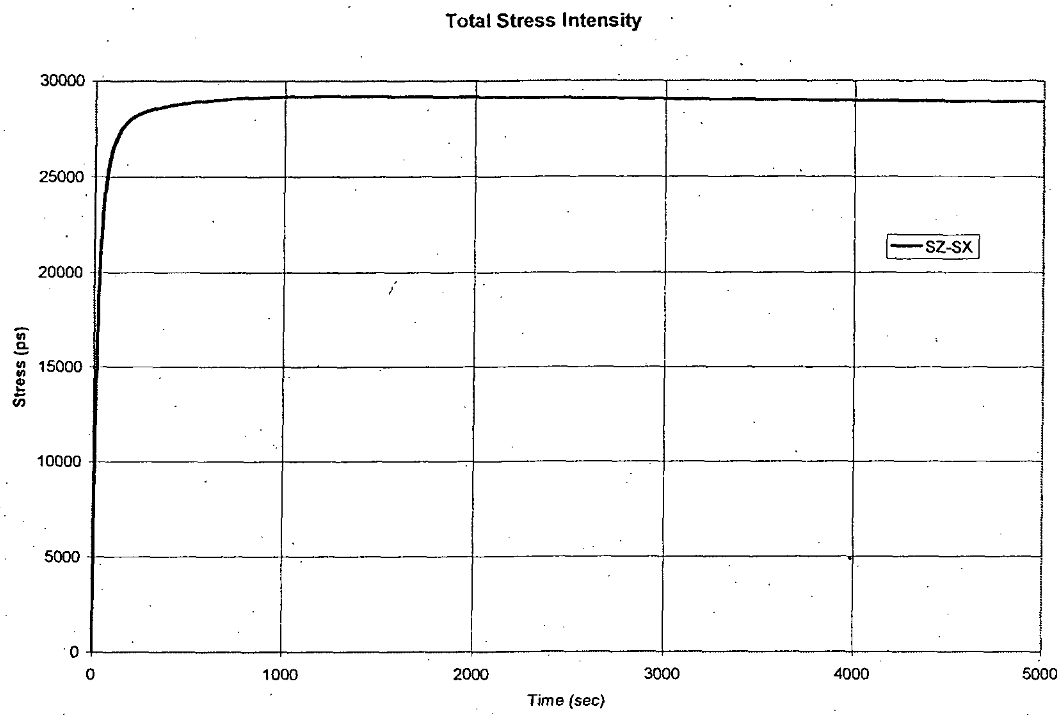



**Figure 20: Blend Radius Total Stress History for 40% Flow**

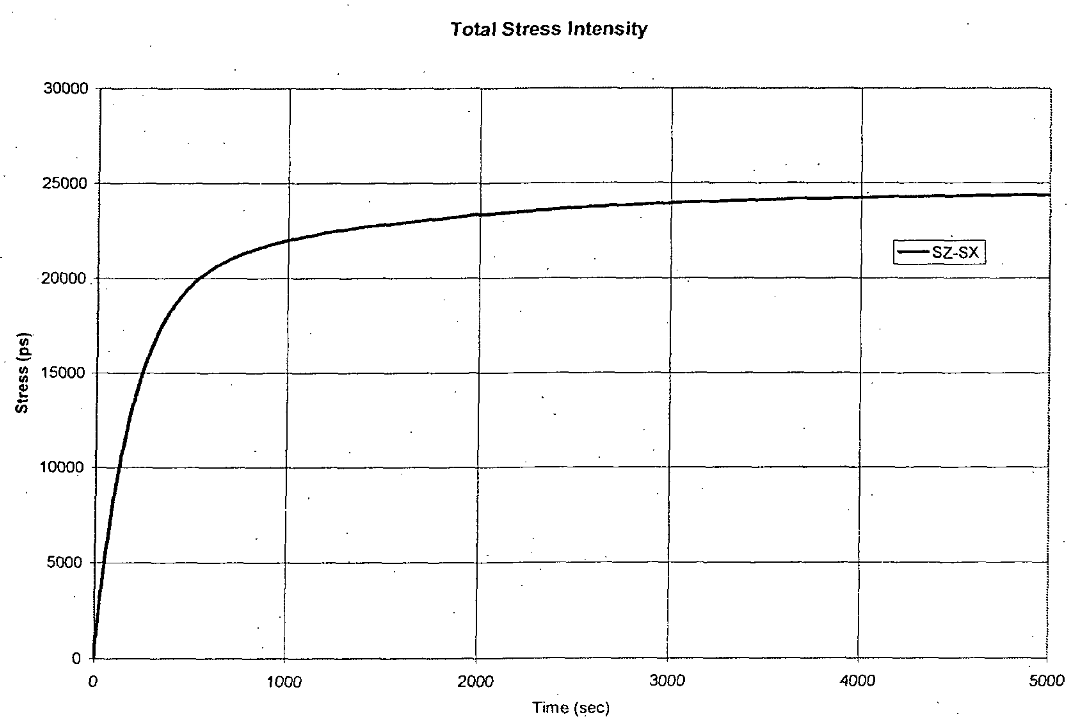



**Figure 21: Blend Radius Membrane Plus Bending Stress History for 40% Flow**

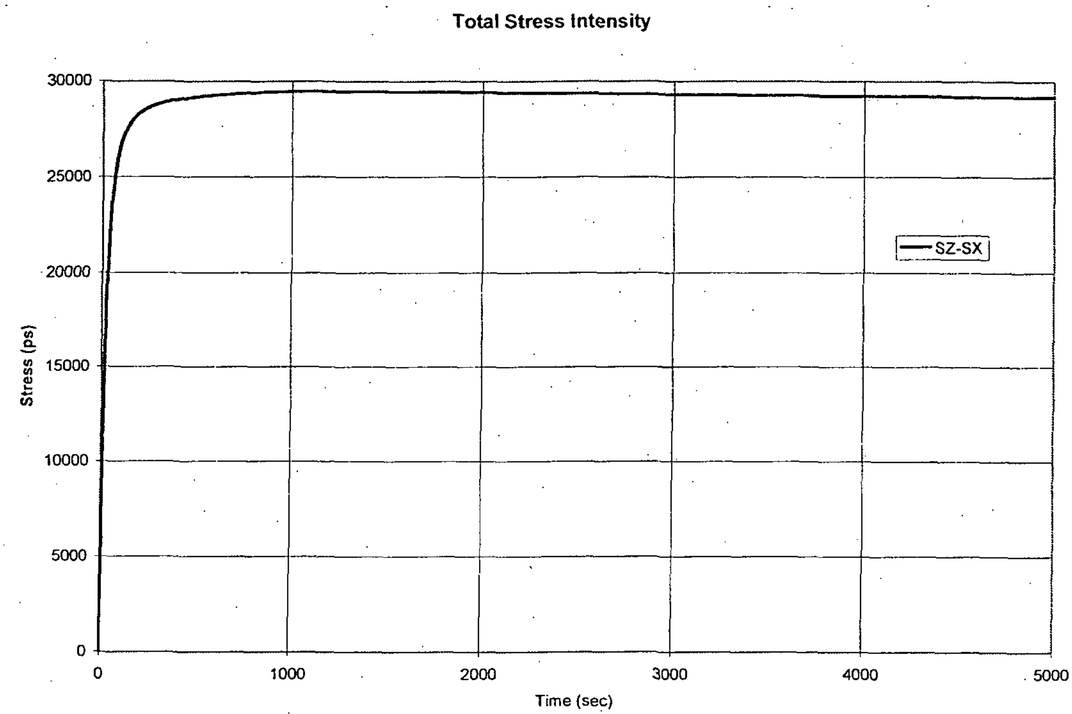



**Figure 22: Blend Radius Total Stress History for 25% Flow**

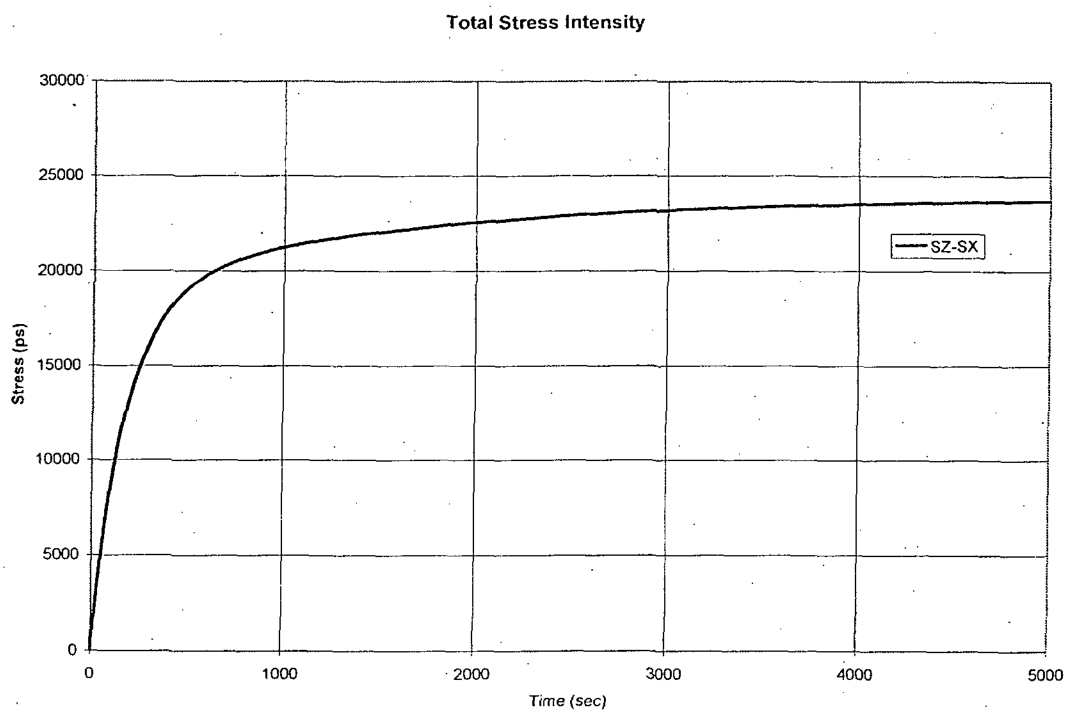



**Figure 23: Blend Radius Membrane Plus Bending Stress History for 25% Flow**

# APPENDIX A

# FINITE ELEMENT ANALYSIS FILES

| | | |
|---|---|---|
| FWP_VY.INP | Input File for Pressure Load | In Computer files |
| FWT_VY_100.INP | Input File for 100% Flow Thermal Analysis | In Computer files |
| FWS_VY_100.INP | Input File for 100% Flow Stress Analysis | In Computer files |
| FWT_VY_40.INP | Input File for 40% Flow Thermal Analysis | In Computer files |
| FWS_VY_40.INP | Input File for 40% Flow Stress Analysis | In Computer files |
| FWT_VY_25.INP | Input File for 25% Flow Thermal Analysis | In Computer files |
| FWS_VY_25.INP | Input File for 25% Flow Stress Analysis | In Computer files |
| PSE.OUT | Stress Output at Safe End with Pressure Load | In Computer files |
| PBLEND.OUT | Stress Output at Blend Radius with Pressure Load | In Computer files |
| PVESS.OUT | Stress Output at Vessel with Pressure Load | In Computer files |
| #FSE.OUT | Stress Output at Safe End | In Computer files |
| #FBLEND.OUT | Stress Output at Blend Radius | In Computer files |
| #FSE_INSIDE.RED | Stress Extracted at Safe End | In Computer files |
| #FBLEND_INSIDE.RED | Stress Extracted at Blend Radius | In Computer files |
| #FSE_T-Green.XLS | Green Function with Total Stress at Safe End | In Computer files |
| #FSE_M+B-Green.XLS | Green Function with Membrane plus Bending Stress at Safe End | In Computer files |
| #FBR_T-Green.XLS | Green Function with Total Stress at Blend Radius | In Computer files |
| #FBR_M+B-Green.XLS | Green Function with Membrane plus Bending Stress at Blend Radius | In Computer files |

Where # is H, M, L meaning 100%, 40%, and 25% flow rate, respectively.

| Structural Integrity Associates, Inc. CALCULATION PACKAGE | File No.: VY-16Q-302 NEC-JH_05 |
|---|---|
| | Project No.: VY-16Q |

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

| **CLIENT:** | **PLANT:** |
|---|---|
| Entergy Nuclear Operations, Inc. | Vermont Yankee Nuclear Power Station |

**CALCULATION TITLE:**

Fatigue Analysis of Feedwater Nozzle

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-34, Appendix: A1-A2 | Initial Issue | Terry J. Herrmann 7/18/2007 [signature] | Minghao Qin 7/12/2007 [signature] John F. Staples 7/12/2007 [signature] |

## Table of Contents



## List of Tables

## List of Figures

## 1.0 OBJECTIVE

The purpose of this calculation is to perform a revised fatigue analysis for the feedwater nozzle. Two locations will be analyzed for fatigue acceptance: the safe end (SA508 Class 1) and the blend radius (SA508 Class 2). Both locations are chosen based on the highest overall stress of the analysis performed in Reference [1]. A revised cumulative fatigue factor (CUF) will be determined for both locations, the nozzle forging and safe end, respectively. In the end, the environmental fatigue usage factors will be determined for both locations.

## 2.0 METHODOLOGY

In order to provide an overall approach and strategy for evaluating the feedwater nozzle, the Green's Function methodology and associated ASME Code stress and fatigue analyses are described in this section.

Revised stress and fatigue analyses are being performed for the feedwater nozzle using ASME Code, Section III methodology. These analyses are being performed to address license renewal requirements to evaluate environmental fatigue for this component in response to Generic Aging Lessons Learned (GALL) Report [11] requirements. The revised analysis is being performed to refine the fatigue usage so that an environmental fatigue factor can be determined for subsequent license renewal efforts.

Two sets of rules are available under ASME Code, Section III, Class 1 [10]. Subparagraph NB-3600 of Section III provides simplified rules for analysis of piping components, and NB-3200 allows for more detailed analysis of vessel components. The NB-3600 piping equations combine by absolute sum the stresses due to pressure, moments and through wall thermal gradient effects, regardless of where within the pipe cross-section the maximum value of the components of stress are located. By considering stress signs, affected surface (inside or outside) and azimuthal position, the stress ranges may be significantly reduced. In addition, NB-3600 assigns stress indices by which the stresses are multiplied to conservatively incorporate the effects of geometric discontinuities. In NB-3200, stress indices are not required, as the stresses are calculated by finite element analysis and consider applicable stress concentration factors. In addition, NB-3200 methodology accounts for the different locations within a component where stresses due to thermal, pressure or other mechanical loading are a maximum. This generally results in a net reduction of the stress ranges and consequently, in the calculated fatigue usage. Article 4 [12] methodology was originally used to evaluate the feedwater nozzle. NB-3200 methodology, which is the modern day equivalent to Article 4, is used in this analysis to be consistent with the Section III design bases for this component, as well as to allow a more detailed analysis of this component. In addition, several of the conservatisms originally used in the original feedwater nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve a more accurate CUF.

For the feedwater nozzle evaluated as a part of this work, stress histories will be computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's

Function integration scheme is similar in concept to the well-known Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [2]. A general outline is provided in this section.

The steps involved in the evaluation are as follows:

- Develop finite element model
- Develop heat transfer coefficients and boundary conditions for the finite element model
- Develop Green's Functions
- Develop thermal transient definitions
- Perform stress analysis to determine stresses for thermal transients
- Perform fatigue analysis

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 1 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 2. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 2. These five step changes produce the five successive stress responses in the second plot shown in Figure 2. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY reactor feedwater nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.

Fatigue calculations are performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology. Fatigue analysis is performed for the two limiting locations (one in the safe end and one in the nozzle forging, representing the two materials of the nozzle assembly) using the Green's Functions developed for thee three feedwater flow conditions and 60-year projected cycle counts.

Three Structural Integrity utility programs will be used to perform the fatigue analysis. The first two calculate stresses in response to transients. The transients analyzed are those described in the thermal cycle diagrams [3] for the feedwater nozzle. These transients are shown in Figures 4 – 20. The temperatures and pressures for these transients have been modified to account for power uprate [4]. The power uprate pressures and temperatures were used for this analysis. The last program calculates fatigue based on the stress output. The three programs are STRESS.EXE, P-V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys, as required by ASME Code fatigue evaluation methods. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III range-pair methodology. All three programs are explained in detail and have been independently verified for generic use in the Reference [5] calculation.

In order to perform the fatigue analysis, Green's Functions are developed using the finite element model. Then, input files with the necessary data are prepared and the three utility computer programs are run. The first program (STRESS.EXE) requires the following three input files:

- Input file "GREEN.DAT": This file contains the Green's Function for the location being evaluated. For each flow condition, two Green's Functions are determined: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function. This allows computation of total stress, as well as membrane plus bending stress, which is necessary to compute $K_e$ per ASME Code, Section III requirements.
- Input file "GREEN.CFG": This file is a configuration file containing parameters that define the Green's Function (i.e., number of points, temperature drop analyzed, etc.).
- Input file "TRANSNT.INP": This file contains the input transient history for all thermal transients to be analyzed for the location being evaluated.

Pressure and piping stress intensities are also included for each transient case, based on pressure stress results from finite element analysis and attached piping load calculations.
The second program (P-V.EXE) simply extracts only the maxima and minima stress (i.e., the peaks and valleys) from the stress histories generated by program STRESS.EXE.

The third program (FATIGUE.EXE) performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data consists of the output peak and valley history from program P-V.EXE and a configuration input file that provides ASME Code configuration data relevant to the fatigue analysis (i.e., $K_e$ parameters, $S_m$, Young's modulus, etc.). The output is the final fatigue calculation for the location being evaluated.

The Green's Function methodology described above uses standard industry stress and fatigue analysis practices, and is the same as the methodology used in typical stress reports. Special approval for the use of this methodology is therefore not required.

## 3.0 ANALYSIS

The fatigue analysis involves the preparing of input files for, and running of three programs verified and described in Reference [5]. The programs STRESS.EXE and P-V.EXE are run together through the use of a batch file. The program FATIGUE.EXE is run after processing the output from P_V.EXE. The steps associated with this process are described in the following sub-sections.

### 3.1 Transient Definitions (for program STRESS.EXE)

The program STRESS.EXE requires the following three input files for analyzing an individual transient:

- Green.dat. There are 12 stress history functions obtained from Reference [1]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. Both of the blend radius and the safe end have two stress history functions for each of the following flow conditions; 100%, 40%, and 25% flow..
- Green.cfg is configured as described in Reference [5].
- Transnt.inp. These files are created to represent the transients shown on the thermal cycle diagrams and redefined by power uprate. Note that transients 12, 13, and 15 are nearly identical on the thermal cycle diagram [3] and the results from running transient 12 will be used for all three transients. Transient 16, 17 and 18 will not be considered since there is no temperature change. Tables 1 and 2 show the thermal history used to represent each transient. Based upon the thermal cycle diagram for the feedwater nozzle [3], the transients are split into the following groups based upon flow rate:
    - Transients 3, 20, 20A, and 21-23 are run at 25% flow. Although Reference [3] shows 15% flow rate, it is conservative to use 25% flow rate for these transients. Transient 20, Hot Standby, is split up into two parts. The first portion is "Heatup portion" and the second portion is "Feedwater Injection portion" that are defined from Reference [3].
    - Transient 11 is run at 40% flow. Transient 11 starts off and ends at 100% flow.
    - Transients 5, 6, 9, 10, and 19 are run at 100% flow.
    - Transient 4 is run at 100% flow only to obtain the last stress point. The remainder of the stress points for transient 4 is obtained from the 25% flow stress results. The results are pulled from the two flow case results based upon the flow rates defined in the thermal cycle diagram [3].
    - Transients 12, 13, 14 and 15 were run at 100% flow. Heat transfer coefficients were not re-calculated for the 1 minute intervals each of these transients is at 110% flow. The effect of this small flow rate increase for such a relatively short duration should be minor.
    - Transients 1, 2, 24, and 25 are set as no thermal stress due to very small temperature changes (70°F to 100°F) at these transients.

### 3.2 Peak and Valley Points of the Stress History (for program P-V.EXE)

The program P-V.exe is then run to extract the peaks and valleys from the STRESS.OUT file produced by the STRESS.EXE program. The only input required for this program is STRESS.OUT and it outputs all the peaks and valleys to P-V.OUT. Columns 2 through 5 of Tables 4 (for the blend radius) and 5 (for the safe end) show the final peak and valley output. The pressure for column 6 is then filled in using the thermal cycle diagrams. Pressure and piping loads have to be added to the peak and valley points to calculate the final stress values used for fatigue analysis.

### 3.3 Pressure Load

The pressure stress associated with a 1000 psi internal pressure was determined in Reference [1]. These values are as follows:

Pressure stress for the safe end:

- 8693 psi membrane plus bending stress intensity.
- 8891 psi total linearized stress intensity.

Pressure stress for the blend radius:

- 36653 psi membrane plus bending stress intensity.
- 37733 psi total linearized stress intensity.

These pressure stress values for each location were linearly scaled with pressure. The actual pressure for column 6 of Tables 4 and 5 is obtained from Tables 1 and 2. The scaled pressure stress values are shown in columns 7 and 8 of Tables 4 and 5.

The pressure stress is combined with the thermal and piping loads to calculate the final stress values used for fatigue analysis.

### 3.4 Attached Piping Loads

Additionally, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 3.

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first and second cut locations using the following equations:

For Cut I:
$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:
$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:
$$M_{xy} = \sqrt{(M_x)_1^2 + (M_y)_1^2}$$
$$F_{xy} = \sqrt{(F_x)_1^2 + (F_y)_1^2}$$

For Cut II:
$$M_{xy} = \sqrt{(M_x)_2^2 + (M_y)_2^2}$$
$$F_{xy} = \sqrt{(F_x)_2^2 + (F_y)_2^2}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, $P_M$, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$
$$(P_M)_\theta = \frac{Pa_N}{t_N}$$
$$(P_M)_R = -P$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

Because pressure was considered separately in this analysis, the equations used for Cut I are valid for Cut II.

where: $L_1$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.
$L_2$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.
$M_{xy}$ = The maximum bending moment in the xy plane.
$F_{yx}$ = The maximum shear force in the xy plane.
$N_z$ = The normal force per inch of circumference applied to the end of the nozzle in the z direction.
$q_N$ = The shear force per inch of circumference applied to the nozzle.
$R_N$ = The mid-wall nozzle radius.

Since the pressure was considered separately in this analysis, the equations can be simplified as follows:

$$(P_M)_z = \frac{Nz}{t_N}$$
$$(P_M)_\theta = 0$$
$$(P_M)_R = 0$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2(\tau_M)_{z\theta}$$
*or*
$$SI_{MAX} = 2\sqrt{\left(\frac{Nz}{2t_N}\right)^2 + (\tau_M)_{z\theta}^{\ 2}}$$

Per Reference [6], the feedwater nozzle piping loads are as follows:

$F_x$ = 3,000 lbs
$F_y$ = 15,000 lbs
$F_z$ = 3,200 lbs

$M_x$ = 28,000 ft-lb = 336,000 in-lb
$M_y$ = 13,000 ft-lb = 156,000 in-lb
$M_z$ = 40,000 ft-lb = 480,000 in-lb

The loads are applied at the connection of the piping and safe end. Therefore, the $L_1$ is equal to 12.0871 inches and the $L_2$ is equal to 27.572 inches. The calculations for the safe end and blend radius are shown in Table 3. The first cut location is the same as the Green's Function cross section per [1] at the safe end, and the second cut is from Node 645 (outside) to Node 501 (inside). The maximum stress intensities due to piping loads are 5707.97 psi at the safe end and 265.47 psi at the blend radius, respectively. The piping load sign is set as the same as the thermal stress sign.

These piping stress values are scaled assuming no stress occurs at an ambient temperature of 70°F and the full values are reached at reactor design temperature, 575°F. The scaled piping stress values are shown in columns 9 and 10 of Tables 4 and 5. Columns 11 and 12 of Tables 4 and 5 show the summation of all stresses for each thermal peak and valley stress point.

### 3.5 Fatigue Analysis (for program FATIGUE.EXE)

The number of cycles projected for the 60-year operating life is used for each transient [3]:

Column 13 in Tables 4 and 5 shows the number of cycles associated with each transient. The number of cycles for 60 years was obtained from Reference [3].

The program FATIGUE.EXE performs the "ASME Code style" peak event pairing required to calculate a fatigue usage value. The input data for FATIGUE.CFG is as follows:

| | Blend Radius | Safe End |
|---|---|---|
| Parameters *m* and *n* for Computing $K_e$ | 2.0 & 0.2 (low alloy steel) [10] | 3.0 & 0.2 (carbon steel) [10] |
| Design Stress Intensity Values, $S_m$ | 26700 psi [8] @ 600°F | 17800 psi [8] @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi [10] | $30.0 \times 10^6$ psi [10] |
| Elastic Modulus Used in Finite Element Model | $26.7 \times 10^6$ psi | $28.1 \times 10^6$ psi |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 1.34 [7, page 35 of S4] |

The results of the fatigue analyses are presented in Tables 6 and 7 for the blend radius and safe end for 60 years, respectively.

The results described are contained in EXCEL files *BRresults.xls* and *SEresults.xls*, which are contained in the computer files.

## 4.0 FATIGUE USAGE RESULTS

The blend radius cumulative usage factor (CUF) from system cycling is 0.0636 for 60 years. The safe end CUF is 0.1471 for 60 years.

## 5.0 ENVIRONMENTAL FATIGUE ANALYSIS

In the response to NRC request for additional information (RAI) 4.3-H-02, VYNPS states that they have conservatively assumed that fatigue cracks may be present in the clad. VYNPS manages this cracking by performing periodic inspections that were implemented in response to Generic Letters 80-095 and

81-11, and NUREG-0619. The inspection frequency is based on the calculated fatigue crack growth of a postulated flaw in the nozzle inner blend radius. The VYNPS fatigue crack growth calculation uses methods in compliance with GE BWR Owners Group Topical Report "Alternate BWR Feedwater Nozzle Inspection Requirements", GE-NE-523-A71-0594, Revision 1, August 1999 and the associated NRC Final Safety Evaluation (TAC No. MA6787) dated March 10, 2000. The NRC has reviewed and approved this approach to handling FW nozzle inner blend radius cracking (Letter D.H. Dorman (USNRC) to D.A. Reid (VYNPC), Subject: Evaluation of Request for Relief from NUREG-0619 for VYNPS dated 2/6/95, (TAC No. M88803)).

The analysis performed for the feedwater nozzle calculated fatigue in the blend radius base metal, not the clad. This is consistent with the VYNPS position stated in the response to RAI 4.3-H-02, and is also consistent with ASME Code methodology since cladding is structurally neglected in fatigue analyses, per ASME Code, Section III, NB-3122.3.

Per Reference [9], the dissolved Oxygen (DO) calculation shows the overall HWC availability is 47%. This means the time ratio under NWC (pre-HWC) is 53%.

For the safe end location, the environmental fatigue factors for post-HWC and pre-HWC are all 1.74 from Table 3 of Reference [9]. It results in an EAF adjusted CUF of 1.74 x 0.1471 = 0.2560 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 1.74.

For the blend radius location, the environmental fatigue factors for post-HWC and pre-HWC are 11.14 and 8.82 from Table 4 of Reference [9]. These results in an EAF adjusted CUF of (11.14 x 53% + 8.82 x 47%) x 0.0636 = 0.6392 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 10.0496.

## 6.0 REFERENCES


1. SI Calculation No. VY-16Q-301, Revision 0, "Feedwater Nozzle Stress History Development for Green Functions."
2. Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green's Functions," ASME PVP Conference, Chicago, 1986.
3. Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.
4. GE Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," SI File No. VY-05Q-236.
5. Structural Integrity Associates Calculation (Generic) No. SW-SPVF-01Q-301, Revision 0, "STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification."
6. GE Drawing No. 919D294, Revision 11, Sht. No. 7, "Reactor Vessel," SI File No. VY-05Q-241.
7. Chicago Bridge & Iron Company Contractor 9-6201, Revision 2, "Section S4, Stress Analysis Feedwater Nozzle Vermont Yankee Reactor Vessel," SI File No. VY-05Q-238.

8. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
9. SI Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell Bottom Head."
10. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III Subsection NB, 1998 Edition, 2000 Addenda.
11. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.
12. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection A, Article 4, 1965 Edition with Winter 1966 Addenda.

## Table 1: Blend Radius Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 1. Bolt-up | 0 | 70 | | 0 |
| 123 Cycles | 10 | 70 | 10 | 0 |
| 2. Design | 0 | 70 | | 0 |
| HYD Test | 1080 | 100 | 1080 | 0 |
| 120 Cycles | 1680 | 100 | 600 | 1100 |
| | 5280 | 100 | 3600 | 1100 |
| | 5880 | 100 | 600 | 50 |
| | 10880 | 100 | 5000 | 50 |
| 3. Startup | 0 | 100 | | 50 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 |
| LF_25 | 21164 | 549 | 5000 | 1010 |
| 4. Turbine Roll | 0 | 549 | | 1010 |
| and Increased to | 1 | 100 | 1 | 1010 |
| Rated | 1801 | 100 | 1800 | 1010 |
| Power | 1802 | 260 | 1 | 1010 |
| 300 cycles | 3602 | 392 | 1800 | 1010 |
| LF_25, HF_100 | 8602 | 392 | 5000 | 1010 |
| 5. Daily | 0 | 392 | | 1010 |
| Reduction | 900 | 310 | 900 | 1010 |
| 75% Power | 2700 | 310 | 1800 | 1010 |
| 10,000 Cycles | 3600 | 392 | 900 | 1010 |
| HF_100 | 8600 | 392 | 5000 | 1010 |
| 6. Weekly Reduct | 0 | 392 | | 1010 |
| 60% Power | 1800 | 280 | 1800 | 1010 |
| 2,000 Cycles | 3600 | 280 | 1800 | 1010 |
| HF_100 | 5400 | 392 | 1800 | 1010 |
| | 10400 | 392 | 5000 | 1010 |
| 9. Turbine | 0 | 392 | | 1010 |
| Trip at 25% | 1800 | 265 | 1800 | 1010 |
| Power | 1980 | 265 | 180 | 1010 |
| 10 Cycles | 2340 | 90 | 360 | 1010 |
| HF_100 | 2520 | 90 | 180 | 1010 |
| | 3420 | 265 | 900 | 1010 |
| | 3600 | 265 | 180 | 1010 |
| | 5400 | 392 | 1800 | 1010 |
| | 10400 | 392 | 5000 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 10. FW Heater | 0 | 392 | | 1010 |
| Bypass | 90 | 265 | 90 | 1010 |
| 70 Cycles | 1890 | 265 | 1800 | 1010 |
| HF_100 | 2070 | 392 | 180 | 1010 |
| | 7070 | 392 | 5000 | 1010 |
| 11. Loss of | 0 | 392 | | 1010 |
| FW Pumps | 1 | 565 | 1 | 1010 |
| 10 Cycles | 3.5 | 565 | 2.5 | 1190 |
| MF_40, HF_100 | 4.5 | 50 | 1 | 1185 |
| | 13.5 | 50 | 9 | 1135 |
| | 184.5 | 50 | 171 | 1135 |
| | 1564.5 | 440 | 1380 | 1135 |
| | 1565.5 | 565 | 1 | 1135 |
| | 2165.5 | 565 | 600 | 1135 |
| | 2166.5 | 50 | 1 | 1135 |
| | 2346.5 | 50 | 180 | 885 |
| | 5406.5 | 440 | 3060 | 1055 |
| | 5407.5 | 565 | 1 | 1055 |
| | 6727.5 | 565 | 1320 | 1135 |
| | 6728.5 | 50 | 1 | 1135 |
| | 7148.5 | 50 | 420 | 675 |
| | 7448.5 | 300 | 300 | 675 |
| | 11048.5 | 400 | 3600 | 232 |
| | 16411.5 | 549 | 5363 | 885 |
| | 16412.5 | 549 | 1 | 1010 |
| | 18212.5 | 549 | 1800 | 1010 |
| | 18213.5 | 100 | 1 | 1010 |
| | 20013.5 | 100 | 1800 | 1010 |
| | 20014.5 | 260 | 1 | 1010 |
| | 21814.5 | 392 | 1800 | 1010 |
| | 26814.5 | 392 | 5000 | 1010 |
| 12. Turbine | 0 | 392 | | 1010 |
| Generator Trip | 10 | 392 | *10* | 1135/1375[2] |
| 60 Cycles | 15 | 392 | *5* | 1135/1375[2] |
| 13. Reactor | 30 | 392 | 15 | 940 |
| Overpressure | 90 | 275 | 60 | 940 |
| 1 Cycles | 990 | 100 | 900 | 940 |
| 15. Other | 2790 | 100 | 1800 | 940 |
| SCRAMs | 2791 | 260 | 1 | 940 |
| 228 cycles | 3210 | 291 | 419 | 1010 |
| HF_100 | 4591 | 392 | 1381 | 1010 |
| | 9591 | 392 | 5000 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 14. SRV | 0 | 392 | | 1010 |
| Blowdown | 60 | 275 | 60 | 885 |
| 1 Cycles | 960 | 100 | 900 | 50 |
| HF_100 | 5960 | 100 | 5000 | 50 |
| 19. Reduction to 0% | 0 | 392 | | 1010 |
| Power 300 Cycles | 1800 | 265 | 1800 | 1010 |
| HF_100 | 6800 | 265 | 5000 | 1010 |
| 20. Hot Standby | 0 | 265 | | 1010 |
| (Heatup Portion) | 1 | 440 | 1 | 1010 |
| 300 Cycles | 3925 | 549 | 3924 | 1010 |
| LF_25 | 8925 | 549 | 5000 | 1010 |
| 20A. Hot Standby | 0 | 549 | | 1010 |
| (FW Injection Portion) | 1 | 100 | 1 | 1010 |
| 300 Cycles | 181 | 100 | 180 | 1010 |
| LF_25 | 241 | 290 | 60 | 1010 |
| | 451 | 549 | 210 | 1010 |
| | 5451 | 549 | 5000 | 1010 |
| 21-23. Shutdown | 0 | 549 | | 1010 |
| 300 Cycles | 6264 | 375 | 6264 | 50 |
| LF_25 | 6864 | 330 | 600 | 50 |
| | 15144 | 100 | 8280 | 50 |
| | 20144 | 100 | 5000 | 50 |
| 24. Hydrostatic | 0 | 100 | | 50 |
| Test | 600 | 100 | 600 | 1563 |
| 1 Cycles | 1200 | 100 | 600 | 1563 |
| | 1800 | 100 | 600 | 50 |
| | 2400 | 100 | 600 | 50 |
| 25. Unbolt | 0 | 100 | | 0 |
| 123 Cycles | 1080 | 70 | 1080 | 0 |
| | 6080 | 70 | 5000 | 0 |

*Note: 1. The indicated time or pressure was assumed.*
*2. 1375 psi is for Transient 13 only.*

## Table 2: Safe End Transient

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 1. Bolt-up | 0 | 70 | | 0 |
| 123 Cycles | 10 | 70 | 10 | 0 |
| 2. Design | 0 | 70 | | 0 |
| HYD Test | 1080 | 100 | 1080 | 0 |
| 120 Cycles | 1680 | 100 | 600 | 1100 |
| | 5280 | 100 | 3600 | 1100 |
| | 5880 | 100 | 600 | 50 |
| | 6380 | 100 | 500 | 50 |
| 3. Startup | 0 | 100 | | 50 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 |
| LF_25 | 16664 | 549 | 500 | 1010 |
| 4. Turbine Roll | 0 | 549 | | 1010 |
| and Increased to | 1 | 100 | 1 | 1010 |
| Rated | 1801 | 100 | 1800 | 1010 |
| Power | 1802 | 260 | 1 | 1010 |
| 300 cycles | 3602 | 392 | 1800 | 1010 |
| LF_25, HF_100 | 4102 | 392 | 500 | 1010 |
| 5. Daily | 0 | 392 | | 1010 |
| Reduction | 900 | 310 | 900 | 1010 |
| 75% Power | 2700 | 310 | 1800 | 1010 |
| 10,000 Cycles | 3600 | 392 | 900 | 1010 |
| HF_100 | 4100 | 392 | 500 | 1010 |
| 6. Weekly Reduct | 0 | 392 | | 1010 |
| 50% Power | 1800 | 280 | 1800 | 1010 |
| 2,000 Cycles | 3600 | 280 | 1800 | 1010 |
| HF_100 | 5400 | 392 | 1800 | 1010 |
| | 5900 | 392 | 500 | 1010 |
| 9. Turbine | 0 | 392 | | 1010 |
| Trip at 25% | 1800 | 265 | 1800 | 1010 |
| Power | 1980 | 265 | 180 | 1010 |
| 10 Cycles | 2340 | 90 | 360 | 1010 |
| HF_100 | 2520 | 90 | 180 | 1010 |
| | 3420 | 265 | 900 | 1010 |
| | 3600 | 265 | 180 | 1010 |
| | 5400 | 392 | 1800 | 1010 |
| | 5900 | 392 | 500 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 10. FW Heater | 0 | 392 | | 1010 |
| Bypass | 90 | 265 | 90 | 1010 |
| 70 Cycles | 1890 | 265 | 1800 | 1010 |
| HF_100 | 2070 | 392 | 180 | 1010 |
| | 2570 | 392 | 500 | 1010 |
| 11. Loss of | 0 | 392 | | 1010 |
| FW Pumps | 1 | 565 | 1 | 1010 |
| 10 Cycles | 3.5 | 565 | 2.5 | 1190 |
| MF_40, HF_100 | 4.5 | 50 | 1 | 1185 |
| | 13.5 | 50 | 9 | 1135 |
| | 184.5 | 50 | 171 | 1135 |
| | 1564.5 | 440 | 1380 | 1135 |
| | 1565.5 | 565 | 1 | 1135 |
| | 2165.5 | 565 | 600 | 1135 |
| | 2166.5 | 50 | 1 | 1135 |
| | 2346.5 | 50 | 180 | 885 |
| | 5406.5 | 440 | 3060 | 1055 |
| | 5407.5 | 565 | 1 | 1055 |
| | 6727.5 | 565 | 1320 | 1135 |
| | 6728.5 | 50 | 1 | 1135 |
| | 7148.5 | 50 | 420 | 675 |
| | 7448.5 | 300 | 300 | 675 |
| | 11048.5 | 400 | 3600 | 232 |
| | 16411.5 | 549 | 5363 | 885 |
| | 16412.5 | 549 | 1 | 1010 |
| | 18212.5 | 549 | 1800 | 1010 |
| | 18213.5 | 100 | 1 | 1010 |
| | 20013.5 | 100 | 1800 | 1010 |
| | 20014.5 | 260 | 1 | 1010 |
| | 21814.5 | 392 | 1800 | 1010 |
| | 22314.5 | 392 | 500 | 1010 |
| 12. Turbine | 0 | 392 | | 1010 |
| Generator Trip | 10 | 392 | *10* | 1135/1375[3] |
| 60 Cycles | 15 | 392 | *5* | 1135/1375[3] |
| 13. Reactor | 30 | 392 | 15 | 940 |
| Overpressure | 90 | 275 | 60 | 940 |
| 1 Cycles | 990 | 100 | 900 | 940 |
| 15. Other | 2790 | 100 | 1800 | 940 |
| SCRAMs | 2791 | 260 | 1 | 940 |
| 228 cycles | 3210 | 291 | 419 | 1010 |
| HF_100 | 4591 | 392 | 1381 | 1010 |
| | 5091 | 392 | 500 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 14. SRV | 0 | 392 | | 1010 |
| Blowdown | 60 | 275 | 60 | 885 |
| 1 Cycles | 960 | 100 | 900 | 50 |
| HF_100 | 1460 | 100 | 500 | 50 |
| 19. Reduction to 0% | 0 | 392 | | 1010 |
| Power 300 Cycles | 1800 | 265 | 1800 | 1010 |
| HF_100 | 2300 | 265 | 500 | 1010 |
| 20. Hot Standby | 0 | 265 | | 1010 |
| (Heatup Portion) | 1 | 440 | 1 | 1010 |
| 300 Cycles | 3925 | 549 | 3924 | 1010 |
| LF_25 | 4425 | 549 | 500 | 1010 |
| 20A. Hot Standby | 0 | 549 | | 1010 |
| (FW Injection Portion) | 1 | 100 | 1 | 1010 |
| 300 Cycles | 181 | 100 | 180 | 1010 |
| LF_25 | 241 | 290 | 60 | 1010 |
| | 451 | 549 | 210 | 1010 |
| | 951 | 549 | 500 | 1010 |
| 21-23. Shutdown | 0 | 549 | | 1010 |
| 300 Cycles | 6264 | 375 | 6264 | 50 |
| LF_25 | 6864 | 330 | 600 | 50 |
| | 15144 | 100 | 8280 | 50 |
| | 15644 | 100 | 500 | 50 |
| 24. Hydrostatic | 0 | 100 | | 50 |
| Test | 600 | 100 | 600 | 1563 |
| 1 Cycles | 1200 | 100 | 600 | 1563 |
| | 1800 | 100 | 600 | 50 |
| | 2400 | 100 | 600 | 50 |
| 25. Unbolt | 0 | 100 | | 0 |
| 123 Cycles | 1080 | 70 | 1080 | 0 |
| | 1580 | 70 | 500 | 0 |

*Note: 1. These transients are the same as in Table 1 with the exception of the 500 second steady state time increment that is used. The transients in Table 1 are plotted using a 5000 second steady state increment. The difference is due to the length of the Green's Function for the safe end which is shorter compared to the blend Radius.*
*2. The indicated time or pressure was assumed.*
*3. 1375 psi is for Transient 13 only.*

**Table 3: Maximum Piping Stress Intensity Calculations**

| Safe End External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 3.00 | kips |
| $F_y$ = | 15.00 | kips |
| $F_Z$ = | 3.20 | kips |
| $M_x$ = | 336.00 | in-kips |
| $M_y$ = | 156.00 | in-kips |
| $M_Z$ = | 480.00 | in-kips |
| OD= | 11.86 | in |
| ID= | 10.409 | in |
| $R_N$ = | 5.57 | in |
| L = | 12.09 | in |
| $t_N$ = | 0.72 | in |
| $(M_x)_1$ = | 154.69 | in-kips |
| $(M_y)_1$ = | 192.26 | in-kips |
| $M_{xy}$ = | 246.77 | in-kips |
| $F_{xy}$ = | 15.30 | kips |
| $N_Z$ = | 2.63 | kips/in |
| $q_N$ = | -1.59 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 3.63 | ksi |
| $\tau$ = | -2.20 | ksi |
| $SI_{max}$ = | 5.71 | ksi |
| $SI_{max}$ = | 5707.97 | psi |

| Blend Radius External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 3.00 | kips |
| $F_y$ = | 15.00 | kips |
| $F_Z$ = | 3.20 | kips |
| $M_x$ = | 336.00 | in-kips |
| $M_y$ = | 156.00 | in-kips |
| $M_Z$ = | 480.00 | in-kips |
| OD= | 22.67 | in |
| ID= | 10.750 | in |
| $R_N$ = | 8.35 | in |
| L = | 27.57 | in |
| $t_N$ = | 5.96 | in |
| $(M_x)_2$ = | -77.58 | in-kips |
| $(M_y)_2$ = | 238.72 | in-kips |
| $M_{xy}$ = | 251.01 | in-kips |
| $F_{xy}$ = | 15.30 | kips |
| $N_Z$ = | 1.21 | kips/in |
| $q_N$ = | -0.51 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 0.20 | ksi |
| $\tau$ = | -0.09 | ksi |
| $SI_{max}$ = | 0.27 | ksi |
| $SI_{max}$ = | 265.47 | psi |

Note: The locations for Cut I and Cut II were defined in Reference [1] for safe end and blend radius paths, respectively.

## Table 4: Blend Radius Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |
| | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 120 |
| 2 | 1680 | 0 | 0 | 100 | 1100 | 41506.3 | 40318.3 | 15.77042 | 15.77042 | 41522.07 | 40334.07 | 120 |
| | 10880 | 0 | 0 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 1902.42 | 1848.42 | 120 |
| | 0 | 29166 | 23676 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 31068.42 | 25524.42 | 300 |
| 3 | 16782.8 | -3577 | -3138 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34281.53 | 33629.73 | 300 |
| | 21164 | -3532 | -3138 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34326.53 | 33629.73 | 300 |
| | 0 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| 4 | 1801.9 | 29465 | 22266 | 244.004 | 1010 | 38110.33 | 37019.53 | 91.47053 | 91.47053 | 67666.80 | 59377.00 | 300 |
| | 8602 | 7720 | 6749 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43937.80 | 300 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10000 |
| 5 | 2229.8 | 13598 | 11941 | 311.002 | 1010 | 38110.33 | 37019.53 | 126.6901 | 126.6901 | 51835.02 | 49087.22 | 10000 |
| | 8600 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10000 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 2000 |
| 6 | 2820.3 | 15742 | 13892 | 280.691 | 1010 | 38110.33 | 37019.53 | 110.7562 | 110.7562 | 53963.09 | 51022.29 | 2000 |
| | 10400 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 2000 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10 |
| 9 | 2524 | 29006 | 23417 | 118.311 | 1010 | 38110.33 | 37019.53 | 25.39616 | 25.39616 | 67141.73 | 60461.93 | 10 |
| | 10400 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 70 |
| 10 | 1632.4 | 16828 | 14701 | 267.399 | 1010 | 38110.33 | 37019.53 | 103.7688 | 103.7688 | 55042.10 | 51824.30 | 70 |
| | 7070 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 70 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10 |
| | 3.5 | 6620 | 6632 | 565 | 1190 | 44902.27 | 43617.07 | 260.2119 | 260.2119 | 51782.48 | 50509.28 | 10 |
| | 4.5 | 6190 | 6608 | 50 | 1185 | 44713.61 | 43433.81 | 10.51361 | 10.51361 | 50914.12 | 50052.32 | 10 |
| | 194.5 | 31720 | 21067 | 109.348 | 1135 | 42826.96 | 41601.16 | 20.68448 | 20.68448 | 74567.64 | 62688.84 | 10 |
| | 2166.3 | -4761 | -1859 | 513.483 | 972 | 36676.48 | 35626.72 | -233.1304 | -233.1304 | 31682.35 | 33534.59 | 10 |
| 11 | 2362.5 | 31268 | 22070 | 102.255 | 1010 | 38110.33 | 37019.53 | 16.95583 | 16.95583 | 69395.29 | 59106.49 | 10 |
| | 6728.3 | -4913 | -3149 | 513.448 | 1010 | 38110.33 | 37019.53 | -233.112 | -233.112 | 32964.22 | 33637.42 | 10 |
| | 7149.9 | 32114 | 21472 | 83.333 | 1010 | 38110.33 | 37019.53 | 7.0089 | 7.0089 | 70231.34 | 58498.54 | 10 |
| | 18213.3 | -3565 | -3162 | 503.978 | 1010 | 38110.33 | 37019.53 | -228.1338 | -228.1338 | 34317.20 | 33629.40 | 10 |
| | 19122.6 | 29156 | 23083 | 100.048 | 1010 | 38110.33 | 37019.53 | 15.79565 | 15.79565 | 67282.13 | 60118.33 | 10 |
| | 26814.5 | 7720 | 6410 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43598.80 | 10 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 60 |
| | 10 | 7720 | 6752 | 392 | 1135 | 42826.96 | 41601.16 | 169.2692 | 169.2692 | 50716.22 | 48522.42 | 60 |
| 12 | 30 | 7720 | 6752 | 392 | 940 | 35469.02 | 34453.82 | 169.2692 | 169.2692 | 43358.29 | 41375.09 | 60 |
| | 2033.7 | 28648 | 25301 | 132.007 | 940 | 35469.02 | 34453.82 | 32.59588 | 32.59588 | 64149.62 | 59787.42 | 60 |
| | 9591 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 60 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 1 |
| | 10 | 7720 | 6752 | 392 | 1375 | 51882.88 | 50397.88 | 169.2692 | 169.2692 | 59772.14 | 57319.14 | 1 |
| 13 | 30 | 7720 | 6752 | 392 | 940 | 35469.02 | 34453.82 | 169.2692 | 169.2692 | 43358.29 | 41375.09 | 1 |
| | 2033.7 | 28648 | 25301 | 132.007 | 1010 | 38110.33 | 37019.53 | 32.59588 | 32.59588 | 66790.93 | 62353.13 | 1 |
| | 9591 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 1 |
| 14 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 1 |
| | 5960 | 28487 | 25650 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 30389.42 | 27498.42 | 1 |
| | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 228 |
| | 10 | 7720 | 6752 | 392 | 1135 | 42826.96 | 41601.16 | 169.2692 | 169.2692 | 50716.22 | 48522.42 | 228 |
| 15 | 30 | 7720 | 6752 | 392 | 940 | 35469.02 | 34453.82 | 169.2692 | 169.2692 | 43358.29 | 41375.09 | 228 |
| | 2033.7 | 28648 | 25301 | 132.007 | 1010 | 38110.33 | 37019.53 | 32.59588 | 32.59588 | 66790.93 | 62353.13 | 228 |
| | 9591 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 228 |
| 19 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 300 |
| | 6800 | 16752 | 14971 | 265 | 1010 | 38110.33 | 37019.53 | 102.5077 | 102.5077 | 54964.84 | 52093.04 | 300 |
| 20 | 0 | 17151 | 13815 | 265 | 1010 | 38110.33 | 37019.53 | 102.5077 | 102.5077 | 55363.84 | 50937.04 | 300 |
| | 8925 | -3531 | -3146 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34327.53 | 33621.73 | 300 |
| | 0 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| 20A | 183 | 28102 | 12153 | 233 | 1010 | 38110.33 | 37019.53 | 85.68595 | 85.68595 | 66298.02 | 49258.22 | 300 |
| | 5451 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| 21-23 | 0 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| | 20144 | 29168 | 23656 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 31070.42 | 25504.42 | 300 |
| | 0 | 0 | 0 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 1902.42 | 1848.42 | 1 |
| 24 | 600 | 0 | 0 | 100 | 1563 | 58976.68 | 57288.64 | 15.77042 | 15.77042 | 58992.45 | 57304.41 | 1 |
| | 2400 | 0 | 0 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 1902.42 | 1848.42 | 1 |
| 25 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 15.77042 | 15.77042 | 15.77 | 15.77 | 123 |
| | 1580 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |

## Table 4: Blend Radius Stress Summary (Continue)

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 1.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 37733)/1000 [Table3, 1].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 36653)/1000 [Table 3, 1].
Column 9: Total external stress from calculation in Table 3, 265.47 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

## Table 5: Safe End Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |
| | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 120 |
| 2 | 1680 | 0 | 0 | 100 | 1100 | 9780.1 | 9562.3 | 339.0875 | 339.0875 | 10119.19 | 9901.39 | 120 |
| | 6960 | 0 | 0 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 783.64 | 773.74 | 120 |
| | 0 | -170 | -165 | 100 | 50 | 444.55 | 434.65 | -339.0875 | -339.0875 | -64.54 | -69.44 | 300 |
| 3 | 153.2 | -235 | -212 | 104.256 | 50 | 444.55 | 434.65 | -387.1927 | -387.1927 | -177.64 | -164.54 | 300 |
| | 16328.2 | 2 | 3 | 549 | 1010 | 8979.91 | 8779.93 | 5414.097 | 5414.097 | 14396.01 | 14197.03 | 300 |
| | 16664 | -1 | 0 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | 5414.097 | 3564.81 | 14194.03 | 300 |
| | 0 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| 4 | 3.6 | 44060 | 30988 | 100 | 1010 | 8979.91 | 8779.93 | 339.0875 | 339.0875 | 53379.00 | 40107.02 | 300 |
| | 1804.6 | -15889 | -11224 | 260.286 | 1010 | 8979.91 | 8779.93 | -2150.787 | -2150.787 | -9059.88 | -4594.86 | 300 |
| | 4102 | 21 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12640.45 | 12442.47 | 300 |
| | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10000 |
| | 900.1 | 244 | 189 | 310 | 1010 | 8979.91 | 8779.93 | 2712.7 | 2712.7 | 11936.61 | 11681.63 | 10000 |
| 5 | 3600 | -169 | -110 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5171.37 | 5030.39 | 10000 |
| | 3684.4 | 33 | 35 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12652.45 | 12454.47 | 10000 |
| | 4100 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10000 |
| | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 2000 |
| | 1800.1 | 196 | 159 | 280 | 1010 | 8979.91 | 8779.93 | 2373.612 | 2373.612 | 11549.52 | 11312.54 | 2000 |
| 6 | 5400.2 | -108 | -68 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5232.37 | 5072.39 | 2000 |
| | 5496.6 | 29 | 31 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12648.45 | 12450.47 | 2000 |
| | 5900 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 2000 |
| | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10 |
| | 97.3 | 180 | 137 | 385.135 | 1010 | 8979.91 | 8779.93 | 3561.945 | 3561.945 | 12721.85 | 12478.87 | 10 |
| | 1884.1 | 63 | 65 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11246.98 | 11049.00 | 10 |
| | 2059.2 | 1161 | 859 | 226.597 | 1010 | 8979.91 | 8779.93 | 1770.003 | 1770.003 | 11910.91 | 11408.93 | 10 |
| 9 | 3420.1 | -334 | -211 | 265 | 1010 | 8979.91 | 8779.93 | -2204.069 | -2204.069 | 6441.84 | 6364.86 | 10 |
| | 3490.2 | 97 | 98 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11280.98 | 11082.00 | 10 |
| | 5400.1 | -126 | -80 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5214.37 | 5060.39 | 10 |
| | 5470.6 | 31 | 32 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12650.45 | 12451.47 | 10 |
| | 5900 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10 |
| | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 70 |
| | 77.1 | 2308 | 3188 | 285.461 | 1010 | 8979.91 | 8779.93 | 2435.338 | 2435.338 | 13723.25 | 14403.27 | 70 |
| | 169.4 | -12 | -13 | 265 | 1010 | 8979.91 | 8779.93 | -2204.069 | -2204.069 | 6763.84 | 6562.86 | 70 |
| 10 | 1890 | 74 | 72 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11257.98 | 11056.00 | 70 |
| | 1968.2 | -1069 | -1511 | 322.362 | 1010 | 8979.91 | 8779.93 | -2852.427 | -2852.427 | 5058.48 | 4416.50 | 70 |
| | 2147.2 | 91 | 90 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12710.45 | 12509.47 | 70 |
| | 2570 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 70 |
| | 0 | -29 | -27 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5311.37 | 5113.39 | 10 |
| | 2.9 | -20317 | -13859 | 565 | 1147 | 10197.98 | 9970.871 | -5594.944 | -5594.944 | -15713.97 | -9483.07 | 10 |
| | 6.8 | 42852 | 29563 | 565 | 1172 | 10420.25 | 10188.2 | 5594.944 | 5594.944 | 58867.20 | 45346.14 | 10 |
| | 1567.4 | -15216 | -10526 | 565 | 1135 | 10091.29 | 9866.555 | -5594.944 | -5594.944 | -10719.66 | -6254.39 | 10 |
| | 2168.4 | 60377 | 41773 | 50 | 1134 | 10082.39 | 9857.862 | -226.0583 | -226.0583 | 70233.34 | 51404.80 | 10 |
| 11 | 5409.4 | -14924 | -10329 | 565 | 1054 | 9371.114 | 9162.422 | -5594.944 | -5594.944 | -11147.83 | -6761.52 | 10 |
| | 6730.4 | 60377 | 41773 | 50 | 1133 | 10073.5 | 9849.169 | -226.0583 | -226.0583 | 70224.44 | 51396.11 | 10 |
| | 7243.2 | -1965 | -1434 | 128.917 | 675 | 6001.425 | 5867.775 | -665.9339 | -665.9339 | 3370.49 | 3767.84 | 10 |
| | 18215.4 | 52636 | 36417 | 100 | 1010 | 8979.91 | 8779.93 | 339.0875 | 339.0875 | 61955.00 | 45536.02 | 10 |
| | 20015.5 | -24511 | -16189 | 260.183 | 1010 | 8979.91 | 8779.93 | -2149.623 | -2149.623 | -17680.71 | -9558.69 | 10 |
| | 22314.5 | 22 | 23 | 392 | 937 | 8330.867 | 8145.341 | 3639.539 | 3639.539 | 11992.41 | 11807.88 | 10 |
| | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 60 |
| | 10 | 23 | 22 | 392 | 1135 | 10091.29 | 9866.555 | 3639.539 | 3639.539 | 13753.82 | 13528.09 | 60 |
| 12 | 30 | 23 | 22 | 392 | 940 | 8357.54 | 8171.42 | 3639.539 | 3639.539 | 12020.08 | 11832.96 | 60 |
| | 90 | 3174 | 4383 | 275 | 940 | 8357.54 | 8171.42 | 2317.098 | 2317.098 | 13848.64 | 14871.52 | 60 |
| | 2793.5 | -16189 | -24511 | 260.183 | 941 | 8366.431 | 8180.113 | -2149.623 | -2149.623 | -9972.19 | -18480.51 | 60 |
| | 5091 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 60 |
| | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 1 |
| | 10 | 23 | 22 | 392 | 1375 | 12225.13 | 11952.88 | 3639.539 | 3639.539 | 15887.66 | 15614.41 | 1 |
| 13 | 30 | 23 | 22 | 392 | 940 | 8357.54 | 8171.42 | 3639.539 | 3639.539 | 12020.08 | 11832.96 | 1 |
| | 90 | 3174 | 4383 | 275 | 940 | 8357.54 | 8171.42 | 2317.098 | 2317.098 | 13848.64 | 14871.52 | 1 |
| | 2793.5 | -16189 | -24511 | 260.183 | 941 | 8366.431 | 8180.113 | -2149.623 | -2149.623 | -9972.19 | -18480.51 | 1 |
| | 5091 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 1 |

## Table 5: Safe End Stress Summary (continue)

| 1<br>Transient Number | 2<br>Time (s) | 3<br>Total Stress (psi) | 4<br>M+B Stress (psi) | 5<br>Temperature F | 6<br>Pressure (psig) | 7<br>Total Pressure Stress (psi) | 8<br>M+B Pressure Stress (psi) | 9<br>Total Piping Stress (psi) | 10<br>M+B Piping Stress (psi) | 11<br>Total Total Stress (psi) | 12<br>Total M+B Stress (psi) | 13<br>Number of Cycles (60 years) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 1 |
| | 60 | 4383 | 3174 | 275 | 885 | 7868.535 | 7693.305 | 2317.098 | 2317.098 | 14568.63 | 13184.40 | 1 |
| | 148 | 420 | 300 | 258.492 | 803 | 7139.473 | 6980.479 | 2130.509 | 2130.509 | 9689.98 | 9410.99 | 1 |
| | 960 | 544 | 424 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 1327.64 | 1197.74 | 1 |
| | 1460 | 137 | 139 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 920.64 | 912.74 | 1 |
| 15 | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 228 |
| | 10 | 23 | 22 | 392 | 1135 | 10091.29 | 9866.555 | 3639.539 | 3639.539 | 13753.82 | 13528.09 | 228 |
| | 30 | 23 | 22 | 392 | 940 | 8357.54 | 8171.42 | 3639.539 | 3639.539 | 12020.08 | 11832.96 | 228 |
| | 90 | 3174 | 4383 | 275 | 940 | 8357.54 | 8171.42 | 2317.098 | 2317.098 | 13848.64 | 14871.52 | 228 |
| | 2793.5 | -16189 | -24511 | 260.183 | 941 | 8366.431 | 8180.113 | -2149.623 | -2149.623 | -9972.19 | -18480.51 | 228 |
| | 5091 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 228 |
| 19 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 300 |
| | 1800 | 219 | 177 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11402.98 | 11161.00 | 300 |
| | 2300 | 72 | 74 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11255.98 | 11058.00 | 300 |
| 20 | 0 | -109 | -105 | 265 | 1010 | 8979.91 | 8779.93 | -2204.069 | -2204.069 | 6666.84 | 6470.86 | 300 |
| | 4 | -17288 | -12189 | 440.106 | 1010 | 8979.91 | 8779.93 | -4183.277 | -4183.277 | -12491.37 | -7592.35 | 300 |
| | 4425 | -2 | -1 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3563.81 | 3364.83 | 300 |
| 20A | 0 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| | 4 | 44060 | 30988 | 100 | 1010 | 8979.91 | 8779.93 | 339.0875 | 339.0875 | 53379.00 | 40107.02 | 300 |
| | 241 | -7461 | -5525 | 290.247 | 1010 | 8979.91 | 8779.93 | -2489.433 | -2489.433 | -970.52 | 765.50 | 300 |
| | 572 | 128 | 132 | 549 | 1010 | 8979.91 | 8779.93 | 5414.097 | 5414.097 | 14522.01 | 14326.03 | 300 |
| | 951 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| 21-23 | 0 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| | 138 | 62 | 45 | 545.167 | 989 | 8793.199 | 8597.377 | 5370.773 | 5370.773 | 14225.97 | 14013.15 | 300 |
| | 6264 | -5 | -20 | 374.97 | 50 | 444.55 | 434.65 | -3447.05 | -3447.05 | -3007.50 | -3032.40 | 300 |
| | 6390 | 104 | 59 | 366.172 | 50 | 444.55 | 434.65 | 3347.607 | 3347.607 | 3896.16 | 3841.26 | 300 |
| | 15644 | -173 | -167 | 100 | 50 | 444.55 | 434.65 | -339.0875 | -339.0875 | -67.54 | -71.44 | 300 |
| 24 | 0 | 0 | 0 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 783.64 | 773.74 | 1 |
| | 600 | 0 | 0 | 100 | 1563 | 13896.63 | 13587.16 | 339.0875 | 339.0875 | 14235.72 | 13926.25 | 1 |
| | 2400 | 0 | 0 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 783.64 | 773.74 | 1 |
| 25 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 339.0875 | 339.0875 | 339.09 | 339.09 | 123 |
| | 1580 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 2.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 8891)/1000 [Table 3, 1].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 8693)/1000 [Table3, 1].
Column 9: Total external stress from calculation in Table 3, 5707.97 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

## Table 6: Fatigue Results for Blend Radius (60 Years)

LOCATION = LOCATION NO. 2 -- BLEND RADIUS
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
m = 2.0
n = .2
Sm = 26700. psi
Ecurve = 3.000E+07 psi
Eanalysis = 2.670E+07 psi
Kt = 1.00

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 74568. | 0. | 74568. | 62689. | 1.000 | 41892. | 1.000E+01 | 7.488E+03 | .0013 |
| 70231. | 0. | 70231. | 58499. | 1.000 | 39456. | 1.000E+01 | 8.944E+03 | .0011 |
| 69395. | 0. | 69395. | 59106. | 1.000 | 38986. | 1.000E+01 | 9.268E+03 | .0011 |
| 67667. | 0. | 67667. | 59377. | 1.000 | 38015. | 9.300E+01 | 9.988E+03 | .0093 |
| 67667. | 0. | 67667. | 59377. | 1.000 | 38015. | 1.200E+02 | 9.988E+03 | .0120 |
| 67667. | 0. | 67667. | 59377. | 1.000 | 38015. | 8.700E+01 | 9.988E+03 | .0087 |
| 67282. | 0. | 67282. | 60118. | 1.000 | 37799. | 1.000E+01 | 1.018E+04 | .0010 |
| 67142. | 0. | 67142. | 60462. | 1.000 | 37720. | 1.000E+01 | 1.025E+04 | .0010 |
| 66791. | 0. | 66791. | 62353. | 1.000 | 37523. | 1.000E+00 | 1.044E+04 | .0001 |
| 66791. | 0. | 66791. | 62353. | 1.000 | 37523. | 1.500E+01 | 1.044E+04 | .0014 |
| 66791. | 16. | 66775. | 62337. | 1.000 | 37514. | 1.230E+02 | 1.045E+04 | .0118 |
| 66791. | 1902. | 64889. | 60505. | 1.000 | 36454. | 9.000E+01 | 1.152E+04 | .0078 |
| 66298. | 1902. | 64396. | 47410. | 1.000 | 36177. | 3.000E+01 | 1.182E+04 | .0025 |
| 66298. | 1902. | 64396. | 47410. | 1.000 | 36177. | 1.000E+00 | 1.182E+04 | .0001 |
| 66298. | 1902. | 64396. | 47410. | 1.000 | 36177. | 1.000E+00 | 1.182E+04 | .0001 |
| 66298. | 30389. | 35909. | 21760. | 1.000 | 20173. | 1.000E+00 | 9.581E+04 | .0000 |
| 66298. | 31068. | 35230. | 23734. | 1.000 | 19792. | 2.670E+02 | 1.038E+05 | .0026 |
| 64150. | 31068. | 33081. | 34263. | 1.000 | 18585. | 3.300E+01 | 1.303E+05 | .0003 |
| 64150. | 31070. | 33079. | 34283. | 1.000 | 18584. | 2.700E+01 | 1.303E+05 | .0002 |
| 59772. | 31070. | 28702. | 31815. | 1.000 | 16125. | 1.000E+00 | 2.222E+05 | .0000 |
| 58992. | 31070. | 27922. | 31800. | 1.000 | 15687. | 1.000E+00 | 2.519E+05 | .0000 |
| 55364. | 31070. | 24293. | 25433. | 1.000 | 13648. | 2.710E+02 | 4.757E+05 | .0006 |
| 55364. | 31682. | 23681. | 17402. | 1.000 | 13304. | 1.000E+01 | 5.703E+05 | .0000 |
| 55364. | 32964. | 22400. | 17300. | 1.000 | 12584. | 1.000E+01 | 9.414E+05 | .0000 |
| 55364. | 34282. | 21082. | 17307. | 1.000 | 11844. | 9.000E+00 | 1.912E+06 | .0000 |
| 55042. | 34282. | 20761. | 18195. | 1.000 | 11663. | 7.000E+01 | 2.231E+06 | .0000 |
| 54965. | 34282. | 20683. | 18463. | 1.000 | 11620. | 2.210E+02 | 2.310E+06 | .0001 |
| 54965. | 34317. | 20648. | 18464. | 1.000 | 11600. | 1.000E+01 | 2.348E+06 | .0000 |
| 54965. | 34327. | 20638. | 18463. | 1.000 | 11595. | 6.900E+01 | 2.358E+06 | .0000 |
| 53963. | 34327. | 19637. | 17393. | 1.000 | 11032. | 2.310E+02 | 3.757E+06 | .0001 |
| 53963. | 34328. | 19636. | 17401. | 1.000 | 11031. | 3.000E+02 | 3.758E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 41522. | 12441. | 10688. | 1.000 | 6989. | 1.200E+02 | 1.000E+20 | .0000 |
| 53963. | 43358. | 10605. | 9647. | 1.000 | 5958. | 6.000E+01 | 1.000E+20 | .0000 |
| 53963. | 43358. | 10605. | 9647. | 1.000 | 5958. | 1.000E+00 | 1.000E+20 | .0000 |
| 53963. | 43358. | 10605. | 9647. | 1.000 | 5958. | 8.800E+01 | 1.000E+20 | .0000 |
| 51835. | 43358. | 8477. | 7712. | 1.000 | 4762. | 1.400E+02 | 1.000E+20 | .0000 |
| 51835. | 46000. | 5835. | 5149. | 1.000 | 3278. | 3.000E+02 | 1.000E+20 | .0000 |
| 51835. | 46000. | 5835. | 5146. | 1.000 | 3278. | 9.560E+03 | 1.000E+20 | .0000 |
| 51782. | 46000. | 5783. | 6568. | 1.000 | 3249. | 1.000E+01 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50914. | 46000. | 4915. | 6112. | 1.000 | 2761. | 1.000E+01 | 1.000E+20 | .0000 |
| 50716. | 46000. | 4717. | 4582. | 1.000 | 2650. | 6.000E+01 | 1.000E+20 | .0000 |
| 50716. | 46000. | 4717. | 4582. | 1.000 | 2650. | 2.280E+02 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.320E+02 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+04 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 7.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 7.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 6.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 6.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.280E+02 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.280E+02 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | TOTAL USAGE FACTOR = | | .0636 |

## Table 7: Fatigue Results for Safe End (60 Years)

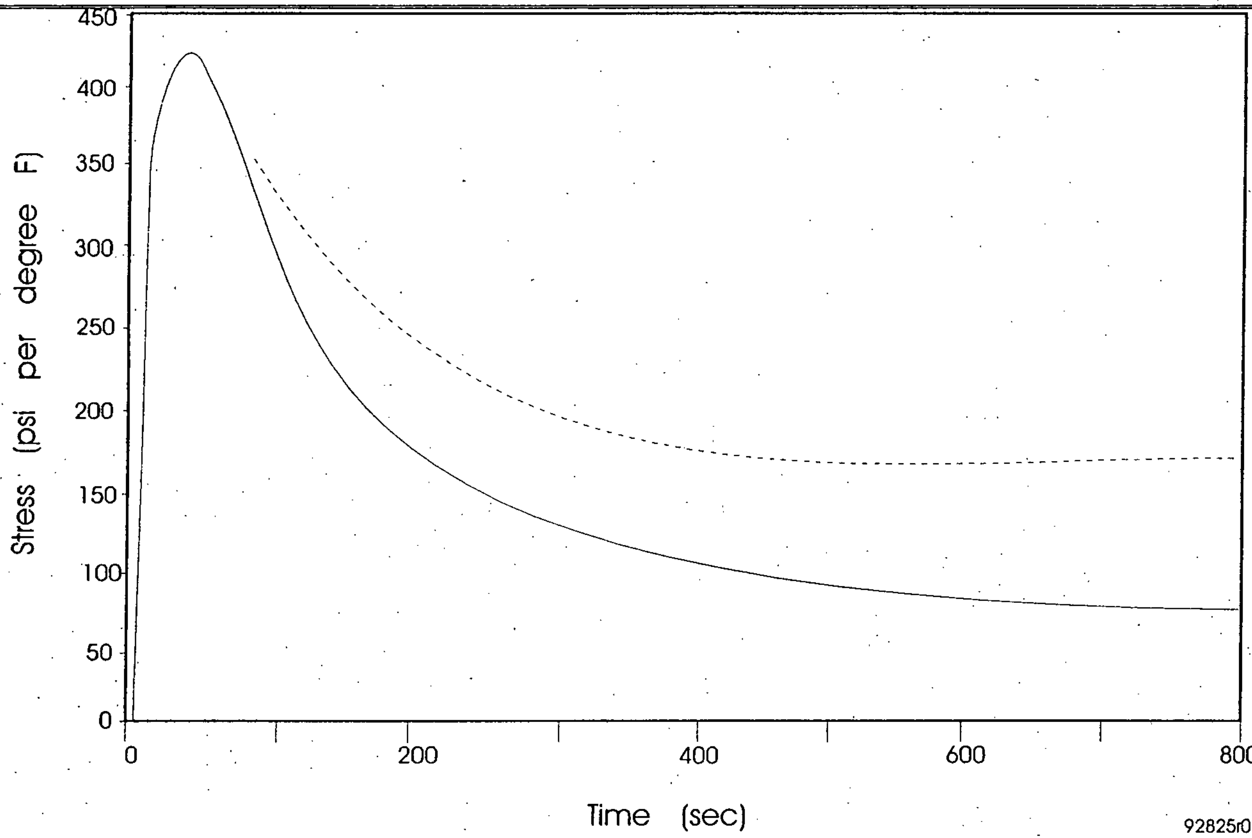
```
         LOCATION = LOCATION NO. 1 -- SAFE END
    FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
                m = 3.0
                n =  .2
               Sm = 17800. psi
           Ecurve = 3.000E+07 psi
        Eanalysis = 2.810E+07 psi
               Kt = 1.34
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 70233. | -17681. | 87914. | 60963. | 1.283 | 74422. | 1.000E+01 | 1.338E+03 | .0075 |
| 70224. | -15714. | 85938. | 60879. | 1.280 | 72869. | 1.000E+01 | 1.415E+03 | .0071 |
| 61955. | -12491. | 74446. | 53128. | 1.000 | 49383. | 1.000E+01 | 4.568E+03 | .0022 |
| 58867. | -12491. | 71359. | 52938. | 1.000 | 47700. | 1.000E+01 | 5.094E+03 | .0020 |
| 53379. | -12491. | 65870. | 47699. | 1.000 | 43819. | 2.800E+02 | 6.552E+03 | .0427 |
| 53379. | -11148. | 64527. | 46869. | 1.000 | 42951. | 1.000E+01 | 6.953E+03 | .0014 |
| 53379. | -10720. | 64099. | 46361. | 1.000 | 42631. | 1.000E+01 | 7.109E+03 | .0014 |
| 53379. | -9972. | 63351. | 58588. | 1.194 | 53087. | 6.000E+01 | 3.628E+03 | .0165 |
| 53379. | -9972. | 63351. | 58588. | 1.194 | 53087. | 1.000E+00 | 3.628E+03 | .0003 |
| 53379. | -9972. | 63351. | 58588. | 1.194 | 53087. | 2.280E+02 | 3.628E+03 | .0628 |
| 53379. | -9060. | 62439. | 44702. | 1.000 | 41444. | 1.100E+01 | 7.731E+03 | .0014 |
| 15888. | -9060. | 24948. | 20209. | 1.000 | 16985. | 1.000E+00 | 1.802E+05 | .0000 |
| 14569. | -9060. | 23629. | 17779. | 1.000 | 15840. | 1.000E+00 | 2.410E+05 | .0000 |
| 14522. | -9060. | 23582. | 18921. | 1.000 | 16022. | 2.870E+02 | 2.287E+05 | .0013 |
| 14522. | -3008. | 17530. | 17358. | 1.000 | 12508. | 1.300E+01 | 9.944E+05 | .0000 |
| 14396. | -3008. | 17404. | 17229. | 1.000 | 12417. | 2.870E+02 | 1.083E+06 | .0003 |
| 14396. | -971. | 15367. | 13432. | 1.000 | 10641. | 1.300E+01 | 5.165E+06 | .0000 |
| 14236. | -971. | 15206. | 13161. | 1.000 | 10506. | 1.000E+00 | 5.563E+06 | .0000 |
| 14226. | -971. | 15196. | 13248. | 1.000 | 10516. | 2.860E+02 | 5.531E+06 | .0001 |
| 14226. | -178. | 14404. | 14178. | 1.000 | 10262. | 1.400E+01 | 6.379E+06 | .0000 |
| 13849. | -178. | 14026. | 15036. | 1.000 | 10216. | 6.000E+01 | 6.547E+06 | .0000 |
| 13849. | -178. | 14026. | 15036. | 1.000 | 10216. | 1.000E+00 | 6.547E+06 | .0000 |
| 13849. | -178. | 14026. | 15036. | 1.000 | 10216. | 2.250E+02 | 6.547E+06 | .0000 |
| 13849. | -68. | 13916. | 14943. | 1.000 | 10141. | 3.000E+00 | 6.837E+06 | .0000 |
| 13754. | -68. | 13821. | 13600. | 1.000 | 9846. | 6.000E+01 | 8.117E+06 | .0000 |
| 13754. | -68. | 13821. | 13600. | 1.000 | 9846. | 2.280E+02 | 8.117E+06 | .0000 |
| 13723. | -68. | 13791. | 14475. | 1.000 | 9989. | 9.000E+00 | 7.465E+06 | .0000 |
| 13723. | -65. | 13788. | 14473. | 1.000 | 9987. | 6.100E+01 | 7.474E+06 | .0000 |
| 12722. | -65. | 12786. | 12548. | 1.000 | 9103. | 1.000E+01 | 1.729E+07 | .0000 |
| 12710. | -65. | 12775. | 12579. | 1.000 | 9102. | 7.000E+01 | 1.730E+07 | .0000 |
| 12652. | -65. | 12717. | 12524. | 1.000 | 9061. | 1.590E+02 | 1.833E+07 | .0000 |
| 12652. | 0. | 12652. | 12454. | 1.000 | 9014. | 1.230E+02 | 1.959E+07 | .0000 |
| 12652. | 0. | 12652. | 12454. | 1.000 | 9014. | 1.200E+02 | 1.959E+07 | .0000 |
| 12652. | 0. | 12652. | 12454. | 1.000 | 9014. | 1.230E+02 | 1.959E+07 | .0000 |
| 12652. | 339. | 12313. | 12115. | 1.000 | 8772. | 1.230E+02 | 2.905E+07 | .0000 |
| 12652. | 784. | 11869. | 11681. | 1.000 | 8456. | 1.200E+02 | 4.952E+07 | .0000 |
| 12652. | 784. | 11869. | 11681. | 1.000 | 8456. | 1.000E+00 | 4.952E+07 | .0000 |
| 12652. | 784. | 11869. | 11681. | 1.000 | 8456. | 1.000E+00 | 4.952E+07 | .0000 |
| 12652. | 921. | 11732. | 11542. | 1.000 | 8357. | 1.000E+00 | 5.462E+07 | .0000 |
| 12652. | 1328. | 11325. | 11257. | 1.000 | 8088. | 1.000E+00 | 7.100E+07 | .0000 |
| 12652. | 3370. | 9282. | 8687. | 1.000 | 6531. | 1.000E+01 | 1.000E+20 | .0000 |
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3564. | 9089. | 9090. | 1.000 | 6501. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3565. | 9088. | -1740. | 1.000 | 4535. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3896. | 8756. | 8613. | 1.000 | 6237. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 5058. | 7594. | 8038. | 1.000 | 5513. | 7.000E+01 | 1.000E+20 | .0000 |
| 12652. | 5171. | 7481. | 7424. | 1.000 | 5341. | 7.048E+03 | 1.000E+20 | .0000 |
| 12650. | 5171. | 7479. | 7421. | 1.000 | 5339. | 1.000E+01 | 1.000E+20 | .0000 |
| 12648. | 5171. | 7477. | 7420. | 1.000 | 5338. | 2.000E+03 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 7.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 7.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 6.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 6.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 1.000E+00 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 1.000E+00 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 2.280E+02 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 2.280E+02 | 1.000E+20 | .0000 |
| 12641. | 5171. | 7470. | 7412. | 1.000 | 5333. | 2.240E+02 | 1.000E+20 | .0000 |
| 12641. | 5214. | 7427. | 7382. | 1.000 | 5304. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 5232. | 7409. | 7370. | 1.000 | 5293. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 5311. | 7330. | 7329. | 1.000 | 5243. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 6442. | 6200. | 6078. | 1.000 | 4412. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 6667. | 5975. | 5972. | 1.000 | 4273. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 6764. | 5878. | 5880. | 1.000 | 4205. | 7.000E+01 | 1.000E+20 | .0000 |
| 12641. | 9690. | 2951. | 3031. | 1.000 | 2126. | 1.000E+00 | 1.000E+20 | .0000 |
| 12641. | 10119. | 2522. | 2541. | 1.000 | 1808. | 1.200E+02 | 1.000E+20 | .0000 |
| 12641. | 11247. | 1394. | 1393. | 1.000 | 997. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11256. | 1385. | 1384. | 1.000 | 991. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 11258. | 1383. | 1386. | 1.000 | 990. | 7.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11281. | 1360. | 1360. | 1.000 | 973. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11403. | 1238. | 1281. | 1.000 | 894. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 11550. | 1092. | 1130. | 1.000 | 788. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 11911. | 731. | 1034. | 1.000 | 578. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11937. | 705. | 761. | 1.000 | 514. | 4.555E+03 | 1.000E+20 | .0000 |
| 12641. | 11937. | 705. | 761. | 1.000 | 514. | 5.445E+03 | 1.000E+20 | .0000 |
| 12641. | 11992. | 649. | 635. | 1.000 | 462. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12020. | 621. | 610. | 1.000 | 442. | 6.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12020. | 621. | 610. | 1.000 | 442. | 1.000E+00 | 1.000E+20 | .0000 |
| 12641. | 12020. | 621. | 610. | 1.000 | 442. | 2.280E+02 | 1.000E+20 | .0000 |
| 12641. | 12640. | 1. | 0. | 1.000 | 1. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 3.956E+03 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |

=======

TOTAL USAGE FACTOR = .1471




Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

**Figure 1: Typical Green's Functions for Thermal Transient Stress**

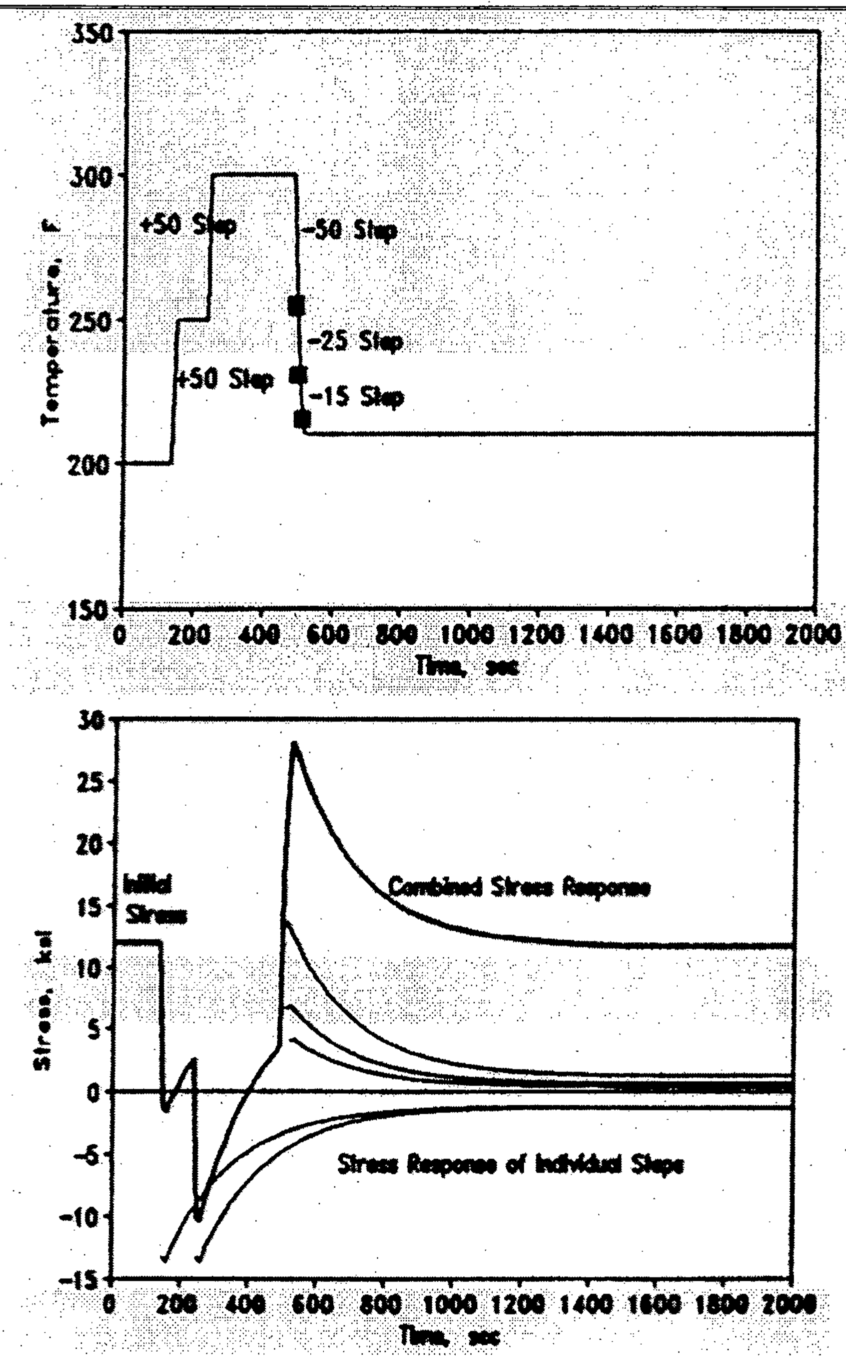



**Figure 2: Typical Stress Response Using Green's Functions**

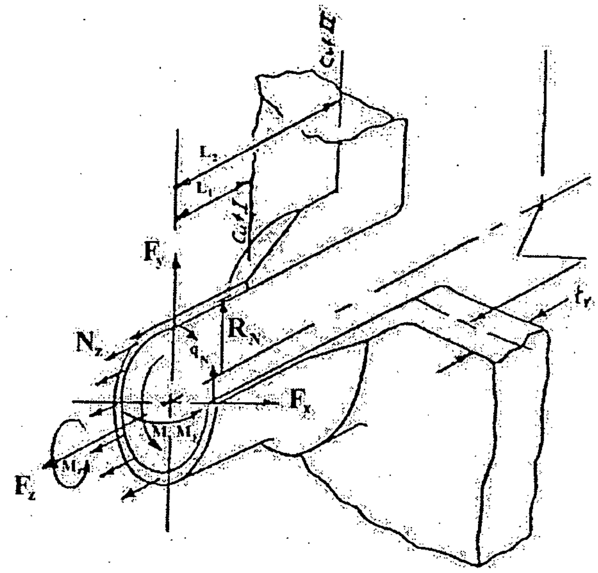



**Figure 3: External Forces and Moments on the Feedwater Nozzle**

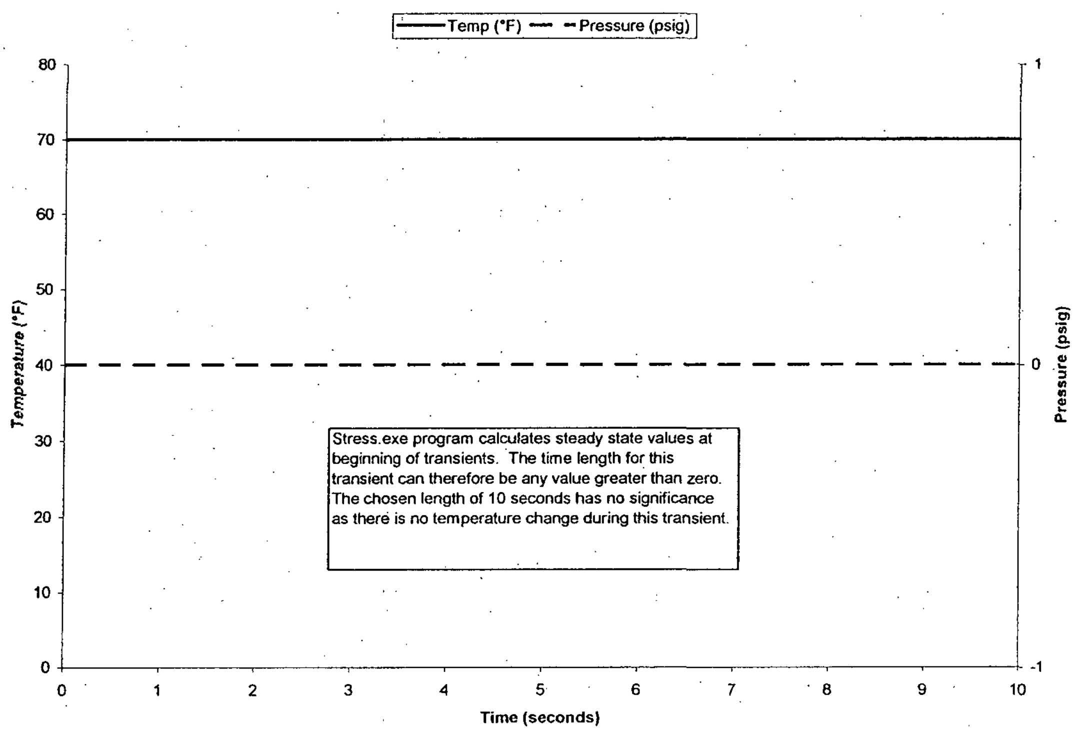



**Figure 4: Transient 1, Bolt-up**

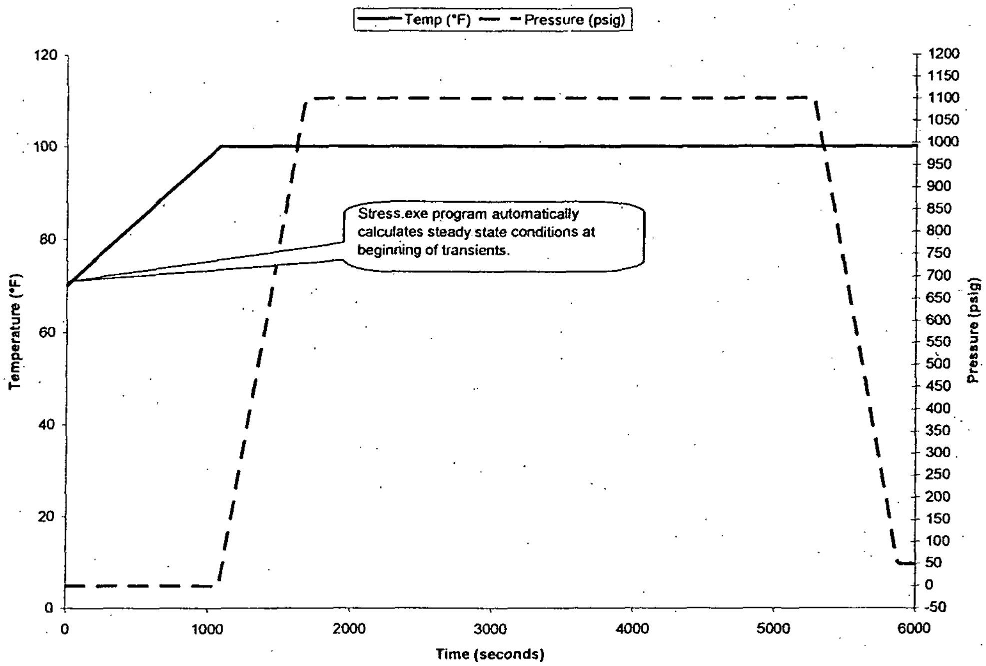



**Figure 5: Transient 2, Design HYD Test**

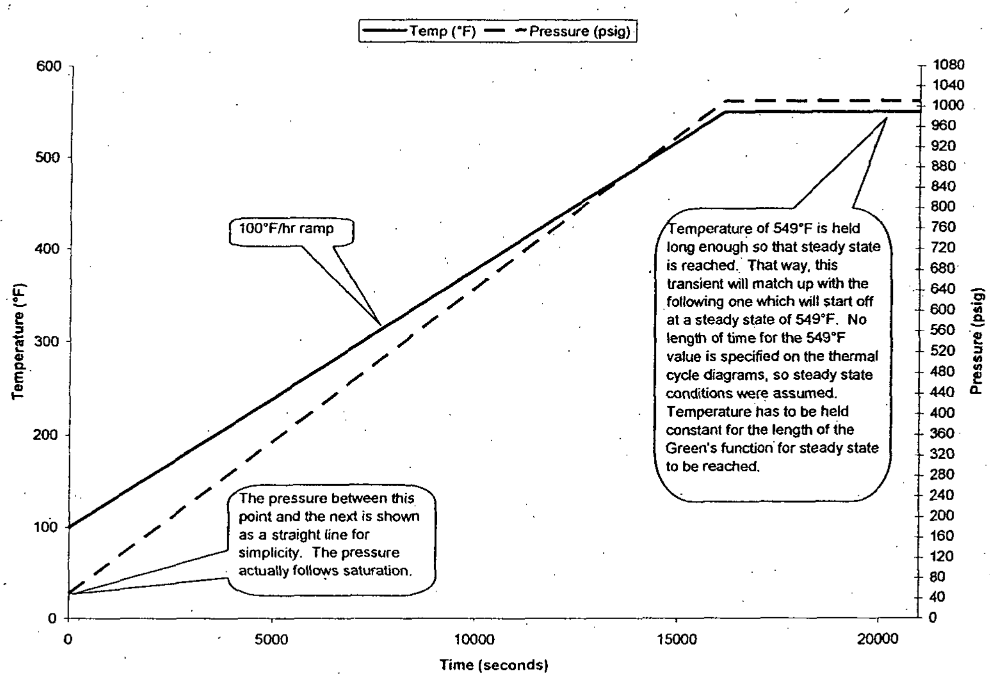



**Figure 6: Transient 3, Startup**

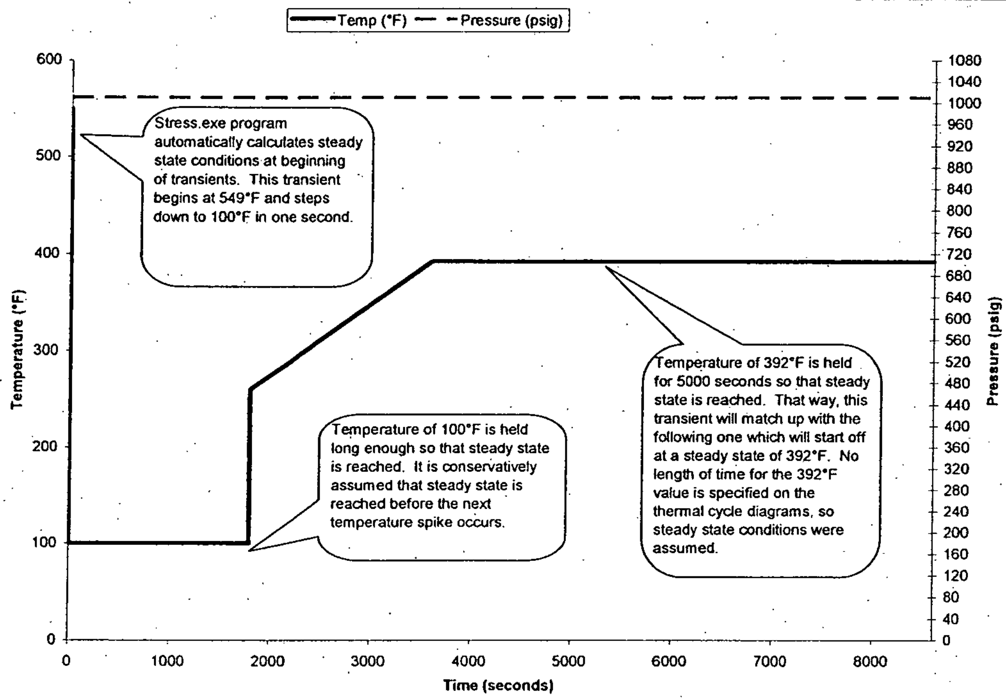



**Figure 7: Transient 4, Turbine Roll and Increased to Rated Power**

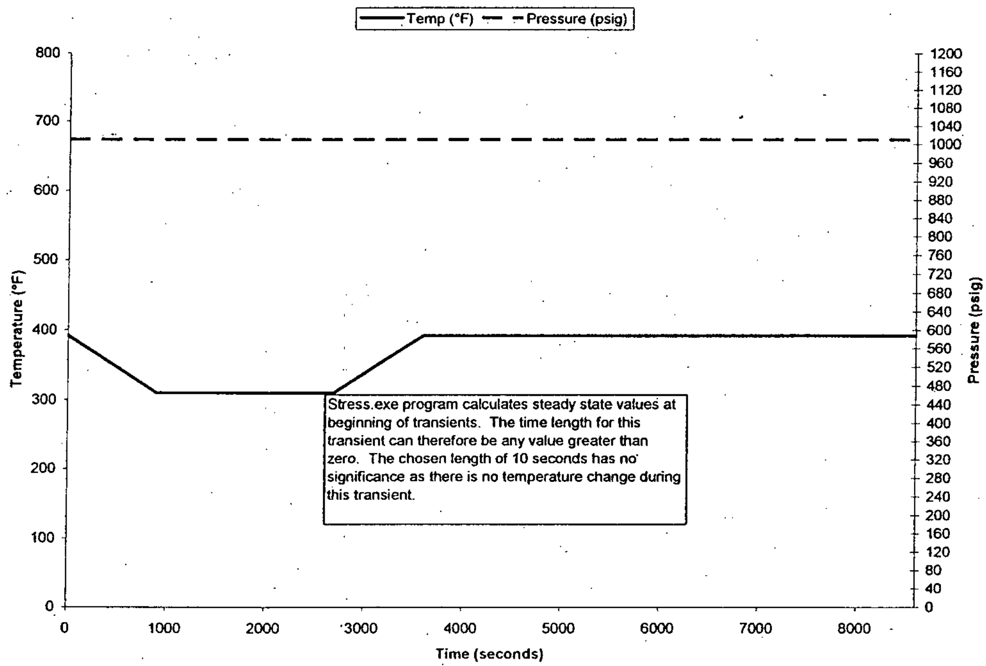



**Figure 8: Transient 5, Daily Reduction 75% Power**

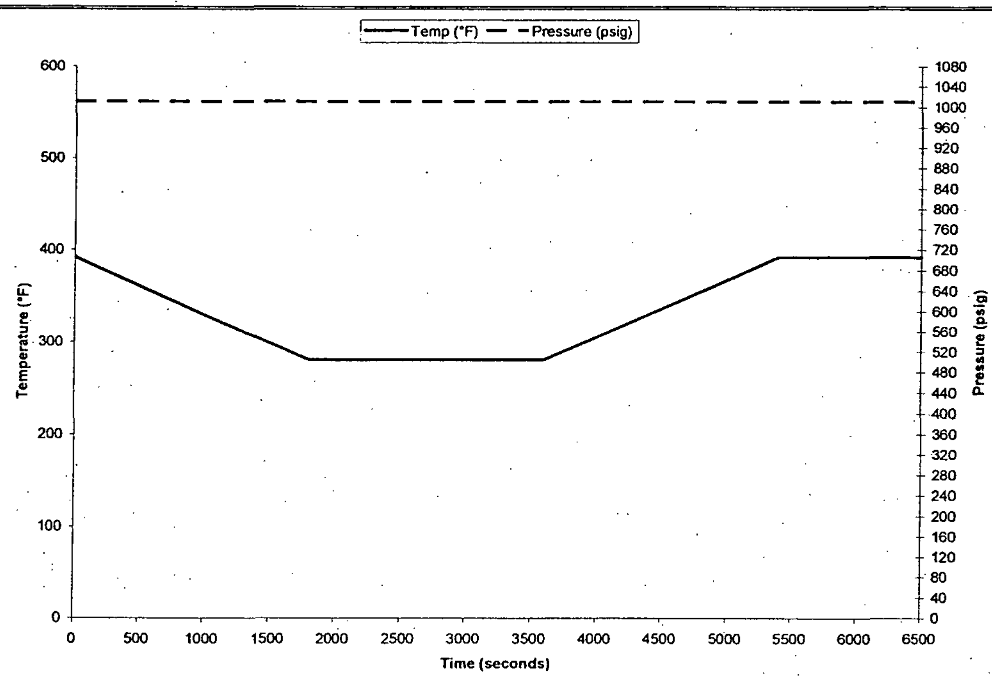



**Figure 9: Transient 6, Weekly Reduction 50% Power**

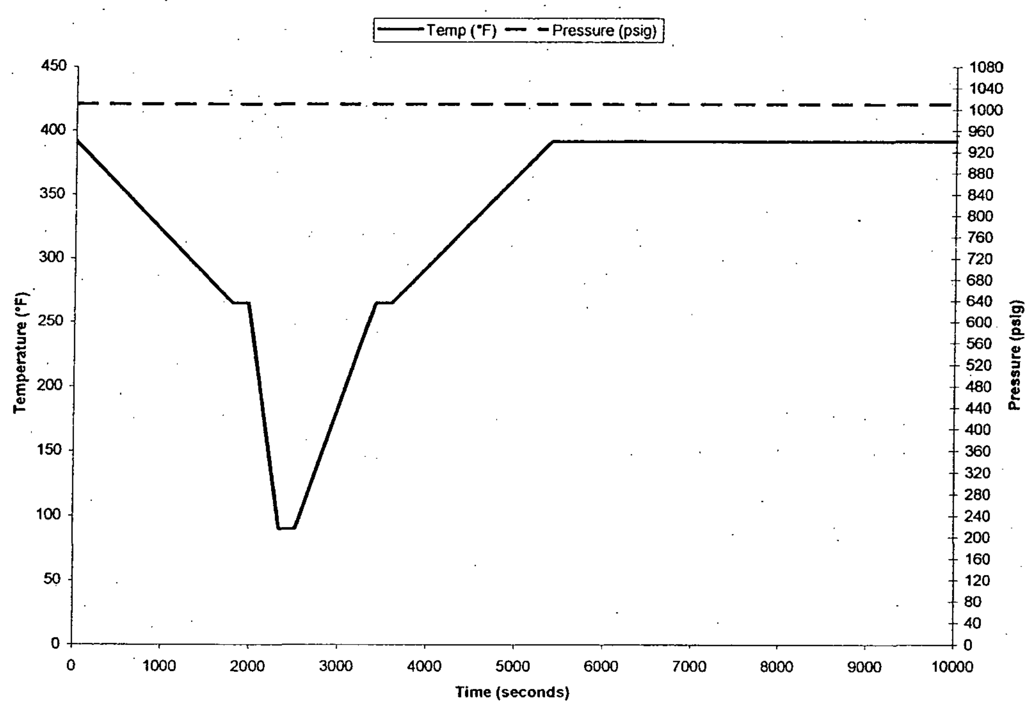



**Figure 10: Transient 9, Turbine Trip at 25% Power**

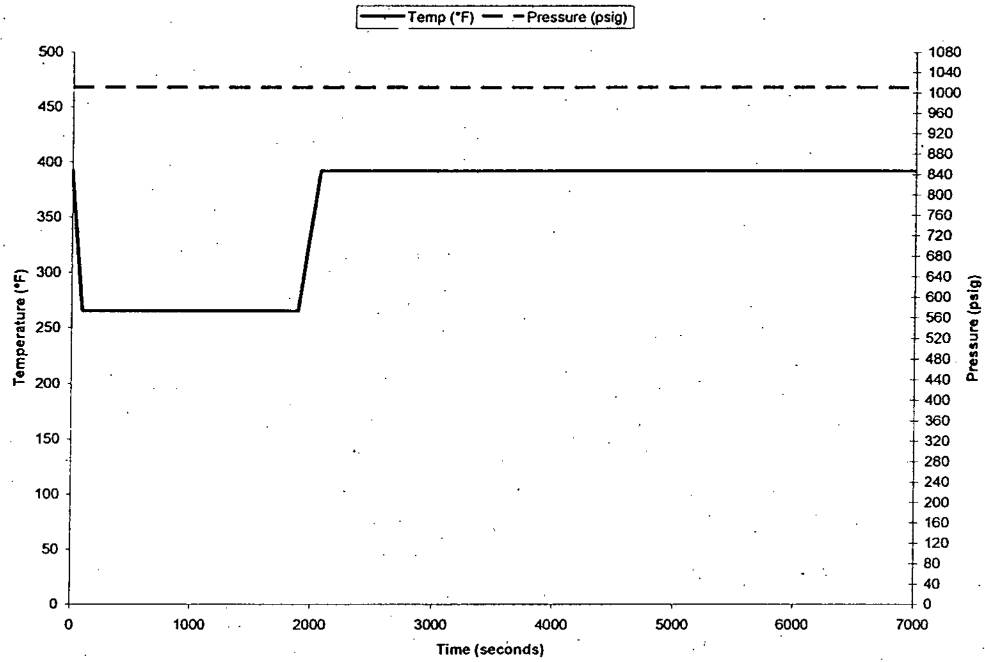



**Figure 11: Transient 10, Feedwater Bypass**

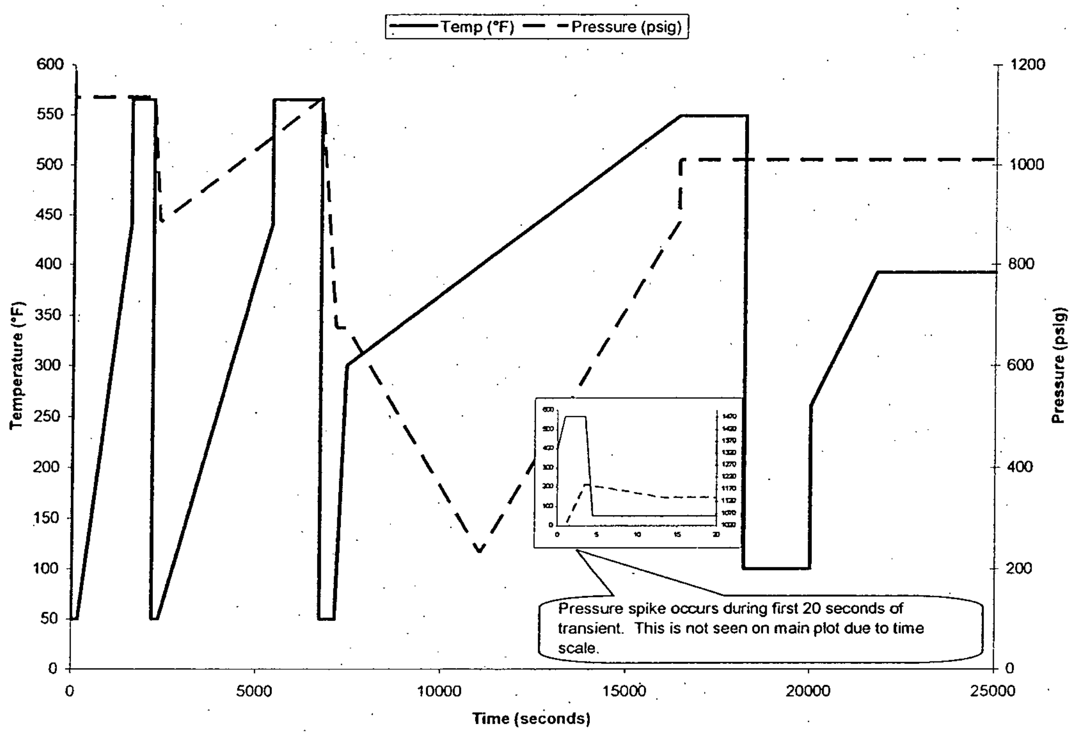



**Figure 12: Transient 11, Loss of Feedwater Pumps**

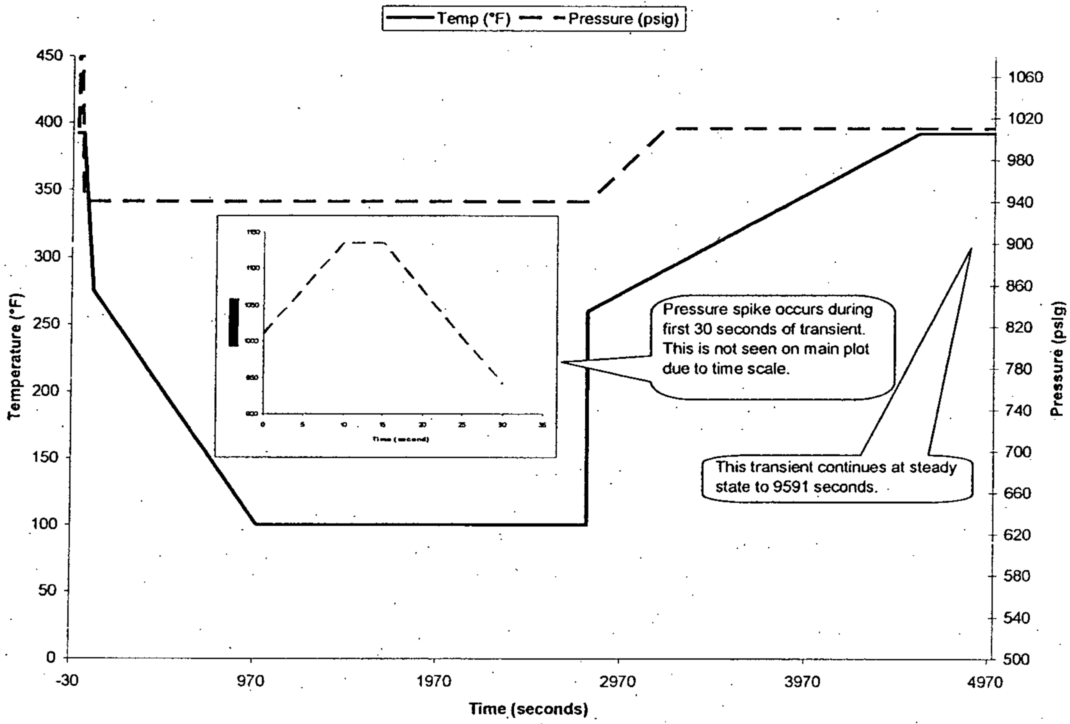



**Figure 13: Transient 12, Turbine Generator Trip**

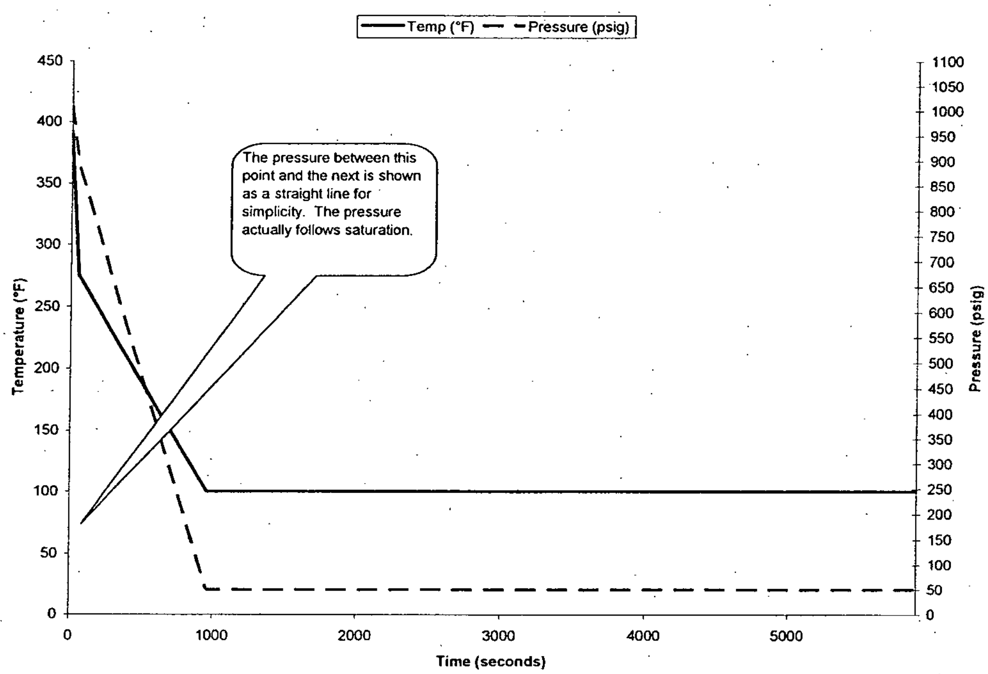



**Figure 14: Transient 14, SRV Blowdown**

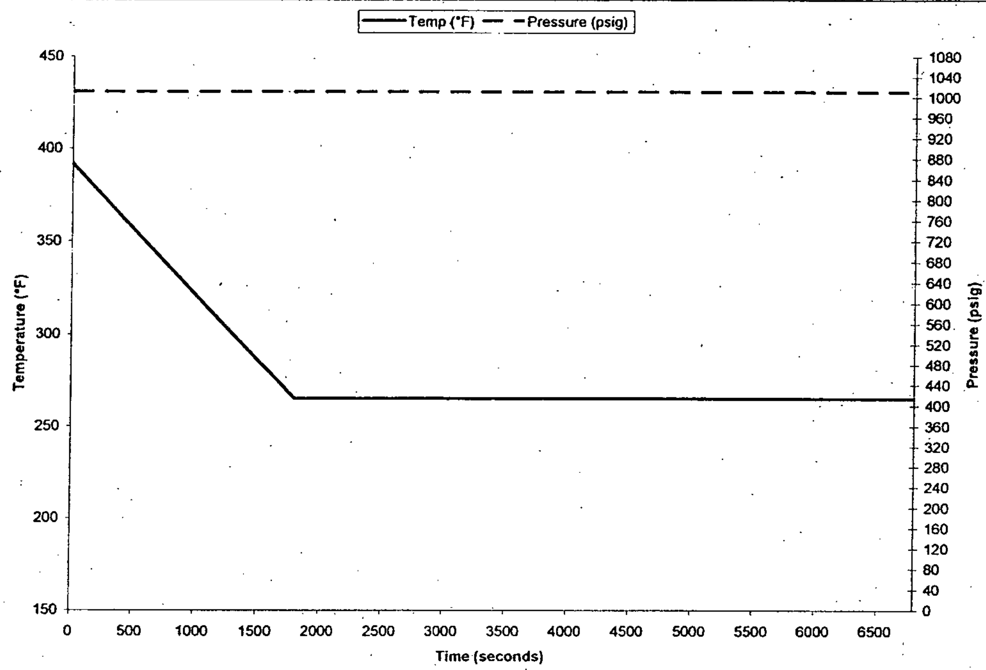



**Figure 15: Transient 19, Reduction to 0% Power**

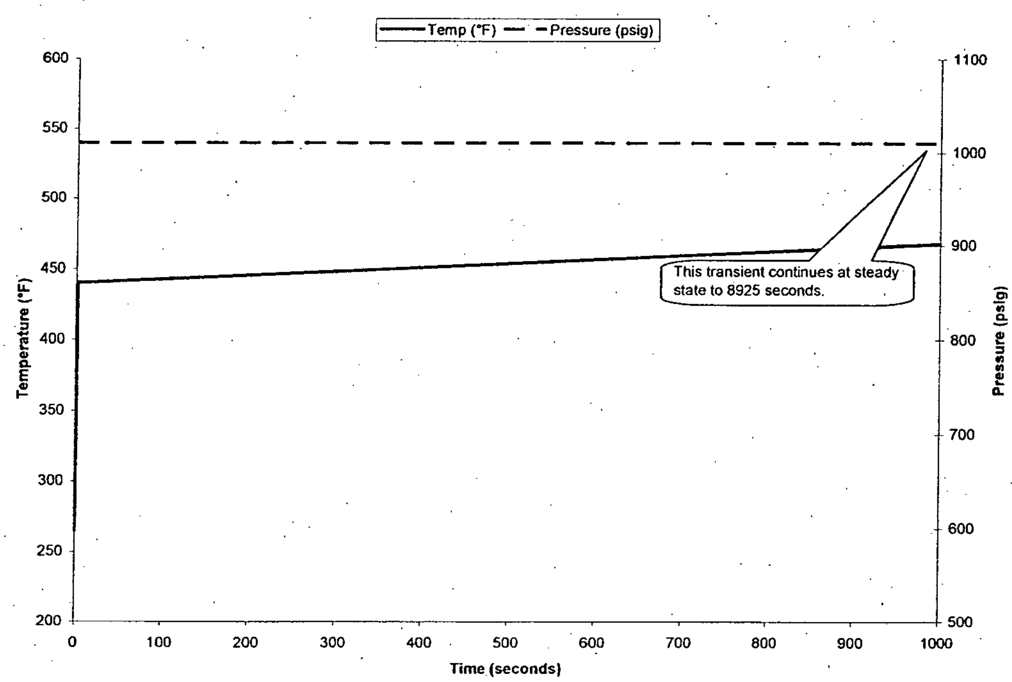



**Figure 16: Transient 20, Hot Standby (Heatup Portion)**

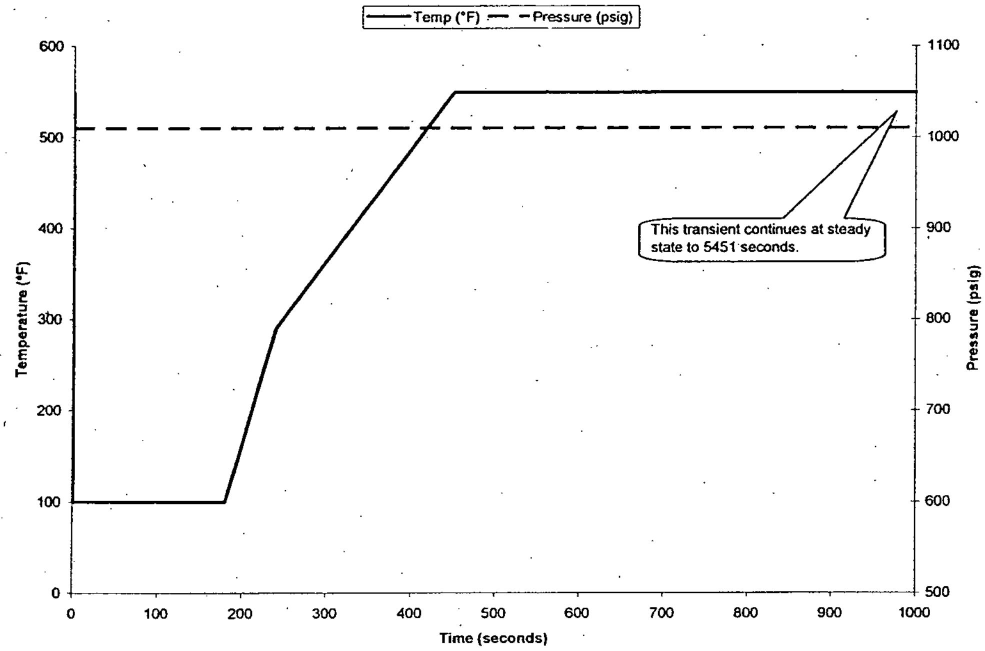



**Figure 17: Transient 20A, Hot Standby (Feedwater Injection Portion)**

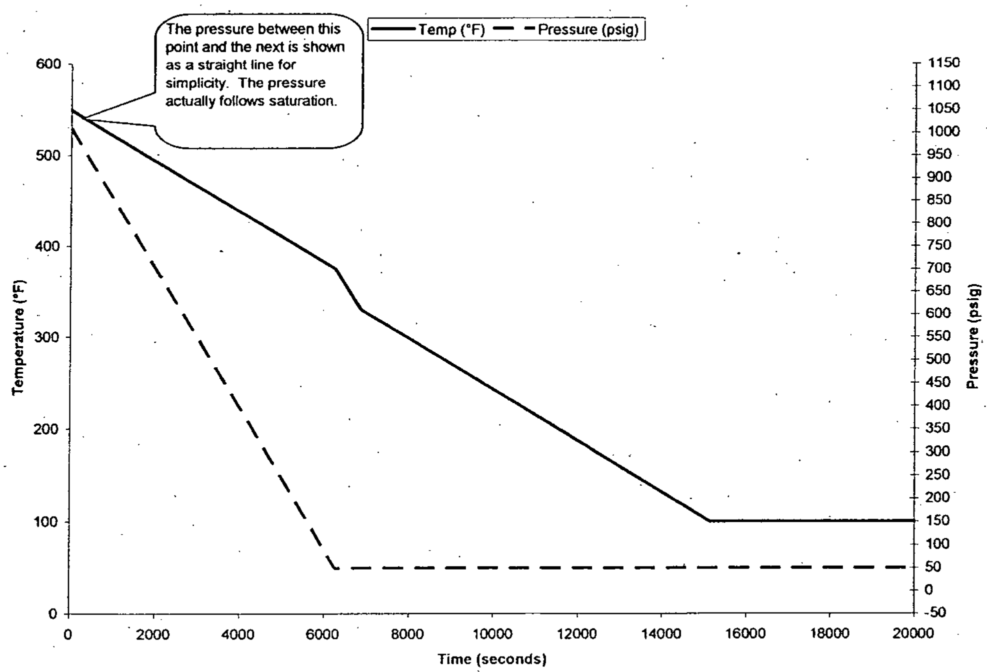



**Figure 18: Transient 21-23, Shutdown**

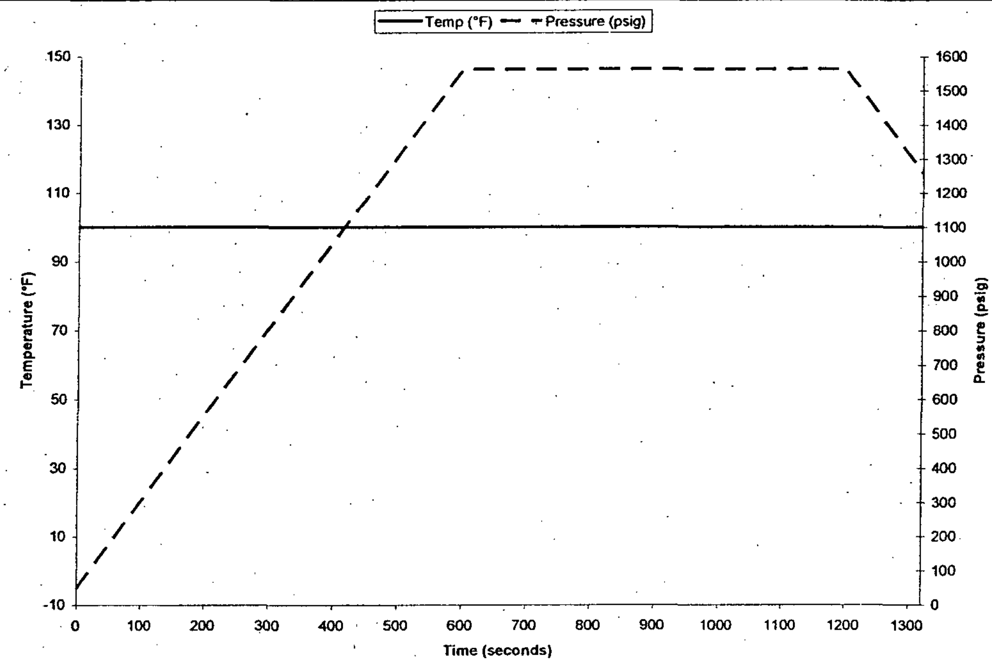



**Figure 19: Transient 24, Hydrostatic Test**

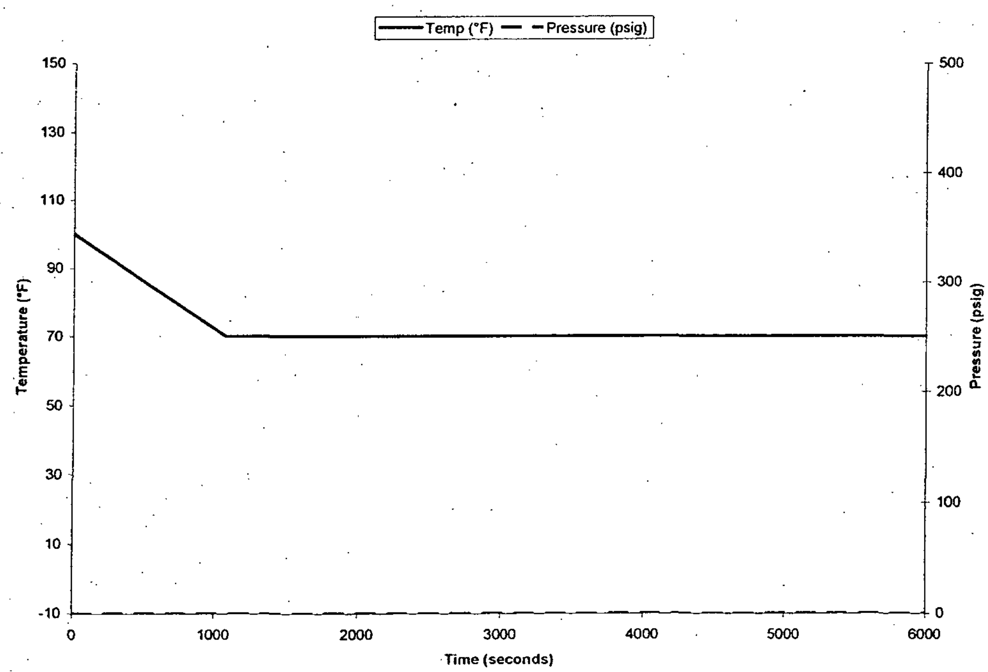



**Figure 20: Transient 25, Unbolt**

# APPENDIX A

# SUMMARY OF OUTPUT FILES

| | | |
|---|---|---|
| Transient Table.xls | Definition of Transients | In Computer files |
| BRresults.xls | Blend Radius Stress Summary | In Computer files |
| SEresults.xls | Safe End Stress Summary | In Computer files |
| TRANSNT_XX.INP | Input File for Each Transient | In Computer files |
| Green.dat | Input File for Green Functions | In Computer files |
| P-V_XX.OUT | Output File for Stress Analysis | In Computer files |
| GREEN.CFG | Input File for Defining Green Function | In Computer files |
| FATIGUE.CFG | Input File for Defining Fatigue Analysis | In Computer files |
| FATIGUE.DAT | Input File for Fatigue Curves | In Computer files |
| FATIGUE.inp | Input file for Fatigue Analysis from BRresults.xls or SEresults.xls | In Computer files |
| FATIGUE.OUT | Fatigue Output File | In Computer files |

Where XX is defined for each transient.

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| | |
|---|---|
| **Structural Integrity Associates, Inc.**<br>CALCULATION PACKAGE | File No.: VY-16Q-303<br>Project No.: VY-16Q NEC-JH_06 |

PROJECT NAME:

Environmental Fatigue Analysis of VYNPS

CONTRACT NO.:

10150394

| CLIENT: | PLANT: |
|---|---|
| Entergy Nuclear Operations, Inc. | Vermont Yankee |

CALCULATION TITLE:

Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1 - 24, Appendices: A1 – A2, B1 – B2 In computer files | Initial issue. | Terry J. Herrmann 07/05/07 [signature] | Gary L. Stevens 07/05/07 [signature]<br>Terry J. Herrmann 07/05/07 [signature] |



~~Contains Vendor Proprietary Information~~

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Table of Contents



List of Tables

## 1.0 INTRODUCTION/STATEMENT OF PROBLEM/ OBJECTIVE

The purpose of this calculation is to perform a plant-specific evaluation of reactor water environmental effects for the reactor recirculation (RR) inlet nozzle and the reactor pressure vessel (RPV) shell/bottom head locations identified within NUREG/CR-6260 [1] for the older vintage General Electric (GE) plant for the Vermont Yankee Nuclear Power Plant (VY).

The water chemistry input used in this calculation covers several portions of the RPV, as well as the feedwater and recirculation lines. Although these regions encompass more areas than needed to address the two components of interest in this calculation, environmental fatigue multipliers are developed for all of these regions in this calculation for potential use in other evaluations associated with this project.

## 2.0 TECHNICAL APPROACH OR METHODOLOGY

Per Chapter X, "Time-Limited Aging Analyses Evaluation of Aging Management Programs Under 10 CFR 54.21(c)(1)(iii)," Section X.M1, "Metal Fatigue of Reactor Coolant Pressure Boundary," of the Generic Aging Lessons Learned (GALL) Report [2], detailed, vintage-specific, fatigue calculations are required for plants applying for license renewal for the locations identified for the appropriate vintage plant in NUREG/CR-6260.

In this calculation, detailed environmentally assisted fatigue (EAF) calculations are performed for VY for two of the locations associated with the older vintage GE plant in NUREG/CR-6260. The older-vintage GE plant is the appropriate comparison to VY since the original piping design at VY was in accordance with USAS B31.1 [3], as well as the fact that the older-vintage boiling water reactor (BWR) in NUREG/CR-6260 was a BWR-4 plant, which is the same as VY.

Entergy performed an initial assessment of EAF effects for VY in their License Renewal Application (LRA) that was submitted to the NRC in January 2006. Table 4.3-3 of the VY LRA provides the results of those evaluations. All but two of the VY locations evaluated for EAF in the LRA did not yield acceptable results for 60 years of operation. Further refined analyses are currently underway in other calculations associated with this project to address those components. This calculation documents the EAF evaluation for the RR inlet nozzle and RPV shell/bottom head locations, where it is expected that acceptable EAF results can be achieved based on the existing analyses without the need for additional refined evaluations.

## 3.0 ASSUMPTIONS / DESIGN INPUTS

Per Section X.M1 of the GALL Report [2], the EAF evaluation must use the appropriate $F_{en}$ relationships from NUREG/CR-6583 [4] (for carbon/low alloy steels) and NUREG/CR-5704 [5] (for stainless steels), as appropriate for the material for each location. These expressions are:

*For Carbon Steel [4, p. 69]:* $F_{en} = \exp(0.585 - 0.00124T' - 0.101 S^* T^* O^* \dot{\varepsilon}^*)$

Substituting T' = 25°C in the above expression, as required by NUREG/CR-6583 to relate room temperature air data to service temperature data in water [6], the following is obtained:

$$F_{en} = \exp(0.585 - 0.00124(25°C) - 0.101\ S^*\ T^*\ O^*\ \dot{\varepsilon}^*)$$
$$= \exp(0.554 - 0.101\ S^*\ T^*\ O^*\ \dot{\varepsilon}^*)$$

*For Low Alloy Steel [4, p. 69]:* $F_{en} = \exp(0.929 - 0.00124T' - 0.101 S^* T^* O^* \dot{\varepsilon}^*)$

Substituting T' = 25°C in the above expression, as required by NUREG/CR-6583 to relate room temperature air data to service temperature data in water [6], the following is obtained:

$$F_{en} = \exp(0.929 - 0.00124(25°C) - 0.101\ S^*\ T^*\ O^*\ \dot{\varepsilon}^*)$$
$$= \exp(0.898 - 0.101\ S^*\ T^*\ O^*\ \dot{\varepsilon}^*)$$

where [4, pp. 60 and 65]:

| | | |
|---|---|---|
| $F_{en}$ | = | fatigue life correction factor |
| $S^*$ | = | S for 0 < sulfur content, S ≤ 0.015 wt. % |
| | = | 0.015 for S > 0.015 wt. % |
| $T^*$ | = | 0 for T < 150°C |
| | = | (T - 150) for 150 ≤ T ≤ 350°C |
| T | = | fluid service temperature (°C) |
| $O^*$ | = | 0 for dissolved oxygen, DO < 0.05 parts per million (ppm) |
| | = | ln(DO/0.04) for 0.05 ppm ≤ DO ≤ 0.5 ppm |
| | = | ln(12.5) for DO > 0.5 ppm |
| $\dot{\varepsilon}^*$ | = | 0 for strain rate, $\dot{\varepsilon}$ > 1%/sec |
| | = | ln($\dot{\varepsilon}^*$) for 0.001 ≤ $\dot{\varepsilon}$ ≤ 1%/sec |
| | = | ln(0.001) for $\dot{\varepsilon}$ < 0.001%/sec |

*For Types 304 and 316 Stainless Steel [5, p. 31]:* $F_{en} = \exp(0.935 - T^* \dot{\varepsilon}^* O^*)$

where [5, pp. 25 and 31]:

| | | |
|---|---|---|
| $F_{en}$ | = | fatigue life correction factor |
| $T^*$ | = | 0 for T < 200°C |
| | = | 1 for T ≥ 200°C |
| T | = | fluid service temperature (°C) |
| $\dot{\varepsilon}^*$ | = | 0 for strain rate, $\dot{\varepsilon} > 0.4\%/\text{sec}$ |
| | = | $\ln(\dot{\varepsilon}/0.4)$ for $0.0004 \le \dot{\varepsilon} \le 0.4\%/\text{sec}$ |
| | = | $\ln(0.0004/0.4)$ for $\dot{\varepsilon} < 0.0004\%/\text{sec}$ |
| $O^*$ | = | 0.260 for dissolved oxygen, DO < 0.05 parts per million (ppm) |
| | = | 0.172 for DO ≥ 0.05 ppm |

Bounding $F_{en}$ values are determined or, where necessary, computed for each load pair in the detailed fatigue calculation for each component. The environmental fatigue is then determined as $U_{env} = (U)(F_{en})$, where U is the original fatigue usage and $U_{env}$ is the environmentally assisted fatigue (EAF) usage factor. All calculations can be found in Excel spreadsheet "*VY-16Q-303 (Env. Fat. Calcs).xls*" associated with this calculation.

From Reference [7], for the BWR, typical DO levels range from just over 200 ppb for normal water chemistry (NWC) conditions to less than 10 ppb for hydrogen water chemistry (HWC) conditions. Typical HWC system availabilities are greater than 90%. Based on VY-specific water chemistry input for Entergy [8], which is also contained in Appendix A of this calculation, the input shown in Table 1 is defined for use in this calculation.

The water chemistry input covers several portions of the RPV, as well as the feedwater and recirculation lines. Although these regions encompass more areas than needed to address the two components of interest in this calculation, environmental fatigue multipliers are developed for all of these regions in this calculation for potential use in other evaluations associated with this project.

Therefore, based on Table 1 and for the purposes of this calculation, the following is assumed:

- Over the 60-year operating life of the plant, HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time.
- All operation through 11/1/2003 was assumed as NWC using the dissolved oxygen values from the "Pre-NMCA" column in Appendix A, and all operation after 11/1/2003 was assumed as HWC using the maximum oxygen values from the "Post-NMCA + HWC (OLP)", "Post-NMCA + HWC (EPU)", and "Future Operation" columns in Appendix A.
- Recirculation line DO is 122 ppb pre-HWC and 48 ppb post-HWC.
- Feedwater line DO is 40 ppb for pre-HWC and 40 ppb for post-HWC conditions.
- RPV Upper Region DO is 114 ppb pre-HWC and 97 ppb post-HWC.
- RPV Beltline DO is 123 ppb pre-HWC and 46 ppb post-HWC.
- RPV Bottom Head Region DO is 128 ppb pre-HWC and 69 ppb post-HWC.

Based on the above typical DO levels, bounding $F_{en}$ multipliers for each of the three applicable materials (carbon, low alloy, and stainless steels) are shown in Tables 2 through 6 for the various RPV and piping regions.

The projected number of cycles used in this calculation is based on the number of cycles actually experienced by the plant in the past and forward-projected with some additional margin for 60 years of operation, as documented in Reference [9]. In addition, the latest governing stress analysis for each location was utilized, and any relevant effects of Extended Power Uprate (EPU) operation were incorporated as necessary. With these assumptions, the cumulative usage factor (CUF) values documented in this calculation are considered applicable for sixty years of operation including all relevant EAF and EPU effects.

## 4.0 CALCULATIONS

The analyses for the NUREG/CR-6260 locations identified in Section 2.0 are provided in this section. As previously noted, the fatigue calculations for 60 years for all locations make use of the 60-year projected cycles for VY from Reference [9], and incorporate EPU effects.

Since the $F_{en}$ methodology documented in References [4] and [5] is relatively "new" technology, it is intended to apply to "modern-day" fatigue analyses, i.e., applied to fatigue analyses that use current ASME Code fatigue curves, etc. Therefore, to be consistent with this approach, the evaluation for the all locations will also utilize modern-day fatigue calculation methodology using the 1998 Edition, 2000 Addenda of the ASME Code [11]. This involves applying a Young's Modulus correction factor (i.e., $E_{fatigue\ curve}/E_{analysis}$) to the calculated stresses, applying $K_e$ where appropriate, and utilizing the 2000 Addenda fatigue curve.

NOTE: *It is recognized that some of the references used in this calculation are not the latest revision; for example, Reference [12] (VYC-378, Revision 0) has been revised. However, the details necessary to perform the evaluations in this calculation are not necessarily contained in the latest revision of all documents. Therefore, wherever necessary, the appropriate revision of the governing document is referenced in order to obtain all appropriate inputs necessary to perform the EAF calculations. So, it should be recognized that, despite using what appear to be outdated revisions of some references, use of these references is for input data use only. All calculations represent the latest available analyses for all locations.*

NOTE: *Hand calculations may yield results slightly different than the values shown in the tables of this calculation due to round-off based on the significant figures utilized by the spreadsheet used for these calculations.*

## 4.1 RPV Lower Head

The 60-year CUF value (without EAF effects) for the RPV shell/bottom head location was reported in Table 4.3-3 of the VY LRA submittal to be 0.400. The EAF CUF estimated by Entergy for this location was 0.98, based on an overall $F_{en}$ of 2.45. Based on this result, further refined analysis would not normally be necessary to show acceptable EAF CUF results for this component. However, the calculation for this location is updated in this section to reflect the updated water chemistry information supplied for this project.

The CUF value reported in the VY LRA for the RPV shell/bottom head location is 0.400. This value is the original design basis CUF from the RPV Stress Report, as noted on page B8 of Reference [12]. However, as noted on page A61 of Reference [12], this CUF corresponds to Point 8, which is located on the outside surface of the RPV bottom head at the junction with the support skirt. Therefore, this location is not exposed to the reactor coolant, and EAF effects do not apply. Based on this, evaluation of the limiting location along the inside surface of the RPV bottom head was performed.

Based on a review of the primary plus secondary stresses tabulated for all locations along the bottom head on page A52 of Reference [12], Point 14 was selected for EAF evaluation. Per Section 3.2.1.2 of Reference [13], none of the CUF values for the RPV bottom head region were evaluated for the effects of EPU, as the CUF values are below the EPU screening criteria value of 0.5. Therefore, as a part of the evaluation for this location, EPU effects were included. Per References [14] and [19], the RPV shell material is low alloy steel (A-533, Grade B).

The new CUF calculation for Point 14 for 40 years, which includes the use of updated methodology and incorporates EPU effects [14], is shown at the top portion of Table 7. The CUF for 40 years (without EAF effects) is 0.0057.

The fatigue calculation for 60 years for the RPV shell/bottom head location is also shown in Table 7. The results show a CUF (without EAF effects) of 0.0085 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RPV shell/bottom head location is shown in Table 7. Bounding $F_{en}$ multipliers were applied in the calculations. RPV bottom head water chemistry conditions from Tables 1 and 6 are used for this location. The results show an EAF adjusted CUF of 0.0809 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

The CUF determined for Point 14 is very low. Comparison to other locations of the RPV shell/bottom head region indicates it is not the limiting location from a fatigue perspective. Review of the CUF values in Table 3-1 of Reference [15] reveals that the shroud support (at vessel wall junction) location is potentially more limiting, so EAF evaluation of that location is also performed.

Per page S3-99f of Reference [16], the design basis CUF of 0.06 is for Point 9. Page S3-85 of Reference [16] reveals that this point is on the RPV shell at the junction of the shroud support plate. Per References [14] and [19], the RPV shell material is low alloy steel (A-533, Grade B).

The revised and updated CUF calculation for Point 9 for 40 years, which includes the use of updated methodology and incorporates EPU effects, is shown at the top portion of Table 8. The CUF for 40 years (without EAF effects) is 0.0549. This CUF value is more limiting than the RPV shell/bottom head location evaluated in Table 7, so it is considered to be the governing location for VY with respect to the equivalent NUREG/CR-6260 RPV shell/bottom head location.

The fatigue calculation for 60 years for the RPV shell/shroud support location is also shown in Table 8. The results show a CUF (without EAF effects) of 0.0774 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RPV shell/shroud support location is shown in Table 8. Bounding $F_{en}$ multipliers were applied in the calculations. RPV bottom head water chemistry conditions from Table 6 are used for this location. The results show an EAF adjusted CUF of 0.7364 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

## 4.2 RR Inlet Nozzle

For conservatism due to the different materials involved, two locations are evaluated for the RR inlet nozzle: (1) the limiting location in the nozzle forging, and (2) the limiting location in the safe end.

The 60-year CUF value (without EAF effects) for the RR inlet nozzle in the VY LRA submittal is 0.610. However, that analysis used conservative transient definitions and cyclic projections for 60 years of operation that have since been updated. The applicable CUF values are those shown in Table 3-1 of Reference [15] (0.1058 for the safe end, and 0.03 for the nozzle for 40-years), except that these values are pre-EPU.

For the RR inlet nozzle forging, the governing CUF calculation is shown on page B28 of Reference [12], where a value of 0.03 was obtained. From pages A269 and A270 of Reference [12], the CUF calculation corresponds to Point 12 in the nozzle forging, which is on the outside surface of the nozzle on the outboard end of the nozzle transition. Although this location is not exposed to the reactor coolant, it will be conservatively evaluated for EAF effects as it is the bounding fatigue location in the nozzle forging. As a part of the evaluation for this location, EPU effects were included. Per page I-S8-4 of Reference [17], the RR inlet nozzle material is low alloy steel (A-508 Class II).

The new CUF calculation for Point 12 for 40 years, which includes the use of updated methodology and incorporates EPU effects [14], is shown at the top portion of Table 9. The CUF for 40 years (without EAF effects) is 0.0433.

The fatigue calculation for 60 years for the RR inlet nozzle forging location is also shown in Table 9. The results show a CUF (without EAF effects) of 0.0650 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RR inlet nozzle forging location is shown in Table 9. Bounding $F_{en}$ multipliers were applied in the calculations. RPV beltline water chemistry conditions from Table 5 are used for this location. The results show an EAF adjusted CUF of 0.5034 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0)

For the RR inlet nozzle safe end, the governing CUF calculation is shown on page B27 of Reference [12], where a value of 0.1058 was obtained. From pages A257 and A259 of Reference [12], the CUF calculation corresponds to Line 6 at the inside surface of the safe end. Page A238 of Reference [12] reveals that this location is location at the nozzle-to-safe end weld. Per Section 3.2.1.2 of Reference [13], the CUF value for the RR inlet nozzle safe end was evaluated for the effects of EPU, since the original CUF calculated in Reference [18] was 0.551 (which was adjusted downward to 0.1058 by Entergy in Reference [12] based on further refined evaluation). Therefore, as a part of the evaluation for this location, EPU effects were included. Per page 8 of Reference [18], the RR inlet nozzle safe end material is 316L stainless steel.

The new CUF calculation for the RR inlet nozzle safe end for 40 years, which includes the use of updated methodology and incorporates EPU effects [14], is shown at the top portion of Table 10. The CUF for 40 years (without EAF effects) is 0.0017.

The fatigue calculation for 60 years for the RR inlet nozzle safe end location is also shown in Table 10. The results show a CUF (without EAF effects) of 0.0017 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RR inlet nozzle safe end location is shown in Table 10. Bounding $F_{en}$ multipliers were applied in the calculations. Recirculation line water chemistry conditions from Table 2 are used for this location. The results show an EAF adjusted CUF of 0.0199 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0)

## 5.0 RESULTS OF ANALYSIS

The final environmental fatigue results contained in Sections 4.1 and 4.2 (and associated Tables 7 through 10) for the RPV shell/bottom head and RR inlet nozzle locations are summarized in Table 11.

## 6.0 CONCLUSIONS AND DISCUSSION

In this calculation, EAF calculations were performed in accordance with the GALL Report [2] for the following VY locations:

- RR inlet nozzle, consisting of the following bounding locations:
  - Nozzle forging (low alloy steel)
  - Safe end (stainless steel)
- RPV shell/bottom head, consisting of the following bounding locations:
  - Limiting bottom head shell inside surface location (low alloy steel)
  - Limiting RPV shell/shroud support location (low alloy steel)

The above locations were selected based on the locations identified in NUREG/CR-6260 for the older vintage GE plant and plant-specific fatigue calculations that determined the limiting locations for VY. Calculations for the remaining NUREG/CR-6260 locations will be documented in other analyses performed under this project.

The EAF results for the locations identified above are shown in Table 11. These results indicate that the fatigue usage factors, including environmental effects, are within the allowable value for 60 years of operation for all locations evaluated. The calculations for all locations make use of the 60-year projected cycles for VY and incorporate EPU effects. Therefore, no additional evaluation is required for these components, and the GALL requirements are satisfied.

## 7.0 REFERENCES


1. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

2. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.

3. USAS B31.1.0 – 1967, USA Standard Code for Pressure Piping, "Power Piping," American Society of Mechanical Engineers, New York.

4. NUREG/CR-6583 (ANL-97/18), "Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels," March 1998.

5. NUREG/CR-5704 (ANL-98/31), "Effects of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steels," April 1999.

6. EPRI/BWRVIP Memo No. 2005-271, "Potential Error in Existing Fatigue Reactor Water Environmental Effects Analyses," July 1, 2005.

REDACTED

8. "Vermont Yankee Dissolved Oxygen (DO) Levels for Use in EAF Evaluations," page 11 of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.

9. "Reactor Thermal Cycles for 60 Years of Operation," Attachment 1 of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.

10. VY LRA, page 1-4 (*included as Appendix B to this calculation*).

11. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, and Section II, Materials, Part D, "Properties (Customary)," 1998 Edition including the 2000 Addenda.

12. Yankee Atomic Electric Company Calculation No. VYC-378, Revision 0, "Vermont Yankee Reactor Cyclic Limits for Transient Events," 10/16/85, SI File No. VY-05Q-211.

REDACTED

14. GE Nuclear Energy Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," June 2, 2003, SI File No. VY-05Q-236.

15. Structural Integrity Associates Report No. SIR-01-130, Rev. 0, "System Review and Recommendations for a Transient and Fatigue Monitoring System at the Vermont Yankee Nuclear Power Station," February 2002, SI File No. W-VY-05Q-401.

16. CB&I RPV Stress Report, Section S3, Revision 4, "Stress Analysis, Shroud Support, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," 2-3-70, SI File No. VY-16Q-203.

17. CB&I RPV Stress Report, Section S8, Revision 4, "Stress Analysis, Recirculation Inlet Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," 2-3-70, SI File No. VY-16Q-203.

18. GE Nuclear Energy Certified Stress Report No. 23A4292, Revision 4, "Reactor Vessel – Recirculation Inlet Safe End Nozzle," March 12, 1986, SI File No. VY-16Q-203.

19. Entergy Drawing No. 5920-5752, Revision 3 (CB&I Drawing No. R15, Revision 1), "Vessel & Attachments Mat'l. Identifications," 1/20/88, SI File No. VY-16Q-209.

Table 1: Water Chemistry Calculations

| | | |
|---|---|---|
| Date of HWC Implementation: | 11/01/2003 | *(see Appendix A)* |
| Availability of HWC System Since HWC Implementation: | 98.54% | *(see Appendix A)* |
| Projected Future HWC System Availability: | 98.5% | *(see Appendix A, assume same as recent experience)* |
| Recirculation Line DO | | |
| pre-HWC: | 122 | ppb *(see Appendix A)* |
| post-HWC: | 48 | ppb *(see Appendix A)* |
| Feedwater Line DO | | |
| pre-HWC: | 40 | ppb *(see Appendix A)* |
| post-HWC: | 40 | ppb *(see Appendix A)* |
| RPV Upper Region DO | | |
| pre-HWC: | 114 | ppb *(see Appendix A)* |
| post-HWC: | 97 | ppb *(see Appendix A)* |
| RPV Beltline Region DO | | |
| pre-HWC: | 123 | ppb *(see Appendix A)* |
| post-HWC: | 46 | ppb *(see Appendix A)* |
| RPV Bottom Head Region DO | | |
| pre-HWC: | 128 | ppb *(see Appendix A)* |
| post-HWC: | 69 | ppb *(see Appendix A)* |
| Plant Startup Date: | 03/22/1972 | *(see Appendix B)* |
| Time at pre-HWC Conditions: | 31.61 | years *(calculated, includes leap years.)* |
| Date of Calculations: | 04/30/2007 | |
| Time Since HWC Implementation: | 3.49 | years *(calculated, includes leap years.)* |
| Projected Future Time for HWC Operation: | 24.90 | years *(calculated, includes leap years.)* |
| Overall HWC Availability: | 47% | |

Note: All operation through 11/1/2003 was assumed as NWC using the dissolved oxygen values from the "Pre-NMCA" column in Appendix A, and all operation after 11/1/2003 was assumed as HWC using the maximum oxygen values from the "Post-NMCA + HWC (OLP)", "Post-NMCA + HWC (EPU)", and "Future Operation" columns in Appendix A.

## Table 2: Bounding $F_{en}$ Multipliers for Recirculation Line

*Low Alloy Steel:*

$F_{en} = \exp(0.898 - 0.101S^*T^*O^*\varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 48 ppb ≈ 0.048 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 2.45 |
| 250 | 482 | 2.45 |
| 288 | 550 | 2.45 |

Thus, maximum $F_{en}$ = 2.45

[$T^*$= (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 122 ppb = 0.122 ppm, so $O^* = \ln(0.122/0.04) = 1.115$

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.40 |
| 250 | 482 | 7.89 |
| 288 | 550 | 12.29 |

Thus, maximum $F_{en}$ = 12.29

*Carbon Steel:*

$F_{en} = \exp(0.554 - 0.101S^*T^*O^*\varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 48 ppb ≈ 0.048 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

[$T^*$= (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 122 ppb = 0.122 ppm, so $O^* = \ln(0.122/0.04) = 1.115$

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 3.12 |
| 250 | 482 | 5.59 |
| 288 | 550 | 8.71 |

Thus, maximum $F_{en}$ = 8.71

*Stainless Steel:*

$F_{en} = \exp(0.935 - T^*\varepsilon^*O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 48 ppb ≈ 0.048 ppm < 0.050 ppm, so $O^* = 0.260$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

For a BWR with NWC environment (pre-HWC implementation):
DO = 122 ppb = 0.122 ppm > 0.05 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

| | HWC | | NWC | |
|---|---|---|---|---|
| $\varepsilon^* = 0$ for $\varepsilon > 0.4\%$/sec | so $F_{en}$ = | 2.55 | so $F_{en}$ = | 2.55 |
| $\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4\%$/sec | so $F_{en}$ ranges from | 2.55 | so $F_{en}$ ranges from | 2.55 |
| | to | 15.35 | to | 8.36 |
| $\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004\%$/sec | so $F_{en}$ = | 15.35 | so $F_{en}$ = | 8.36 |
| | Thus, maximum $F_{en}$ = | 15.35 | Thus, maximum $F_{en}$ = | 8.36 |

# Table 3: Bounding $F_{en}$ Multipliers for Feedwater Line

*Low Alloy Steel:*

$F_{en} = \exp(0.898 - 0.101S^*T^*O^*\varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 2.45 |
| 250 | 482 | 2.45 |
| 288 | 550 | 2.45 |

Thus, maximum $F_{en}$ = 2.45

For a BWR with NWC environment (pre-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 2.45 |
| 250 | 482 | 2.45 |
| 288 | 550 | 2.45 |

Thus, maximum $F_{en}$ = 2.45

[$T^*$ = (T-150) for T > 150°C]

*Carbon Steel:*

$F_{en} = \exp(0.554 - 0.101S^*T^*O^*\varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

For a BWR with NWC environment (pre-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

[$T^*$ = (T-150) for T > 150°C]

*There is no stainless steel in the Class 1 feedwater line.*

# Table 4: Bounding $F_{en}$ Multipliers for RPV Upper Region

*Low Alloy Steel:*

$F_{en} = exp(0.898 - 0.101S^*T^*O^*\varepsilon^*)$

Assume S* = 0.015 (maximum)
Assume ε* = ln(0.001) = -6.908 (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 97 ppb = 0.097 ppm, so O* = ln(0.097/0.04) = 0.886

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 3.90 |
| 250 | 482 | 6.20 |
| 288 | 550 | 8.82 |

Thus, maximum $F_{en}$ = 8.82 [T*= (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 114 ppb = 0.114 ppm, so O* = ln(0.114/0.04) = 1.047

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.25 |
| 250 | 482 | 7.35 |
| 288 | 550 | 11.14 |

Thus, maximum $F_{en}$ = 11.14

*Carbon Steel:*

$F_{en} = exp(0.554 - 0.101S^*T^*O^*\varepsilon^*)$

Assume S* = 0.015 (maximum)
Assume ε* = ln(0.001) = -6.908 (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 97 ppb = 0.097 ppm, so O* = ln(0.097/0.04) = 0.886

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 2.77 |
| 250 | 482 | 4.40 |
| 288 | 550 | 6.25 |

Thus, maximum $F_{en}$ = 6.25 [T*= (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 114 ppb = 0.114 ppm, so O* = ln(0.114/0.04) = 1.047

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 3.01 |
| 250 | 482 | 5.21 |
| 288 | 550 | 7.90 |

Thus, maximum $F_{en}$ = 7.90

*Stainless Steel:*

$F_{en} = exp(0.935 - T^*\varepsilon^*O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 97 ppb = 0.097 ppm > 0.050 ppm, so O* = 0.172
Conservatively use T* = 1 for T > 200°C

For a BWR with NWC environment (pre-HWC implementation):
DO = 114 ppb = 0.114 ppm > 0.05 ppm, so O* = 0.172
Conservatively use T* = 1 for T > 200°C

Thus:

| Strain rate | | HWC | | NWC |
|---|---|---|---|---|
| ε* = 0 for ε > 0.4%/sec | so $F_{en}$ = | 2.55 | so $F_{en}$ = | 2.55 |
| ε* = ln(ε/0.4) for 0.0004 <= ε <= 0.4%/sec | so $F_{en}$ ranges from | 2.55 | so $F_{en}$ ranges from | 2.55 |
| | to | 8.36 | to | 8.36 |
| ε* = ln(0.0004/0.4) for ε < 0.0004%/sec | so $F_{en}$ = | 8.36 | so $F_{en}$ = | 8.36 |
| | Thus, maximum $F_{en}$ = | 8.36 | Thus, maximum $F_{en}$ = | 8.36 |

## Table 5: Bounding $F_{en}$ Multipliers for RPV Beltline Region

*Low Alloy Steel:*

$F_{en} = \exp(0.898 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 46 ppb = 0.046 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 2.45 |
| 269.45 | 517.01 | 2.45 |
| 288 | 550 | 2.45 |

Thus, maximum $F_{en}$ = 2.45

[$T^*$ = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 123 ppb = 0.123 ppm, so $O^* = \ln(0.123/0.04) = 1.123$

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.42 |
| 269.45 | 517.01 | 10.00 |
| 288 | 550 | 12.43 |

Thus, maximum $F_{en}$ = 12.43

*Carbon Steel:*

$F_{en} = \exp(0.554 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 46 ppb = 0.046 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

[$T^*$ = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 123 ppb = 0.123 ppm, so $O^* = \ln(0.123/0.04) = 1.123$

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 3.13 |
| 250 | 482 | 5.64 |
| 288 | 550 | 8.81 |

Thus, maximum $F_{en}$ = 8.81

*Stainless Steel:*

$F_{en} = \exp(0.935 - T^* \varepsilon^* O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 46 ppb = 0.046 ppm < 0.050 ppm, so $O^* = 0.260$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

For a BWR with NWC environment (pre-HWC implementation):
DO = 123 ppb = 0.123 ppm > 0.05 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

| | HWC | | NWC | |
|---|---|---|---|---|
| $\varepsilon^* = 0$ for $\varepsilon > 0.4\%/\text{sec}$ | so $F_{en}$ = | 2.55 | so $F_{en}$ = | 2.55 |
| $\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4\%/\text{sec}$ | so $F_{en}$ ranges from | 2.55 | so $F_{en}$ ranges from | 2.55 |
| | to | 15.35 | to | 8.36 |
| $\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004\%/\text{sec}$ | so $F_{en}$ = | 15.35 | so $F_{en}$ = | 8.36 |
| | Thus, maximum $F_{en}$ = | 15.35 | Thus, maximum $F_{en}$ = | 8.36 |

# Table 6: Bounding $F_{en}$ Multipliers for RPV Bottom Head Region

*Low Alloy Steel:*

$F_{en} = \exp(0.898 - 0.101S^*T^*O^*\varepsilon^*)$

Assume S* = 0.015 (maximum)
Assume ε* = ln(0.001) = -6.908 (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 69 ppb = 0.069 ppm, so O* = ln(0.069/0.04) = 0.545
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 3.27 |
| 250 | 482 | 4.34 |
| 288 | 550 | 5.39 |

Thus, maximum $F_{en}$ = 5.39

[T* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 128 ppb = 0.128 ppm, so O* = ln(0.128/0.04) = 1.163
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.51 |
| 250 | 482 | 8.29 |
| 288 | 550 | 13.17 |

Thus, maximum $F_{en}$ = 13.17

*Carbon Steel:*

$F_{en} = \exp(0.554 - 0.101S^*T^*O^*\varepsilon^*)$

Assume S* = 0.015 (maximum)
Assume ε* = ln(0.001) = -6.908 (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 69 ppb = 0.069 ppm, so O* = ln(0.069/0.04) = 0.545
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 2.31 |
| 250 | 482 | 3.08 |
| 288 | 550 | 3.82 |

Thus, maximum $F_{en}$ = 3.82

[T* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 128 ppb = 0.128 ppm, so O* = ln(0.128/0.04) = 1.163
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 3.20 |
| 250 | 482 | 5.88 |
| 288 | 550 | 9.34 |

Thus, maximum $F_{en}$ = 9.34

*Stainless Steel:*

$F_{en} = \exp(0.935 - T^*\varepsilon^*O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 69 ppb = 0.069 ppm > 0.050 ppm, so O* = 0.172
Conservatively use T* = 1 for T > 200°C
Thus:

For a BWR with NWC environment (pre-HWC implementation):
DO = 128 ppb = 0.128 ppm > 0.05 ppm, so O* = 0.172
Conservatively use T* = 1 for T > 200°C
Thus:

| Strain rate condition | | HWC $F_{en}$ | | NWC $F_{en}$ |
|---|---|---|---|---|
| ε* = 0 for ε > 0.4%/sec | so $F_{en}$ = | 2.55 | so $F_{en}$ = | 2.55 |
| ε* = ln(ε/0.4) for 0.0004 <= ε <= 0.4%/sec | so $F_{en}$ ranges from | 2.55 | so $F_{en}$ ranges from | 2.55 |
| | to | 8.36 | to | 8.36 |
| ε* = ln(0.0004/0.4) for ε < 0.0004%/sec | so $F_{en}$ = | 8.36 | so $F_{en}$ = | 8.36 |
| | Thus, maximum $F_{en}$ = | 8.36 | Thus, maximum $F_{en}$ = | 8.36 |

# Table 7: EAF Evaluation for RPV Shell/Bottom Head Location

Component: RPV Shell/Bottom Head
NUREG/CR-6260 CUF: 0.032 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-102
Stress Report CUF: 0.0057 *(for Point 14, see below)*
Material: Low Alloy Steel *(Material = A-533 Gr. B per References [14] and [19])*

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.149 | *Conservatively used minimum E of 26.1 from Section S2 Appendix of RPV Stress Report.* |
| Power Uprate = | 1.0067 | *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]* |
| $K_t$ = | 1.000 | *stress concentration factor* |
| m = | 2.0 | *NB-3228.5 of ASME Code, Section III [11]* |
| n = | 0.2 | *NB-3228.5 of ASME Code, Section III [11]* |
| $S_m$ = | 26,700 | psi *(ASME Code, Section II, Part D [11])* |

| $P_L+P_B+Q$ *(see Note 1)* | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 4)* | N *(see Note 5)* | U |
|---|---|---|---|---|---|
| 44,526 | 1.00 | 25,762 | 200 | 35,300 | 0.0057 |
| | | | | Total, $U_{40}$ = | 0.0057 |

*Notes:*
1. $P_L+P_B+Q$ is obtained for Point 14 from p. A52 of VYC-378, Rev. 0.
2. $K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.
3. $S_{alt} = 0.5 * K_e * K_t * E_{fatigue\ curve}/E_{analysis} *$ Power Uprate $* (P_L+P_B+Q)$.
4. n for 40 years is the number of Heatup-Cooldown cycles, per p. B8 of VYC-378, Rev. 0.
5. N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.
6. n for 60 years is the projected number of Heatup-Cooldown cycles.

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 6)* | N *(see Note 4)* | U |
|---|---|---|---|---|---|
| 44,526 | 1.00 | 25,762 | 300 | 35,300 | 0.0085 |
| | | | | Total, $U_{60}$ = | 0.0085 |

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = 5.39 *(from Table 6)*
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = 13.17 *(from Table 6)*

$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47 =$ 0.0809
Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = 9.51

# Table 8: EAF Evaluation for Limiting RPV Shell/Shroud Support Location

Component: RPV Shell at Shroud Support
NUREG/CR-6260 CUF: 0.032 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-102
Stress Report CUF: 0.0549 *(for Point 9, see below)*
Material: Low Alloy Steel *(Material = A-533 Gr. B per References [14] and [19])*

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| Hydrotest $\sigma_\phi$ = | 26,240 | psi *(p. S3-97 of RPV Stress Report)* |
| Hydrotest $\sigma_r$ = | -1,250 | psi *(p. S3-97 of RPV Stress Report)* |
| Stress Concentration Factor, $K_t$ = | 2.40 | *(p. S3-99d of RPV Stress Report)* |
| Hydrotest $K_t\sigma_\phi$ = | 62,976 | psi *(p. S3-97 of RPV Stress Report)* |
| Improper Startup $\sigma_\phi$ = | 28,060 | psi *(p. S3-98 of RPV Stress Report)* |
| Improper Startup $\sigma_r$ = | -1,025 | psi *(p. S3-98 of RPV Stress Report)* |
| Improper Startup Skin Stress = | 156,099 | psi *(p. S3-98 of RPV Stress Report)* |
| Improper Startup $K_t\sigma_\phi$ + Skin Stress = | 223,443 | psi *(p. S3-98 of RPV Stress Report)* |
| Warmup $\sigma_\phi$ = | -5,707 | psi *(p. S3-99a of RPV Stress Report)* |
| Warmup $\sigma_r$ = | -102 | psi *(p. S3-99a of RPV Stress Report)* |
| Warmup $K_t\sigma_\phi$ = | -13,696 | psi *(p. S3-99a of RPV Stress Report)* |
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.0417 | *30.0 / 28.8 per S3-99f of RPV Stress Report and ASME Code fatigue curve* |
| Power Uprate = | 1.0067 | *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]* |
| m = | 2.0 | *NB-3228.5 of ASME Code, Section III [11]* |
| n = | 0.2 | *NB-3228.5 of ASME Code, Section III [11]* |
| $S_m$ = | 26,700 | psi *(ASME Code, Section II, Part D [11])* |

| $P_L+P_B+Q$ *(see Note 1)* | Events | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 4)* | N *(see Note 5)* | U |
|---|---|---|---|---|---|---|
| 34,690 | Improper Startup - Warmup | 1.00 | 124,825 | 5 | 332 | 0.0151 |
| 33,095 | Hydrotest - Warmup | 1.00 | 40,804 | 322 | 8,095 | 0.0398 |
| | | | | | Total, $U_{40}$ = | 0.0549 |

*Notes:*
1. *$P_L+P_B+Q$ is computed for Point 9 based on the $[(\sigma_\phi - \sigma_r)_{Event1} - (\sigma_\phi - \sigma_r)_{Event2}]$ stress intensity.*
2. *$K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.*
3. *$S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis} *$ Power Uprate $* [(K_t\sigma_\phi - \sigma_r)_{Event1} - (K_t\sigma_\phi - \sigma_r)_{Event2}]$.*
4. *n for 40 years is the number of cycles as follows per p. S3-99e and S3-99f of the RPV Stress Report:*

| | | |
|---|---|---|
| *Improper Startup =* | *5* | *cycles* |
| *Hydrotest =* | *2* | *cycles* |
| *Isothermal at 70°F and 1,000 psi =* | *120* | *cycles (same as number of Startup events)* |
| *Warmup-Cooldown =* | *199* | *cycles* |
| *Warmup-Blowdown =* | *1* | *cycle* |
| *TOTAL =* | *327* | *cycles* |

5. *N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.*
6. *n for 60 years is the projected number of cycles as follows:*

| | | |
|---|---|---|
| *Improper Startup =* | *1* | *cycles* |
| *Hydrotest =* | *1* | *cycles* |
| *Isothermal at 70°F and 1,000 psi =* | *300* | *cycles (same as number of Startup events)* |
| *Warmup-Cooldown =* | *300* | *cycles* |
| *Warmup-Blowdown =* | *1* | *cycle* |
| *TOTAL =* | *603* | *cycles* |

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 6)* | N *(see Note 4)* | U |
|---|---|---|---|---|---|---|
| 34,690 | Improper Startup - Warmup | 1.00 | 124,825 | 1 | 332 | 0.0030 |
| 33,095 | Hydrotest - Warmup | 1.00 | 40,804 | 602 | 8,095 | 0.0744 |
| | | | | | Total, $U_{60}$ = | 0.0774 |

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = 5.39 *(from Table 6)*
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = 13.17 *(from Table 6)*

$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ = 0.7364
Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = 9.51

# Table 9: EAF Evaluation for RR Inlet Nozzle Forging Location

Component: Recirculation Inlet Nozzle Forging
NUREG/CR-6260 CUF: 0.310 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-105
Stress Report CUF: 0.0433 *(updated for Point 12, see below)*
Material: Low Alloy Steel *(Material = A-508 Cl. II per p. I-S8-4 of CBIN Stress Report Section S8)*

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.1278 | = 30.0 / 26.6 (per p. I-S8-24 of CBIN Stress Report Section S8 and ASME Code fatigue curve) |
| Power Uprate = | 1.0067 | =(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14] |
| $K_t$ = | 1.660 | stress concentration factor (p. A270 of VYC-378, Rev. 0 [12]) |
| m = | 2.0 | NB-3228.5 of ASME Code, Section III [11] |
| n = | 0.2 | NB-3228.5 of ASME Code, Section III [11] |
| $S_m$ = | 26,700 | psi (ASME Code, Section II, Part D [11]) |

| $P_L+P_B+Q$ *(see Note 1)* | Skin Stress *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 6)* | U |
|---|---|---|---|---|---|---|
| 43,110 | 15,145 | 1.00 | 49,224 | 200 | 4,614 | 0.0433 |
| | | | | | Total, $U_{40}$ = | 0.0433 |

*Notes:*
1. $P_L+P_B+Q$ is obtained for Point 12 from p. A270 of VYC-378, Rev. 0.
2. Skin Stress is obtained for Point 12 from p. A270 of VYC-378, Rev. 0.
3. $K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.
4. $S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis}$ * Power Uprate * [ $(P_L+P_B+Q)\ K_t$ + Skin Stress ].
5. n for 40 years is the number of Heatup-Cooldown cycles, per p. B28 of VYC-378, Rev. 0.
6. N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.
7. n for 60 years is the projected number of Heatup-Cooldown cycles.

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | Skin Stress *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 7)* | N *(see Note 6)* | U |
|---|---|---|---|---|---|---|
| 43,110 | 15,145 | 1.00 | 49,224 | 300 | 4,614 | 0.0650 |
| | | | | | Total, $U_{60}$ = | 0.0650 |

Environmental CUF Calculation for 60 Years:

Maximum $F_{en-HWC}$ Multiplier for HWC Conditions = 2.45 *(from Table 5)*
Maximum $F_{en-NWC}$ Multiplier for NWC Conditions = 12.43 *(from Table 5)*

$U_{env-60} = U_{60} \times F_{en-NWC} \times 0.53 + U_{60} \times F_{en-HWC} \times 0.47$ = 0.5034
Overall Multiplier = $U_{env-60}/U_{60}$ = 7.74

# Table 10: EAF Evaluation for RR Inlet Nozzle Safe End Location

Component: Recirculation Inlet Nozzle Safe End
NUREG/CR-6260 CUF: 0.310 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-105
Stress Report CUF: 0.0017 *(updated for Location 6-I, see below)*
Material: Stainless Steel *(316L per p. 8 of 23A4292, Rev. 4)*

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.1076 | *= 28.3 / 25.55 (per p. 62 of Reference [18] and ASME Code fatigue curve)* |
| Power Uprate = | 1.0067 | *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]* |
| $K_t$ = | 1.280 | *stress concentration factor (p. B27 of VYC-378, Rev. 0 [12])* |
| m = | 1.7 | *NB-3228.5 of ASME Code, Section III [11]* |
| n = | 0.3 | *NB-3228.5 of ASME Code, Section III [11]* |
| $S_m$ = | 16,600 | psi *(ASME Code, Section II, Part D [11])* |

| $P_L+P_B+Q$ *(see Note 1)* | P+Q+F *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 6)* | U |
|---|---|---|---|---|---|---|
| 47,183 | 36,972 | 1.00 | 26,385 | 2,076 | 1,242,266 | 0.0017 |
| | | | | | Total, $U_{40}$ = | 0.0017 |

*Notes:*
1. *$P_L+P_B+Q$ is obtained for Surface I (after weld overlay) from p. 117 of Reference [18].*
2. *P+Q+F is obtained for Point 6-I from p. 118 of Reference [18] (BEFORE weld overlay).*
3. *$K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.*
4. *$S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis}$ * Power Uprate * [ (P+Q+F) $K_t$ ].*
5. *n for 40 years is the number of cycles as follows per p. B26 of VYC-378, Rev. 0:*

| | | |
|---|---|---|
| Design Hydrotest = | 130 | |
| Loss of Feedpumps Composite: | | |
| Startup/Shutdown = | 290 | |
| SRV Blowdown = | 8 | |
| Loss of Feedwater Pumps | 30 | 10 events x 3 up/down cycles per event |
| SCRAM = | 270 | |
| Normal +/- Seismic = | 11 | 10 cycles of upset seismic, plus 1 Level C seismic event |
| Normal = | 739 | = Sum of all of above events |
| Zeroload = | 598 | = Startup/Shutdown + SRV Blowdown + Scram + LOFP |
| Total number of cycles = | 2,076 | |

6. *N obtained from Figure I-9.2 of Appendix I of ASME Code, Section III.*
7. *n for 60 years is the projected number of cycles as follows:*

| | | |
|---|---|---|
| Design Hydrotest = | 120 | |
| Loss of Feedpumps Composite: | | |
| Startup/Shutdown = | 300 | |
| SRV Blowdown = | 1 | |
| Loss of Feedwater Pumps | 30 | 10 events x 3 up/down cycles per event |
| SCRAM = | 289 | All remaining scrams |
| Normal +/- Seismic = | 11 | Assume the same |
| Normal = | 751 | = Sum of all of above events |
| Zeroload = | 620 | = Startup/Shutdown + SRV Blowdown + Scram + LOFP |
| Total number of cycles = | 2,122 | |

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | P+Q+F *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 7)* | U |
|---|---|---|---|---|---|---|
| 47,183 | 36,972 | 1.00 | 26,385 | 2,122 | 1,242,266 | 0.0017 |
| | | | | | Total, $U_{60}$ = | 0.0017 |

Environmental CUF Calculation for 60 Years:

| | | |
|---|---|---|
| Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = | 15.35 | *(from Table 2)* |
| Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = | 8.36 | *(from Table 2)* |
| $U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ = | 0.0199 | |
| Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = | 11.64 | |

Table 11: Summary of EAF Evaluation Results for VY

| No. | Component | Material | 40-Year Design CUF (1) | 60-Year CUF (2) | Overall Environmental Multiplier | 60-Year Environmental CUF (2,3) |
|---|---|---|---|---|---|---|
| 1 | RPV Shell/Bottom Head | Low Alloy Steel | 0.0057 | 0.0085 | 9.51 | 0.0809 |
| 2 | RPV Shell at Shroud Support | Low Alloy Steel | 0.0549 | 0.0774 | 9.51 | 0.7364 |
| 3 | Recirculation Inlet Nozzle Safe End | Stainless Steel | 0.0017 | 0.0017 | 11.64 | 0.0199 |
| 4 | Recirculation Inlet Nozzle Forging | Low Alloy Steel | 0.0433 | 0.0650 | 7.74 | 0.5034 |

Notes:
1. Updated 40-year CUF calculation based on recent ASME Code methodology and design basis cycles.
2. CUF results using updated ASME Code methodology and actual cycles accumulated to-date and projected to 60 years.
3. An $F_{en}$ multiplier was used for each respective component with the following conditions:
   + 47% HWC conditions and 53% NWC conditions

# APPENDIX A

## VY WATER CHEMISTRY INFORMATION [8]

| Location | Pre-NMCA<br><br>1593 MWth (OLP) | Post-NMCA + HWC<br><br>1593 MWth (OLP) | Post-NMCA + HWC<br><br>1912 MWth (EPU) | Future Operation<br><br>Post-NMCA + HWC<br>1912 MWth (EPU) |
|---|---|---|---|---|
| | --- | Average Availability 98.5% | Average Availability 98.5% | Average Availability 99% |
| | Implementation Date = 11/1972 | NMCA Application Date = 04/27/2001<br>HWC Implementation Date = 11/01/2003 | EPU Implementation Date = 5/2006 | --- |
| FW Line | 40 ppb | 40 ppb | 40 ppb | 40 ppb |
| Recirc. Line | 122 ppb | 48 ppb | 34 ppb | 34 ppb |
| RPV Bottom Head ** | 128 ppb | 69 ppb | 55 ppb | 55 ppb |
| RPV Upper Region | 114 ppb | 97 ppb | 90 ppb | 90 ppb |
| RPV Beltline Region | 123 ppb | 46 ppb | 31 ppb | 31 ppb |

** RPV Bottom head at "Lower Plenum, Downflow" (i.e. outside core support columns)

APPENDIX B

VY LICENSE DATE [10]

| | |
|---|---|
| Michael A. Balduzzi<br>Vice President -<br>Pilgrim Nuclear Power Station | Pilgrim Nuclear Power Station<br>600 Rocky Hill Road<br>Plymouth, Massachusetts 02360 |
| Fred R. Dacimo<br>Vice President -<br>Indian Point Energy Center | Indian Point Energy Center<br>Bleakley Avenue & Broadway<br>Buchanon, New York 10511 |
| Randall K. Edington<br>Vice President -<br>Operations Support | Cooper Nuclear Power Station<br>1200 Prospect Road<br>P.O. Box 98<br>Brownsville, Nebraska 68321 |
| Christopher J. Schwarz<br>Vice President -<br>Operations Support | Entergy Nuclear Operations, Inc<br>440 Hamilton Avenue<br>White Plains, New York 10601 |
| Theodore A. Sullivan<br>Vice President -<br>Fitzpatrick Nuclear Power Station | Fitzpatrick Nuclear Power Station<br>268 Lake Road East<br>Lycoming, New York 13093 |
| Jay K. Thayer<br>Vice President -<br>Vermont Yankee Nuclear Power Station | Entergy Nuclear Vermont Yankee<br>Corporate Office<br>P.O. Box 0500<br>185 Old Ferry Road<br>Brattleboro, VT 05302-0500 |

### 1.1.5 Class and Period of License Sought

ENO requests renewal of the facility operating license for VYNPS (facility operating license DPR-28) for a period of 20 years. The license was issued under Section 104b of the Atomic Energy Act of 1954 as amended. License renewal would extend the facility operating license from midnight March 21, 2012, to midnight March 21, 2032.

This application also applies to renewal of those NRC source materials, special nuclear material, and by-product material licenses that are subsumed or combined with the facility operating license.

### 1.1.6 Alteration Schedule

ENO does not propose to construct or alter any production or utilization facility in connection with this renewal application.





~~Contains Vendor Proprietary Information~~

| Structural Integrity Associates, Inc. CALCULATION PACKAGE | File No.: VY-16Q-304<br>Project No.: VY-16Q NEC-JH_07 |
|---|---|

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

| CLIENT: | PLANT: |
|---|---|
| Entergy Nuclear Operations, Inc | Vermont Yankee Nuclear Power Station |

**CALCULATION TITLE:**

Recirculation Outlet Nozzle Finite Element Model

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-6, Appendix: A1-A20 | Initial Issue | Terry J. Herrmann 7/12/2007 | Minghao Qin 7/12/2007<br>Jennifer E. Smith 7/12/2007 |

## Table of Contents



## List of Tables



## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation is to create a finite element model of the Vermont Yankee Nuclear Power Station recirculation outlet nozzle. This model will be used to develop a Green's Function to be used in a subsequent fatigue analysis.

## 2.0 GEOMETRY / MATERIAL PROPERTIES

A 2-D axisymmetric finite element model (FEM) of the nozzle was developed with element type PLANE182. The developed model includes the safe end, the nozzle forging, a portion of the vessel shell, and cladding. The model used the vessel radius multiplied by a factor 2.0 due to the model being axisymmetric.

The 2-D axisymmetric FEM was constructed using the dimensions and information from References [4 and 5] based on ANSYS [2] finite element software. Figure 1 shows the resulting finite element model.

The materials of the various components of the model are listed below:

- Safe End – SA182 F316 [4] (16Cr-12Ni-2Mo)
- Piping – SA376 TP316 [7] (16Cr-12Ni-2Mo)
- Nozzle Forging – SA508 Class 2 [5] (3/4Ni-1/2Mo-1/3Cr-V)
- Vessel – SA533 Grade B [6] (Mn-1/2Mo-1.2Ni)
- Cladding – SA240 Type 304 [1, Sheet 7] (18Cr-8Ni)

Material properties for these materials are based upon the 1998 ASME Code, Section II, Part D, with 2000 Addenda [3] and are shown in Table 1. The properties are taken at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which will be applied to the FEM model for Green's Function development.

## 3.0 PROGRAM INPUT

The input file, RON_VY.INP (included in Appendix A), creates the finite element model for the recirculation outlet nozzle.

## 4.0 REFERENCES


1. GE. Stress Report No. 23A4316, Revision 0, "Reactor Vessel Recirculation Outlet Safe End," SI File No. VY-16Q-204.
2. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.
3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
4. Vermont Yankee Drawing 5920-06623, Rev. 0, (Hitachi, Ltd. Drawing No IOR290-127), "Recirc. Outlet Safe End," SI File No. VY-16Q-204.
5. Vermont Yankee Drawing 5920-00238, Rev. 4, (Chicago Bridge & Iron Company, Contract No. 9-6201, Drawing No. 21), "36"x28" Nozzles Mk N1A/B," SI File No. VY-16Q-204.
6. Vermont Yankee Drawing 5920-05752, Rev. 3, "Vessel & Attachments Material Identifications," SI File No. VY-16Q-209.
7. SI File No. VY-16Q-103, "Vermont Yankee Comments on VY-16Q-304."

## Table 1: Material Properties @ 300°F [1]

| Material | SA533 Grade B (Mn-1/2Mo-1/2Ni) | SA508 Class 2 (3/4Ni-1/2Mo-1/3Cr-V) | SA240 Type 304 (18Cr-8Ni) | SA182 F316/ SA376 TP316 (16Cr-12Ni-2Mo) |
|---|---|---|---|---|
| Modulus of Elasticity, e-6 psi | 28.0 | 26.7 | 27.0 | 27.0 |
| Coefficient of Thermal Expansion, e-6, in/in/°F | 7.7 | 7.3 | 9.8 | 9.8 |
| Thermal Conductivity, Btu/hr-ft-°F | 23.4 | 23.4 | 9.8 | 9.3 |
| Thermal Diffusivity, $ft^2/hr$ | 0.401 | 0.401 | 0.160 | 0.150 |
| Specific Heat, Btu/lb-°F [2] | 0.119 | 0.119 | 0.125 | 0.127 |
| Density, $lb/in^3$ | 0.283 | 0.283 | 0.283 | 0.283 |
| Poisson's Ratio | 0.3 | 0.3 | 0.3 | 0.3 |

Notes:

1. The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, Section II, Part D, with 2000 Addenda, except for density and Poisson's ratio, which are assumed typical values.
2. Calculated as $[k/(\rho d)]/12^3$.

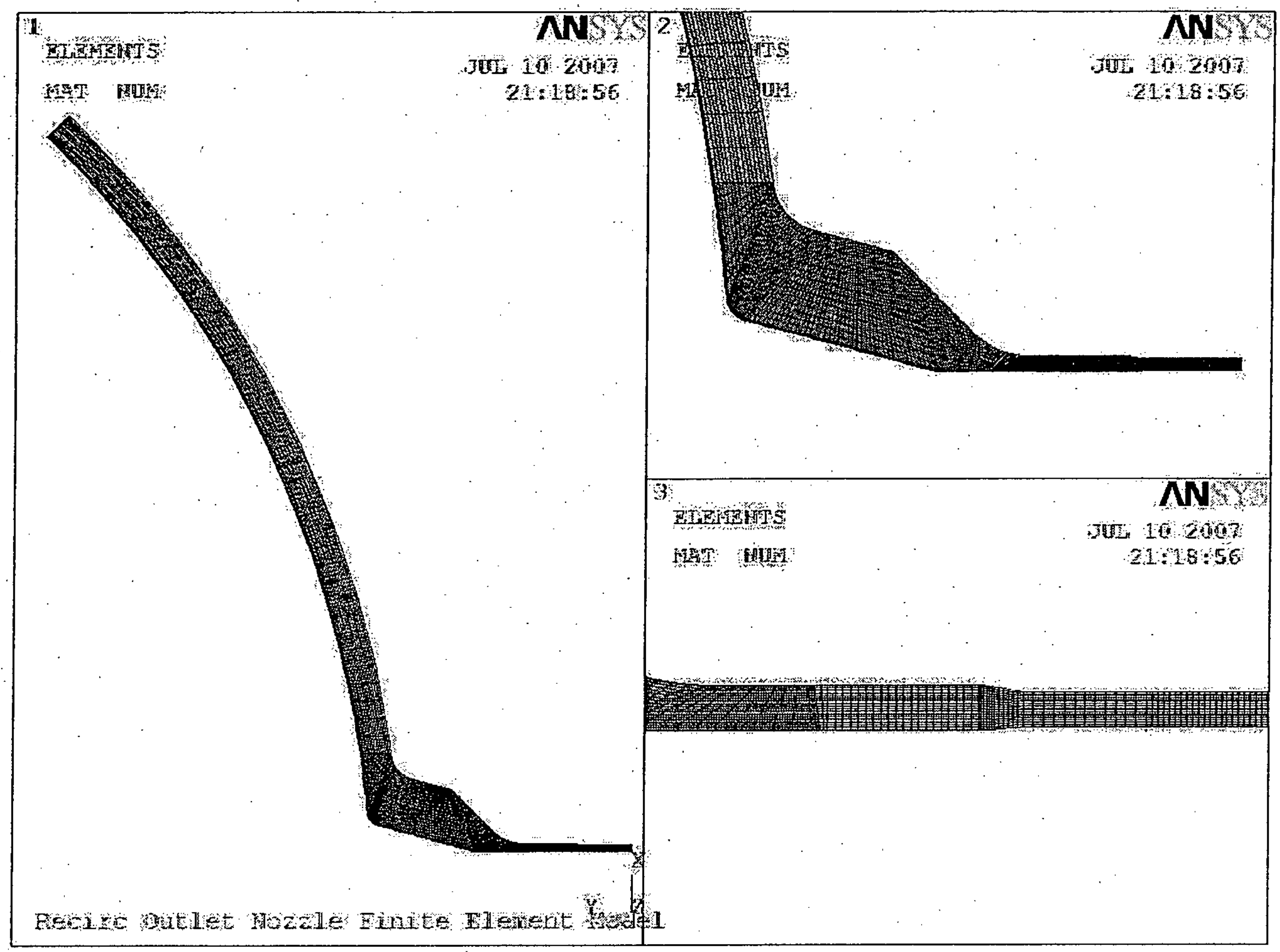


**Figure 1: ANSYS Finite Element Model**

# APPENDIX A

RON_VY.inp

```
finish
/clear,start
/prep7
/title, Recirc Outlet Nozzle Finite Element Model

/com, PLANE182, 2-D Solid
et,1,PLANE182,,,1   !Axisymmetric

/com, ****************************
/com, Material Properties @T=300F
/com, ****************************

/COM, Material #1 (Safe-End and Piping) SA-182 F316 (16Cr-12Ni-2Mo)
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mp,alpx,1,9.8E-06
mp,kxx,1,9.3/3600/12
mp,c,1,0.127
mp,nuxy,1,0.3
mp,dens,1,0.283

/COM, Material #2 (Nozzle Forging) SA-508 Class 2 (3/4Ni-1/2Mo-1/3Cr-V)
mp,ex,2,26.7E+06
mp,alpx,2,7.3E-06
mp,kxx,2,23.4/3600/12
mp,c,2,0.119
mp,nuxy,2,0.3
mp,dens,2,0.283

/COM, Material #3 (Cladding) SA-240 Type 304 (18Cr-8Ni)
mp,ex,3,27E+06
mp,alpx,3,9.8E-06
mp,kxx,3,9.8/3600/12
mp,c,3,0.125
mp,nuxy,3,0.3
mp,dens,3,0.283

/COM, Material #4 (Vessel) SA-533, GR. B (Mn-1/2Mo-1/2Ni)
mp,ex,4,28.0E+06
mp,alpx,4,7.7E-06
mp,kxx,4,23.4/3600/12
mp,c,4,0.119
mp,nuxy,4,0.3
mp,dens,4,0.283

*AFUN,DEG
/com, *** Geometric Parameters ***
*set,vira,(103+3/16)     !Actual Vessel Inner Radius to base metal used for model
*set,vir,2.0*vira         !2.0 time of  Vessel Inner Radius to base metal used for model
*set,tvw,5+5/8-3/16      !Vessel Wall Thickness
*set,ri1,25.75/2
*set,ro1,28.375/2
*set,L1,5
*set,ro2,28.375/2
```

```
*set,L2,4.25
*set,ro3,28.875/2
*set,ro4,48.75/2
*set,L3,1.5
*set,L4,5.25
*set,L5,7+1/16
*set,L6,12+13/16
*set,L7,9+7/8
*set,L8,9+3/8
*set,L9,31+15/16
*set,L10,L9-12-13/16-tvw
*set,ra,7
*set,rb,1
*set,rc,5.25
*set,rd,2.5
*set,tv,3/16
*set,dimA,vir-(tv*2.0)+L9+11+L1  !Vessel Centerline to End of Safe End used for model
*set,L21,1
*set,L22,4.25
*set,ri21,(25+15/16)/2

/com,*****************************************************************
/com, Geometry
/com,*****************************************************************
local,13,0,,dimA,,,,

csys,13

/com, Begin at end of Safe-End - Carbon Section

k, 1, ri1, -1*(dimA)
k, 2, ri1+tv, -1*(dimA)
k, 3, ro1, -1*(dimA)
k, 4, ri1, -1*(dimA-L1)
k, 5, ri1+tv, -1*(dimA-L1)
k, 6, ro1, -1*(dimA-L1)
k, 7, ri1, -1*(dimA-L1-L2)
k, 8, ri1+tv, -1*(dimA-L1-L2)
k, 9, ro2, -1*(dimA-L1-L2)
k, 10, ri1, -1*(dimA-L1-L2-L3)
k, 11, ri1+tv, -1*(dimA-L1-L2-L3)
k, 12, ro3, -1*(dimA-L1-L2-L3)
k, 13, ri1, -1*(dimA-L1-L2-L3-L4)
k, 14, ri1+tv, -1*(dimA-L1-L2-L3-L4)
k, 15, ro3, -1*(dimA-L1-L2-L3-L4)
k, 16, ri1, -1*(dimA-L1-L2-L3-L4-L5)
k, 17, ri1+tv, -1*(dimA-L1-L2-L3-L4-L5)
k, 18, ro3, -1*(dimA-L1-L2-L3-L4-L5)

k,19,   ro4, -1*(dimA-L1-L2-L3-L4-L5-L7)! Temporary Point
l,19,18
l,18,15
lfillt,1,2,ra
k,22,   ro4+(L8+6)*tan(15), -1*(dimA-L1-L2-L3-L4-L5-L7-(L8+6))
l,19,22
```

```
LFILLT,1,4,rb

k, 25, ri1, -1*(dimA-L1-L2-L3-L4-L6)
k, 26, ri1+tv, -1*(dimA-L1-L2-L3-L4-L6)

k, 27, ri1+(L10+tvw+tv+4)*tan(15), -1*(vir-tv-4)
k, 28, ri1+tv+(L10+tvw+tv+4)*tan(15), -1*(vir-tv-4)

k,29,    (vir+tvw+tv)*sin(45), -1*(vir+tvw+tv)*cos(45)
k,30,    0, -1*(vir+tvw+tv)  ! Temporary Point
k,31,    0, 0 ! Temporary Point

larc,29,30,31,vir+tvw+tv

k,32,    (vir+tv)*sin(45), -1*(vir+tv)*cos(45)
k,33,    0, -1*(vir+tv)  ! Temporary Point
larc,32,33,31,vir+tv

k,34,    vir*sin(45), -1*vir*cos(45)
k,35,    0, -1*vir  ! Temporary Point
larc,34,35,31,vir

LSTR,    4,    5
LSTR,    5,    6
LSTR,    6,    9
LSTR,    9,   12
LSTR,   12,   15
LSTR,    5,    8
LSTR,    4,    7
LSTR,    7,   10
LSTR,    8,   11
LSTR,   11,   14
LSTR,   10,   13
LSTR,   13,   16
LSTR,   14,   17
LSTR,   16,   25
LSTR,   17,   26
LSTR,   26,   28
LSTR,   25,   27
LSTR,    4,    1
LSTR,    1,    2
LSTR,    2,    3
LSTR,    3,    6
LSTR,    5,    2
LSTR,    7,    8
LSTR,    8,    9
LSTR,   12,   11
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FITEM,2,24
LPTN,P51X

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FITEM,2,40
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FITEM,2,44
LDELE,P51X, , ,1

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!*
LFILLT,43,8,rd, ,
!*
LFILLT,39,38,rc, ,

FLST,2,3,4,ORDE,3
FITEM,2,1
FITEM,2,3
FITEM,2,5
LCOMB,P51X, ,0
LSTR,    16,    17
LSTR,    17,    21
LSTR,    25,    26
LSTR,    26,    24
LSTR,    22,    30
LSTR,    30,    35
LSTR,    27,    28
LSTR,    28,    33
LSTR,    29,    32
LSTR,    32,    34

k,39,   0, -1*(vir+tvw+tv)

!Create Areas
FLST,2,4,4
FITEM,2,27
FITEM,2,30
FITEM,2,26
FITEM,2,9
AL,P51X
FLST,2,4,4
FITEM,2,28
FITEM,2,29
```

```
FITEM,2,10
FITEM,2,30
AL,P51X
FLST,2,4,4
FITEM,2,11
FITEM,2,32
FITEM,2,10
FITEM,2,14
AL,P51X
FLST,2,4,4
FITEM,2,15
FITEM,2,14
FITEM,2,9
FITEM,2,31
AL,P51X
FLST,2,4,4
FITEM,2,32
FITEM,2,33
FITEM,2,12
FITEM,2,17
AL,P51X
FLST,2,4,4
FITEM,2,16
FITEM,2,17
FITEM,2,31
FITEM,2,34
AL,P51X
FLST,2,4,4
FITEM,2,36
FITEM,2,13
FITEM,2,33
FITEM,2,18
AL,P51X
FLST,2,4,4
FITEM,2,19
FITEM,2,18
FITEM,2,35
FITEM,2,34
AL,P51X
FLST,2,4,4
FITEM,2,2
FITEM,2,5
FITEM,2,36
FITEM,2,21
AL,P51X
FLST,2,4,4
FITEM,2,20
FITEM,2,21
FITEM,2,3
FITEM,2,35
AL,P51X
FLST,2,4,4
FITEM,2,1
FITEM,2,37
FITEM,2,23
```

```
FITEM,2,5
AL,P51X
FLST,2,4,4
FITEM,2,22
FITEM,2,23
FITEM,2,25
FITEM,2,3
AL,P51X
FLST,2,4,4
FITEM,2,38
FITEM,2,42
FITEM,2,37
FITEM,2,8
AL,P51X
FLST,2,4,4
FITEM,2,4
FITEM,2,8
FITEM,2,25
FITEM,2,40
AL,P51X
FLST,2,4,4
FITEM,2,24
FITEM,2,45
FITEM,2,7
FITEM,2,42
AL,P51X
FLST,2,4,4
FITEM,2,6
FITEM,2,7
FITEM,2,44
FITEM,2,40
AL,P51X
FLST,2,4,4
FITEM,2,41
FITEM,2,43
FITEM,2,47
FITEM,2,44
AL,P51X
FLST,2,4,4
FITEM,2,39
FITEM,2,46
FITEM,2,45
FITEM,2,43
AL,P51X

! define materials
FLST,5,8,5,ORDE,2
FITEM,5,1
FITEM,5,-8
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
```

```
AATT,     1, ,  1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,5,5,ORDE,5
FITEM,5,9
FITEM,5,11
FITEM,5,13
FITEM,5,15
FITEM,5,18
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     2, ,  1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,5,5,ORDE,5
FITEM,5,10
FITEM,5,12
FITEM,5,14
FITEM,5,16
FITEM,5,-17
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     3, ,  1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*

!/com, Map mesh areas
FLST,5,10,4,ORDE,10
FITEM,5,5
FITEM,5,10
FITEM,5,28
FITEM,5,32
FITEM,5,-33
FITEM,5,36
FITEM,5,-37
FITEM,5,42
FITEM,5,45
FITEM,5,-46
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
```

```
CMSEL,,_Y
!*
LESIZE,_Y1, , ,15, , , , ,1
!*
FLST,5,10,4,ORDE,10
FITEM,5,3
FITEM,5,9
FITEM,5,25
FITEM,5,27
FITEM,5,31
FITEM,5,34
FITEM,5,-35
FITEM,5,40
FITEM,5,44
FITEM,5,47
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,2, , , , ,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,39
FITEM,5,41
FITEM,5,43
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,80, , , , ,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,6
FITEM,5,-7
FITEM,5,24
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,20, , , , ,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,4
FITEM,5,8
FITEM,5,38
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,40, , , , ,1
!*
```

```
FLST,5,3,4,ORDE,3
FITEM,5,1
FITEM,5,22
FITEM,5,-23
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,30, , , , ,1
!*
FLST,5,6,4,ORDE,6
FITEM,5,2
FITEM,5,20
FITEM,5,-21
FITEM,5,26
FITEM,5,29
FITEM,5,-30
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,40, , , , ,1
!*
FLST,5,9,4,ORDE,2
FITEM,5,11
FITEM,5,-19
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,20, , , , ,1
!*

! Meshing
FLST,5,18,5,ORDE,2
FITEM,5,1
FITEM,5,-18
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
MSHKEY,1
AMESH,_Y1
MSHKEY,0
!*
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*
```

```
!Modify the safe end ID
FLST,2,6,5,ORDE,2
FITEM,2,1
FITEM,2,-6
ACLEAR,P51X
FLST,2,6,5,ORDE,2
FITEM,2,1
FITEM,2,-6
ADELE,P51X
FLST,2,9,4,ORDE,7
FITEM,2,9
FITEM,2,14
FITEM,2,-17
FITEM,2,26
FITEM,2,-27
FITEM,2,30
FITEM,2,-31
LDELE,P51X, , ,1

FLST,2,3,4,ORDE,3
FITEM,2,10
FITEM,2,28
FITEM,2,32
LDELE,P51X, , ,1
FLST,3,2,3,ORDE,2
FITEM,3,3
FITEM,3,6
KGEN,2,P51X, , ,-ro2+ri21, , , ,0
FLST,3,1,3,ORDE,1
FITEM,3,2
KGEN,2,P51X, , , ,L22, , ,0
FLST,3,3,3,ORDE,3
FITEM,3,1
FITEM,3,-2
FITEM,3,4
KGEN,2,P51X, , ,tv, , , ,0
FLST,3,2,3,ORDE,2
FITEM,3,10
FITEM,3,-11
KGEN,2,P51X, , , ,-(L3-L21), , ,0
FLST,3,1,3,ORDE,1
FITEM,3,23
KGEN,2,P51X, , ,5, , , ,0
LSTR,      23,      40
FLST,2,2,4,ORDE,2
FITEM,2,9
FITEM,2,12
LPTN,P51X
LDELE,      16, , ,1
FLST,2,4,3
FITEM,2,11
FITEM,2,23
FITEM,2,41
FITEM,2,12
A,P51X
```

```
FLST,2,4,3
FITEM,2,23
FITEM,2,8
FITEM,2,9
FITEM,2,41
A,P51X
FLST,2,4,3
FITEM,2,8
FITEM,2,7
FITEM,2,6
FITEM,2,9
A,P51X
FLST,2,4,3
FITEM,2,7
FITEM,2,5
FITEM,2,3
FITEM,2,6
A,P51X
FLST,2,4,3
FITEM,2,10
FITEM,2,20
FITEM,2,23
FITEM,2,11
A,P51X
FLST,2,4,3
FITEM,2,20
FITEM,2,4
FITEM,2,8
FITEM,2,23
A,P51X
FLST,2,4,3
FITEM,2,4
FITEM,2,2
FITEM,2,7
FITEM,2,8
A,P51X
FLST,2,4,3
FITEM,2,2
FITEM,2,1
FITEM,2,5
FITEM,2,7
A,P51X
FLST,5,8,5,ORDE,4
FITEM,5,1
FITEM,5,-6
FITEM,5,19
FITEM,5,-20
CM,_Y,AREA
ASEL, , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     1, ,  1,      0,
CMSEL,S,_Y
```

```
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,4,4,ORDE,4
FITEM,5,15
FITEM,5,-16
FITEM,5,26
FITEM,5,28
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,15, , , , ,1
!*
FLST,5,4,4,ORDE,4
FITEM,5,31
FITEM,5,48
FITEM,5,50
FITEM,5,52
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,2, , , , ,1
!*
FLST,5,6,4,ORDE,6
FITEM,5,9
FITEM,5,-10
FITEM,5,12
FITEM,5,14
FITEM,5,30
FITEM,5,32
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,6, , , , ,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,11
FITEM,5,17
FITEM,5,49
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,12, , , , ,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,27
FITEM,5,29
```

```
FITEM,5,51
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,25, , , , ,1
!*
FLST,5,8,5,ORDE,4
FITEM,5,1
FITEM,5,-6
FITEM,5,19
FITEM,5,-20
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
MSHKEY,1
AMESH,_Y1
MSHKEY,0
!*
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*

FLST,2,2,5,ORDE,2
FITEM,2,17
FITEM,2,-18
ACLEAR,P51X

csys,0
k, 51,62/2,0,0
k, 52,62/2,60,0
LSTR,     51,     52
FLST,2,2,5,ORDE,2
FITEM,2,17
FITEM,2,-18
ADELE,P51X
lplo
FLST,2,4,4,ORDE,4
FITEM,2,39
FITEM,2,41
FITEM,2,43
FITEM,2,53
LPTN,P51X
FLST,2,2,4,ORDE,2
FITEM,2,60
FITEM,2,-61
LDELE,P51X, , ,1
FLST,2,4,4
FITEM,2,54
FITEM,2,62
```

```
FITEM,2,55
FITEM,2,44
AL,P51X
FLST,2,4,4
FITEM,2,55
FITEM,2,63
FITEM,2,58
FITEM,2,45
AL,P51X
FLST,2,4,4
FITEM,2,63
FITEM,2,56
FITEM,2,57
FITEM,2,46
AL,P51X
FLST,2,4,4
FITEM,2,47
FITEM,2,59
FITEM,2,57
FITEM,2,62
AL,P51X

CM,_Y,AREA
ASEL, , , ,     18
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     2, ,   1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,2,5,ORDE,2
FITEM,5,17
FITEM,5,22
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     3, ,   1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*
CM,_Y,AREA
ASEL, , , ,     21
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     4, ,   1,     0,
CMSEL,S,_Y
```

```
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,3,4,ORDE,3
FITEM,5,54
FITEM,5,-55
FITEM,5,58
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,8, , , , ,1
!*
FLST,5,3,4,ORDE,3
FITEM,5,56
FITEM,5,-57
FITEM,5,59
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,40, , , , ,1
!*
FLST,5,2,5,ORDE,2
FITEM,5,17
FITEM,5,-18
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
MSHKEY,1
AMESH,_Y1
MSHKEY,0
!*
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*
FLST,5,2,5,ORDE,2
FITEM,5,21
FITEM,5,-22
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
MSHKEY,1
AMESH,_Y1
MSHKEY,0
!*
```

```
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*

!Simulating Butter
FLST,2,2,5,ORDE,2
FITEM,2,9
FITEM,2,-10
ACLEAR,P51X
FLST,2,2,5,ORDE,2
FITEM,2,9
FITEM,2,-10
ADELE,P51X

KGEN,2,15, , , ,11/16, , ,0
KGEN,2,44, , , ,-0.25, , ,0
KGEN,2,14, , , ,11/16-1.375*tan(7.5), , ,0
KGEN,2,46, , , ,-0.25, , ,0

FLST,2,3,4,ORDE,3
FITEM,2,2
FITEM,2,20
FITEM,2,-21
LDELE,P51X
LSTR,      21,     44
LSTR,      44,     45
LSTR,      45,     15
LSTR,      17,     46
LSTR,      46,     47
LSTR,      47,     14
LSTR,      46,     44
LSTR,      45,     47
LSTR,      13,     16
FLST,3,2,3,ORDE,2
FITEM,3,46
FITEM,3,-47
KGEN,2,P51X, , ,-0.25, , , ,0
LSTR,      48,     46
LSTR,      49,     47
FLST,2,3,4,ORDE,3
FITEM,2,61
FITEM,2,64
FITEM,2,-65
LPTN,P51X
FLST,2,2,4,ORDE,2
FITEM,2,70
FITEM,2,-71
LDELE,P51X, , ,1
FLST,2,4,4
FITEM,2,67
FITEM,2,39
FITEM,2,68
FITEM,2,3
AL,P51X
```

```
FLST,2,4,4
FITEM,2,39
FITEM,2,5
FITEM,2,2
FITEM,2,53
AL,P51X
FLST,2,4,4
FITEM,2,20
FITEM,2,60
FITEM,2,53
FITEM,2,41
AL,P51X
FLST,2,4,4
FITEM,2,72
FITEM,2,68
FITEM,2,69
FITEM,2,41
AL,P51X
FLST,2,4,4
FITEM,2,21
FITEM,2,60
FITEM,2,36
FITEM,2,43
AL,P51X
FLST,2,4,4
FITEM,2,66
FITEM,2,69
FITEM,2,35
FITEM,2,43
AL,P51X

CM,_Y,AREA
ASEL, , , ,     10
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     2, ,  1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,3,5,ORDE,3
FITEM,5,9
FITEM,5,23
FITEM,5,-24
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     3, ,  1,     0,
CMSEL,S,_Y
CMDELE,_Y
```

```
CMDELE,_Y1
!*
FLST,5,2,5,ORDE,2
FITEM,5,25
FITEM,5,-26
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CMSEL,S,_Y
!*
CMSEL,S,_Y1
AATT,     1, ,  1,     0,
CMSEL,S,_Y
CMDELE,_Y
CMDELE,_Y1
!*
FLST,5,3,4,ORDE,3
FITEM,5,2
FITEM,5,39
FITEM,5,67
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,10, , , , ,1
!*
FLST,5,6,4,ORDE,6
FITEM,5,20
FITEM,5,-21
FITEM,5,41
FITEM,5,43
FITEM,5,66
FITEM,5,72
CM,_Y,LINE
LSEL, , , ,P51X
CM,_Y1,LINE
CMSEL,,_Y
!*
LESIZE,_Y1, , ,2, , , , ,1
!*
FLST,5,2,5,ORDE,2
FITEM,5,9
FITEM,5,-10
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
MSHKEY,1
AMESH,_Y1
MSHKEY,0
!*
CMDELE,_Y
```

```
CMDELE,_Y1
CMDELE,_Y2
!*
FLST,5,4,5,ORDE,2
FITEM,5,23
FITEM,5,-26
CM,_Y,AREA
ASEL, , , ,P51X
CM,_Y1,AREA
CHKMSH,'AREA'
CMSEL,S,_Y
!*
MSHKEY,1
AMESH,_Y1
MSHKEY,0
!*
CMDELE,_Y
CMDELE,_Y1
CMDELE,_Y2
!*

save
finish
```

Structural Integrity Associates, Inc.

# CALCULATION PACKAGE

**File No.:** VY-16Q-305

**Project No.:** VY-16Q

NEC-JH_08

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Recirculation Outlet Stress History Development for Nozzle Green Function

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-29, Appendix: A1-A2 | Initial Issue | Terry J. Herrmann 07/18/2007 [signature] | Jennifer E. Smith 07/18/2007 [signature]<br>Minghao Qin 07/18/2007 [signature] |

## Table of Contents



## List of Tables

## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation is to compute the pressure stresses, thermal stresses, and the Green's Functions for high (100%), mid (50%), and no (0%) flow thermal loading of the Vermont Yankee Nuclear Power Station recirculation outlet nozzle.

## 2.0 RECIRCULATION OUTLET NOZZLE MODEL

An axisymmetric finite element model of the recirculation outlet nozzle was developed in Reference [1] using ANSYS [2]. The geometry and model in Reference [1] is used in this calculation. The material properties are taken at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which will be applied to the FE model for Green's Function development. Table 1 listed the material properties at 300°F. The meshed model is shown in Figure 1.

## 3.0 APPLIED LOADS

Both pressure and thermal loads will be applied to the finite element model.

### 3.1 Pressure Load

A uniform pressure of 1000 psi was applied along the inside surface of the recirculation outlet nozzle and the vessel wall. A pressure load of 1000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the nozzle. This cap load was calculated as follows:

$$P_{cap} = P \cdot \frac{\left(D_i^{\,2}\right)}{\left(D_o^{\,2} - D_i^{\,2}\right)}$$

where:

$P$ = Pressure = 1,000 psi
$D_i$ = Inner Radius = 12.96875 in
$D_o$ = Outer Radius = 14.18750 in
$P_{cap}$ = Tension stress on the end of the nozzle. (psi)

Therefore, the cap load is 5081.7 psi. The calculated value was given a negative sign in order for it to exert tension on the end of the model. The ANSYS input file VY_RON_P.INP, in the computer files, applies the pressure loading to the geometry in file RON_VY.INP. Figures 2, 3, and 4 show the internal pressure distribution, cap load, and symmetry condition applied to the vessel end of the model, respectively.

### 3.2 Thermal Load

Thermal loads are applied to the recirculation outlet nozzle model. The heat transfer coefficients after power uprate were determined by scaling the values from Reference [4]. These values were determined for various regions of the finite element model and for 100% (28,294 GPM, converted from 12.3 Mlbm/hr [7]), 50% (14,147 GPM), and 0% (0 GPM) flow rates. The temperatures used are based upon a thermal shock from 500°F to 100°F. The calculated heat transfer coefficients for each region are shown below. The GPM values are calculated from the Mlbm/hr values at an average temperature of 300°F.

#### 3.2.1 *Heat Transfer Coefficients*

The heat transfer coefficients for the 100% flow and 50% flow cases were calculated from Reference [4] as follows:

$$h_{Df} = h_{300}\left(\frac{f_{Df}}{25}\right)^{0.8}\left(\frac{26}{D_{Df}}\right)^{0.2}$$

Where:
$h_{Df}$ = the heat transfer coefficient at a Diameter and flow rate
$h_{300}$ = the heat transfer coefficient from Reference [4] at 300°F
$f_{Df}$ = the flow rate corresponding to $h_{Df}$ (ft/sec)
$D_{Df}$ = the diameter corresponding to $h_{Df}$ (in)

The heat transfer coefficients for 0% flow were calculated in spreadsheet Ht_coeffs.xls for natural convection and are shown in Tables 3 and 4.

As shown in Figure 5, the following heat transfer coefficients were applied:

<u>Region 1</u>

The heat transfer coefficient, h, for 100% flow is $4789\left(\frac{17.364}{25}\right)^{0.8} = 3577.8$ BTU/hr-ft$^2$-°F at 300°F. [4]

where 17.364 ft/sec is converted from 28,294 GPM and 25.8 in ID.

The heat transfer coefficient, h, for 50% flow is $4789\left(\frac{8.682}{25}\right)^{0.8} = 2054.9$ BTU/hr-ft$^2$-°F at 300°F. [4]

where 8.682 ft/sec is converted from 14,147 GPM and 25.8 in ID.

The heat transfer coefficient, h, for 0% flow is 112.34 BTU/hr-ft$^2$-°F at 300°F. [Table 3, for natural convection]

Region 2

The heat transfer coefficient for Region 2 is linearly transitioned from the value of the heat transfer coefficient used in Region 1 to the value used for Region 3.

Region 3 (the point between Region 2 and Region 4)

The heat transfer coefficient, h, for 100% flow is $4789\left(\frac{17.364}{25}\right)^{0.8}\cdot\left(\frac{26}{35.49}\right)^{0.2}=3361$ BTU/hr-ft$^2$-°F at 300°F. [4]

where the flow rate is the same as that for Region 1, and the ID is 35.49 in.

The heat transfer coefficient, h, for 50% flow is $4789\left(\frac{8.682}{25}\right)^{0.8}\cdot\left(\frac{26}{35.49}\right)^{0.2}=1930.9$ BTU/hr-ft$^2$-°F at 300°F. [4]

where the flow rate is the same as that for Region 1, and the ID is 35.49 in.

The heat transfer coefficient, h, for 0% flow is 112.34 BTU/hr-ft$^2$-°F at 300°F. using the same HTC as Region 1 [Table 3, for natural convection]

Region 4

Per Reference [1], the heat transfer coefficient for Region 4 (Nozzle Blend Radius) is linearly transitioned from the value of the heat transfer coefficient used in Region 3 to the value used in Region 5.

Region 5

The heat transfer coefficient, h, for 100% flow is 0.5 x 3577.8 = 1788.9 BTU/hr-ft$^2$-°F at 300°F. [4]

The heat transfer coefficient, h, for 50% flow is 0.5 x 2054.9 = 1027.4 BTU/hr-ft$^2$-°F at 300°F. [4]

The heat transfer coefficient, h, for 0% flow is 101 BTU/hr-ft$^2$-°F at 300°F. [Table 4, for natural convection] by using 40 in. hydraulic diameter [4].

Region 6

The heat transfer coefficient, h, is 0.4 BTU/hr-ft$^2$-°F [4].

### 3.2.2 *Boundary Fluid Temperatures*

For the Green's Functions, a 500°F to 100°F thermal shock is run to determine the stress response to a one-degree change in temperature. The following temperatures are valid when there is water flow. Values between defined points are linearly interpolated. For the 100%, 50%, and 0% flow cases, the thermal shock is run as follows:

Regions 1 to 5
T = 500°F – 100°F
Region 6
T = 120°F

## 4.0 THERMAL AND PRESSURE LOAD RESULTS

The three flow dependent thermal load cases outlined in Section 3.0 were run on the finite element model. Appendix A contains the thermal transient input files VY_RON_T_100.INP, VY_RON_T_50.INP, and VY_RON_T_0.INP for 100%, 50%, and 0% flow rates, respectively. The three flow dependent input files for the stress runs are also included in Appendix A. The stress filenames are VY_RON_S_100.INP, VY_RON_S_50.INP, and VY_RON_S_0.INP for 100%, 50%, and 0% flow rates, respectively.

The critical safe end location was chosen as node 6395, which has the highest stress intensity due to thermal loading under high flow conditions. As shown in Figures 6 and 7, Node 6395 is located on the inside diameter of the nozzle safe end of the model and the maximum stress occurs at 5.1 seconds.

The critical blend radius location was chosen, based upon the highest pressure stress. Assumed the cladding has cracked, therefore, as shown in Figures 8 and 9, the critical location is selected as node 3829 at base metal of the nozzle.

The stress intensity for use in the Green's functions are calculated from the component stresses (X, Y, and Z) and compared to the stress intensity reported by ANSYS. As seen in Figure 10, the Y-X calculated total stress intensity best matches the ANSYS reported stress intensity for 100% flow at the safe end. Therefore, the Y-X stress will be used for the total and membrane plus bending Green's functions for all flow rates for the safe end. As seen in Figure 11, the Z-X calculated total stress intensity best matches the ANSYS reported stress intensity for 100% flow at the blend radius in very beginning. Therefore, the Z-X stress will be used for the total and membrane plus bending Green's functions for all flow rates for the blend radius.

The stress time history for the critical paths was extracted during the stress run for 100% flow rate. This produced two files, HFSE.OUT and HFBR.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the files HFSE_Inside.RED and HFBR_Inside.RED, where SE and BR corresponded to the safe end and blend radius locations, respectively. The total stress intensity (SI) was extracted from these files to produce the files HFSE.CLD and HFBR.CLD, where SE and BR corresponded to the safe end and the blend radius, respectively.

The stress time history for the critical paths was extracted during the stress run for 50% flow rate. This produced two files, MFSE.OUT and MFBR.OUT which contains the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from the file to produce the file MFSE_Inside.RED, where SE corresponds to the safe end location.

The stress time history for the critical paths was extracted during the stress run for 0% flow rate. This produced two files, LFSE.OUT and LFBR.OUT which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from the file to produce the file LFSE_Inside.RED, where SE corresponds to the safe end location.

The stress time history for the recirculation outlet nozzle during 100% flow, 50% flow, and 0% flow are shown in Figures 12 to 23. The data for the Green's Functions is included in the files HFBR_M+B-Green.xls, HFBR_T-Green.xls, HFSE_M+B-Green.xls, HFSE_T-Green.xls, MFBR_M+B-Green.xls, MFBR_T_Green.xls, MFSE_M+B-Green.xls, MFSE_T-Green.xls, LFBR_M+B-Green.xls, LFBR_T-Green.xls, LFSE_M+B-Green.xls, and LFSE_T-Green.xls in the project Files. Where HF, MF, and LF corresponded to 100% flow, 50% flow, and 0% flow rate, respectively. M+B and T corresponded to membrane plus bending stress and total stress, respectively.

The pressure stress intensities for the path were extracted during the pressure run. The pressure stresses were extracted along the nodal path as shown in Figures 7 and 9. This produced two files, PSE.OUT and PBR.OUT for the safe end and blend radius locations, respectively.

For the pressure loading specified (1000 psig), the total stress intensities at Node 6395 and Node 3829 were determined to be 11490 psi and 31300 psi, respectively. The membrane plus bending stress intensities at Node 6395 and Node 3829 were determined to be 11350 psi and 33640 psi, respectively. Table 2 shows the final pressure results.

Results were also extracted from the vessel portion of the model to verify the accuracy of the results obtained from the ANSYS model, and to check the results due to the use of the 2.0 multiplier on the vessel radius. These results are contained in the file PVESS.OUT. The radius of the finite element model (FEM) was multiplied by a factor of 2.0 [1] to account for the fact that the vessel portion of the 2D axisymmetric model is a sphere but the true geometry is the intersection of two cylinders.

The equation for the membrane hoop stress for a sphere is:

$$\sigma = \left( \frac{(pressure) \times (radius)}{2 \times thickness} \right)$$

Considering a vessel base metal radius, R, of 105.906 inches increased by a factor of 2.0, a vessel base metal thickness, t, of 5.4375 inches, and an applied pressure, P, of 1,000 psi, the calculated stress for a sphere is PR/(2t) = 19,477 psi. This compares very well with the remote vessel wall membrane hoop stress from the ANSYS result file, PVESS.OUT, of 19,540 psi. Thus, considering the peak total pressure stress of 31,300 psi reported above, the stress concentrating effect of the nozzle corner is 31,300/19,477 = 1.61. In other words, the peak nozzle corner stress is 1.61 times higher than nominal vessel wall stress for the 2D axisymmetric model.

The equation for the membrane hoop stress in a cylinder is:

$$\sigma = \left( \frac{(pressure) \times (radius)}{thickness} \right).$$

Based on the previous dimensions, the calculated stress for a cylinder without the 2.0 factor is 19,477 psi. Increasing this by a factor of 1.61 yields an expected peak nozzle corner stress of 31,358 psi, which would be expected from a cylindrical geometry that is representative of the nozzle configuration. Therefore, the result from the ANSYS file for the peak nozzle corner stress (31,300 psi) is close to the peak nozzle corner stress for a cylindrical geometry because of the use of the 2.0 multiplier. This is consistent with SI's experience where a factor of two increase in radius is typical for representing the three-dimensional (3D) effect in a 2D axisymmetric model.

## 5.0 REFERENCES

1. SI Calculation No. VY-16Q-304, Revision 0, "Recirculation Outlet Nozzle Finite Element Model"
2. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.
3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
4. CB&I, RPV Stress Report Section: T9 "Thermal Analysis Recirculation Outlet Nozzle Vermont Yankee Reactor Vessel." 9-6201, SI document, VY-16Q-204.
5. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.
6. J. P. Holman, "Heat Transfer," 5th Edition, 1981.
7. Entergy Nuclear Northeast Engineering Report, Report No. VY-RPT-05-00022, "Task T0100 Reactor Heat Balance EPU Task Report for ER-04-1409," SI File No. VY-16Q-205.

## Table 1: Material Properties @ 300°F[1]

| Material | SA-533 Gr B (Mn-1/2Mo-1/2Ni) | SA-508 Cl 2 (3/4Ni-1/2Mo-1/3Cr-V) | SA-240 Type 304 (18Cr-8Ni) | SA-182 F316/ SA 376 TP316 (16Cr-12Ni-2Mo) |
|---|---|---|---|---|
| Modulus of Elasticity, $e^{-6}$ psi | 28.0 | 26.7 | 27.0 | 27.0 |
| Coefficient of Thermal Expansion, $e^{-6}$, in/in/°F | 7.7 | 7.3 | 9.8 | 9.8 |
| Thermal Conductivity, Btu/hr-ft-°F | 23.4 | 23.4 | 9.8 | 9.3 |
| Thermal Diffusivity, $ft^2$/hr | 0.401 | 0.401 | 0.160 | 0.150 |
| Calculated Specific Heat, Btu/lb-°F [2] | 0.119 | 0.119 | 0.125 | 0.127 |
| Density, $lb/in^3$ | 0.283 | 0.283 | 0.283 | 0.283 |
| Poisson's Ratio | 0.3 | 0.3 | 0.3 | 0.3 |

Notes: [1]The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, Section II, Part D, with 2000 Addenda, except for density and Poisson's ratio, which are assumed typical values.
[2] Calculated as $[k/(\rho d)]/12^3$.

## Table 2: Pressure Results

| Location | Membrane Plus Bending Stress Intensity (psi) | Total Stress Intensity (psi) |
|---|---|---|
| Safe End | 11350 | 11490 |
| Blend Radius | 33640 | 31300 |

## Table 3: 0% Flow Regions 1 and 3 Heat Transfer Coefficients

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 25.800 | inches = | 2.150 | ft | | | | |
| | | = | 0.655 | m | | | | |
| Outer Pipe, Inside radius, $r_o$ = | 12.9 | inches = | 1.075 | ft | | | | |
| | | | 0.328 | m | | | | |
| Inner Pipe Outside Diameter, D = | n/a | inches = | 0.000 | ft | | | | |
| | | = | 0.000 | m | | | 0.000 | |
| Inner Pipe, Outside radius, $r_i$ = | 0 | inches = | 0.000 | ft | | | | |
| | | | 0.000 | m | | | | |
| Fluid Velocity, V = | 17.364 | ft/sec = | 28293.595 | gpm= | | 12.3 Mlb/hr | | |
| Characteristic Length, L = D = | 2.150 | ft = | 0.655 | m | | | | |
| (Outside) $T_{fluid} - T_{surface}$, ΔT = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [1] | Value at Fluid Temperature, T [3] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k (Thermal Conductivity) | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ (Specific Heat) | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ (Density) | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β (Volumetric Rate of Expansion) | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g (Gravitational Constant) | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ (Dynamic Viscosity) | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | $\rho VD/\mu$ | 3473691 | 5061789 | 10891437 | 16454670 | 21515912 | 26132199 | 27337904 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 2441754517 | 1.2697E+10 | 2.417E+11 | 1.252E+12 | 3.977E+12 | 1.034E+13 | 2.16049E+13 | --- |
| Grashof Number, $Gr_\delta$ | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | 3.05E+08 | 1.59E+09 | 3.02E+10 | 1.57E+11 | 4.97E+11 | 1.29E+12 | 2.70E+12 | --- |
| Rayleigh Number, Ra | GrPr | 17043446531 | 5.7265E+10 | 4.616E+11 | 1.528E+12 | 3.778E+12 | 8.883E+12 | 2.31172E+13 | --- |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 2.13E+09 | 7.16E+09 | 5.77E+10 | 1.91E+11 | 4.72E+11 | 1.11E+12 | 2.89E+12 | --- |
| *From [1]:* | | | | | | | | | |
| ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ | $0.023Re^{0.8}Pr^{0.4}k/D$ | 7,823.02 | 9,326.34 | 13,148.12 | 15,405.24 | 16,705.40 | 17,126.15 | 16,275.32 | $W/m^2$-°C |
| | | 1,377.74 | 1,642.50 | 2,315.56 | 2,713.07 | 2,942.05 | 3,016.15 | 2,866.31 | $Btu/hr-ft^2$-°F |
| *From [1]:* | | | | | | | | | |
| ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | | | |
| $H_{free}$ | $C(GrPr)^n k/L$ | 181.85 | 258.65 | 469.34 | 637.89 | 773.57 | 875.17 | 933.22 | $W/m^2$-°C |
| | | 32.03 | 45.55 | 82.66 | 112.34 | 136.24 | 154.13 | 164.35 | $Btu/hr-ft^2$-°F |

# Table 4: 0% Flow Region 5 Heat Transfer Coefficient

## Heat Transfer Coefficients

*References: 1. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.*
*2. J. P. Holman, "Heat Transfer," 5th Edition, 1981.*
*3. N. P. Cheremisinoff, "Heat Transfer Pocket Handbook," Gulf Publishing Co., 1984.*
*(Required Inputs are Shaded!)*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Title = | Piping | | | | | | | |
| Pipe Inside Diameter, D = | 40.000 | inches = | 3.333 | ft | | | | |
| | | = | 1.016 | m | | | | |
| Outer Pipe, Inside radius, $r_o$ = | 20 | inches = | 1.667 | ft | | | | |
| | | | 0.508 | m | | | | |
| Inner Pipe Outside Diameter, D = | n/a | inches = | 0.000 | ft | | | | |
| | | = | 0.000 | m | | | 0.000 | |
| Inner Pipe, Outside radius, $r_i$ = | 0 | inches = | 0.000 | ft | | | | |
| | | | 0.000 | m | | | | |
| Fluid Velocity, V = | 7.224 | ft/sec = | 28293.595 | gpm= | | 12.3 Mlb/hr | | |
| Characteristic Length, L = D = | 3.333 | ft = | 1.016 | m | | | | |
| (Outside) $T_{fluid}$ - $T_{surface}$, ΔT = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [1] | Value at Fluid Temperature, T [3] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | kg/m$^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | lbm/ft$^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | m$^3$/m$^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | ft$^3$/ft$^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | m/s$^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | ft/s$^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | ρVD/μ | 2240531 | 3264854 | 7024977 | 10613262 | 13877763 | 16855268 | 17632948 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 9099611606 | 4.732E+10 | 9.01E+11 | 4.667E+12 | 1.48E+13 | 3.85E+13 | 8.05143E+13 | --- |
| Grashof Number, $Gr_\delta$ | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | 1.14E+09 | 5.91E+09 | 1.13E+11 | 5.83E+11 | 1.85E+12 | 4.82E+12 | 1.01E+13 | --- |
| Rayleigh Number, Ra | GrPr | 6.3515E+10 | 2.134E+11 | 1.72E+12 | 5.694E+12 | 1.41E+13 | 3.31E+13 | 8.61503E+13 | --- |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 7.94E+09 | 2.67E+10 | 2.15E+11 | 7.12E+11 | 1.76E+12 | 4.14E+12 | 1.08E+13 | --- |

*From [1]:*
***Inside Surface Forced Convection Heat Transfer Coefficient:***

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $H_{forced}$ | $0.023Re^{0.8}Pr^{0.4}k/D$ | 3,552.89 | 4,235.64 | 5,971.33 | 6,996.42 | 7,586.90 | 7,777.99 | 7,391.58 | W/m$^2$-°C |
| | | 625.71 | 745.95 | 1,051.63 | 1,232.17 | 1,336.16 | 1,369.81 | 1,301.76 | Btu/hr-ft$^2$-°F |

*From [1]:*
***Inside Surface Natural Convection Heat Transfer Coefficient:***

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | | | |
| $H_{free}$ | $C(GrPr)^nk/L$ | 162.97 | 231.79 | 420.60 | 571.66 | 693.25 | 784.30 | 836.32 | W/m$^2$-°C |
| | | 28.70 | 40.82 | 74.07 | 100.68 | 122.09 | 138.13 | 147.29 | Btu/hr-ft$^2$-°F |

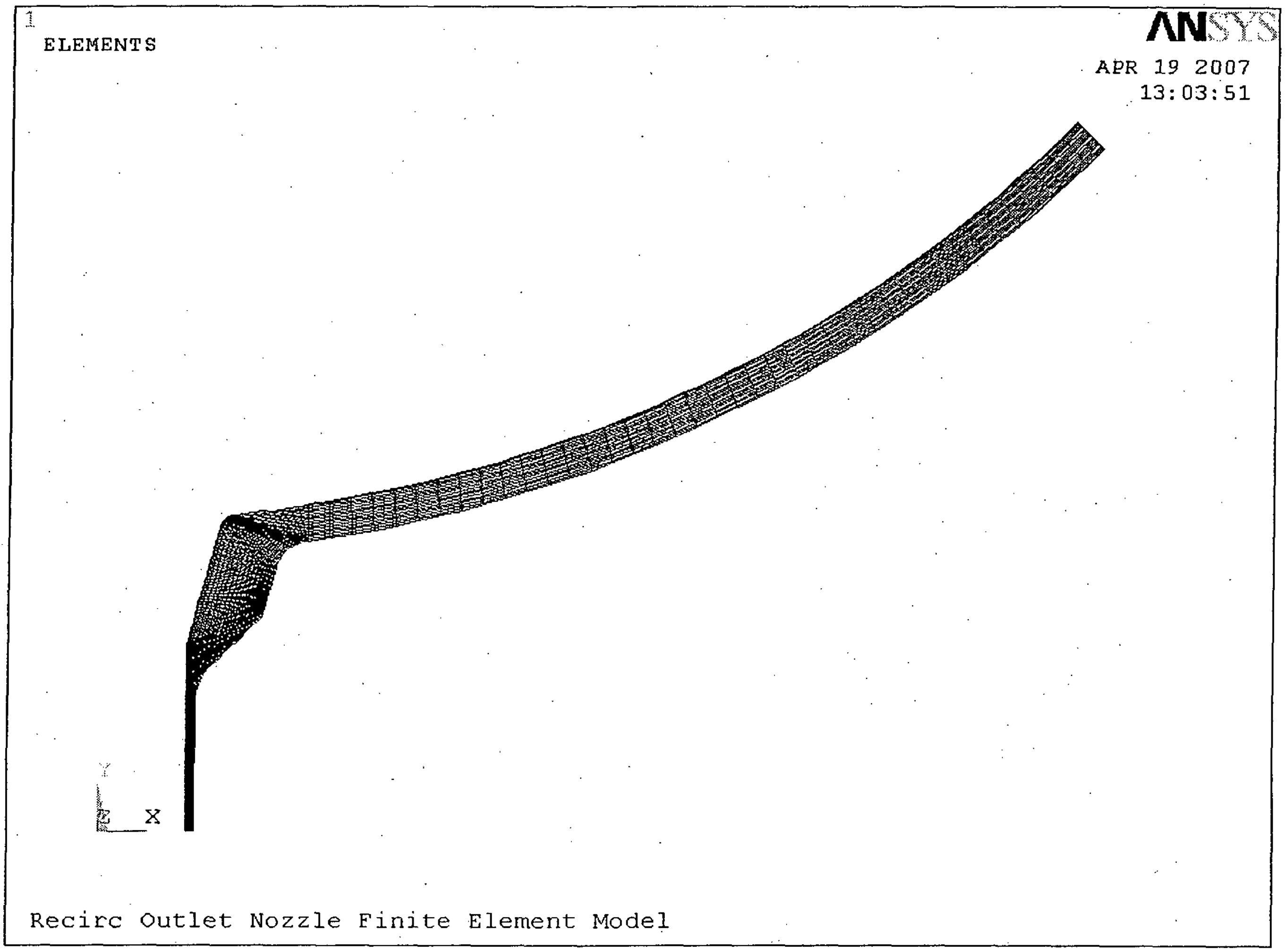



**Figure 1: ANSYS Finite Element Model**

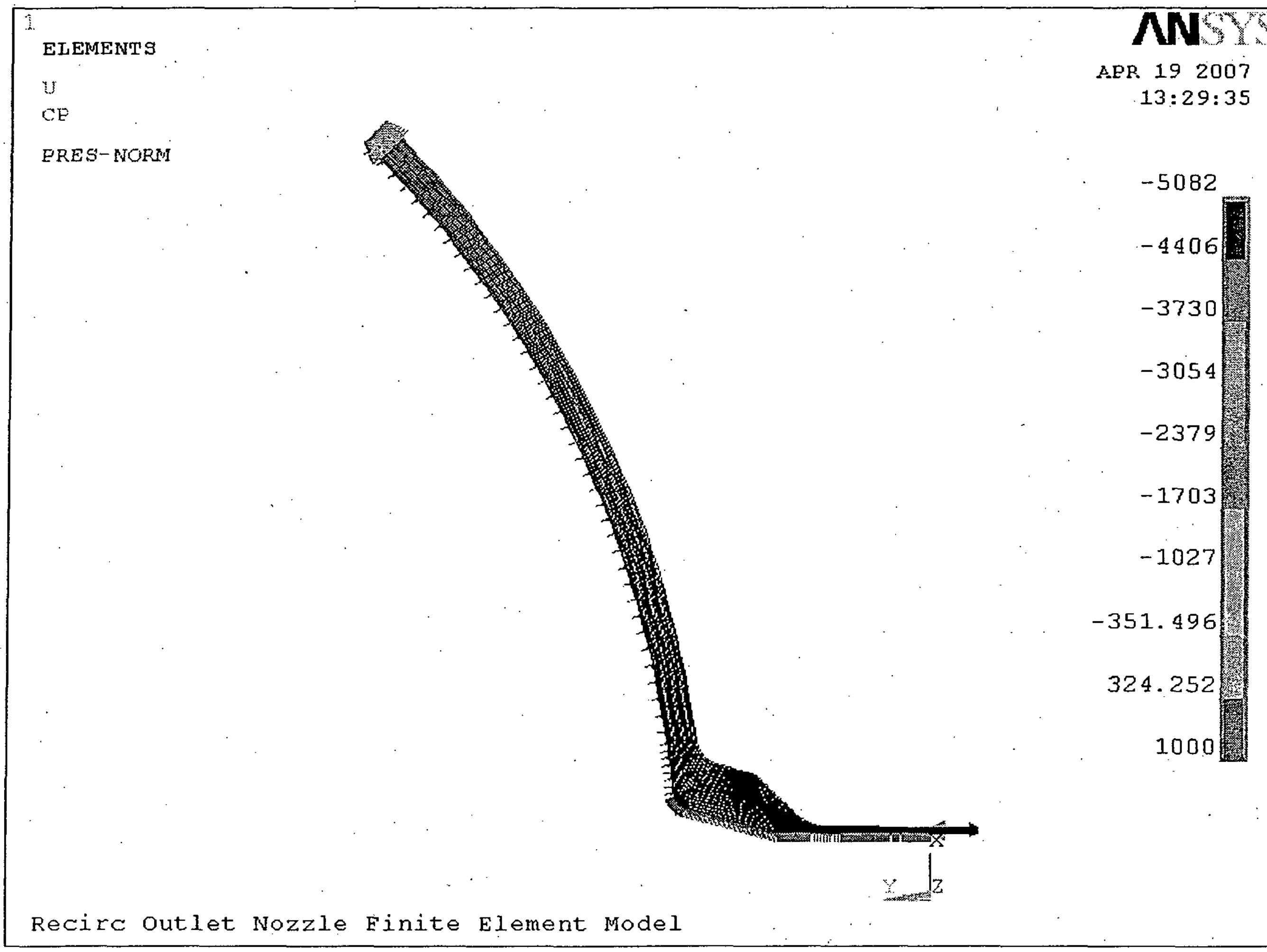



**Figure 2: Recirculation Outlet Nozzle Internal Pressure Distribution**

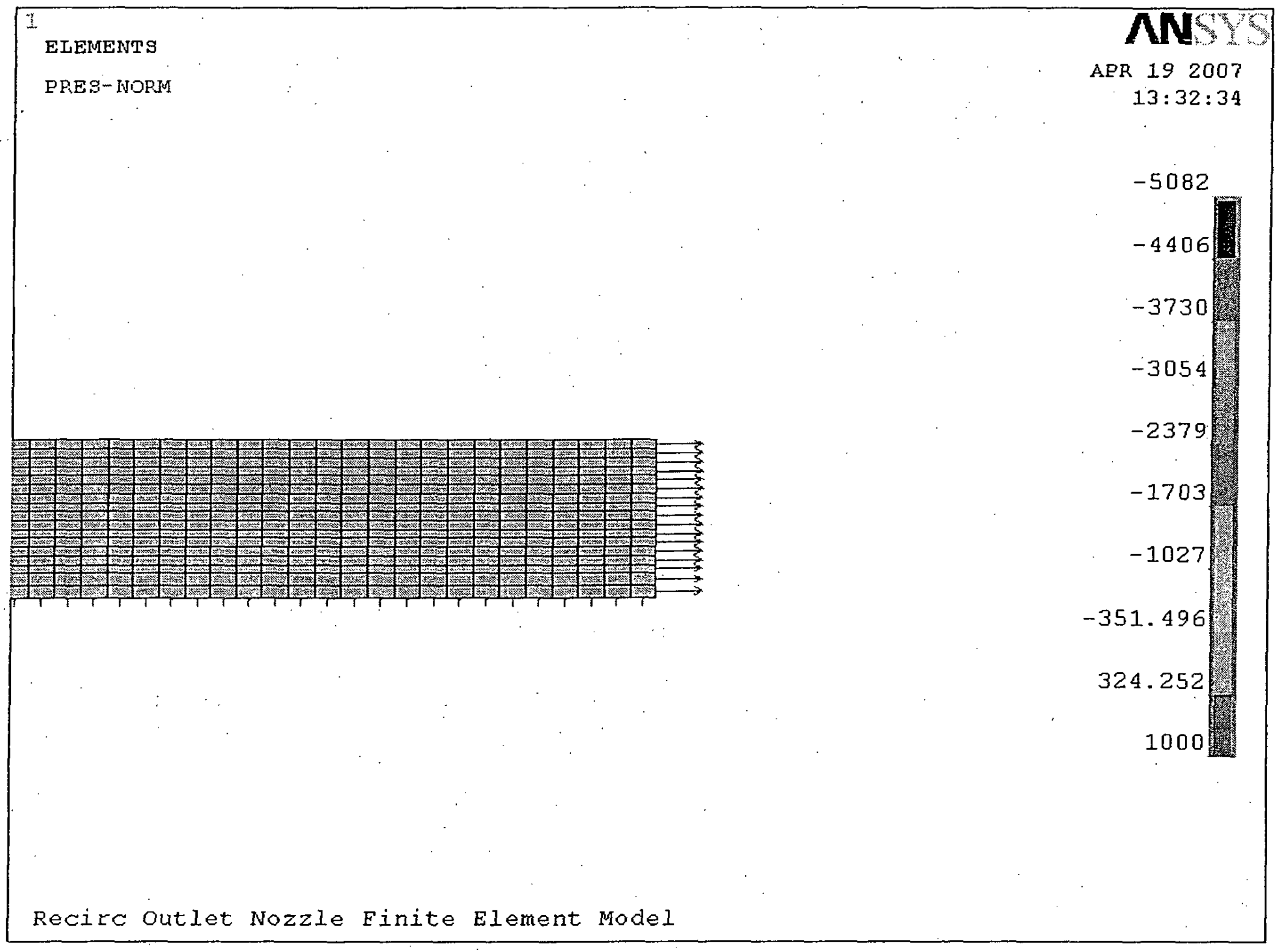



**Figure 3: Recirculation Outlet Nozzle Pressure Cap Load**

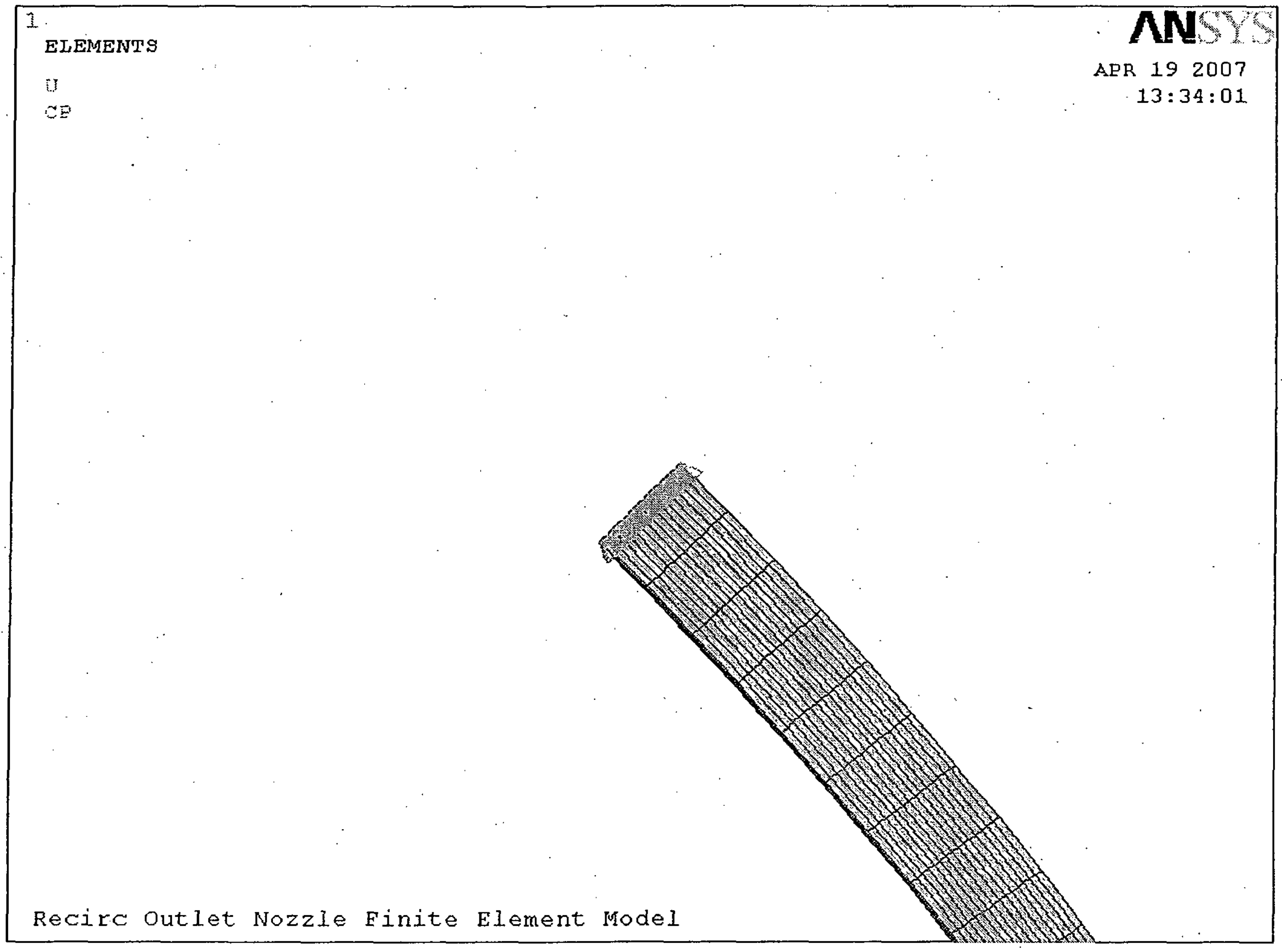



**Figure 4: Recirculation Outlet Nozzle Vessel Boundary Conditions**

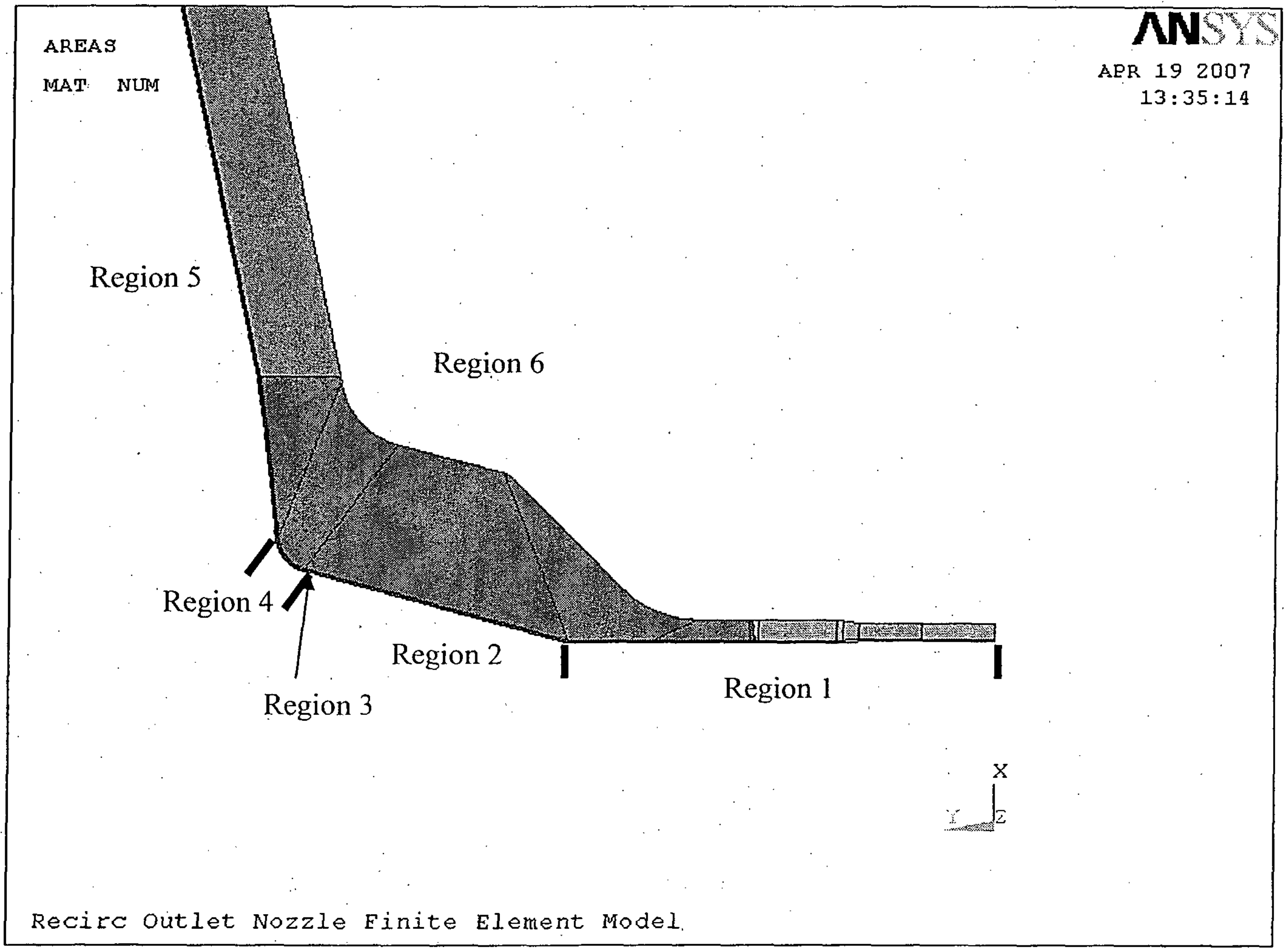



**Figure 5: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries**

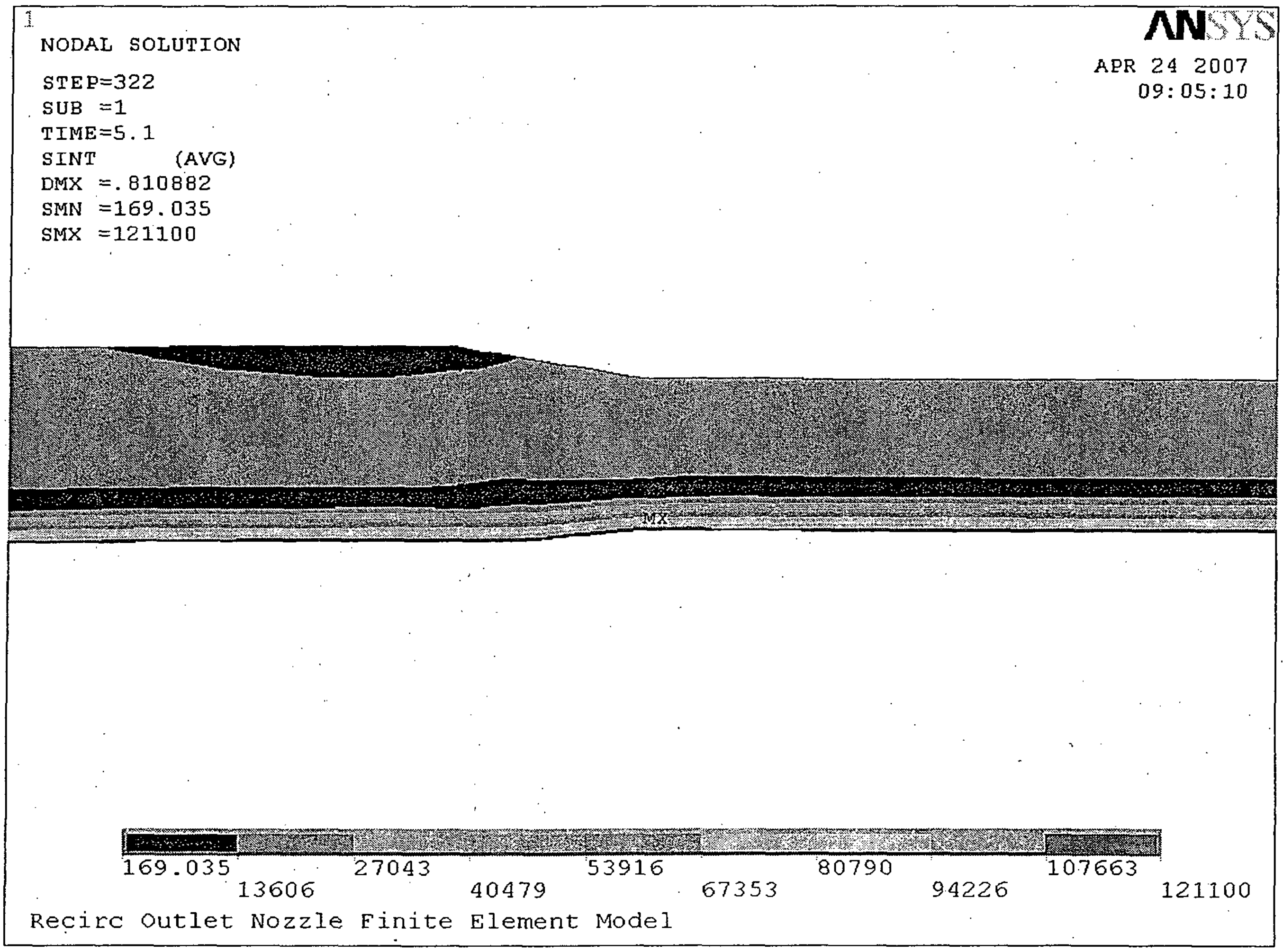



**Figure 6: Safe End Critical Thermal Stress Location**

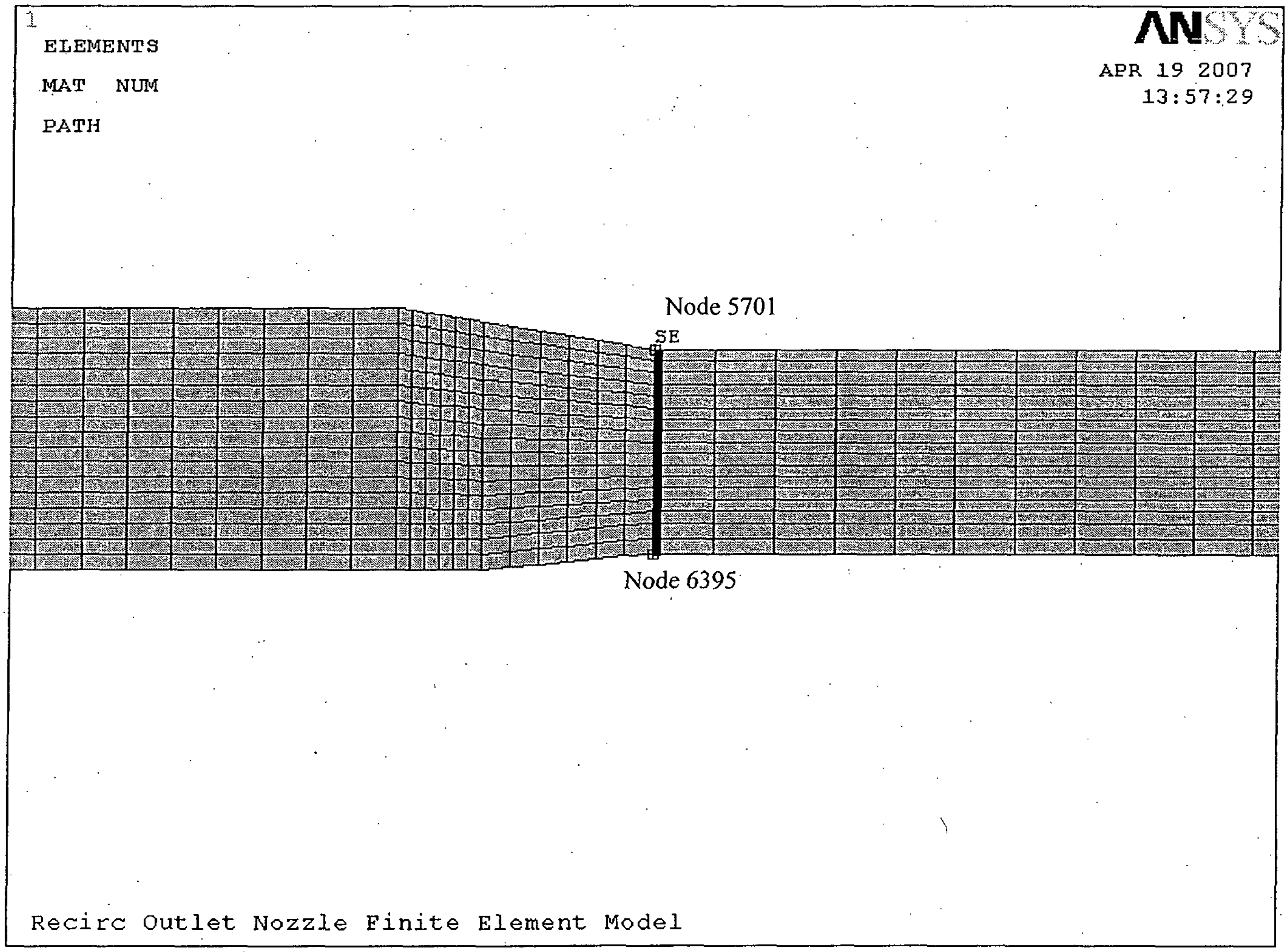



**Figure 7: Safe End Limiting Linearized Stress Paths**

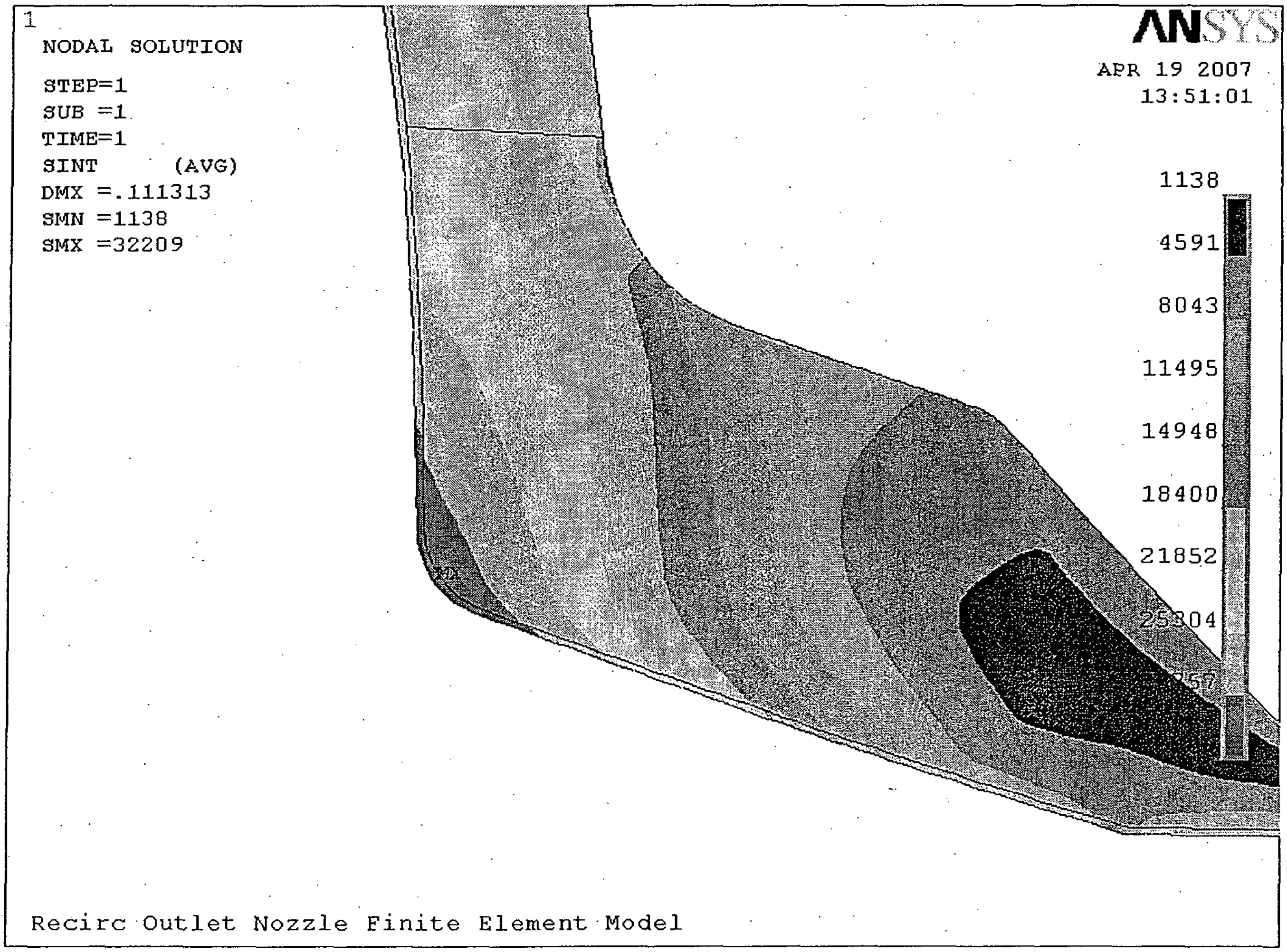



**Figure 8: Blend Radius Limiting Pressure Stress Location**

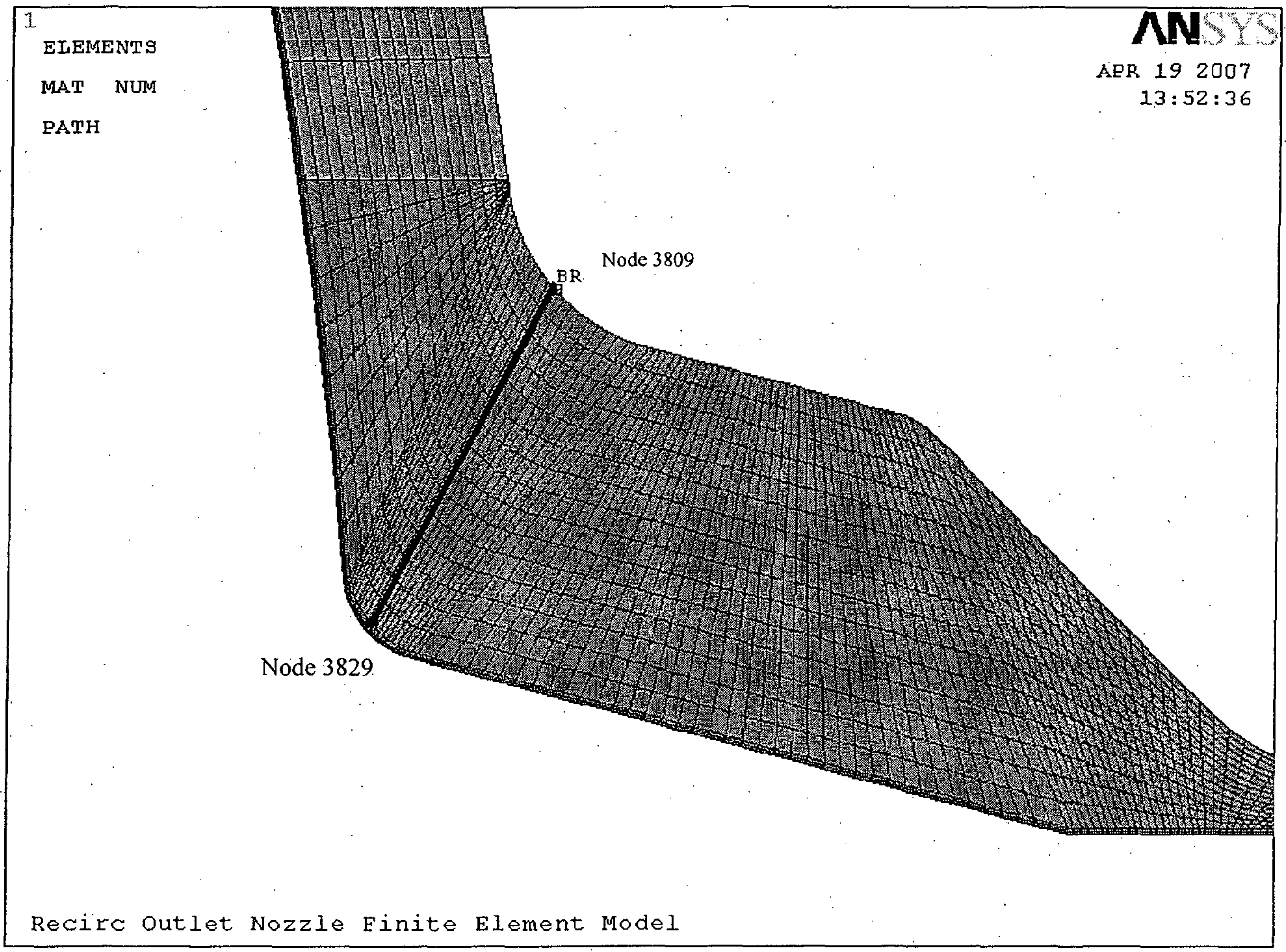



**Figure 9: Blend Radius Linearized Stress Path**

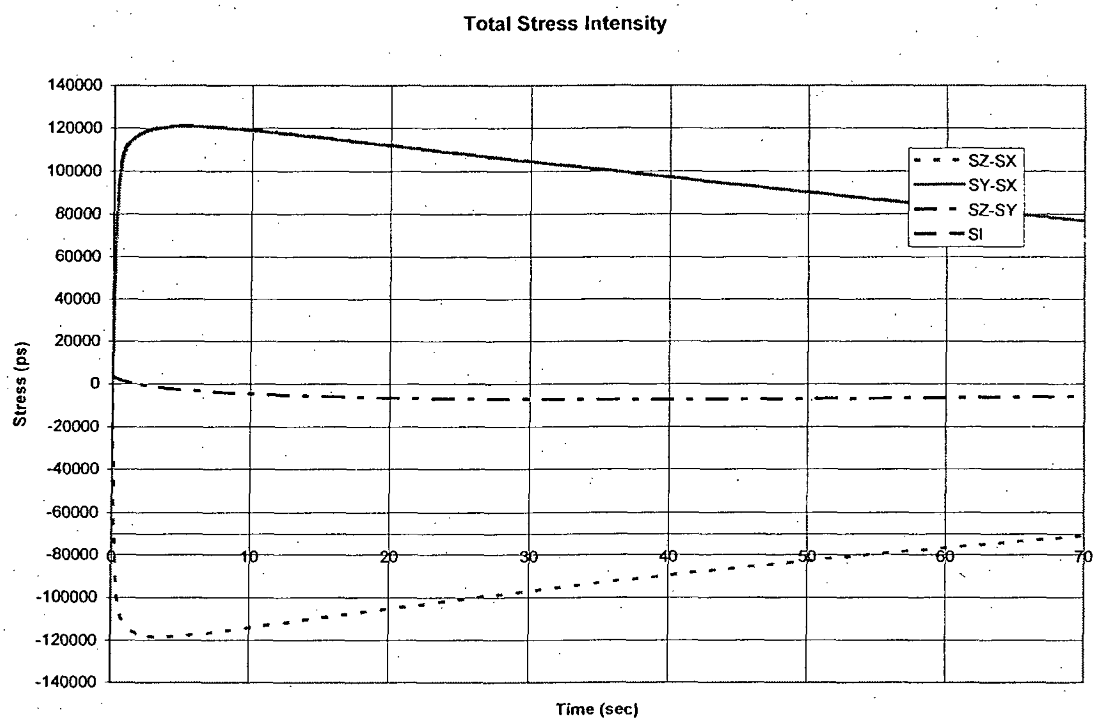



Figure 10: Safe End 100% Flow Total Stress Intensity

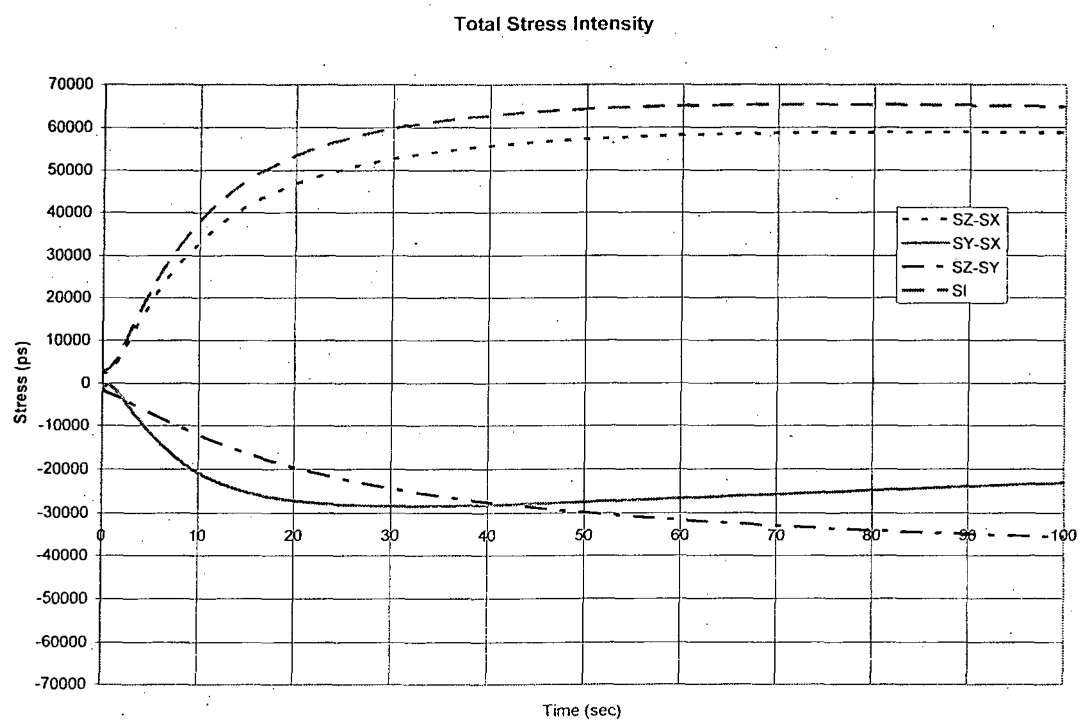



Figure 11: Blend Radius 100% Flow Total Stress Intensity

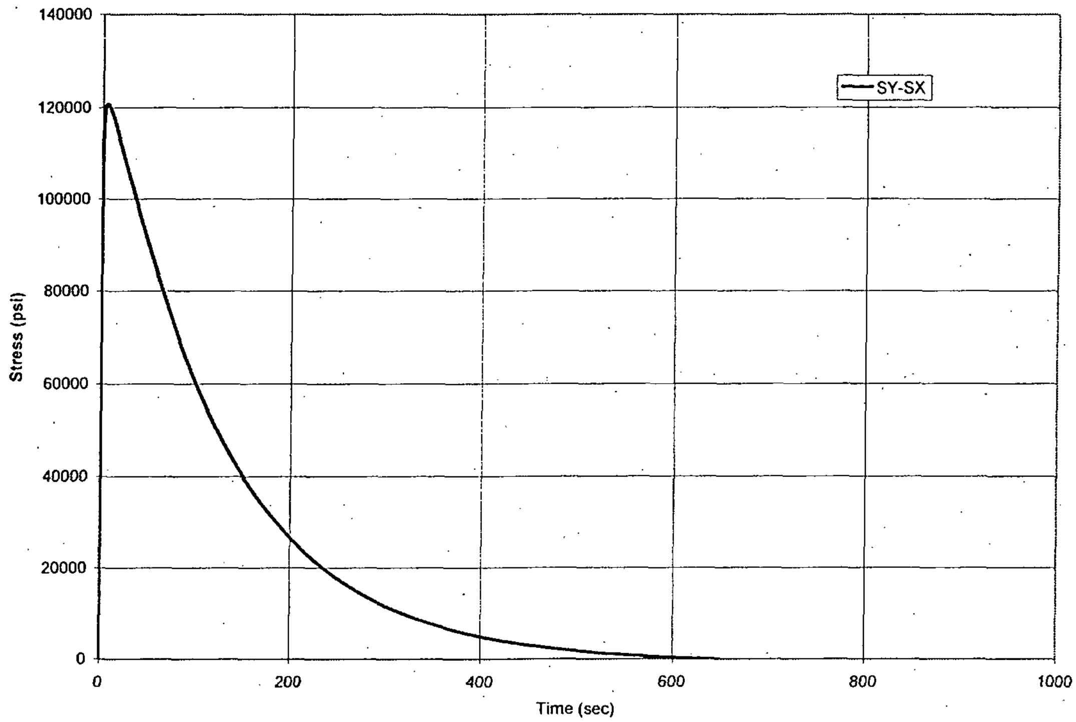



**Figure 12: Safe End Total Stress History for 100% Flow**

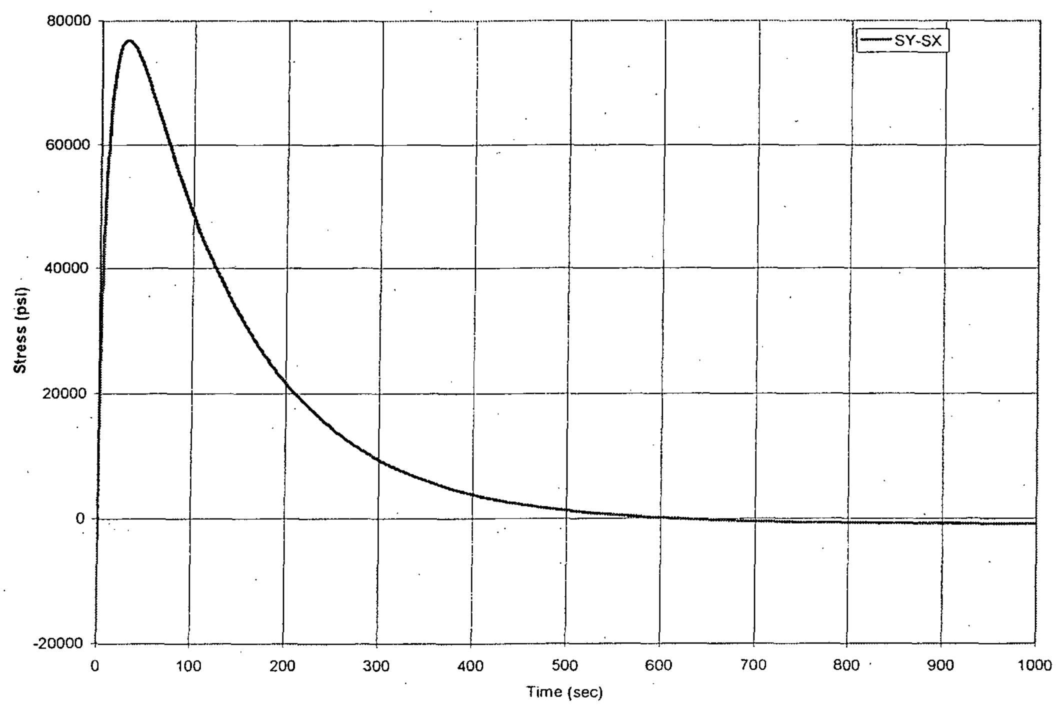



**Figure 13: Safe End Membrane Plus Bending Stress History for 100% Flow**

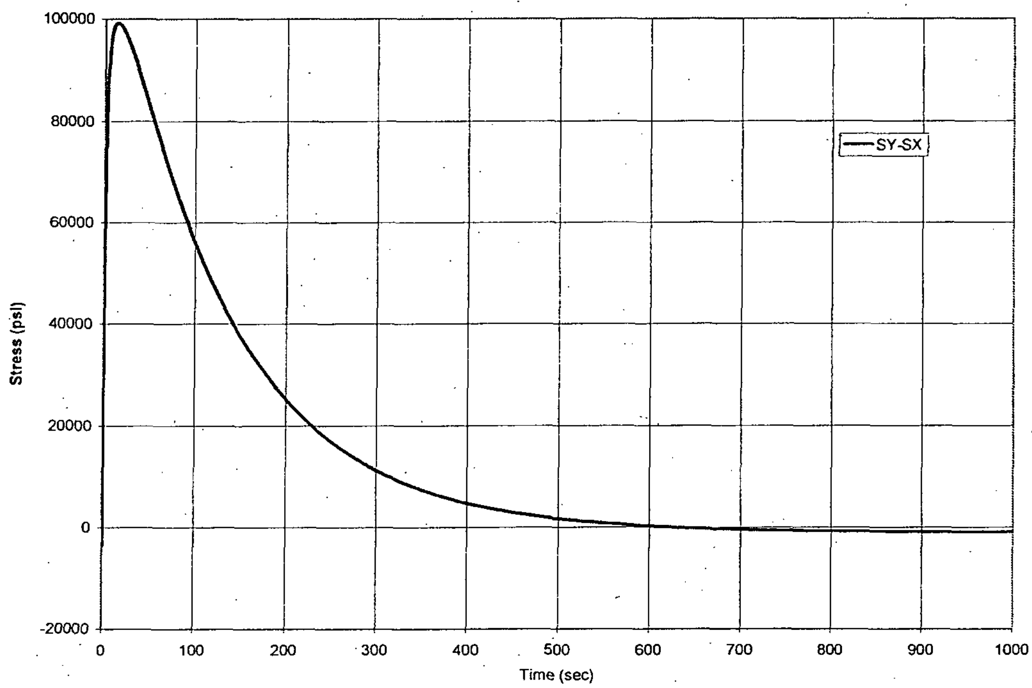



**Figure 14: Safe End Total Stress History for 50% Flow**

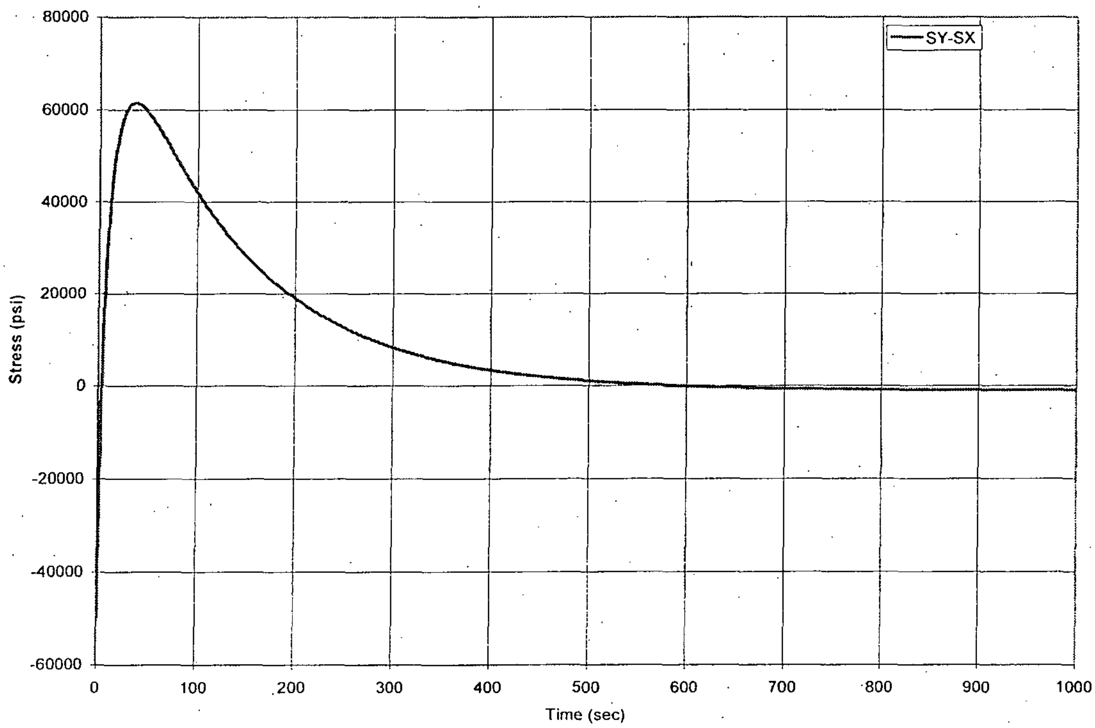



**Figure 15: Safe End Membrane Plus Bending Stress History for 50% Flow**

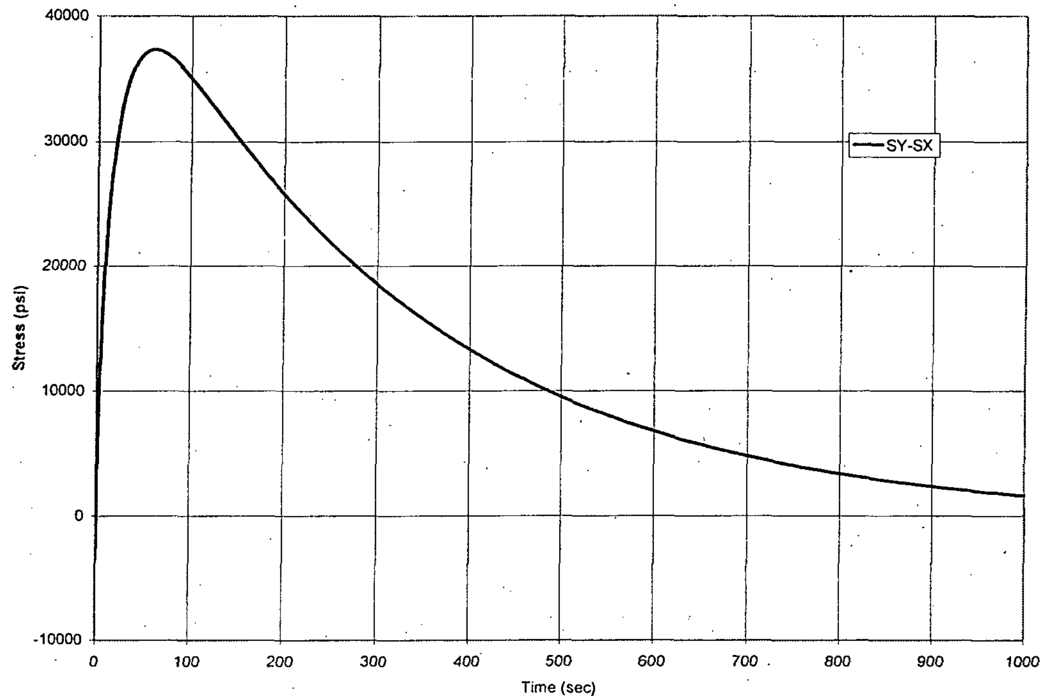



**Figure 16: Safe End Total Stress History for 0% Flow**

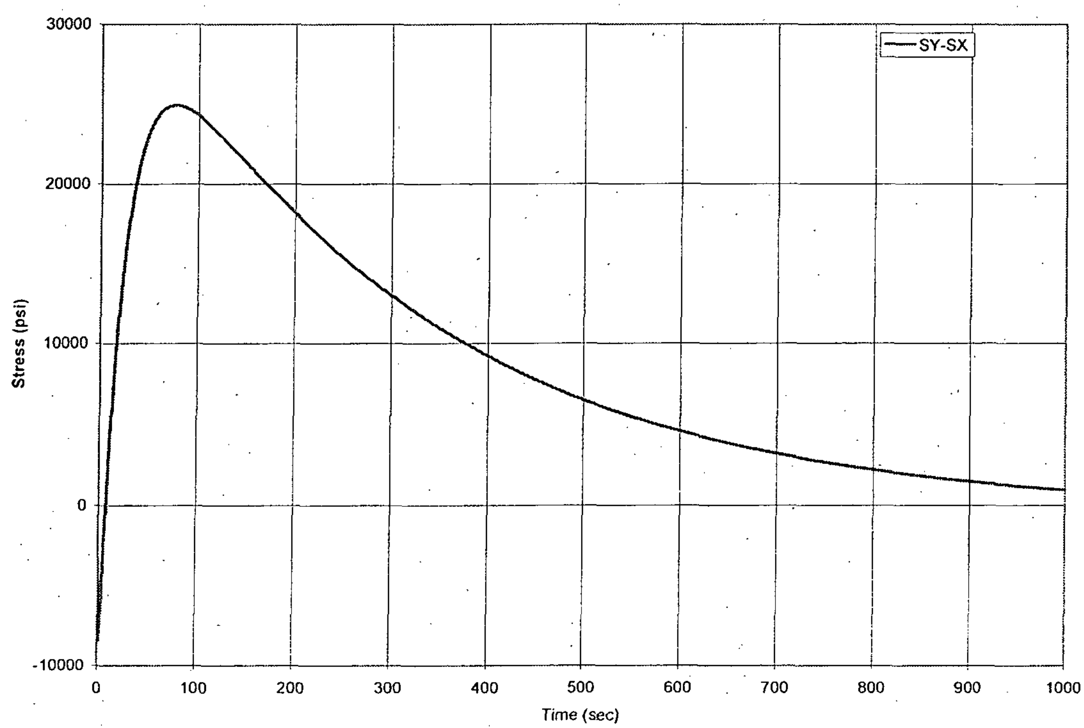



**Figure 17: Safe End Membrane Plus Bending Stress History for 0% Flow**

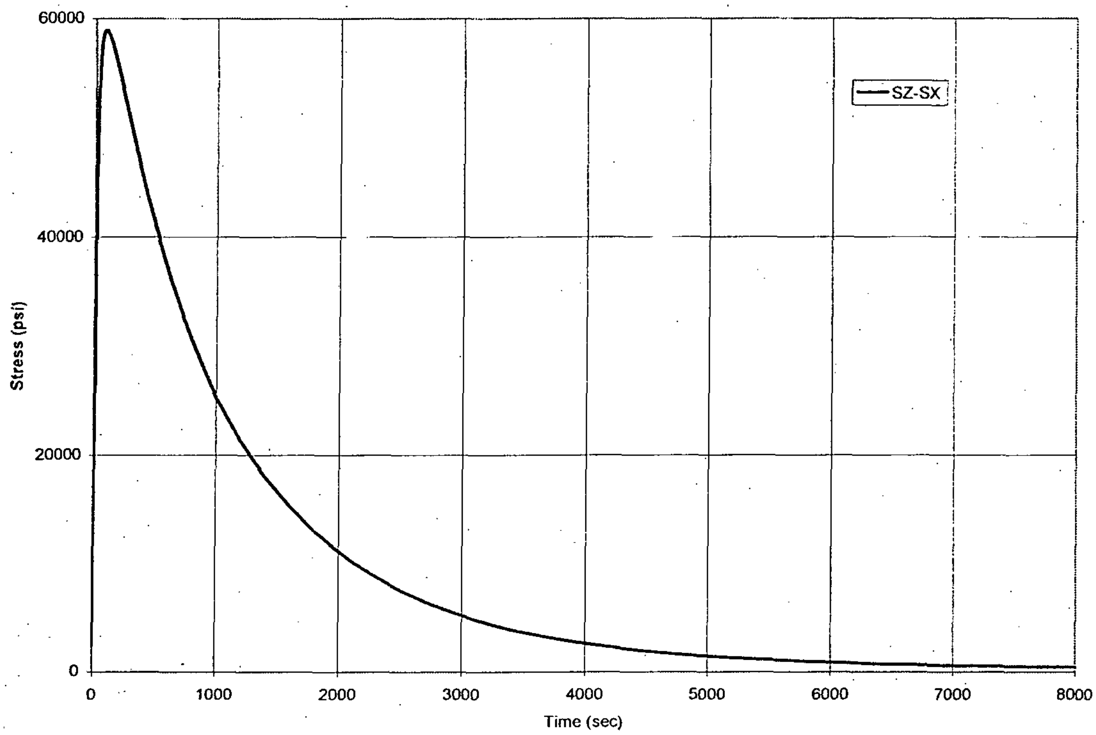



Figure 18: Blend Radius Total Stress History for 100% Flow

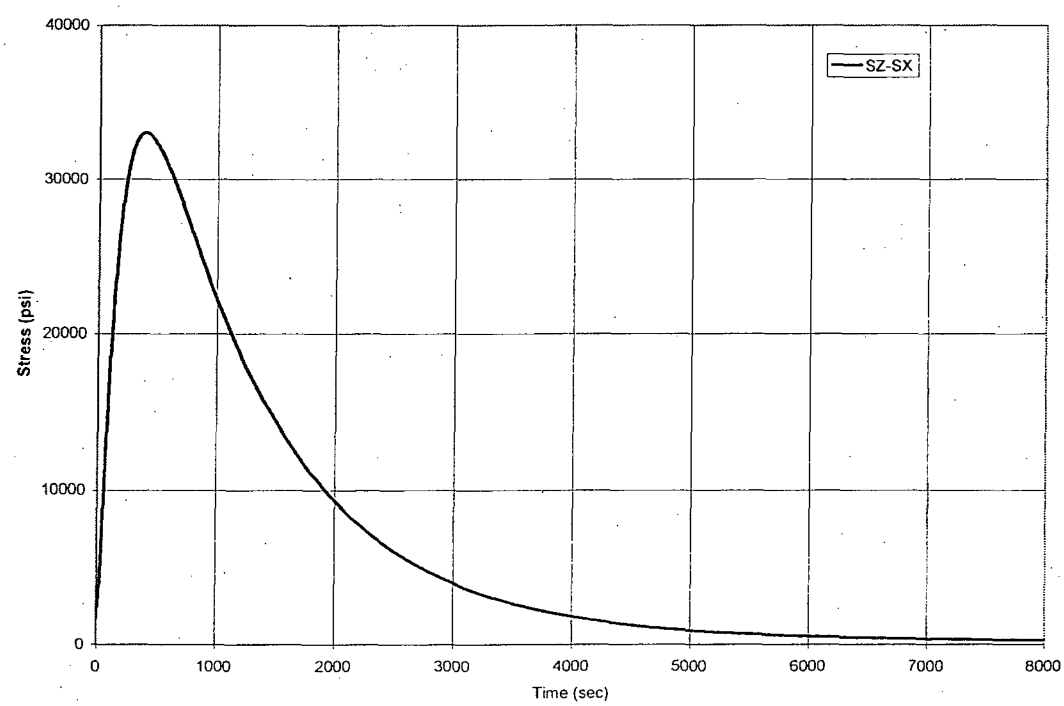



Figure 19: Blend Radius Membrane Plus Bending Stress History for 100% Flow

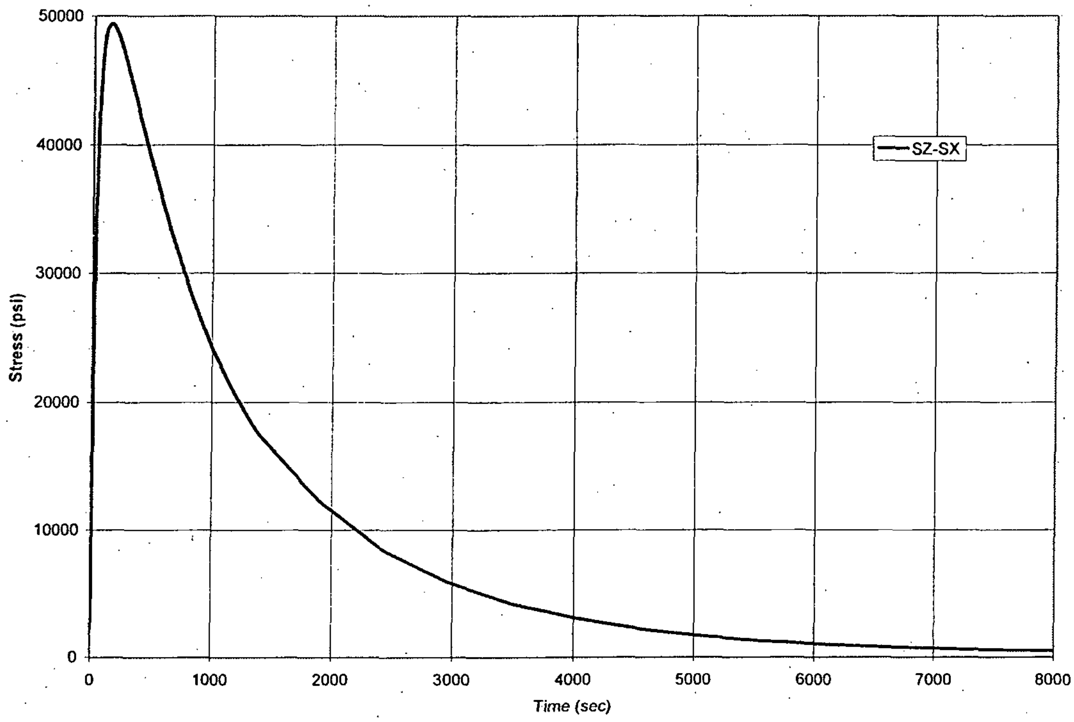



**Figure 20: Blend Radius Total Stress History for 50% Flow**

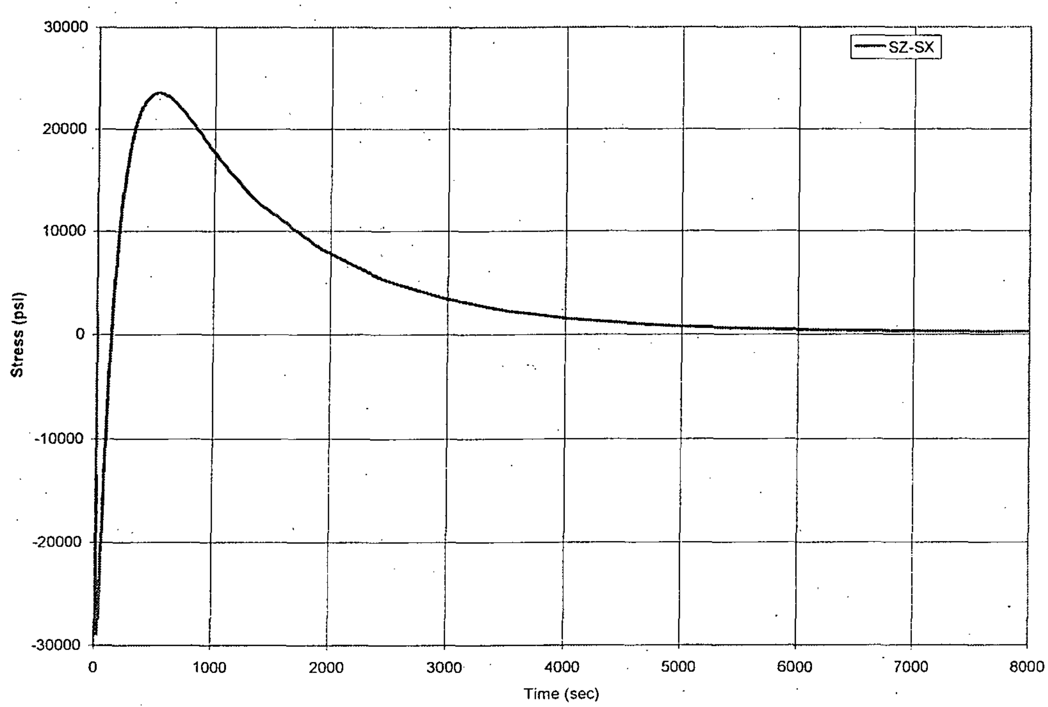



**Figure 21: Blend Radius Membrane Plus Bending Stress History for 50% Flow**

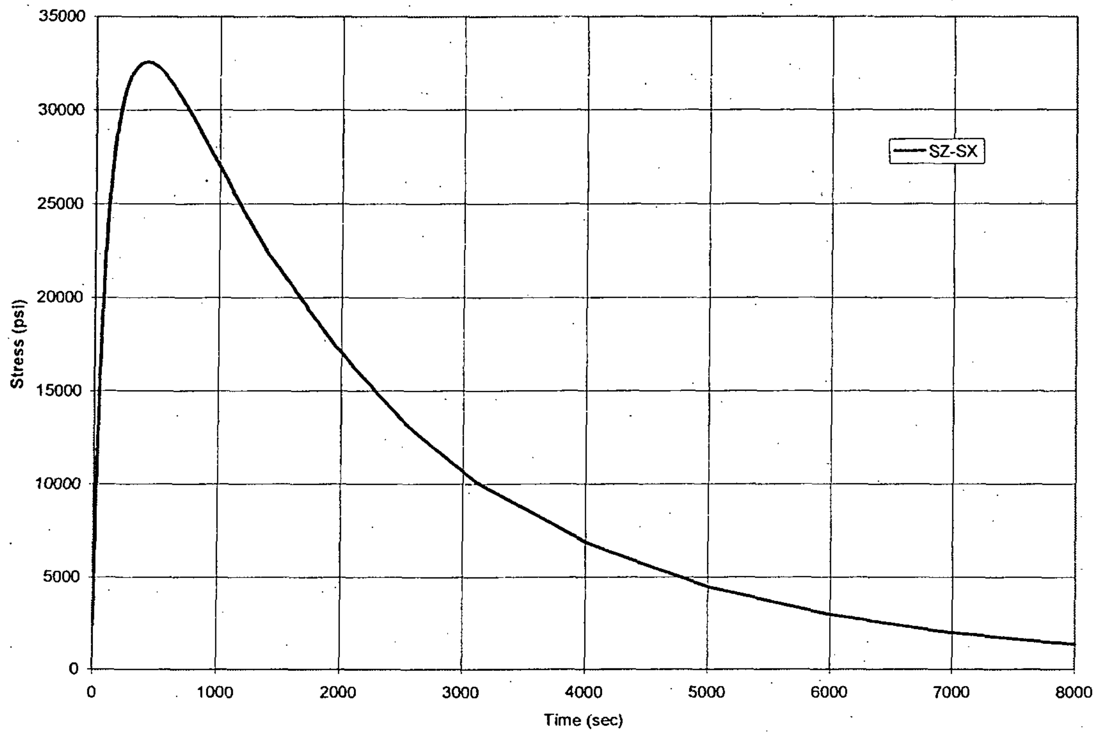



**Figure 22: Blend Radius Total Stress History for 0% Flow**

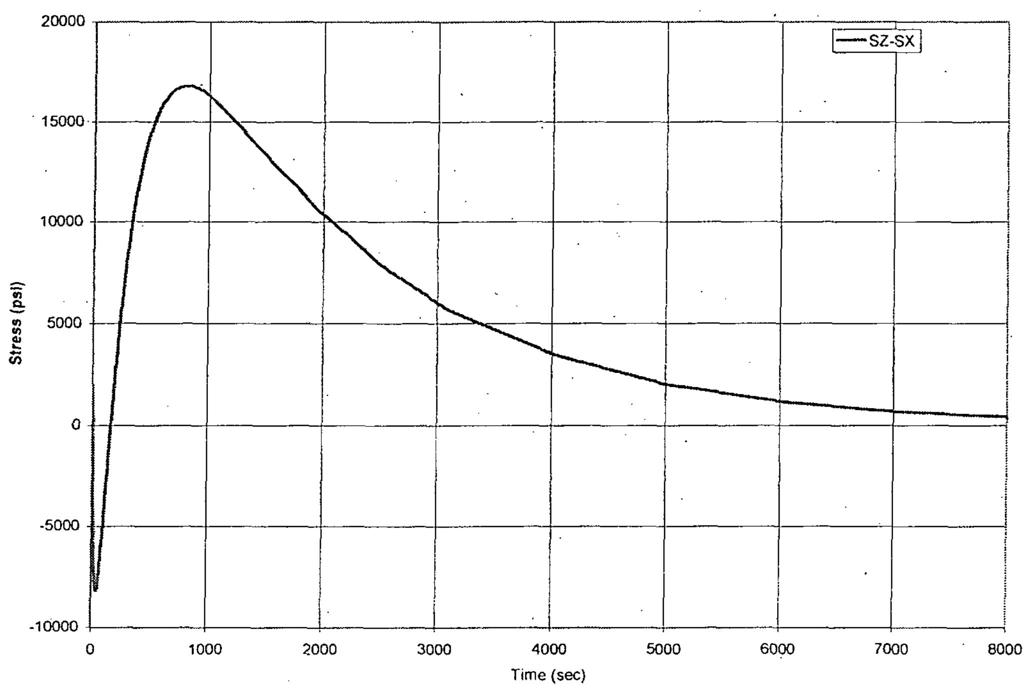



**Figure 23: Blend Radius Membrane Plus Bending Stress History for 0% Flow**

# APPENDIX A

# FINITE ELEMENT ANALYSIS FILES

| | | |
|---|---|---|
| RON_VY.INP | Input File for Pressure Load | In Computer files |
| VY_RON_T_100.INP | Input File for 100% Flow Thermal Analysis | In Computer files |
| VY_RON_S_100.INP | Input File for 100% Flow Stress Analysis | In Computer files |
| VY_RON_T_50.INP | Input File for 50% Flow Thermal Analysis | In Computer files |
| VY_RON_T_50.INP | Input File for 50% Flow Stress Analysis | In Computer files |
| VY_RON_0.INP | Input File for 0% Flow Thermal Analysis | In Computer files |
| VY_RON_0.INP | Input File for 0% Flow Stress Analysis | In Computer files |
| PVESS.OUT | Stress Output across the shell with Pressure Load | In Computer files |
| PSE.OUT | Stress Output at Safe End with Pressure Load | In Computer files |
| PBLEND.OUT | Stress Output at Blend Radius with Pressure Load | In Computer files |
| #FSE.OUT | Stress Output at Safe End | In Computer files |
| #FBR.OUT | Stress Output at Blend Radius | In Computer files |
| #FSE_INSIDE.RED | Stress Extracted at Safe End | In Computer files |
| #FBR_INSIDE.RED | Stress Extracted at Blend Radius | In Computer files |
| #FSE_T-Green.XLS | Green Function with Total Stress at Safe End | In Computer files |
| #FSE_M+B-Green.XLS | Green Function with Membrane plus Bending Stress at Safe End | In Computer files |
| HFBR_T-Green.XLS | Green Function with Total Stress at Blend Radius at 100% flow | In Computer files |
| HFBR_M+B-Green.XLS | Green Function with Membrane plus Bending Stress at Blend Radius at 100% flow | In Computer files |

Where # is H, M, L meaning 100%, 50%, and 0% flow rate, respectively.

Structural Integrity Associates, Inc.

# CALCULATION PACKAGE

File No.: VY-16Q-306

NEC-JH_09

Project No.: VY-16Q

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Fatigue Analysis of Recirculation Outlet Nozzle

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-34, Appendix: A1-A1 | Initial Issue | Terry J. Herrmann 7/27/2007 | J. E. Smith 7/27/2007<br>Minghao Qin 7/27/2007 |

## Table of Contents



## List of Tables

## List of Figures

## 1.0 OBJECTIVE

The purpose of this calculation is to perform a revised fatigue analysis for the Entergy Vermont Yankee (VY) reactor pressure vessel (RPV) recirculation outlet nozzle. Two locations will be analyzed for fatigue acceptance: the safe end (SA182 F316) and the nozzle inner corner blend radius (SA508 Class 2). Both locations are chosen based on the highest overall stress of the analysis performed in Reference [1]. Fatigue usage will be determined for each location, the nozzle forging and safe end, respectively. An environmental fatigue usage factor will also be determined for each of these locations.

## 2.0 METHODOLOGY

In order to provide an overall approach and strategy for evaluating the recirculation outlet nozzle, the Green's Function methodology and associated ASME Code stress and fatigue analyses are described in this section.

Revised stress and fatigue analyses are being performed for the recirculation outlet nozzle using ASME Code, Section III methodology. These analyses are being performed to address license renewal requirements to evaluate environmental fatigue for this component in response to Generic Aging Lessons Learned (GALL) Report [14] requirements. The revised analysis is being performed to refine the fatigue usage so that an environmental fatigue factor can be determined for subsequent license renewal efforts.

Two sets of rules are available under ASME Code, Section III, Class 1 [13]. Subparagraph NB-3600 of Section III provides simplified rules for analysis of piping components, and NB-3200 allows for more detailed analysis of vessel components. The NB-3600 piping equations combine by absolute sum the stresses due to pressure, moments and through wall thermal gradient effects, regardless of where within the pipe cross-section the maximum value of the components of stress are located. By considering stress signs, affected surface (inside or outside) and azimuthal position, the stress ranges may be significantly reduced. In addition, NB-3600 assigns stress indices by which the stresses are multiplied to conservatively incorporate the effects of geometric discontinuities. In NB-3200, stress indices are not required, as the stresses are calculated by finite element analysis and consider applicable stress concentration factors. In addition, NB-3200 methodology accounts for the different locations within a component where stresses due to thermal, pressure or other mechanical loading are a maximum. This generally results in a net reduction of the stress ranges and consequently, in the calculated fatigue usage. Article 4 [17] methodology was originally used to evaluate the recirculation outlet nozzle. NB-3200 methodology, which is the modern day equivalent to Article 4, is used in this analysis to be consistent with the Section III design bases for this component, as well as to allow a more detailed analysis of this component. In addition, several of the conservatisms originally used in the original recirculation outlet nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve a more accurate CUF.

For the recirculation outlet nozzle evaluated as a part of this work, stress histories will be computed by a time integration of the product of a pre-determined Green's Function and the transient data.

This Green's Function integration scheme is similar in concept to the Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [15]. A general outline is provided in this section.

The steps involved in the evaluation are as follows:

- Develop finite element model
- Develop heat transfer coefficients and boundary conditions for the finite element model
- Develop Green's Functions
- Develop thermal transient definitions
- Perform stress analysis to determine stresses for thermal transients
- Perform fatigue analysis

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 13 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 14. The input transient temperature history contains five step-changes of varying size, as shown in Figure 14. These five step changes produce the five successive stress responses in the second plot shown in Figure 14. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY reactor recirculation outlet nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.

Fatigue calculations are performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology. Fatigue analysis is performed for the two limiting locations (one in the safe end and one in the nozzle forging, representing the two materials of the nozzle assembly) using the Green's Functions developed for these three Recirculation flow conditions and 60-year projected cycle counts.

Three Structural Integrity utility computer programs are used to facilitate the fatigue analysis process: STRESS.EXE, P V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys, as required by ASME Code fatigue evaluation methods. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III range-pair methodology. All three programs are explained in detail and have been independently verified for generic use in the Reference [5] calculation.

In order to perform the fatigue analysis, Green's Functions are developed using the finite element model. Then, input files with the necessary data are prepared and the three utility computer programs are run. The first program (STRESS.EXE) requires the following three input files:

- Input file "GREEN.DAT": This file contains the Green's Function for the location being evaluated. For each flow condition, two Green's Functions are determined: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function. This allows computation of total stress, as well as membrane plus bending stress, which is necessary to compute $K_e$ per ASME Code, Section III requirements.
- Input file "GREEN.CFG": This file is a configuration file containing parameters that define the Green's Function (i.e., number of points, temperature drop analyzed, etc.).
- Input file "TRANSNT.INP": This file contains the input transient history for all thermal transients to be analyzed for the location being evaluated.

Pressure and piping stress intensities are also included for each transient case, based on pressure stress results from finite element analysis and attached piping load calculations.
The second program (P-V.EXE) simply extracts only the maxima and minima stress (i.e., the peaks and valleys) from the stress histories generated by program STRESS.EXE.

The third program (FATIGUE.EXE) performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data consists of the output peak and valley history from program P-V.EXE and a configuration input file that provides ASME Code configuration data relevant to the fatigue analysis (i.e., $K_e$ parameters, $S_m$, Young's modulus, etc.). The output is the final fatigue calculation for the location being evaluated.

The Green's Function methodology described above uses standard industry stress and fatigue analysis practices, and is the same as the methodology used in typical stress reports. Special approval for the use of this methodology is therefore not required.

The 10 transients to be analyzed are described in Reference [2], for the recirculation outlet nozzle. Transients 11 and 12 are hydrostatic tests that have only a small temperature change and are not modeled. Transients 1 to 10 are shown in Figures 3 – 12. The analysis of transient 9 is an exception to this process because there are two different thermal shocks at the nozzle and vessel regions. Transient 9 is analyzed separately using ANSYS instead of STRESS.EXE and P-V.EXE. The results from ANSYS are input directly into FATIGUE.EXE with the other transient stress results.

## 3.0 ANALYSIS

The fatigue analysis involves preparing the input files and running the three programs. The programs STRESS.EXE and P-V.EXE are run together through the use of a batch file. The program FATIGUE.EXE is run after processing the output from P-V.EXE. The ANSYS results from transient 9 are added to the P-V.EXE results for the other transients and input into FATIGUE.EXE.

The steps associated with this process are described in the following sub-sections.

### 3.1 Transient Definitions (for program STRESS.EXE)

The program STRESS.EXE requires the following three input files for analyzing an individual transient:

- GREEN.DAT. There are 12 stress history functions (Green's Functions) obtained from Reference [1]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. The blend radius and the safe end have three stress history functions for the 100% flow, 50%, and no-flow conditions.
- GREEN.CFG is configured as described in Reference [5].
- Several TRANSNT.INP files are created to simulate the transients shown on Reference [2]. Tables 2 and 3 show the thermal history used to simulate each transient for the blend radius and safe end locations, respectively. The aforementioned transient information for each location is contained in EXCEL files *Blend_Radius_Transients.xls* and *Safe_End_Transients.xls*, which are contained in the computer files. Transients are split into the following groups based upon flow rate:
    - Transients 2, 3, 5, 6, 7, and 8 are run at 100% flow Green's Function
    - Transients 1 and 10 are run at 50% flow Green's Function
    - Transient 4 is run at no flow, 50% flow, and 100% flow Green's Functions, as shown in Tables 2 and 3.
    - Transient 9 is simulated by ANSYS [11] model and the thermal results are taken from ANSYS directly. See Section 4 for details.
    - Transients 11 and 12 have only small temperature change (70°F to 100°F). Therefore, the thermal stresses for these two transient are ignored. Only the piping load and the pressure load are considered in these two transients.
    - The loss of feedwater heaters (Feedwater Heater Bypass) event has a negligible temperature change (526 °F to 516 °F) associated with it. Therefore this transient is ignored.

### 3.2 Peak and Valley Points of the Stress History (for program P-V.EXE)

After STRESS.EXE runs are completed, the program P-V.EXE is run to extract only the peaks and valleys from the STRESS.OUT stress history file produced by the STRESS.EXE program. The only input required for this program is the stress history file (STRESS.OUT), and the program outputs all of the resulting peaks and valleys to output file P-V.OUT. The resulting peak and valley stress summaries for all transients are summarized in Tables 4 and 5 for both locations. Columns 2 through 5 of Tables 4 (for the blend radius) and 5 (for the safe end) show the final peak and valley output. These final peaks and valleys were selected from the total stress and membrane plus bending stress intensities that were calculated by STRESS.EXE and screened with P-V.EXE.

### 3.3 Pressure Load

The pressure stress associated with a 1,000 psi internal pressure was determined in Reference [1]. These values are as follows:

Pressure stress for the safe end:

- 11,350 psi membrane plus bending linearized stress intensity.
- 11,490 psi total stress intensity.

Pressure stress for the blend radius:

- 33,640 psi membrane plus bending linearized stress intensity.
- 31,300 psi total stress intensity.

The pressure stress intensity values for each transient were linearly scaled based on the pressure. The actual pressure for column 6 of Tables 4 and 5 is obtained from Tables 2 and 3, respectively. The scaled pressure stress values are shown in columns 7 and 8 of Tables 4 and 5.

The pressure stress is combined with the peak and valley points to calculate the final stress values used for fatigue analysis.

### 3.4 Attached Piping Loads

Additionally, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 1.

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first and second cut locations using the following equations:

For Cut I:

$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:
$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:
$$M_{xy} = \sqrt{(M_x)_1^{\,2} + (M_y)_1^{\,2}}$$
$$F_{xy} = \sqrt{(F_x)_1^{\,2} + (F_y)_1^{\,2}}$$

For Cut II:
$$M_{xy} = \sqrt{(M_x)_2^{\,2} + (M_y)_2^{\,2}}$$
$$F_{xy} = \sqrt{(F_x)_2^{\,2} + (F_y)_2^{\,2}}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, $P_M$, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$
$$(P_M)_\theta = \frac{Pa_N}{t_N}$$
$$(P_M)_R = -P$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^{\,2}}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^{\,2}}$$

Because pressure was considered separately in this analysis, the equations used for Cut I are valid for Cut II.

where:
- $L_1$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.
- $L_2$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.
- $M_{xy}$ = The maximum bending moment in the xy plane.
- $F_{yx}$ = The maximum shear force in the xy plane.
- $N_z$ = The normal force per inch of circumference applied to the end of the nozzle in the z direction.
- $q_N$ = The shear force per inch of circumference applied to the nozzle.
- $R_N$ = The mid-wall nozzle radius.

Since the pressure was considered separately in this analysis, the equations can be simplified as follows:

$$(P_M)_z = \frac{Nz}{t_N}$$

$$(P_M)_\theta = 0$$

$$(P_M)_R = 0$$

$$\tau_M = \frac{q_N}{t_N}$$

$$SI_{MAX} = 2(\tau_M)_{z\theta}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{Nz}{2t_N}\right)^2 + (\tau_M)_{z\theta}^{\ 2}}$$

Per Reference [7], the recirculation outlet nozzle piping loads (Total thermal, weight and seismic loads) are as follows:

| | |
|---|---|
| $F_x$ = 20,000 lbs | $M_x$ = 2,004,000 in-lb |
| $F_y$ = 20,000 lbs | $M_y$ = 3,000,000 in-lb |
| $F_z$ = 30,000 lbs | $M_z$ = 2,004,000 in-lb |

$L_1$ is equal to 4.25 inches and the $L_2$ is equal to 42.77 inches. The calculations for the safe end and blend radius are shown in Table 1. The first cut location is the same as the Green's Function cross section per [1] at the safe end, and the second cut is from Node 3829 (inside) to Node 3809 (outside). This gives the maximum ID and minimum OD for the cross section calculation. The maximum stress intensities due to the piping loads are 5708.89 psi at the safe end and 280.16 psi at the blend radius. The piping load sign is set as the same as the thermal stress sign.

These piping stress values are scaled assuming no stress occurs at an ambient temperature of 70°F, and the full values are reached at reactor design temperature, 575°F [6]. The scaled piping stress values are shown in columns 9 and 10 of Tables 4 and 5. Columns 11 and 12 of Tables 4 and 5 show the summation of all stresses for each thermal peak and valley stress point.

### 3.5 Fatigue Analysis (for program FATIGUE.EXE)

The number of cycles projected for the 60-year operating life is used for each transient [2]:

Column 13 in Tables 4 and 5 shows the number of cycles associated with each transient. The number of cycles for 60 years was obtained from Reference [2] unless otherwise noted.

The program FATIGUE.EXE performs the "ASME Code style" peak event pairing required to calculate a fatigue usage value. The input data for FATIGUE.CFG is as follows:

| | Blend Radius | Safe End |
|---|---|---|
| Parameters *m* and *n* for Computing $K_e$ | 2.0 & 0.2 (low alloy steel) [13] | 1.7 & 0.3 (stainless steel) [13] |
| Design Stress Intensity Values, $S_m$ | 26700 psi [9] @ 600°F | 17000 psi [9] @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi [13] | $28.3 \times 10^6$ psi [13] |
| Elastic Modulus Used in Finite Element Model | $26.7 \times 10^6$ psi [1] | $27.0 \times 10^6$ psi [1] |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 1.53 [3] |

The results of the fatigue analyses are presented in Tables 6 and 7 for the blend radius and safe end for 60 years, respectively.

The fatigue run inputs described are contained in EXCEL files *BRresults.xls* and *SEresults.xls*, which are contained in the computer files.

## 4.0 CALCULATION OF THERMAL STRESSES FOR TRANSIENT 9

Per Tables 2 and 3, the thermal shocks are from 526°F to 268°F and from 526°F to 130°F at the blend radius and the safe end, respectively. Therefore, the average temperatures for these two locations are about 400°F and 330°F. Since there are two different temperature shocks in the same model, ANSYS [10] will be used to calculate stresses directly. In this section, ANSYS [10] is used to simulate this transient and the results will then be used as input to FATIGUE.EXE, as shown in Tables 4 and 5. This case corresponds to the downhill (RPV) side of the blend radius.

An additional case was also run to simulate the uphill (RPV) side of the blend radius, where the thermal shocks are from 526°F to 130°F at the safe end, and no temperature change at the blend radius. This case at the uphill side of the blend radius was found to produce lower stresses than the previously mentioned downhill case. Due to this, the downhill case was used for the rest of the analysis in this calculation.

### 4.1 Thermal Load

Since the average temperatures in the blend radius and safe end respectively are 400°F and 330°F, the material properties for 400°F are used for the blend radius, cladding and vessel. Table 8 shows the material properties at 400°F. The flow rate at this transient is 3395.2 GPM (calculated from 12% of max flow rate [2]) and is shown in Tables 2 and 3.

Heat transfer coefficients listed on Reference [4] are for pre power uprate. The heat transfer coefficients can be scaled by power uprate flow rate and diameter to values corresponding to the flow and location conditions. Referring to Figure 2, heat transfer coefficients were applied as follows:

Region 1

Per [4], the heat transfer coefficient at 500°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$4911\cdot\left(\frac{2.084}{25}\right)^{0.8} = 672.8\ \text{BTU/hr-ft}^2\text{-°F}.$$

Per [4], the heat transfer coefficient at 100°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$2250\cdot\left(\frac{2.084}{25}\right)^{0.8} = 308.24\ \text{BTU/hr-ft}^2\text{-°F}.$$

The fluid temperature shock is:

T = 526°F - 130°F - 526°F

Region 2

Per [4], the heat transfer coefficient at 500°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$4911\cdot\left(\frac{2.084}{25}\right)^{0.8}\left(\frac{26}{35.49}\right)^{0.2} = 632.21\ \text{BTU/hr-ft}^2\text{-°F}.$$

Per [4], the heat transfer coefficient at 300°F, h, for 3395.2 GPM (2.084 ft/s) flow is

$$4789\cdot\left(\frac{2.084}{25}\right)^{0.8}\left(\frac{26}{35.49}\right)^{0.2} = 616.57\ \text{BTU/hr-ft}^2\text{-°F}.$$

The fluid temperature shock is:

T = 526°F - 268°F - 526°F

Region 3

Per [4], the heat transfer coefficient at 500°F, h, for 3395.2 GPM flow is

$672.8(0.5) = 336.4$ BTU/hr-ft$^2$-°F.

Per [4], the heat transfer coefficient at 300°F, h, for 3395.2 GPM flow is

$336.4\left(\frac{4789}{4911}\right) = 328.04$ BTU/hr-ft$^2$-°F.

The fluid temperature shock is:

Case 1: T = 526°F - 268°F - 526°F
Case 2: T = 526°F

Region 4

The heat transfer coefficient, h, is 0.4 BTU/hr-ft$^2$-°F [4].

The temperature is:

T = 120°F

## 4.2 Thermal Results

The flow dependent thermal load case outlined in Section 4.1 was run on the finite element model. Appendix A contains the thermal transient input file VY_RON_T_T9.INP for 3395.2 GPM flow rate. The flow dependent input files for the stress run is also included in Appendix A. The stress filename is VY_RON_S_T9.INP for 3395.2 GPM flow rate.

The critical safe end and blend radius locations are defined in Reference [1] at nodes 6395 and 3829, respectively.

The stress time history for the critical paths was extracted during the stress run. This produced two files, T9SE.OUT and T9BR.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses were extracted from these files to produce the files T9SE_Inside.RED and T9BR_Inside.RED, where SE and BR corresponded to the safe end and blend radius locations, respectively.

The data for the stress results is included in the files T9BR_M+B.xls, T9BR_T.xls, T9SE_M+B.xls, and T9SE_T.xls in the project Files. Where SE and BR corresponded to the safe end and blend radius locations, respectively. M+B and T corresponded to membrane plus bending stress and total stress, respectively.

## 5.0 FATIGUE USAGE RESULTS

The blend radius cumulative usage factor (CUF) from system cycling is 0.0108 for 60 years (Table 6). The safe end CUF is 0.0015 for 60 years (Table 7).

## 6.0 ENVIRONMENTAL FATIGUE ANALYSIS

The Recirculation Outlet nozzle has three materials: a Ni-Cr-Fe dissimilar metal weld (DMW), a low alloy steel forging, and a stainless steel safe end. To ensure the maximum CUF considering environmental effects was identified, locations in the safe end and nozzle forging were selected. This selection produces bounding environmental fatigue results for the entire nozzle assembly for the following reasons:

- The highest thermal stresses from the FEM analysis occur in the stainless steel safe end. Stainless steel Fen multipliers are significantly higher than Ni-Cr-Fe multipliers (Fen values are 2.55 or higher for stainless steel [12] vs. a constant value of 1.49 for Ni-Cr-Fe [16]). Therefore, evaluation of the safe end bounds the Ni-Cr-Fe weld material.
- The highest pressure stresses from the FEM analysis occur in the low alloy steel nozzle forging. Low alloy steel Fen multipliers are higher than Ni-Cr-Fe multipliers (Fen values are 2.45 or higher for low alloy steel [12] vs. a constant value of 1.49 for Ni-Cr-Fe [16]). Therefore, evaluation of the nozzle forging bounds the Ni-Cr-Fe weld material.

Per Reference [12], the dissolved oxygen (DO) calculation shows the overall hydrogen water chemistry (HWC) availability is 47%. This means the time ratio under normal water chemistry (NWC, or pre-HWC) is 53%.

For the safe end location, the environmental fatigue factors for post-HWC and pre-HWC are 15.35 and 8.36 from Table 5 of Reference [12]. These result in an EAF adjusted CUF of (15.35 x 47% + 8.36 x 53%) x 0.0015 = 0.0175 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 11.6453.

For the blend radius location, the environmental fatigue factors for post-HWC and pre-HWC are 2.45 and 12.43 from Table 5 of Reference [12]. These result in an EAF adjusted CUF of (2.45 x 47% + 12.43 x 53%) x 0.0108 = 0.08358 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 7.739.

## 7.0 REFERENCES


1. Structural Integrity Associates Calculation No. VY-16Q-305, Revision 0, "Recirculation Outlet Nozzle Green's Functions."
2. Entergy Design Input Record (DIR), Rev. 1, EC No. 1773, Rev. 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/07, SI File No. VY-16Q-209.
3. CB&I, RPV Stress Report Section: S9 "Stress Analysis Recirculation Outlet Nozzle Vermont Yankee Reactor Vessel." 9-6201, SI document, VY-16Q-204.
4. CB&I, RPV Stress Report Section: T9 "Thermal Analysis Recirculation Outlet Nozzle Vermont Yankee Reactor Vessel." 9-6201, SI document, VY-16Q-204.
5. Structural Integrity Associates Calculation (Generic) No. SW-SPVF-01Q-301, Revision 0, "STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification."
6. VY Drawing, 5920-06623 Rev. 0, (Hitachi, Ltd. Drawing No IOR290-127, Revision 0), "Recirc. Outlet Safe End," SI File No. VY-16Q-204.
7. GE. Stress Report No. 23A4316, Revision 0, "Reactor Vessel Recirculation Outlet Safe End," SI File No. VY-16Q-204.
8. VY Drawing 5920-00238 Rev. 4, (Chicago Bridge & Iron Company, Contract No. 9-6201, Drawing No. 21, Revision 4), "36"x28" Nozzles Mk N1A/B," SI File No. VY-16QQ-204.
9. ASME Boiler and Pressure Vessel Code, Section II, Materials, Part D, Properties, 1998 Edition with 2000 Addenda.
10. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.
11. Structural Integrity Associates Calculation No. VY-16Q-304, Revision 0, "Recirculation Outlet Nozzle Finite Element Model."
12. Structural Integrity Associates Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head."
13. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection NB, 1998 Edition, 2000 Addenda.
14. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.
15. Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green's Functions," ASME PVP Conference, Chicago, 1986.
16. EPRI Report No. TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," December 1995.
17. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection A, 1965 Edition with Winter 1966 Addenda.

**Table 1: Maximum Piping Stress Intensity Calculations**

| Blend Radius External Piping Loads | | | Safe End External Piping Loads | | |
|---|---|---|---|---|---|
| Parameters | | | Parameters | | |
| $F_x$ = | 20.00 | kips | $F_x$ = | 20.00 | kips |
| $F_y$ = | 20.00 | kips | $F_y$ = | 20.00 | kips |
| $F_Z$ = | 30.00 | kips | $F_Z$ = | 30.00 | kips |
| $M_x$ = | 2004.00 | in-kips | $M_x$ = | 2004.00 | in-kips |
| $M_y$ = | 3000.00 | in-kips | $M_y$ = | 3000.00 | in-kips |
| $M_Z$ = | 2004.00 | in-kips | $M_Z$ = | 2004.00 | in-kips |
| OD= | 55.88 | in | OD= | 28.38 | in |
| ID= | 37.368 | in | ID= | 25.938 | in |
| $R_N$ = | 23.31 | in | $R_N$ = | 13.58 | in |
| L = | 42.77 | in | L = | 4.25 | in |
| $t_N$ = | 9.25 | in | $t_N$ = | 1.22 | in |
| $(M_x)_2$ = | 1148.54 | in-kips | $(M_x)_1$ = | 1919.00 | in-kips |
| $(M_y)_2$ = | 3855.46 | in-kips | $(M_y)_1$ = | 3085.00 | in-kips |
| $M_{xy}$ = | 4022.90 | in-kips | $M_{xy}$ = | 3633.15 | in-kips |
| $F_{xy}$ = | 28.28 | kips | $F_{xy}$ = | 28.28 | kips |
| $N_Z$ = | 2.56 | kips/in | $N_Z$ = | 6.62 | kips/in |
| $q_N$ = | -0.20 | kips/in | $q_N$ = | -1.07 | kips/in |
| Primary Membrane Stress Intensity | | | Primary Membrane Stress Intensity | | |
| $PM_Z$ = | 0.28 | ksi | $PM_Z$ = | 5.43 | ksi |
| $\tau$ = | -0.02 | ksi | $\tau$ = | -0.88 | ksi |
| $SI_{max}$ = | 0.28 | ksi | $SI_{max}$ = | 5.71 | ksi |
| $SI_{max}$ = | 280.16 | psi | $SI_{max}$ = | 5708.89 | psi |

Note: The locations for Cut I and Cut II were defined in Reference [1] for safe end and blend radius paths, respectively.

# Table 2: Blend Radius Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 1. Normal Startup with | 0 | 100 | | 0 | 14147.0 |
| Heatup at 100°F/hr | 16164 | 549 | 16164 | 1010 | (50%)' |
| 300 Cycles | 22164 | 549 | 6000 | 1010 | |
| 2. Turbine Roll and | 0 | 549 | | 1010 | 28294 |
| Increase to Rated Power | 1 | 542 | 1 | 1010 | (100%)' |
| 300 Cycles | 601 | 542 | 600 | 1010 | |
| | 602 | 526 | 1 | 1010 | |
| | 6602 | 526 | 6000 | 1010 | |
| 3. Loss of Feedwater | 0 | 526 | | 1010 | 28294 |
| Heaters | 1800 | 542 | 1800 | 1010 | (100%)' |
| Turbine Trip 25% Power | 2100 | 542 | 300 | 1010 | |
| 10 Cycles | 2460 | 526 | 360 | 1010 | |
| | 3060 | 526 | 600 | 1010 | |
| | 3960 | 542 | 900 | 1010 | |
| | 4260 | 542 | 300 | 1010 | |
| | 6060 | 526 | 1800 | 1010 | |
| | 12060 | 526 | 6000 | 1010 | |
| 4. Loss of Feedwater | 0 | 526 | | 1010 | 0 |
| Pumps | 3 | 526 | 3 | 1190 | (0%)' |
| 10 Cycles | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1136 | |
| | 2393 | 300 | 180 | 885 | |
| | 6773 | 500 | 4380 | 1135 | |
| | 7193 | 300 | 420 | 675 | 14147 |
| | 7493 | 300 | 300 | 675 | (50%) |
| | 11093 | 400 | 3600 | 240 | |
| | 16457 | 549 | 5364 | 1010 | |
| | 16517 | 549 | 60 | 1010 | |
| | 16518 | 542 | 1 | 1010 | 28294 |
| | 17118 | 542 | 600 | 1010 | (100%) |
| | 17119 | 526 | 1 | 1010 | |
| | 23119 | 526 | 6000 | 1010 | |
| 5. Turbine Generator Trip | 0 | 526 | | 1010 | 28294 |
| 60 Cycles | 10 | 526 | 10 | 1135 | (100%)' |
| | 15 | 526 | 5 | 1135 | |
| | 30 | 526 | 15 | 940 | |
| | 1830 | 526 | 1800 | 940 | |
| | 2250 | 549 | 420 | 1010 | |
| | 2310 | 549 | 60 | 1010 | |
| | 2311 | 542 | 1 | 1010 | |
| | 2911 | 542 | 600 | 1010 | |
| | 2912 | 526 | 1 | 1010 | |
| | 8912 | 526 | 6000 | 1010 | |
| 6. Reactor Overpressure | 0 | 526 | | 1010 | 28294 |
| 1 Cycle | 2 | 526 | 2 | 1375 | (100%)' |
| | 32 | 526 | 30 | 940 | |
| | 1832 | 526 | 1800 | 940 | |
| | 2252 | 549 | 420 | 1010 | |
| | 2312 | 549 | 60 | 1010 | |
| | 2313 | 542 | 1 | 1010 | |
| | 2913 | 542 | 600 | 1010 | |
| | 2914 | 526 | 1 | 1010 | |
| | 8914 | 526 | 6000 | 1010 | |
| 7. SRV Blowdown | 0 | 526 | | 1010 | 28294 |
| 1 Cycle | 600 | 375 | 600 | 170 | (100%)' |
| | 11580 | 70 | 10980 | 50 | |
| | 17580 | 70 | 6000 | 50 | |
| 8. SCRAM Other | 0 | 526 | | 1010 | 28294 |
| 228 Cycles | 15 | 526 | 15 | 940 | (100%)' |
| | 1815 | 526 | 1800 | 940 | |
| | 2235 | 549 | 420 | 1010 | |
| | 2295 | 549 | 60 | 1010 | |
| | 2296 | 542 | 1 | 1010 | |
| | 2356 | 542 | 60 | 1010 | |
| | 2357 | 526 | 1 | 1010 | |
| | 8357 | 526 | 6000 | 1010 | |
| 9. Improper Startup | 0 | 526 | | 1010 | 3395 |
| 1 Cycle | 1 | 268 (3) | 1 | 1010 | (12%)' |
| | 27 | 268 (3) | 26 | 1010 | |
| | 28 | 526 | 1 | 1010 | |
| | 6028 | 526 | 6000 | 1010 | |
| 10. Shutdown | 0 | 549 | | 1010 | 14147 |
| 300 Cycles | 6264 | 375 | 6264 | 170 | (50%)' |
| | 6864 | 330 | 600 | 88 | |
| | 16224 | 70 | 9360 | 50 | |
| | 22224 | 70 | 6000 | 50 | |
| 11. Design Hydrostatic | — | 100 | --- | 50 | 1981 |
| Test | | | | 1563 | (7%) |
| 120 cycles | | | | 50 | |
| 12. Hydrostatic Test | — | 100 | --- | 0 | 1981 |
| 1 Cycle | | | | 1100 | (7%) |
| | | | | 50 | |

Notes:
1. The instant temperature change is assumed as 1 second time step.
2. The number of cycles is for 60 years [2].
3. 268°F is the blend radius temperature for this transient. The safe end has a different temperature for Transient 9. [2]

# Table 3: Safe End Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 1. Normal Startup with | 0 | 100 | | 0 | 14147.0 |
| Heatup at 100°F/hr | 16164 | 549 | 16164 | 1010 | (50%)' |
| 300 Cycles | 16864 | 549 | 700 | 1010 | |
| 2. Turbine Roll and | 0 | 549 | | 1010 | 28294 |
| Increase to Rated Power | 1 | 542 | 1 | 1010 | (100%)' |
| 300 Cycles | 601 | 542 | 600 | 1010 | |
| | 602 | 526 | 1 | 1010 | |
| | 1302 | 526 | 700 | 1010 | |
| 3. Loss of Feedwater | 0 | 526 | | 1010 | 28294 |
| Heaters | 1800 | 542 | 1800 | 1010 | (100%)' |
| Turbine Trip 25% Power | 2100 | 542 | 300 | 1010 | |
| 10 Cycles | 2460 | 526 | 360 | 1010 | |
| | 3060 | 526 | 600 | 1010 | |
| | 3960 | 542 | 900 | 1010 | |
| | 4260 | 542 | 300 | 1010 | |
| | 6060 | 526 | 1800 | 1010 | |
| | 6760 | 526 | 700 | 1010 | |
| 4. Loss of Feedwater | 0 | 526 | | 1010 | 0 |
| Pumps | 3 | 526 | 3 | 1190 | (0%)' |
| 10 Cycles | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6773 | 500 | 4380 | 1135 | |
| | 7193 | 300 | 420 | 675 | 14147 |
| | 7493 | 300 | 300 | 675 | (50%)' |
| | 11093 | 400 | 3600 | 240 | |
| | 16457 | 549 | 5364 | 1010 | |
| | 16517 | 549 | 60 | 1010 | |
| | 16518 | 542 | 1 | 1010 | 28294 |
| | 17118 | 542 | 600 | 1010 | (100%)' |
| | 17119 | 526 | 1 | 1010 | |
| | 17819 | 526 | 700 | 1010 | |
| 5. Turbine Generator Trip | 0 | 526 | | 1010 | 28294 |
| 60 Cycles | 10 | 526 | 10 | 1135 | (100%)' |
| | 15 | 526 | 5 | 1135 | |
| | 30 | 526 | 15 | 940 | |
| | 1830 | 526 | 1800 | 940 | |
| | 2250 | 549 | 420 | 1010 | |
| | 2310 | 549 | 60 | 1010 | |
| | 2311 | 542 | 1 | 1010 | |
| | 2911 | 542 | 600 | 1010 | |
| | 2912 | 526 | 1 | 1010 | |
| | 3612 | 526 | 700 | 1010 | |
| 6. Reactor Overpressure | 0 | 526 | | 1010 | 28294 |
| 1 Cycle | 2 | 526 | 2 | 1375 | (100%)' |
| | 32 | 526 | 30 | 940 | |
| | 1832 | 526 | 1800 | 940 | |
| | 2252 | 549 | 420 | 1010 | |
| | 2312 | 549 | 60 | 1010 | |
| | 2313 | 542 | 1 | 1010 | |
| | 2913 | 542 | 600 | 1010 | |
| | 2914 | 526 | 1 | 1010 | |
| | 3614 | 526 | 700 | 1010 | |
| 7. SRV Blowdown | 0 | 526 | | 1010 | 28294 |
| 1 Cycle | 600 | 375 | 600 | 170 | (100%)' |
| | 11580 | 70 | 10980 | 50 | |
| | 12280 | 70 | 700 | 50 | |
| 8. SCRAM Other | 0 | 526 | | 1010 | 28294 |
| 228 Cycles | 15 | 526 | 15 | 940 | (100%)' |
| | 1815 | 526 | 1800 | 940 | |
| | 2235 | 549 | 420 | 1010 | |
| | 2295 | 549 | 60 | 1010 | |
| | 2296 | 542 | 1 | 1010 | |
| | 2356 | 542 | 60 | 1010 | |
| | 2357 | 526 | 1 | 1010 | |
| | 3057 | 526 | 700 | 1010 | |
| 9. Improper Startup | 0 | 526 | | 1010 | 3395 |
| 1 Cycle | 1 | 130 [3] | 1 | 1010 | (12%)' |
| | 27 | 130 [3] | 26 | 1010 | |
| | 28 | 526 | 1 | 1010 | |
| | 728 | 526 | 700 | 1010 | |
| 10. Shutdown | 0 | 549 | | 1010 | 14147 |
| 300 Cycles | 6264 | 375 | 6264 | 170 | (50%)' |
| | 6864 | 330 | 600 | 88 | |
| | 16224 | 70 | 9360 | 50 | |
| | 16924 | 70 | 700 | 50 | |
| 11. Design Hydrostatic Test | — | 100 | --- | 0 | 1981 |
| 120 Cycles | | | | 1100 | (7%)' |
| | | | | 50 | |
| 12. Hydrostatic Test | --- | 100 | --- | 50 | 1981 |
| 1 Cycle | | | | 1563 | (7%)' |
| | | | | 50 | |

Notes:
1. The instant temperature change is assumed as 1 second time step.
2. The number of cycles is for 60 years [2].
3. 130°F is the safe end temperature for this transient. The blend radius has a different temperature for Transient 9. [2]

*Note: These transients are the same as in Table 2 with the exception of the 700 second steady state time increment that is used. The transients in Table 2 are plotted using a 6000 second steady state increment. The difference is due to the length of the Green's Function for the safe end which is shorter compared to the blend Radius.*

## Table 4: Blend Radius Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | 459 | 388 | 100.00 | 0 | 0 | 0 | 16.64312 | 16.64312 | 475.64 | 404.64 | 300 |
| | 4303 | -3417 | -1594 | 219.53 | 1010 | 31613 | 33976.4 | -82.95209 | -82.95209 | 28113.05 | 32299.45 | 300 |
| | 22164 | 2713 | 2306 | 549.00 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34591.74 | 36548.14 | 300 |
| 2 | 0.00 | 3094 | 1934 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34972.74 | 36176.14 | 300 |
| | 94.30 | 4079 | 2481 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 35953.85 | 36719.25 | 300 |
| | 601.70 | 3683 | 2435 | 538.8 | 1010 | 31613 | 33976.4 | 260.0765 | 260.0765 | 35556.08 | 36671.48 | 300 |
| | 680.10 | 5891 | 3489 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 37756.98 | 37718.38 | 300 |
| | 6602.00 | 2977 | 1859 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34842.98 | 36088.38 | 300 |
| 3 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 10 |
| | 1807.20 | 1834 | 1043 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 33708.85 | 35281.25 | 10 |
| | 2491.50 | 4425 | 2667 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36290.98 | 36896.38 | 10 |
| | 3974.40 | 1706 | 1060 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 33580.85 | 35298.25 | 10 |
| | 6070.80 | 3971 | 2551 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35836.98 | 36780.38 | 10 |
| | 12060.00 | 2965 | 1852 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34830.98 | 36081.38 | 10 |
| 4 | 0 | 2465 | -703 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | -252.9754 | 34330.98 | 33020.42 | 10 |
| | 3 | 2465 | -703 | 526.00 | 1190 | 37247 | 40031.6 | 252.9754 | -252.9754 | 39964.98 | 39075.62 | 10 |
| | 13 | 2465 | -703 | 526.00 | 1135 | 35525.5 | 38181.4 | 252.9754 | -252.9754 | 38243.48 | 37225.42 | 10 |
| | 435.6 | 18138 | 9690 | 356.38 | 1135 | 35525.5 | 38181.4 | 158.8774 | 158.8774 | 53822.38 | 48030.28 | 10 |
| | 2222.5 | -1169 | -2598 | 489.44 | 1135 | 35525.5 | 38181.4 | -232.6952 | -232.6952 | 34123.80 | 35350.70 | 10 |
| | 2665.5 | 12763 | 6695 | 328.40 | 885 | 27700.5 | 29771.4 | 143.3539 | 143.3539 | 40606.85 | 36609.75 | 10 |
| | 6779.2 | -4008 | -2829 | 497.05 | 1010 | 31613 | 33976.4 | -236.9137 | -236.9137 | 27368.09 | 30910.49 | 10 |
| | 7243.8 | 19275 | 9965 | 302.91 | 1010 | 31613 | 33976.4 | 129.2122 | 129.2122 | 51017.21 | 44070.61 | 10 |
| | 13996 | -2135 | 34 | 542.00 | 1010 | 31613 | 33976.4 | -261.8518 | 261.8518 | 29216.15 | 34272.25 | 10 |
| | 17247 | 3413 | 2074 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35278.98 | 36303.38 | 10 |
| | 23119 | 2971 | 1855 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34836.98 | 36084.38 | 10 |
| 5 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 60 |
| | 10.00 | 2959 | 1849 | 526 | 1135 | 35525.5 | 38181.4 | 252.9754 | 252.9754 | 38737.48 | 40283.38 | 60 |
| | 15.00 | 2959 | 1849 | 526 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 60 |
| | 2269.50 | 111 | 295 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 60 |
| | 3010.10 | 4407 | 2579 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36272.98 | 36808.38 | 60 |
| | 8912.00 | 2968 | 1854 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34833.98 | 36083.38 | 60 |
| 6 | 0.00 | 2959 | 1849 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 1 |
| | 2.00 | 2959 | 1849 | 526.00 | 1375 | 43037.5 | 46255 | 252.9754 | 252.9754 | 46249.48 | 48356.98 | 1 |
| | 32.00 | 2959 | 1849 | 526.00 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 1 |
| | 2271.50 | 111 | 295 | 549.00 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 1 |
| | 3022.00 | 4407 | 2579 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36272.98 | 36808.38 | 1 |
| | 8914.00 | 2968 | 1854 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34833.98 | 36083.38 | 1 |
| 7 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 1 |
| | 615.10 | 20260 | 12980 | 374.581 | 170 | 5321 | 5718.8 | 168.9726 | 168.9726 | 25749.97 | 18867.77 | 1 |
| | 17580.00 | 279 | 179 | 70 | 50 | 1565 | 1682 | 0 | 0 | 1844.00 | 1861.00 | 1 |
| 8 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 228 |
| | 15.00 | 2959 | 1849 | 526 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 228 |
| | 2254.50 | 111 | 295 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 228 |
| | 2491.20 | 3792 | 2234 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35657.98 | 36463.38 | 228 |
| | 8357.00 | 2963 | 1851 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34828.98 | 36080.38 | 228 |
| 9 | 0 | 2058 | 961 | 525.8 | 1010 | 31613 | 33976.4 | 252.8645 | 252.8645 | 33923.86 | 35190.26 | 1 |
| | 0.52 | 1956 | 734 | 525.6 | 1010 | 31613 | 33976.4 | 252.7535 | 252.7535 | 33821.75 | 34963.15 | 1 |
| | 28 | 23747 | 3188 | 504.5 | 1010 | 31613 | 33976.4 | 241.0479 | 241.0479 | 55601.05 | 37405.45 | 1 |
| | 425 | 1520 | 611 | 525.5 | 1010 | 31613 | 33976.4 | 252.698 | 252.698 | 33385.70 | 34840.10 | 1 |
| | 12400 | 2058 | 879 | 525.8 | 1010 | 31613 | 33976.4 | 252.8645 | 252.8645 | 33923.86 | 35108.26 | 1 |
| 10 | 0 | 2767 | 2176 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34645.74 | 36418.14 | 300 |
| | 4240.8 | 6643 | 4158 | 445.775 | 441 | 13803.3 | 14835.24 | 208.469 | 208.469 | 20654.77 | 19201.71 | 300 |
| | 6268 | 6498 | 3675 | 374.7 | 170 | 5321 | 5718.8 | 169.0386 | 169.0386 | 11988.04 | 9562.84 | 300 |
| | 6891.8 | 9282 | 5241 | 329.228 | 88 | 2754.4 | 2960.32 | 143.8121 | 143.8121 | 12180.21 | 8345.13 | 300 |
| | 22224 | 361 | 120 | 70 | 50 | 1565 | 1682 | 0 | 0 | 1926.00 | 1802.00 | 300 |
| 11 | | 0 | 0 | 100 | 0 | 0 | 0 | 16.64312 | 16.64312 | 16.64 | 16.64 | 120 |
| | | 0 | 0 | 100 | 1100 | 34430 | 37004 | 16.64312 | 16.64312 | 34446.64 | 37020.64 | 120 |
| | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 120 |
| 12 | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 1 |
| | | 0 | 0 | 100 | 1563 | 48921.9 | 52579.32 | 16.64312 | 16.64312 | 48938.54 | 52595.96 | 1 |
| | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 1 |

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 2.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 31300)/1000.
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 33640)/1000.
Column 9: Total external stress from calculation in Table 1, 280.16 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

# Table 5: Safe End Stress Summary

| 1 | 2 | 3 | 4 | 6 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | -925 | -949 | 100.00 | 0 | 0 | 0 | -339.1419 | -339.1419 | -1264.14 | -1288.14 | 300 |
| | 16164 | -4814 | -4433 | 549.00 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 1375.93 | 1615.53 | 300 |
| | 16864 | -3749 | -3705 | 549.00 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2440.93 | 2343.53 | 300 |
| 2 | 0 | -3838 | -3665 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2351.93 | 2383.53 | 300 |
| | 6 | -1664 | -2263 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 4605.07 | 3864.67 | 300 |
| | 601 | -3773 | -3607 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 2496.07 | 2520.67 | 300 |
| | 606.6 | 1196 | -403 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17955.86 | 5905.54 | 300 |
| | 1302 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 300 |
| 3 | 0 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 10 |
| | 1800.1 | -4165 | -3904 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 2104.07 | 2223.67 | 10 |
| | 2460.2 | -1932 | -2200 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 4517.94 | 4108.54 | 10 |
| | 3960.2 | -4537 | -4185 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 1732.07 | 1942.67 | 10 |
| | 6060.2 | -3315 | -3241 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 3134.94 | 3067.54 | 10 |
| | 6760 | -3687 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2762.94 | 2786.54 | 10 |
| 4 | 0.00 | -3756 | -3716 | 526 | 1020 | 11719.8 | 11577 | -5154.958 | -5154.958 | 2808.84 | 2706.04 | 10 |
| | 3.00 | -3756 | -3716 | 526 | 1190 | 13673.1 | 13506.5 | -5154.958 | -5154.958 | 4762.14 | 4635.54 | 10 |
| | 13.00 | -3756 | -3716 | 526 | 1135 | 13041.15 | 12882.25 | -5154.958 | -5154.958 | 4130.19 | 4011.29 | 10 |
| | 242.30 | 15878 | 10049 | 302.374 | 1135 | 13041.15 | 12882.25 | 2626.926 | 2626.926 | 31546.08 | 25558.18 | 10 |
| | 2213.10 | -6388 | -5428 | 499.889 | 1135 | 13041.15 | 12882.25 | -4859.78 | -4859.78 | 1793.37 | 2594.47 | 10 |
| | 2408.60 | 13203 | 8265 | 301.443 | 885 | 10168.65 | 10044.75 | 2616.401 | 2616.401 | 25988.05 | 20926.15 | 10 |
| | 6773.40 | -4763 | -4312 | 499.809 | 1135 | 13041.15 | 12882.25 | -4858.875 | -4858.875 | 3419.27 | 3711.37 | 10 |
| | 7193.10 | 15374 | 9801 | 300 | 675 | 7755.75 | 7661.25 | 2600.088 | 2600.088 | 25729.84 | 20062.34 | 10 |
| | 16457.50 | -4812 | -5032 | 549 | 240 | 2757.6 | 2724 | -5414.966 | -5414.966 | -7469.37 | -7722.97 | 10 |
| | 16524.70 | -2358 | -2725 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3911.07 | 3402.67 | 10 |
| | 17118.00 | -3778 | -3610 | 541.996 | 1010 | 11604.9 | 11463.5 | -5335.788 | -5335.788 | 2491.11 | 2517.71 | 10 |
| | 17123.60 | 1192 | -406 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17951.86 | 5902.54 | 10 |
| | 17819.00 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 10 |
| 5 | 0.00 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 60 |
| | 10.00 | -3688 | -3522 | 526 | 1135 | 13041.15 | 12882.25 | -5154.958 | -5154.958 | 4198.19 | 4205.29 | 60 |
| | 30.00 | -3688 | -3522 | 526 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 60 |
| | 2250.10 | -6054 | -5337 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 60 |
| | 2319.90 | -2977 | -3123 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 60 |
| | 2911.00 | -3782 | -3613 | 541.999 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 2487.08 | 2514.68 | 60 |
| | 2916.70 | 1188 | -408 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17947.86 | 5900.54 | 60 |
| | 3612.00 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 60 |
| 6 | 0.00 | -3688 | -3522 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 1 |
| | 2.00 | -3688 | -3522 | 5.26E+02 | 1375 | 15798.75 | 15606.25 | -5154.958 | -5154.958 | 6955.79 | 6929.29 | 1 |
| | 32.00 | -3688 | -3522 | 5.26E+02 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 1 |
| | 2252.10 | -6054 | -5337 | 5.49E+02 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 1 |
| | 2322.20 | -2977 | -3123 | 5.42E+02 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 1 |
| | 2913.00 | -3782 | -3613 | 5.42E+02 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 2487.08 | 2514.68 | 1 |
| | 2918.70 | 1188 | -408 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17947.86 | 5900.54 | 1 |
| | 3614.00 | -3670 | -3509 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 1 |
| 7 | 0 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 1 |
| | 600 | 7773 | 5336 | 375 | 170 | 1953.3 | 1929.5 | 3447.943 | 3447.943 | 13174.24 | 10713.44 | 1 |
| | 1367.9 | -1390 | -1567 | 354.172 | 162 | 1861.38 | 1838.7 | -3212.488 | -3212.488 | -2741.11 | -2940.79 | 1 |
| | 11580.1 | 454 | 190 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | 1028.50 | 757.50 | 1 |
| | 12280 | -707 | -689 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | -132.50 | -121.50 | 1 |
| 8 | 0.00 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 228 |
| | 15.00 | -3688 | -3522 | 526 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 228 |
| | 2235.10 | -6054 | -5337 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 228 |
| | 2305.20 | -2977 | -3123 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 228 |
| | 2356.00 | -3183 | -3151 | 541.999 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 3086.08 | 2976.68 | 228 |
| | 2361.50 | 1761 | -28 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 18520.86 | 6280.54 | 228 |
| | 3057.00 | -3667 | -3506 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2782.94 | 2802.54 | 228 |
| 9 | 0 | -2968 | -2837 | 525.7 | 1010 | 11604.9 | 11463.5 | -5151.566 | -5151.566 | 3485.22 | 3474.82 | 1 |
| | 27 | 68473 | 45303 | 291.3 | 1010 | 11604.9 | 11463.5 | 2501.737 | 2501.737 | 82579.74 | 59268.34 | 1 |
| | 80.7 | -11546 | -8877 | 518.4 | 1010 | 11604.9 | 11463.5 | -5069.042 | -5069.042 | -5010.04 | -2482.14 | 1 |
| | 5200 | -2967 | -2832 | 525.7 | 1010 | 11604.9 | 11463.5 | -5151.566 | -5151.566 | 3486.21 | 3479.78 | 1 |
| 10 | 0 | -3745 | -3709 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2444.93 | 2339.53 | 300 |
| | 6864.2 | 501 | -405 | 329.994 | 170 | 1953.3 | 1929.5 | 2939.162 | -2939.162 | 5393.46 | -1414.66 | 300 |
| | 7455.5 | -1183 | -1528 | 314.325 | 88 | 1011.12 | 998.8 | -2762.029 | -2762.029 | -2933.91 | -3291.23 | 300 |
| | 16224.1 | 334 | -35 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | 908.50 | 532.50 | 300 |
| | 16924 | -731 | -763 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | -156.50 | -195.50 | 300 |
| 11 | | 0 | 0 | 100 | 0 | 0 | 0 | 339.1419 | 339.1419 | 339.14 | 339.14 | 120 |
| | | 0 | 0 | 100 | 1100 | 12639 | 12485 | 339.1419 | 339.1419 | 12978.14 | 12824.14 | 120 |
| | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 120 |
| 12 | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 1 |
| | | 0 | 0 | 100 | 1563 | 17958.87 | 17740.05 | 339.1419 | 339.1419 | 18298.01 | 18079.19 | 1 |
| | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 1 |

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 3.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 11490)/1000.
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 11350)/1000.
Column 9: Total external stress from calculation in Table 1, 5708.89 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

## Table 6: Fatigue Results for Blend Radius (60 Years)

```
     LOCATION = LOCATION NO. 2 -- BLEND RADIUS
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
            m = 2.0
            n =  .2
           Sm = 26700. psi
       Ecurve = 3.000E+07 psi
    Eanalysis = 2.670E+07 psi
           Kt = 1.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 55601. | 17. | 55584. | 37389. | 1.000 | 31227. | 1.000E+00 | 1.951E+04 | .0001 |
| 53822. | 17. | 53806. | 48014. | 1.000 | 30228. | 1.000E+01 | 2.161E+04 | .0005 |
| 51017. | 17. | 51001. | 44054. | 1.000 | 28652. | 1.000E+01 | 2.547E+04 | .0004 |
| 48939. | 17. | 48922. | 52579. | 1.000 | 27484. | 1.000E+00 | 2.894E+04 | .0000 |
| 46249. | 17. | 46233. | 48340. | 1.000 | 25974. | 1.000E+00 | 3.443E+04 | .0000 |
| 40607. | 17. | 40590. | 36593. | 1.000 | 22803. | 1.000E+01 | 5.217E+04 | .0002 |
| 39965. | 17. | 39948. | 39059. | 1.000 | 22443. | 1.000E+01 | 5.647E+04 | .0002 |
| 38737. | 17. | 38721. | 40267. | 1.000 | 21753. | 6.000E+01 | 6.592E+04 | .0009 |
| 38243. | 17. | 38227. | 37209. | 1.000 | 21476. | 1.000E+01 | 7.025E+04 | .0001 |
| 37757. | 17. | 37740. | 37702. | 1.000 | 21202. | 7.000E+00 | 7.486E+04 | .0001 |
| 37757. | 476. | 37281. | 37314. | 1.000 | 20945. | 2.930E+02 | 7.954E+04 | .0037 |
| 36291. | 476. | 35815. | 36492. | 1.000 | 20121. | 7.000E+00 | 9.705E+04 | .0001 |
| 36291. | 1582. | 34709. | 35198. | 1.000 | 19500. | 3.000E+00 | 1.096E+05 | .0000 |
| 36273. | 1582. | 34691. | 35110. | 1.000 | 19490. | 6.000E+01 | 1.098E+05 | .0005 |
| 36273. | 1582. | 34691. | 35110. | 1.000 | 19490. | 1.000E+00 | 1.098E+05 | .0000 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 5.600E+01 | 1.135E+05 | .0005 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 1.000E+00 | 1.135E+05 | .0000 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 1.000E+00 | 1.135E+05 | .0000 |
| 35954. | 1844. | 34110. | 34858. | 1.000 | 19163. | 1.000E+00 | 1.167E+05 | .0000 |
| 35954. | 1926. | 34028. | 34917. | 1.000 | 19117. | 2.410E+02 | 1.177E+05 | .0020 |
| 35837. | 1926. | 33911. | 34978. | 1.000 | 19051. | 1.000E+01 | 1.191E+05 | .0001 |
| 35658. | 1926. | 33732. | 34661. | 1.000 | 18951. | 4.900E+01 | 1.214E+05 | .0004 |
| 35658. | 11988. | 23670. | 26901. | 1.000 | 13298. | 1.790E+02 | 5.728E+05 | .0003 |
| 35556. | 11988. | 23568. | 27109. | 1.000 | 13240. | 1.210E+02 | 5.955E+05 | .0002 |
| 35556. | 12180. | 23376. | 28326. | 1.000 | 13133. | 1.790E+02 | 6.411E+05 | .0003 |
| 35279. | 12180. | 23099. | 27958. | 1.000 | 12977. | 1.000E+01 | 7.138E+05 | .0000 |
| 34973. | 12180. | 22793. | 27831. | 1.000 | 12805. | 1.110E+02 | 8.050E+05 | .0001 |
| 34973. | 20655. | 14318. | 16974. | 1.000 | 8044. | 1.890E+02 | 7.421E+07 | .0000 |
| 34843. | 20655. | 14188. | 16887. | 1.000 | 7971. | 1.110E+02 | 7.983E+07 | .0000 |
| 34843. | 25750. | 9093. | 17221. | 1.000 | 5108. | 1.000E+00 | 1.000E+20 | .0000 |
| 34843. | 27368. | 7475. | 5178. | 1.000 | 4199. | 1.000E+01 | 1.000E+20 | .0000 |
| 34843. | 28113. | 6730. | 3789. | 1.000 | 3781. | 1.780E+02 | 1.000E+20 | .0000 |
| 34837. | 28113. | 6724. | 3785. | 1.000 | 3777. | 1.000E+01 | 1.000E+20 | .0000 |
| 34834. | 28113. | 6721. | 3784. | 1.000 | 3776. | 6.000E+01 | 1.000E+20 | .0000 |
| 34834. | 28113. | 6721. | 3784. | 1.000 | 3776. | 1.000E+00 | 1.000E+20 | .0000 |
| 34831. | 28113. | 6718. | 3782. | 1.000 | 3774. | 1.000E+01 | 1.000E+20 | .0000 |
| 34829. | 28113. | 6716. | 3781. | 1.000 | 3773. | 4.100E+01 | 1.000E+20 | .0000 |
| 34829. | 29216. | 5613. | 1808. | 1.000 | 3153. | 1.000E+01 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 6.000E+01 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 1.000E+00 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 1.160E+02 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+01 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 6.000E+01 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 4.000E+01 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 6.000E+01 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 1.270E+02 | 1.000E+20 | .0000 |
| 34646. | 32634. | 2012. | 2695. | 1.000 | 1130. | 1.010E+02 | 1.000E+20 | .0000 |
| 34646. | 33386. | 1260. | 1578. | 1.000 | 708. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33581. | 1065. | 1120. | 1.000 | 598. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 33709. | 937. | 1137. | 1.000 | 526. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 33822. | 824. | 1455. | 1.000 | 463. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33924. | 722. | 1228. | 1.000 | 406. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33924. | 722. | 1310. | 1.000 | 406. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 34124. | 522. | 1067. | 1.000 | 293. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 34331. | 315. | 3398. | 1.000 | 177. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 34447. | 199. | -603. | 1.000 | 112. | 1.200E+02 | 1.000E+20 | .0000 |
| 34646. | 34592. | 54. | -130. | 1.000 | 30. | 3.500E+01 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | TOTAL USAGE FACTOR = | | .0108 |

## Table 7: Fatigue Results for Safe End (60 Years)

```
      LOCATION = LOCATION NO. 1 -- SAFE END
 FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 1.7
             n =  .3
            Sm = 17000. psi
        Ecurve = 2.830E+07 psi
     Eanalysis = 2.700E+07 psi
            Kt = 1.53
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 82580. | -7469. | 90049. | 66991. | 2.045 | 134573. | 1.000E+00 | 6.765E+02 | .0015 |
| 31546. | -7469. | 39015. | 33281. | 1.000 | 29691. | 9.000E+00 | 6.857E+05 | .0000 |
| 31546. | -5010. | 36556. | 28040. | 1.000 | 26947. | 1.000E+00 | 1.160E+06 | .0000 |
| 25988. | -2934. | 28922. | 24217. | 1.000 | 21884. | 1.000E+01 | 2.383E+06 | .0000 |
| 25730. | -2934. | 28664. | 23354. | 1.000 | 21509. | 1.000E+01 | 2.566E+06 | .0000 |
| 18521. | -2934. | 21455. | 9572. | 1.000 | 13903. | 2.280E+02 | 9.710E+08 | .0000 |
| 18298. | -2934. | 21232. | 21370. | 1.000 | 17063. | 1.000E+00 | 7.876E+06 | .0000 |
| 17956. | -2934. | 20890. | 9197. | 1.000 | 13502. | 5.100E+01 | 1.000E+20 | .0000 |
| 17956. | -2741. | 20697. | 8846. | 1.000 | 13304. | 1.000E+00 | 1.000E+20 | .0000 |
| 17956. | -1264. | 19220. | 7194. | 1.000 | 12071. | 2.480E+02 | 1.000E+20 | .0000 |
| 17952. | -1264. | 19216. | 7191. | 1.000 | 12068. | 1.000E+01 | 1.000E+20 | .0000 |
| 17948. | -1264. | 19212. | 7189. | 1.000 | 12065. | 4.200E+01 | 1.000E+20 | .0000 |
| 17948. | -157. | 18104. | 6096. | 1.000 | 11181. | 1.800E+01 | 1.000E+20 | .0000 |
| 17948. | -157. | 18104. | 6096. | 1.000 | 11181. | 1.000E+00 | 1.000E+20 | .0000 |
| 13174. | -157. | 13331. | 10909. | 1.000 | 10016. | 1.000E+00 | 1.000E+20 | .0000 |
| 12978. | -157. | 13135. | 13020. | 1.000 | 10500. | 1.200E+02 | 1.000E+20 | .0000 |
| 6956. | -157. | 7112. | 7125. | 1.000 | 5706. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | -157. | 5550. | -1219. | 1.000 | 2570. | 1.590E+02 | 1.000E+20 | .0000 |
| 5393. | -133. | 5526. | -1293. | 1.000 | 2537. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 6.000E+01 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 7.900E+01 | 1.000E+20 | .0000 |
| 4762. | 136. | 4626. | 3924. | 1.000 | 3514. | 1.000E+01 | 1.000E+20 | .0000 |
| 4605. | 136. | 4469. | 3153. | 1.000 | 3218. | 1.390E+02 | 1.000E+20 | .0000 |
| 4605. | 339. | 4266. | 3526. | 1.000 | 3215. | 1.200E+02 | 1.000E+20 | .0000 |
| 4605. | 909. | 3697. | 3332. | 1.000 | 2863. | 4.100E+01 | 1.000E+20 | .0000 |
| 4518. | 909. | 3609. | 3576. | 1.000 | 2885. | 1.000E+01 | 1.000E+20 | .0000 |
| 4198. | 909. | 3290. | 3673. | 1.000 | 2744. | 6.000E+01 | 1.000E+20 | .0000 |
| 4130. | 909. | 3222. | 3479. | 1.000 | 2655. | 1.000E+01 | 1.000E+20 | .0000 |
| 3911. | 909. | 3003. | 2870. | 1.000 | 2371. | 1.000E+01 | 1.000E+20 | .0000 |
| 3486. | 909. | 2578. | 2947. | 1.000 | 2170. | 1.000E+00 | 1.000E+20 | .0000 |
| 3485. | 909. | 2577. | 2942. | 1.000 | 2168. | 1.000E+00 | 1.000E+20 | .0000 |
| 3419. | 909. | 2511. | 3179. | 1.000 | 2199. | 1.000E+01 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 6.000E+01 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 9.600E+01 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.200E+02 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 1029. | 2264. | 2247. | 1.000 | 1810. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 1376. | 1916. | 1389. | 1.000 | 1390. | 9.000E+00 | 1.000E+20 | .0000 |
| 3135. | 1376. | 1759. | 1452. | 1.000 | 1325. | 1.000E+01 | 1.000E+20 | .0000 |
| 3086. | 1376. | 1710. | 1361. | 1.000 | 1274. | 2.280E+02 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2809. | 1376. | 1433. | 1091. | 1.000 | 1054. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1376. | 1407. | 1187. | 1.000 | 1067. | 4.300E+01 | 1.000E+20 | .0000 |
| 2783. | 1732. | 1051. | 860. | 1.000 | 790. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1793. | 990. | 208. | 1.000 | 576. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 6.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 1.000E+00 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 1.040E+02 | 1.000E+20 | .0000 |
| 2780. | 1958. | 822. | 808. | 1.000 | 655. | 1.240E+02 | 1.000E+20 | .0000 |
| 2780. | 2104. | 676. | 576. | 1.000 | 514. | 1.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.660E+02 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 6.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.000E+00 | 1.000E+20 | .0000 |
| 2763. | 2352. | 411. | 403. | 1.000 | 327. | 1.000E+01 | 1.000E+20 | .0000 |
| 2762. | 2352. | 410. | 403. | 1.000 | 327. | 1.000E+01 | 1.000E+20 | .0000 |
| 2762. | 2352. | 410. | 403. | 1.000 | 327. | 4.300E+01 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.700E+01 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.000E+00 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.000E+00 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 2.280E+02 | 1.000E+20 | .0000 |
| 2496. | 2441. | 55. | 177. | 1.000 | 78. | 5.300E+01 | 1.000E+20 | .0000 |
| 2496. | 2445. | 51. | 181. | 1.000 | 77. | 2.470E+02 | 1.000E+20 | .0000 |
| 2491. | 2445. | 46. | 178. | 1.000 | 74. | 1.000E+01 | 1.000E+20 | .0000 |
| 2487. | 2445. | 42. | 175. | 1.000 | 71. | 4.300E+01 | 1.000E+20 | .0000 |
| 2487. | 2487. | 0. | 0. | 1.000 | 0. | 1.700E+01 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | TOTAL USAGE FACTOR = | | .0015 |

Table 8: Material Properties (For Transient 9)[1]

| Material | SA-533 Gr B @400 °F (Mn-1/2Mo-1/2Ni) | SA-508 Cl 2 @400 °F (3/4Ni-1/2Mo-1/3Cr-V) | SA-240 Type 304 @400 °F (18Cr-8Ni) | SA-182 F316 @300 °F (16Cr-12Ni-2Mo) |
|---|---|---|---|---|
| Modulus of Elasticity, $e^{-6}$ psi | 27.4 | 26.1 | 26.5 | 27.0 |
| Coefficient of Thermal Expansion, $e^{-6}$, in/in/°F | 8.0 | 7.7 | 10.2 | 9.8 |
| Thermal Conductivity, Btu/hr-ft-°F | 23.1 | 23.1 | 10.4 | 9.3 |
| Thermal Diffusivity, $ft^2$/hr | 0.378 | 0.378 | 0.165 | 0.150 |
| Specific Heat, Btu/lb-°F[2] | 0.125 | 0.125 | 0.129 | 0.127 |
| Density, lb/in³ | 0.283 | 0.283 | 0.283 | 0.283 |
| Poisson's Ratio | 0.3 | 0.3 | 0.3 | 0.3 |

Notes: [1] Material Properties are evaluated at 400°F from the 1998 ASME Code, Section II, Part D, with 2000 Addenda, except for density and Poisson's ratio, which are assumed typical values. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. The safe end material properties were used for 300°F, the Code table values closest to the average temperature for the safe end for transient 9.

[2] Calculated as $[k/(\rho d)]/12^3$.

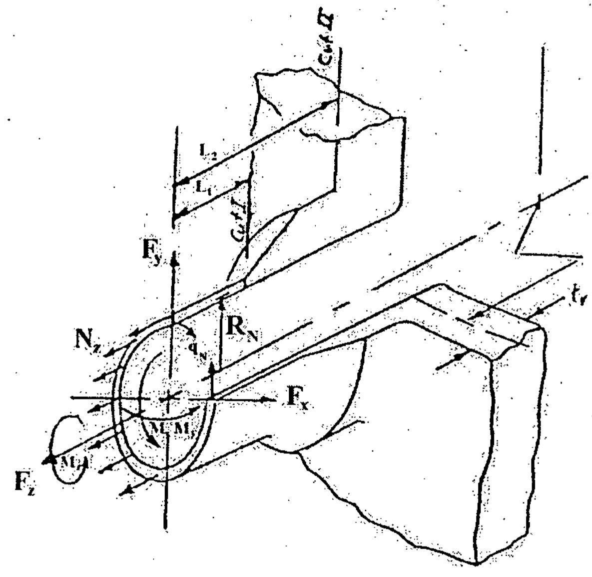



**Figure 1: External Forces and Moments on the Recirculation Outlet Nozzle**

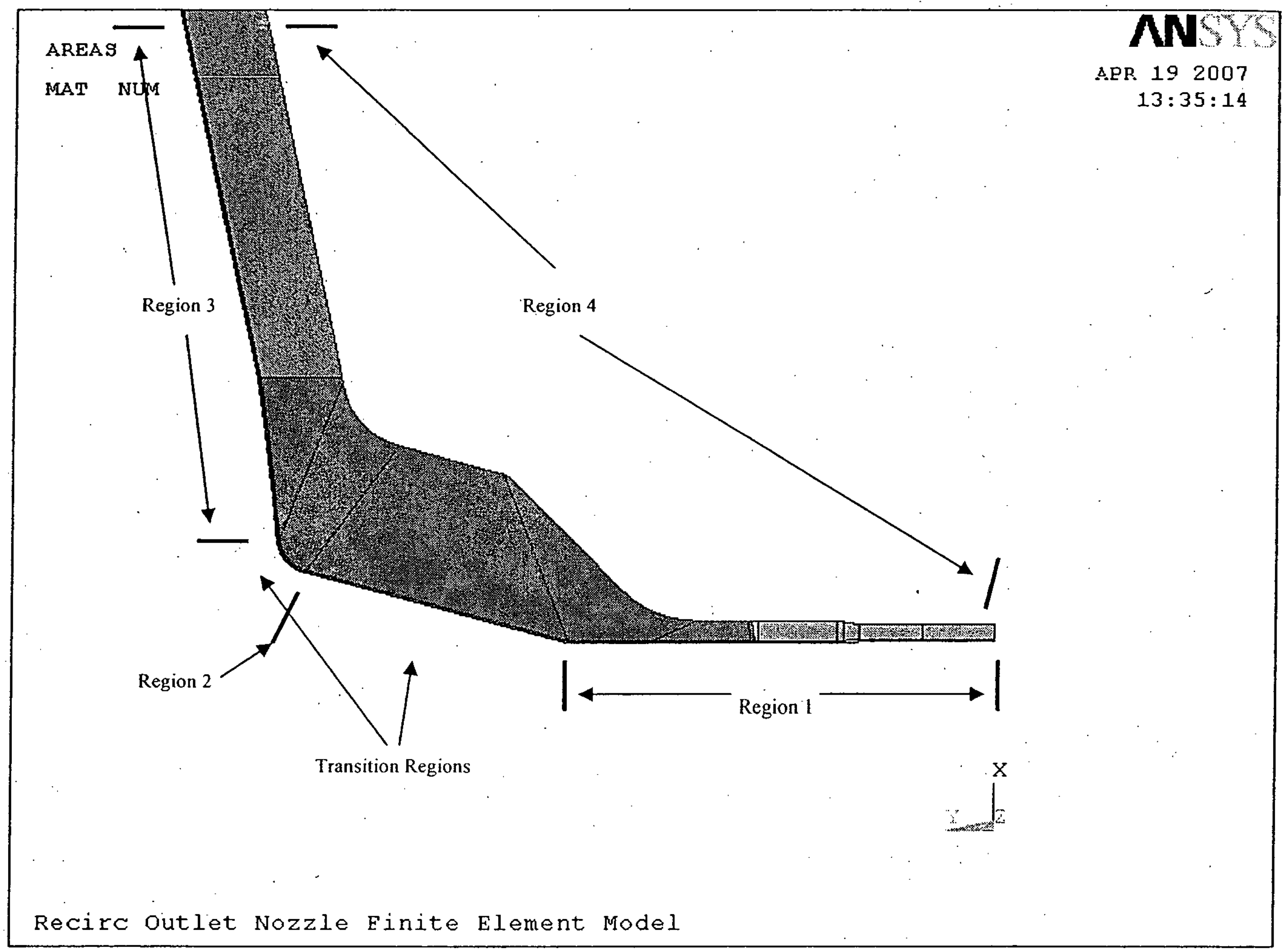



**Figure 2: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries for Transient 9**

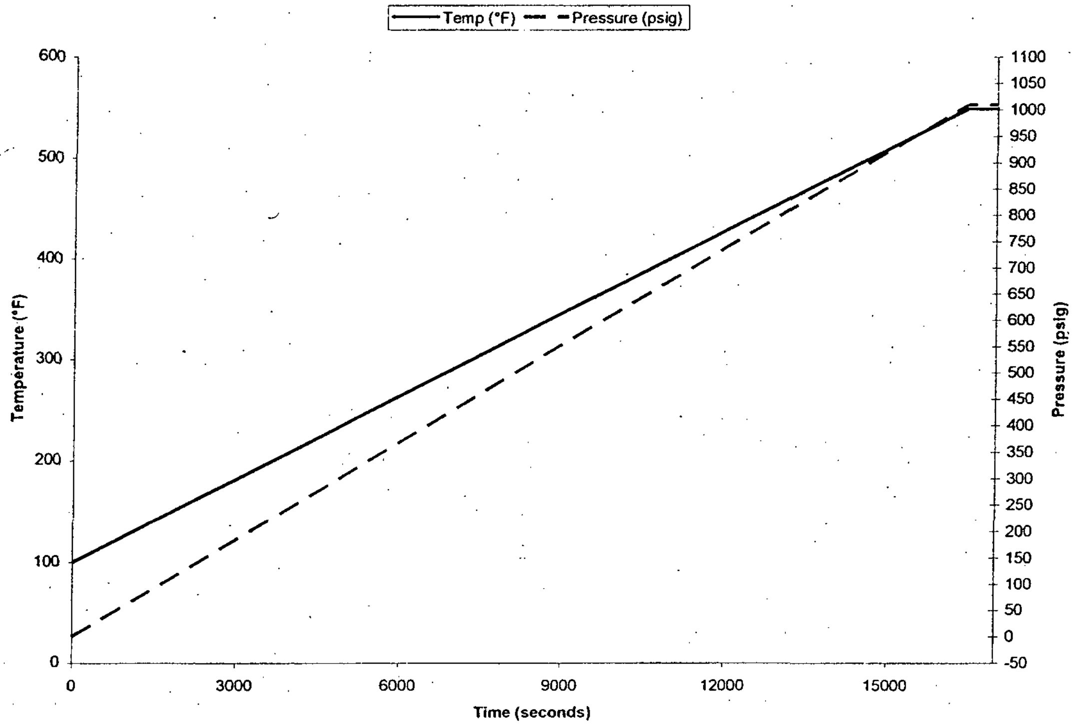



**Figure 3: Transient 1 – Normal Startup at 100°F/hr**

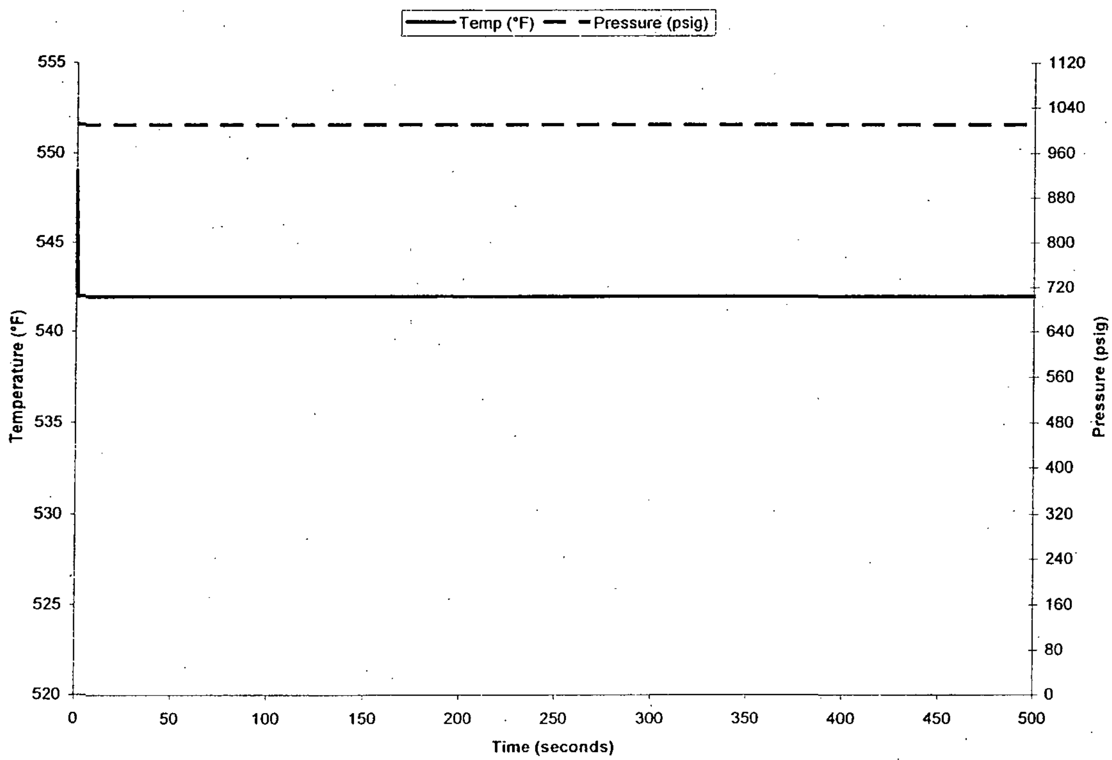



**Figure 4: Transient 2 – Turbine Roll and Increase to Rated Power**

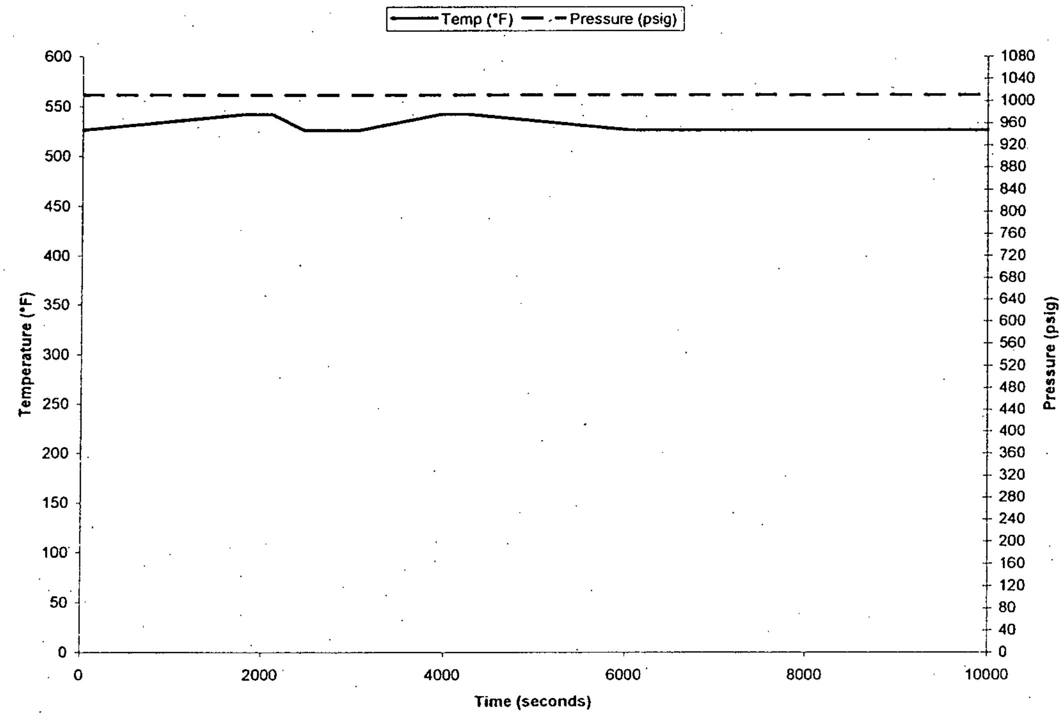



**Figure 5: Transient 3 – Loss of Feedwater Heaters and Turbine Trip 25% Power**

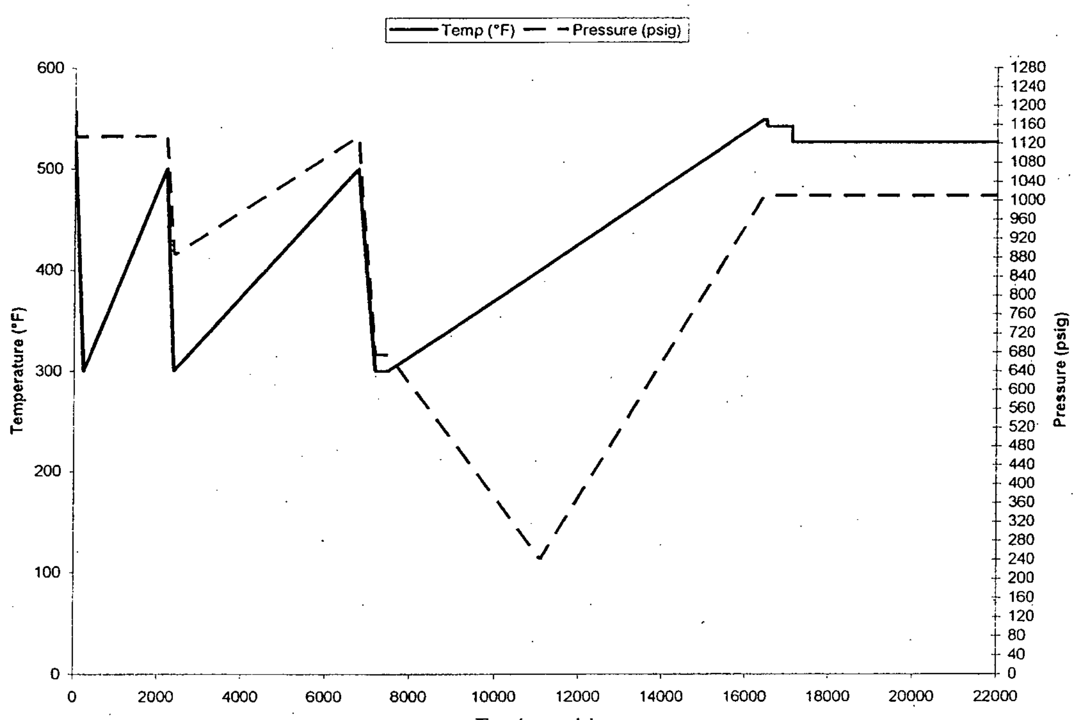



**Figure 6: Transient 4 – Loss of Feedwater Pumps**

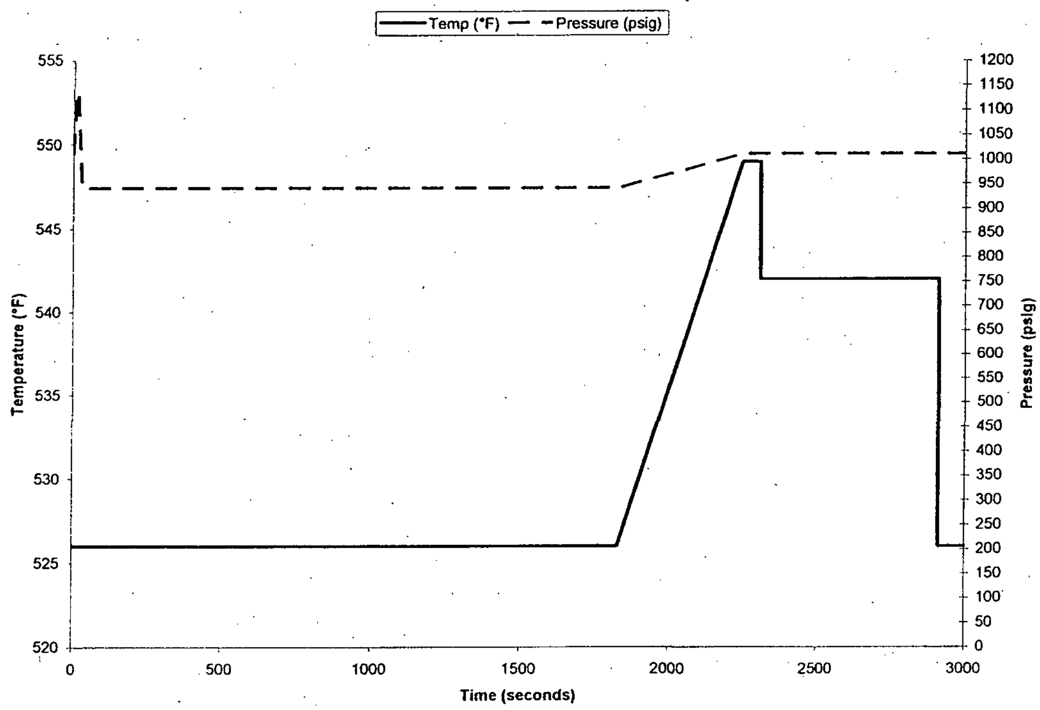



**Figure 7: Transient 5 – Turbine Generator Trip**

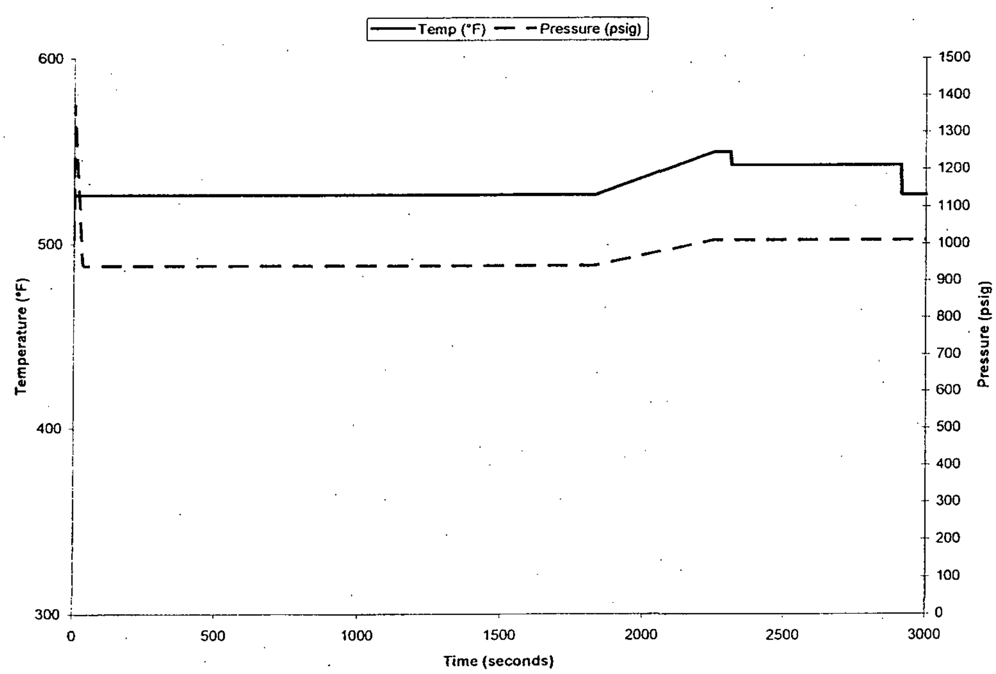



**Figure 8: Transient 6 – Reactor Overpressure**

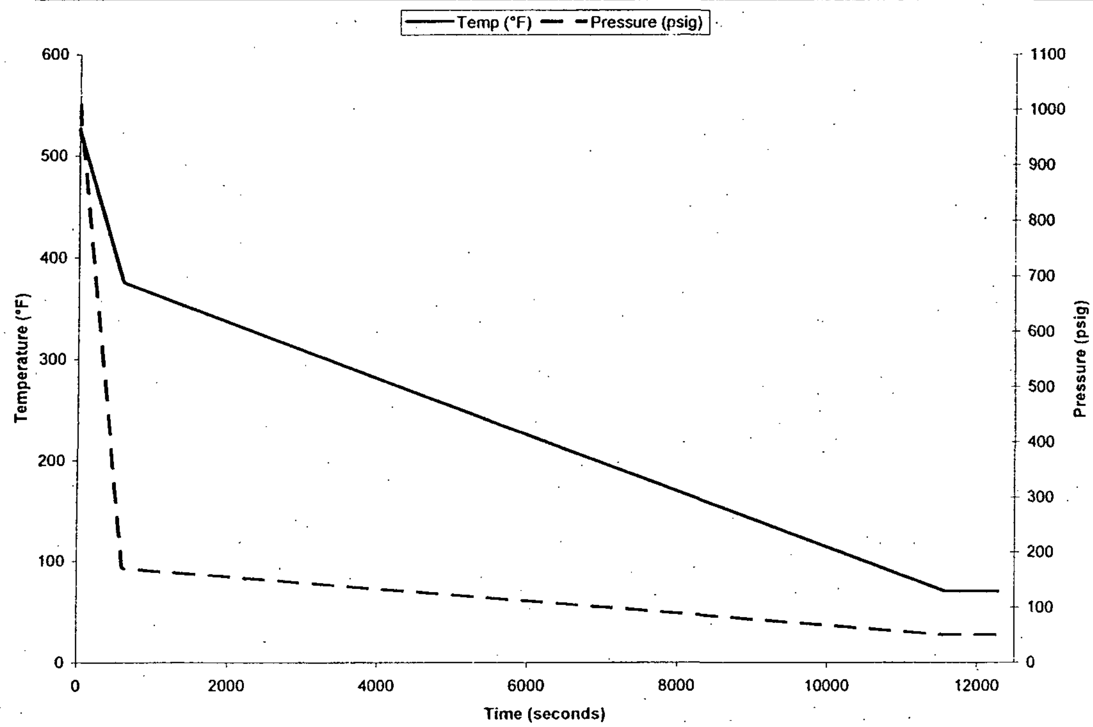



**Figure 9: Transient 7 – SRV Blowdown**

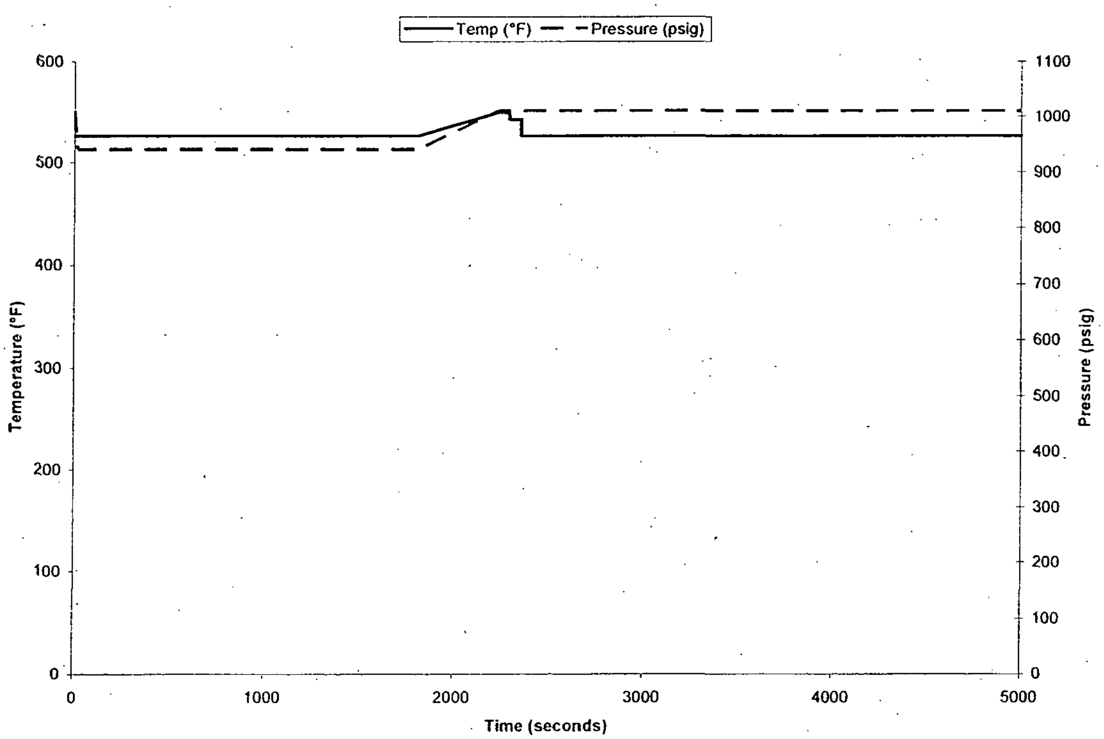



**Figure 10: Transient 8 – SCRAM Other**

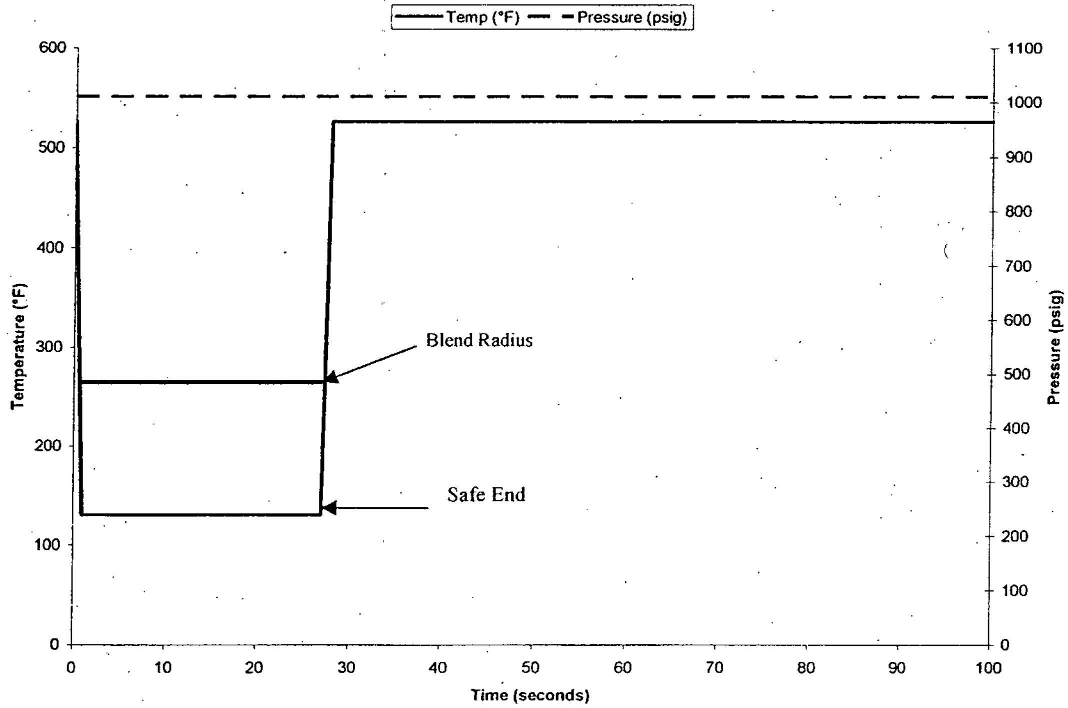



**Figure 11: Transient 9 – Improper Startup**

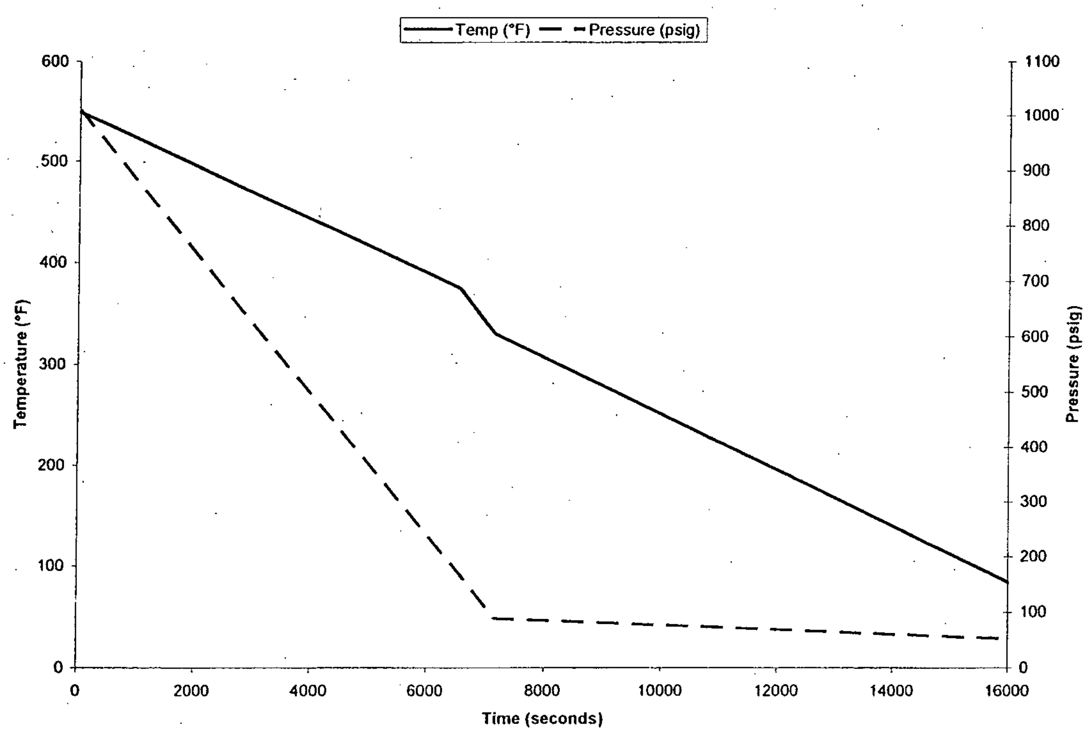
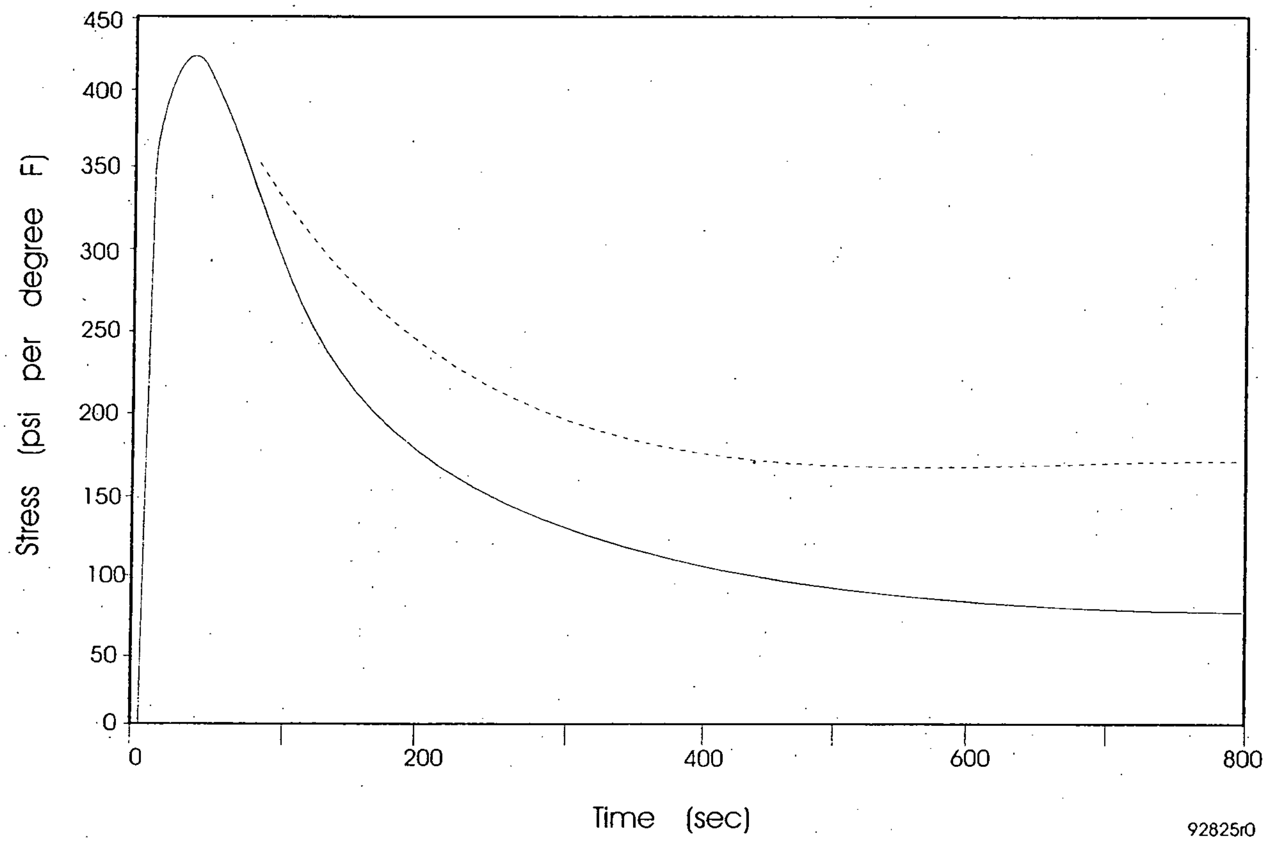



**Figure 12: Transient 10 – Shutdown**




Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

**Figure 13: Typical Green's Functions for Thermal Transient Stress**

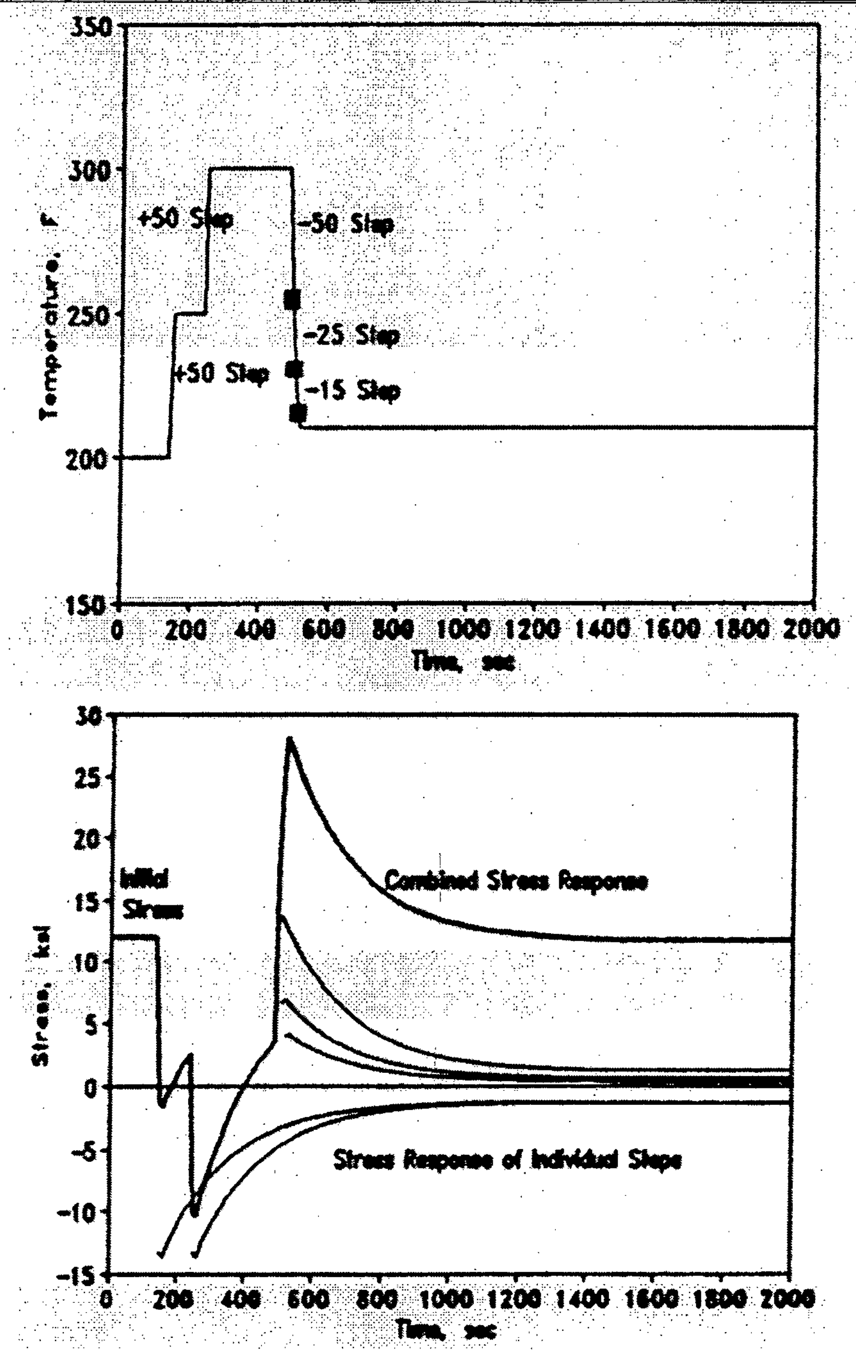



**Figure 14: Typical Stress Response Using Green's Functions**

# APPENDIX A

## SUMMARY OF OUTPUT FILES

| | | |
|---|---|---|
| VY_RON_T_T9.INP | Input File for Transient 9 Thermal Analysis | In Computer files |
| VY_RON_S_T9.INP | Input File for Transient 9 Stress Analysis | In Computer files |
| LFSE.OUT | Stress Output at Safe End | In Computer files |
| LFBR.OUT | Stress Output at Blend Radius | In Computer files |
| LFSE_INSIDE.RED | Stress Extracted at Safe End | In Computer files |
| LFBR_INSIDE.RED | Stress Extracted at Blend Radius | In Computer files |
| LFSE_T.XLS | Stress Results with Total Stress at Safe End | In Computer files |
| LFSE_M+B.XLS | Stress Results with Membrane plus Bending Stress at Safe End | In Computer files |
| LFBR_T.XLS | Stress Results with Total Stress at Blend Radius | In Computer files |
| LFBR_M+B.XLS | Stress Results with Membrane plus Bending Stress at Blend Radius | In Computer files |
| T9SE.OUT | Transient 9 Safe End stress output | In Computer files |
| T9BR.OUT | Transient 9 Blend Radius stress output | In Computer files |
| T9SE_Inside.RED | Transient 9 Stress Extracted at Safe End | In Computer files |
| T9BR_Inside.RED | Transient 9 Stress Extracted at Blend Radius | In Computer files |
| T9BR_M+B.xls | Transient 9 Stress Results with Membrane plus Bending Stress at Blend Radius | In Computer files |
| T9BR_T.xls | Transient 9 Stress Results with Total Stress at Blend Radius | In Computer files |
| T9SE_M+B.xls | Transient 9 Stress Results with Membrane plus Bending Stress at Safe End | In Computer files |
| T9SE_T.xls | Transient 9 Stress Results with Total Stress at Safe End | In Computer files |
| FATIGUE.OUT | Output file from FATIGUE.EXE | In Computer files |
| FATIGUE.inp | Input file for FATIGUE.EXE | In Computer files |
| TRANSNT_XX.inp | Input files for STRESS.EXE | In Computer files |
| P-V_XX.OUT | Output file from P-V.EXE | In Computer files |

**Structural Integrity Associates, Inc.**

# CALCULATION PACKAGE

**File No.:** VY-16Q-307

**Project No.:** VY-16Q

NEC-JH_10

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Recirculation Class 1 Piping Fatigue and EAF Analysis

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-16<br>A1-A51<br>B1-B5<br>Computer Files | Initial Issue | T. J. Herrmann<br>07/27/2007 | R.V. Perry<br>07/27/2007<br>K.R. Evon<br>07/27/2007<br>P. Hirschberg<br>07/27/2007<br>C.J. Fourcade<br>07/27/2007 |

## Table of Contents



## List of Tables



## List of Figures

## 1.0 OBJECTIVE

The purpose of this calculation is to perform an ASME Section III, NB-3600 fatigue usage calculation (including environmental fatigue) for the Loop A NUREG/CR-6260 locations in the Reactor Recirculation (RR) and Residual Heat Removal (RHR) piping.

The fatigue calculation performed herein is not a certified ASME Code NB-3600 stress and fatigue analysis. Rather, it is an evaluation for the purposes of establishing fatigue usage to accommodate fatigue monitoring of the subject B31.1 piping. Although the PIPESTRESS program implements all ASME Code NB-3600 equations, only the fatigue usage results are utilized. All stress limit checks, although calculated by the program, are ignored since satisfactory stress limit checks were performed as a part of the already existing governing B31.1 stress analyses for all piping systems.

## 2.0 METHODOLOGY

### 2.1 Background

Since ASME Section III Design Specifications do not exist for the subject piping systems, SI developed transient definitions and expected number of cycles for the subject piping in a previous evaluation. These definitions are based on SI's experience in piping analysis at other BWR plants, as well as review of VY-specific operating procedures, and are appropriate for BWR-4 plants and tailored specifically to VY. Those transient definitions will reflect current plant operating conditions as shown in references [7 through 10]. Using the PIPESTRESS computer code [5], heat transfer analysis will be performed for the transients defined to establish the necessary parameters for use in an NB-3600 fatigue evaluation. This will result in a detailed usage factor calculation for the RR and RHR NUREG/CR-6260 locations from which to base the environmental fatigue evaluation.

## 2.2 Design Transients and Fatigue Analysis

The temperature time histories are obtained from the reactor thermal cycle diagrams [7] [8]. These diagrams also provide the changes in flow rate and system pressures. These temperatures and pressures were updated to account for EPU [9].

The computer program PIPESTRESS [5] was used, which is a full function, verified piping analysis package. The ASME Code methodology for fatigue analysis of Class 1 piping systems requires determination of the through-wall thermal gradient terms $\Delta T_1$ (linear gradient), $\Delta T_2$ (nonlinear gradient), and $T_a$-$T_b$ (transition gradient) for each transient containing a non-trivial ramp rate. PIPESTRESS calculates these terms for each thermal transient. Load sets were then developed for the critical time points of the transients, that include loads due to pressure, thermal expansion, OBE seismic, and thermal gradient stresses. PIPESTRESS was then used to determine the range of primary plus secondary plus peak stresses for each load set pair, and calculate the cumulative fatigue usage for the design numbers of cycles.

## 3.0 ASSUMPTIONS/DESIGN INPUTS

The Code of construction for VY is ANSI B31.1, 1967 Edition [3, 10]. In order to take advantage of improvements in the ASME Code that result in a lower calculated fatigue usage, this evaluation is done to the ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition with 2000 Addenda [1]. The 1998 Edition of Section III (with 2000 Addenda) has been accepted by the US NRC for use in design analyses. Although there are a few restrictions on the application of this Edition, they involve the use of optional increased allowables that are not being used in this calculation.

The piping analysis input information was based on references provided by VY. The ADLPIPE input file [6] was the source for the piping geometry, and pipe support locations and types. Additional piping support information was obtained from plant drawings [15]. The pipe size, schedule, insulation, and weight per foot, were obtained from [3] (page 10). The flow element located between the pump and RHR return tee was not included in the model. The weight of the element would have no significant impact on the analysis and the element is remote from any areas of severe thermal transients such as the RHR return tee. The weight of the contents was automatically added by the PIPESTRESS program. The design temperature and piping material was obtained from reference [3] (page 9). Table 1 summarizes the material properties used in this analysis.

Reference [6] contains an SSE response spectrum. This spectrum was conservatively used as the OBE spectrum in this analysis. Code case N-411 damping is utilized and directional loading is combined by SRSS [3] (page 20).

Per Reference [9] (Item 14, section 3.2.1), the normal recirculation flow per loop, post EPU, is 12.3Mlbm/hr (at 526°F). Flow is converted to gpm as follows:

$$Q = 12{,}300{,}000\frac{lbm}{hr}\left(\frac{1ft^3}{47.45lbm}\right)\left(\frac{7.48gal}{ft^3}\right)\left(\frac{1hr}{60\min}\right) = 32{,}316gpm$$

Where flow is stopped, a flow rate that gives an equivalent natural convection heat transfer coefficient is calculated.

The applicable transients to consider for the RR and RHR systems are shown in the thermal cycle diagrams [7] and [8]. Level C transients are not required to be included in the fatigue analysis per NB-3224.4. Reference [3] describes which transients are considered level C. Note that a transient for RHR initiation is not accounted for on these diagrams. In order to account for this transient, RHR temperature data from RFO 25 [11] was used to conservatively determine an appropriate temperature change while reference [12] was used to determine flow rates and pressures. Table 2 describes each section and Figure 1 shows the piping model with node numbers. Table 3 contains a list of applicable transients. (Note that the transient RHR initiation contains a section 3B. This section accounts for the portion of the recirculation pump discharge piping that is affected by this transient.) OBE cycles are not listed in Table 3 but are included as Load Set 26 for +OBE and Load Set 27 for –OBE. A review of shutdown cooling mode operation since the recirculation piping was replaced in 1986 was performed by the station and the number of cycles per loop was conservatively estimated to be 150 through year 60 [10]. Based on this, the cycle counts for the Recirculation piping were reduced by a factor of 150/300 (50%) for all transients with the exception of transients that have fewer than 10 transient cycles.

To ensure this cycle reduction adequately considered the potential impact on carbon steel RHR piping, the full number of transient cycles [7] was initially applied to the PIPESTRESS model and the highest CUF for the carbon steel portion of the RHR piping, which has not been replaced, was lower than the value obtained for the recirculation piping with reduced cycles. The Recirculation and RHR line sizes are specified in reference [3] and are shown in Table 4.

# Table 1: Material Properties [1] [3]

ASTM A-106 Grade B (C-Si)

| Temperature (°F) | Young's Modulus (x10^6 psi) | Thermal Conductivity (Btu/hr-ft-°F) | Thermal Diffusivity (ft^2/hr) | Coefficient of Linear Thermal Expansion (in/100 ft) | Mean Coefficient of Thermal Expansion (10-6 /in/in/°F) | Design Stress Intensity (ksi) | Yield Strength (ksi) |
|---|---|---|---|---|---|---|---|
| 70 | 29.5 | 27.5 | 0.529 | 0.00 | 6.40 | 20.0 | 35.0 |
| 100 | 29.3 | 27.6 | 0.512 | 0.20 | | 20.0 | 35.0 |
| 200 | 28.8 | 27.6 | 0.486 | 1.00 | | 20.0 | 32.1 |
| 300 | 28.3 | 27.2 | 0.453 | 1.90 | | 20.0 | 31.0 |
| 400 | 27.7 | 26.7 | 0.428 | 2.80 | | 20.0 | 29.9 |
| 500 | 27.3 | 25.9 | 0.398 | 3.70 | | 18.9 | 28.5 |
| 600 | 26.7 | 25.0 | 0.374 | 4.70 | | 17.3 | 26.8 |

ASME SA-376 TP 316 (16Cr-12Ni-2Mo)

| Temperature (°F) | Young's Modulus (x10^6 psi) | Thermal Conductivity (Btu/hr-ft-°F) | Thermal Diffusivity (ft^2/hr) | Coefficient of Linear Thermal Expansion (in/100 ft) | Mean Coefficient of Thermal Expansion (10-6 /in/in/°F) | Design Stress Intensity (ksi) | Yield Strength (ksi) |
|---|---|---|---|---|---|---|---|
| 70 | 28.3 | 8.2 | 0.139 | 0.00 | 8.50 | 20.0 | 30.0 |
| 100 | 28.1 | 8.3 | 0.140 | 0.30 | | 20.0 | 30.0 |
| 200 | 27.6 | 8.8 | 0.145 | 1.40 | | 20.0 | 25.9 |
| 300 | 27.0 | 9.3 | 0.150 | 2.50 | | 20.0 | 23.4 |
| 400 | 26.5 | 9.8 | 0.155 | 3.70 | | 19.3 | 21.4 |
| 500 | 25.8 | 10.2 | 0.160 | 5.00 | | 18.0 | 20.0 |
| 600 | 25.3 | 10.7 | 0.165 | 6.30 | | 17.0 | 18.9 |

ASME SA-403 WP 316 (16Cr-12Ni-2Mo)

| Temperature (°F) | Young's Modulus (x10^6 psi) | Thermal Conductivity (Btu/hr-ft-°F) | Thermal Diffusivity (ft^2/hr) | Coefficient of Linear Thermal Expansion (in/100 ft) | Mean Coefficient of Thermal Expansion (10-6 /in/in/°F) | Design Stress Intensity (ksi) | Yield Strength (ksi) |
|---|---|---|---|---|---|---|---|
| 70 | 28.3 | 8.2 | 0.139 | 0.00 | 8.50 | 20.0 | 30.0 |
| 100 | 28.1 | 8.3 | 0.140 | 0.30 | | 20.0 | 30.0 |
| 200 | 27.6 | 8.8 | 0.145 | 1.40 | | 20.0 | 25.9 |
| 300 | 27 | 9.3 | 0.150 | 2.50 | | 20.0 | 23.4 |
| 400 | 26.5 | 9.8 | 0.155 | 3.70 | | 18.7 | 21.4 |
| 500 | 25.8 | 10.2 | 0.160 | 5.00 | | 17.5 | 20.0 |
| 600 | 25.3 | 10.7 | 0.165 | 6.30 | | 16.4 | 18.9 |

*The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions.*

**Table 2: Recirculation and RHR Piping Segment Numbers**

| Piping Region | Node Points Start | Node Points End | Description |
|---|---|---|---|
| 1 | 3 | 500 | Outlet |
| 2 | 500 | 50 | Pump suction |
| 3 | 150 | 210 | Pump discharge |
| 3B* | 188 | 210 | Down Stream of RHR Return |
| 4 | 210 | 340 | Inlet Header |
| | 210 | 320 | Inlet Header |
| 5A | 340 | 365 | Riser |
| 5B | 340 | 345 | Riser |
| 5C | 210 | 334 | Riser |
| 5D | 320 | 325 | Riser |
| 5E | 320 | 315 | Riser |
| 6A | 365 | 366 | Inlet Nozzle |
| 6B | 345 | 346 | Inlet Nozzle |
| 6C | 334 | 336 | Inlet Nozzle |
| 6D | 325 | 326 | Inlet Nozzle |
| 6E | 315 | 316 | Inlet Nozzle |
| 7A | 500 | 550 | RHR Supply; tee to valve |
| 7B | 550 | 565 | RHR Supply; valve to penetration |
| 8 | 152 | 176 | 4" Bypass |
| 9A | 600 | 660 | RHR Return; valve to tee |
| 9B | 660 | 675 | RHR Return; penetration to valve |

*Only applicable for RHR initiation

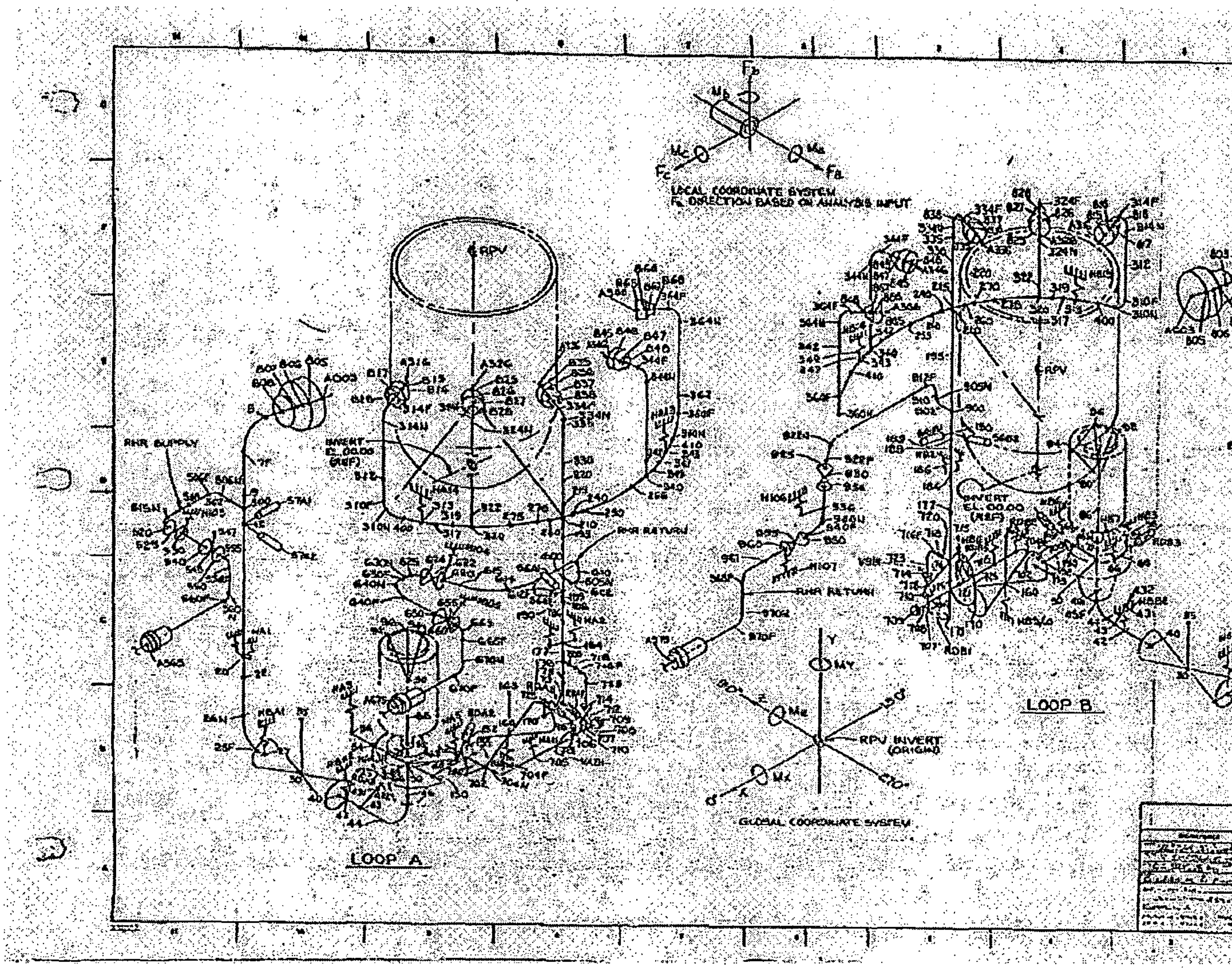



**Figure 1. Recirculation and RHR Piping Diagram**

# Table 3: VY Thermal Transients

| Transient Case | Description | Piping Region | Thermal Conditions [4] [7] [8] [10] Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | Flow [9] (gpm) | Pressure Initial (psig) | Final (psig) | No. of Cycles [10] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Design Hydrotest (Leak Test) + | 1 | 100 | 70 | 100 | 1800 | 60 | 2,262 | 0 | 1,100 | 60 |
| | | 2 | 100 | 70 | 100 | 1800 | 60 | 2,262 | 0 | 1,100 | |
| | | 3 | 100 | 70 | 100 | 1800 | 60 | 2,262 | 0 | 1,100 | |
| | | 4 | 100 | 70 | 100 | 1800 | 60 | 905 | 0 | 1,100 | |
| | | 5 | 100 | 70 | 100 | 1800 | 60 | 452 | 0 | 1,100 | |
| | | 6 | 100 | 70 | 100 | 1800 | 60 | 452 | 0 | 1,100 | |
| | | 7A | 100 | 70 | 100 | 1800 | 60 | 0 | 0 | 1,100 | |
| | | 7B | 100 | 70 | 100 | 1800 | 60 | 0 | 0 | 120 | |
| | | 8 | 100 | 70 | 100 | 1800 | 60 | 0 | 0 | 1,100 | |
| | | 9A | 100 | 70 | 100 | 1800 | 60 | 0 | 0 | 1,100 | |
| | | 9B | 100 | 70 | 100 | 1800 | 60 | 0 | 0 | 1,100 | |
| 2 | Design Hydrotest (Leak Test) - | 1 | 100 | 100 | 100 | 1800 | 0 | 2,262 | 1,100 | 50 | 60 |
| | | 2 | 100 | 100 | 100 | 1800 | 0 | 2,262 | 1,100 | 50 | |
| | | 3 | 100 | 100 | 100 | 1800 | 0 | 2,262 | 1,100 | 50 | |
| | | 4 | 100 | 100 | 100 | 1800 | 0 | 905 | 1,100 | 50 | |
| | | 5 | 100 | 100 | 100 | 1800 | 0 | 452 | 1,100 | 50 | |
| | | 6 | 100 | 100 | 100 | 1800 | 0 | 452 | 1,100 | 50 | |
| | | 7A | 100 | 100 | 100 | 1800 | 0 | 0 | 1,100 | 50 | |
| | | 7B | 100 | 100 | 100 | 1800 | 0 | 0 | 120 | 50 | |
| | | 8 | 100 | 100 | 100 | 1800 | 0 | 0 | 1,100 | 50 | |
| | | 9A | 100 | 100 | 100 | 1800 | 0 | 0 | 1,100 | 50 | |
| | | 9B | 100 | 100 | 100 | 1800 | 0 | 0 | 1,100 | 50 | |
| 3 | Startup | 1 | 549 | 100 | 549 | 16164 | 100 | 16,158 | 50 | 1,010 | 150 |
| | | 2 | 549 | 100 | 549 | 16164 | 100 | 16,158 | 50 | 1,010 | |
| | | 3 | 549 | 100 | 549 | 16164 | 100 | 16,158 | 50 | 1,035 | |
| | | 4 | 549 | 100 | 549 | 16164 | 100 | 6,463 | 50 | 1,035 | |
| | | 5 | 549 | 100 | 549 | 16164 | 100 | 3,232 | 50 | 1,035 | |
| | | 6 | 549 | 100 | 549 | 16164 | 100 | 3,232 | 50 | 1,035 | |
| | | 7A | 549 | 100 | 549 | 16164 | 100 | 300 | 50 | 1,010 | |
| | | 7B | 150 | 100 | 150 | 16164 | 0 | 0 | 50 | 120 | |
| | | 8 | 549 | 100 | 549 | 16164 | 100 | 168 | 50 | 1,035 | |
| | | 9A | 549 | 100 | 549 | 16164 | 100 | 0 | 50 | 1,035 | |
| | | 9B | 150 | 100 | 150 | 16164 | 11 | 0 | 50 | 1,035 | |
| 4 | Turbine Roll & Increase to Rated Power + SCRAM - 1 | 1 | 542 | 549 | 542 | 0 | STEP | 32,316 | 1,010 | 1,010 | 290 |
| | | 2 | 542 | 549 | 542 | 0 | STEP | 32,316 | 1,010 | 1,010 | |
| | | 3 | 542 | 549 | 542 | 0 | STEP | 32,316 | 1,035 | 1,035 | |
| | | 4 | 542 | 549 | 542 | 0 | STEP | 12,926 | 1,035 | 1,035 | |
| | | 5 | 542 | 549 | 542 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 6 | 542 | 549 | 542 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 7A | 542 | 549 | 542 | 0 | STEP | 364 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 0 | STEP | 0 | 120 | 120 | |
| | | 8 | 542 | 549 | 542 | 0 | STEP | 335 | 1,035 | 1,035 | |
| | | 9A | 542 | 549 | 542 | 0 | STEP | 520 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 0 | STEP | 0 | 1,035 | 1,035 | |
| 5 | Turbine Roll & Increase to Rated Power + SCRAM - 2 | 1 | 526 | 542 | 526 | 0 | STEP | 32,316 | 1,010 | 1,010 | 290 |
| | | 2 | 526 | 542 | 526 | 0 | STEP | 32,316 | 1,010 | 1,010 | |
| | | 3 | 526 | 542 | 526 | 0 | STEP | 32,316 | 1,035 | 1,035 | |
| | | 4 | 526 | 542 | 526 | 0 | STEP | 12,926 | 1,035 | 1,035 | |
| | | 5 | 526 | 542 | 526 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 6 | 526 | 542 | 526 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 7A | 526 | 542 | 526 | 0 | STEP | 358 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 0 | STEP | 0 | 120 | 120 | |
| | | 8 | 526 | 542 | 526 | 0 | STEP | 335 | 1,035 | 1,035 | |
| | | 9A | 526 | 542 | 526 | 0 | STEP | 511 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 0 | STEP | 0 | 1,035 | 1,035 | |
| 6 | Loss of Feedwater Heater, Turbine Trip (+) | 1 | 542 | 526 | 542 | 900 | 64 | 32,316 | 1,010 | 1,010 | 5 x 2 |
| | | 2 | 542 | 526 | 542 | 900 | 64 | 32,316 | 1,010 | 1,010 | |
| | | 3 | 542 | 526 | 542 | 900 | 64 | 32,316 | 1,035 | 1,035 | |
| | | 4 | 542 | 526 | 542 | 900 | 64 | 12,926 | 1,035 | 1,035 | |
| | | 5 | 542 | 526 | 542 | 900 | 64 | 6,463 | 1,035 | 1,035 | |
| | | 6 | 542 | 526 | 542 | 900 | 64 | 6,463 | 1,035 | 1,035 | |
| | | 7A | 542 | 526 | 542 | 900 | 64 | 358 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 900 | 0 | 0 | 120 | 120 | |
| | | 8 | 542 | 526 | 542 | 900 | 64 | 335 | 1,035 | 1,035 | |
| | | 9A | 542 | 526 | 542 | 900 | 64 | 511 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 900 | 0 | 0 | 1,035 | 1,035 | |
| 7 | Loss of Feedwater Heater, Turbine Trip (-) | 1 | 526 | 542 | 526 | 360 | 160 | 32,316 | 1,010 | 1,010 | 5 x 2 |
| | | 2 | 526 | 542 | 526 | 360 | 160 | 32,316 | 1,010 | 1,010 | |
| | | 3 | 526 | 542 | 526 | 360 | 160 | 32,316 | 1,035 | 1,035 | |
| | | 4 | 526 | 542 | 526 | 360 | 160 | 12,926 | 1,035 | 1,035 | |
| | | 5 | 526 | 542 | 526 | 360 | 160 | 6,463 | 1,035 | 1,035 | |
| | | 6 | 526 | 542 | 526 | 360 | 160 | 6,463 | 1,035 | 1,035 | |
| | | 7A | 526 | 542 | 526 | 360 | 160 | 358 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 360 | 0 | 0 | 120 | 120 | |
| | | 8 | 526 | 542 | 526 | 360 | 160 | 335 | 1,035 | 1,035 | |
| | | 9A | 526 | 542 | 526 | 360 | 160 | 511 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 360 | 0 | 0 | 1,035 | 1,035 | |

# Table 3: VY Thermal Transients (continued)

| Transient Case | Description | Piping Region | Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | Flow [9] (gpm) | Pressure Initial (psig) | Pressure Final (psig) | No. of Cycles [10] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thermal Conditions [4] [7] [8] [10] | | | | | | | | |
| 8 | Loss of Feedwater Heater, Partial FW Heater Bypass (-) | 1 | 516 | 526 | 516 | 0 | STEP | 32,316 | 1,010 | 1,010 | 35 |
| | | 2 | 516 | 526 | 516 | 0 | STEP | 32,316 | 1,010 | 1,010 | |
| | | 3 | 516 | 526 | 516 | 0 | STEP | 32,316 | 1,035 | 1,035 | |
| | | 4 | 516 | 526 | 516 | 0 | STEP | 12,926 | 1,035 | 1,035 | |
| | | 5 | 516 | 526 | 516 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 6 | 516 | 526 | 516 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 7A | 516 | 526 | 516 | 0 | STEP | 351 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 0 | STEP | 0 | 120 | 120 | |
| | | 8 | 516 | 526 | 516 | 0 | STEP | 335 | 1,035 | 1,035 | |
| | | 9A | 516 | 526 | 516 | 0 | STEP | 502 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 0 | STEP | 0 | 1,035 | 1,035 | |
| 9 | Loss of Feedwater Heater, Partial FW Heater Bypass (+) | 1 | 526 | 516 | 526 | 0 | STEP | 32,316 | 1,010 | 1,010 | 35 |
| | | 2 | 526 | 516 | 526 | 0 | STEP | 32,316 | 1,010 | 1,010 | |
| | | 3 | 526 | 516 | 526 | 0 | STEP | 32,316 | 1,035 | 1,035 | |
| | | 4 | 526 | 516 | 526 | 0 | STEP | 12,926 | 1,035 | 1,035 | |
| | | 5 | 526 | 516 | 526 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 6 | 526 | 516 | 526 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 7A | 526 | 516 | 526 | 0 | STEP | 351 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 0 | STEP | 0 | 120 | 120 | |
| | | 8 | 526 | 516 | 526 | 0 | STEP | 335 | 1,035 | 1,035 | |
| | | 9A | 526 | 516 | 526 | 0 | STEP | 502 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 0 | STEP | 0 | 1,035 | 1,035 | |
| 10 | Loss of Feedwater Pumps (Isolation Valves Close) 1st step down | 1 | 300 | 526 | 300 | 220 | 3698 | 600 | 1,190 | 1,135 | 5 |
| | | 2 | 300 | 526 | 300 | 220 | 3698 | 600 | 1,190 | 1,135 | |
| | | 3 | 300 | 526 | 300 | 220 | 3698 | 600 | 1,215 | 1,160 | |
| | | 4 | 300 | 526 | 300 | 220 | 3698 | 400 | 1,215 | 1,160 | |
| | | 5 | 300 | 526 | 300 | 220 | 3698 | 200 | 1,215 | 1,160 | |
| | | 6 | 300 | 526 | 300 | 220 | 3698 | 200 | 1,215 | 1,160 | |
| | | 7A | 300 | 526 | 300 | 220 | 3698 | 306 | 1,190 | 1,135 | |
| | | 7B | 150 | 150 | 150 | 0.01 | 0 | 0 | 120 | 120 | |
| | | 8 | 300 | 526 | 300 | 220 | 3698 | 6 | 1,215 | 1,160 | |
| | | 9A | 300 | 526 | 300 | 220 | 3698 | 437 | 1,215 | 1,160 | |
| | | 9B | 150 | 150 | 150 | 0.01 | 0 | 0 | 1,215 | 1,160 | |
| 11 | Loss of Feedwater Pumps (Isolation Valves Close) 1st & 2nd step up | 1 | 500 | 300 | 500 | 1980 | 364 | 600 | 885 | 1,135 | 5 X 2 |
| | | 2 | 500 | 300 | 500 | 1980 | 364 | 600 | 885 | 1,135 | |
| | | 3 | 500 | 300 | 500 | 1980 | 364 | 600 | 910 | 1,160 | |
| | | 4 | 500 | 300 | 500 | 1980 | 364 | 400 | 910 | 1,160 | |
| | | 5 | 500 | 300 | 500 | 1980 | 364 | 200 | 910 | 1,160 | |
| | | 6 | 500 | 300 | 500 | 1980 | 364 | 200 | 910 | 1,160 | |
| | | 7A | 500 | 300 | 500 | 1980 | 364 | 301 | 885 | 1,135 | |
| | | 7B | 150 | 150 | 150 | 0.01 | 0 | 0 | 120 | 120 | |
| | | 8 | 500 | 300 | 500 | 1980 | 364 | 6 | 910 | 1,160 | |
| | | 9A | 500 | 300 | 500 | 1980 | 364 | 429 | 910 | 1,160 | |
| | | 9B | 150 | 150 | 150 | 0.01 | 0 | 0 | 910 | 1,160 | |
| 12 | Loss of Feedwater Pumps (Isolation Valves Close) 2nd & 3rd step down | 1 | 300 | 500 | 300 | 180 | 4000 | 600 | 1,135 | 675 | 5 X 2 |
| | | 2 | 300 | 500 | 300 | 180 | 4000 | 600 | 1,135 | 675 | |
| | | 3 | 300 | 500 | 300 | 180 | 4000 | 600 | 1,160 | 700 | |
| | | 4 | 300 | 500 | 300 | 180 | 4000 | 400 | 1,160 | 700 | |
| | | 5 | 300 | 500 | 300 | 180 | 4000 | 200 | 1,160 | 700 | |
| | | 6 | 300 | 500 | 300 | 180 | 4000 | 200 | 1,160 | 700 | |
| | | 7A | 300 | 500 | 300 | 180 | 4000 | 301 | 1,135 | 675 | |
| | | 7B | 150 | 150 | 150 | 0.01 | 0 | 0 | 120 | 121 | |
| | | 8 | 300 | 500 | 300 | 180 | 4000 | 6 | 1,160 | 700 | |
| | | 9A | 300 | 500 | 300 | 180 | 4000 | 429 | 1,160 | 700 | |
| | | 9B | 150 | 150 | 150 | 0.01 | 0 | 0 | 1,160 | 700 | |
| 13 | Loss of Feedwater Pumps (Isolation Valves Close) last step up | 1 | 549 | 300 | 549 | 8964 | 100 | 16,158 | 240 | 1,010 | 5 |
| | | 2 | 549 | 300 | 549 | 8964 | 100 | 16,158 | 240 | 1,010 | |
| | | 3 | 549 | 300 | 549 | 8964 | 100 | 16,158 | 265 | 1,035 | |
| | | 4 | 549 | 300 | 549 | 8964 | 100 | 6,463 | 265 | 1,035 | |
| | | 5 | 549 | 300 | 549 | 8964 | 100 | 3,232 | 265 | 1,035 | |
| | | 6 | 549 | 300 | 549 | 8964 | 100 | 3,232 | 265 | 1,035 | |
| | | 7A | 549 | 300 | 549 | 8964 | 100 | 310 | 240 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 8964 | 100 | 0 | 120 | 120 | |
| | | 8 | 549 | 300 | 549 | 8964 | 100 | 168 | 265 | 1,035 | |
| | | 9A | 549 | 300 | 549 | 8964 | 100 | 443 | 265 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 8967 | 100 | 0 | 265 | 1,035 | |
| 14 | Reduction to 0% Power | 1 | 549 | 526 | 549 | 0 | STEP | 32,316 | 1,010 | 1,010 | 150 |
| | | 2 | 549 | 526 | 549 | 0 | STEP | 32,316 | 1,010 | 1,010 | |
| | | 3 | 549 | 526 | 549 | 0 | STEP | 32,316 | 1,035 | 1,035 | |
| | | 4 | 549 | 526 | 549 | 0 | STEP | 12,926 | 1,035 | 1,035 | |
| | | 5 | 549 | 526 | 549 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 6 | 549 | 526 | 549 | 0 | STEP | 6,463 | 1,035 | 1,035 | |
| | | 7A | 549 | 526 | 549 | 0 | STEP | 360 | 1,010 | 1,010 | |
| | | 7B | 150 | 150 | 150 | 0 | STEP | 0 | 120 | 120 | |
| | | 8 | 549 | 526 | 549 | 0 | STEP | 335 | 1,035 | 1,035 | |
| | | 9A | 549 | 526 | 549 | 0 | STEP | 514 | 1,035 | 1,035 | |
| | | 9B | 150 | 150 | 150 | 0 | STEP | 0 | 1,035 | 1,035 | |

## Table 3: VY Thermal Transients (continued)

| Transient Case | Description | Piping Region | Thermal Conditions [4] [7] [8] [10] Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | Flow [9] (gpm) | Pressure Initial (psig) | Pressure Final (psig) | No. of Cycles [10] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Shutdown 1 | 1 | 375 | 549 | 375 | 6264 | 100 | 16,158 | 1,010 | 170 | 150 |
| | | 2 | 375 | 549 | 375 | 6264 | 100 | 16,158 | 1,010 | 170 | |
| | | 3 | 375 | 549 | 375 | 6264 | 100 | 16,158 | 1,035 | 195 | |
| | | 4 | 375 | 549 | 375 | 6264 | 100 | 6,463 | 1,035 | 195 | |
| | | 5 | 375 | 549 | 375 | 6264 | 100 | 3,232 | 1,035 | 195 | |
| | | 6 | 375 | 549 | 375 | 6264 | 100 | 3,232 | 1,035 | 195 | |
| | | 7A | 375 | 549 | 375 | 6264 | 100 | 320 | 1,035 | 170 | |
| | | 7B | 150 | 150 | 150 | 0.01 | 0 | 0 | 120 | 120 | |
| | | 8 | 375 | 549 | 375 | 6264 | 100 | 168 | 1,035 | 195 | |
| | | 9A | 375 | 549 | 375 | 6264 | 100 | 458 | 1,035 | 195 | |
| | | 9B | 150 | 150 | 150 | 0.01 | 0 | 0 | 1,035 | 195 | |
| 16 | Shutdown 2 | 1 | 330 | 375 | 330 | 600 | 270 | 16,158 | 170 | 90 | 150 |
| | | 2 | 330 | 375 | 330 | 600 | 270 | 16,158 | 170 | 90 | |
| | | 3 | 330 | 375 | 330 | 600 | 270 | 16,158 | 195 | 115 | |
| | | 4 | 330 | 375 | 330 | 600 | 270 | 6,463 | 195 | 115 | |
| | | 5 | 330 | 375 | 330 | 600 | 270 | 3,232 | 195 | 115 | |
| | | 6 | 330 | 375 | 330 | 600 | 270 | 3,232 | 195 | 115 | |
| | | 7A | 330 | 375 | 330 | 600 | 270 | 282 | 170 | 90 | |
| | | 7B | 150 | 150 | 150 | 600 | 0 | 0 | 120 | 90 | |
| | | 8 | 330 | 375 | 330 | 600 | 270 | 168 | 195 | 115 | |
| | | 9A | 330 | 375 | 330 | 600 | 270 | 403 | 195 | 115 | |
| | | 9B | 150 | 150 | 150 | 600 | 0 | 0 | 195 | 115 | |
| 17 | Shutdown 3 | 1 | 225 | 330 | 225 | 3780 | 100 | 16,158 | 90 | 0 | 150 |
| | | 2 | 225 | 330 | 225 | 3780 | 100 | 16,158 | 90 | 0 | |
| | | 3 | 225 | 330 | 225 | 3780 | 100 | 16,158 | 115 | 25 | |
| | | 4 | 225 | 330 | 225 | 3780 | 100 | 6,463 | 115 | 25 | |
| | | 5 | 225 | 330 | 225 | 3780 | 100 | 3,232 | 115 | 25 | |
| | | 6 | 225 | 330 | 225 | 3780 | 100 | 3,232 | 115 | 25 | |
| | | 7A | 225 | 330 | 225 | 3780 | 100 | 260 | 90 | 0 | |
| | | 7B | 150 | 150 | 150 | 0 | 0 | 0 | 90 | 0 | |
| | | 8 | 225 | 330 | 225 | 3780 | 100 | 168 | 115 | 25 | |
| | | 9A | 225 | 330 | 225 | 3780 | 100 | 260 | 115 | 25 | |
| | | 9B | 150 | 150 | 150 | 0 | 0 | 0 | 115 | 25 | |
| 18 | Shutdown 4 (RHR SDC Flow is on) | 1 | 100 | 225 | 100 | 4500 | 100 | 22,858 | 0 | 0 | 150 |
| | | 2 | 100 | 225 | 100 | 4500 | 100 | 16,158 | 0 | 0 | |
| | | 3 | 100 | 225 | 100 | 4500 | 100 | 16,158 | 25 | 25 | |
| | | 3B | 100 | 225 | 100 | 4500 | 100 | 22,858 | 25 | 25 | |
| | | 4 | 100 | 225 | 100 | 4500 | 100 | 9,143 | 25 | 25 | |
| | | 5 | 100 | 225 | 100 | 4500 | 100 | 4,572 | 25 | 25 | |
| | | 6 | 100 | 225 | 100 | 4500 | 100 | 4,572 | 25 | 25 | |
| | | 7A | 100 | 225 | 100 | 4500 | 100 | 6,700 | 0 | 0 | |
| | | 7B | 100 | 225 | 100 | 4500 | 100 | 6,700 | 0 | 0 | |
| | | 8 | 100 | 225 | 100 | 4500 | 100 | 168 | 25 | 25 | |
| | | 9A | 100 | 225 | 100 | 4500 | 100 | 6,700 | 100 | 100 | |
| | | 9B | 100 | 225 | 100 | 4500 | 100 | 6,700 | 100 | 100 | |
| 19 | Code Hydro | 1 | 100 | 100 | 100 | 0.01 | 0 | 2,262 | 25 | 1,563 | 1 |
| | | 2 | 100 | 100 | 100 | 0.01 | 0 | 2,262 | 25 | 1,563 | |
| | | 3 | 100 | 100 | 100 | 0.01 | 0 | 2,262 | 25 | 1,563 | |
| | | 4 | 100 | 100 | 100 | 0.01 | 0 | 905 | 25 | 1,563 | |
| | | 5 | 100 | 100 | 100 | 0.01 | 0 | 452 | 25 | 1,563 | |
| | | 6 | 100 | 100 | 100 | 0.01 | 0 | 452 | 25 | 1,563 | |
| | | 7A | 100 | 100 | 100 | 0.01 | 0 | 158 | 25 | 1,563 | |
| | | 7B | 100 | 100 | 100 | 0.01 | 0 | 0 | 0 | 450 | |
| | | 8 | 100 | 100 | 100 | 0.01 | 0 | 23 | 25 | 1,563 | |
| | | 9A | 100 | 100 | 100 | 0.01 | 0 | 226 | 25 | 1,563 | |
| | | 9B | 100 | 100 | 100 | 0.01 | 0 | 0 | 25 | 1,563 | |
| 20 | RHR Initiation (+) | 1 | 225 | 225 | 225 | 0.01 | 0 | 22,858 | 0 | 0 | 150 |
| | | 2 | 225 | 225 | 225 | 0.01 | 0 | 16,158 | 0 | 0 | |
| | | 3 | 225 | 225 | 225 | 0.01 | 0 | 16,158 | 25 | 25 | |
| | | 3B | 225 | 180 | 225 | 60 | 2700 | 22,858 | 25 | 25 | |
| | | 4 | 225 | 180 | 225 | 60 | 2700 | 9,143 | 25 | 25 | |
| | | 5 | 225 | 180 | 225 | 60 | 2700 | 4,572 | 25 | 25 | |
| | | 6 | 225 | 180 | 225 | 60 | 2700 | 4,572 | 25 | 25 | |
| | | 7A | 225 | 225 | 225 | 60 | 0 | 6,700 | 0 | 0 | |
| | | 7B | 225 | 150 | 225 | 60 | 4500 | 6,700 | 0 | 0 | |
| | | 8 | 225 | 225 | 225 | 0.01 | 0 | 237 | 25 | 25 | |
| | | 9A | 225 | 70 | 225 | 60 | 9300 | 6,700 | 25 | 25 | |
| | | 9B | 225 | 70 | 225 | 60 | 9300 | 6,700 | 25 | 25 | |
| 21 | RHR Initiation (-) | 1 | 225 | 225 | 225 | 0.01 | 0 | 22,858 | 0 | 0 | 150 |
| | | 2 | 225 | 225 | 225 | 0.01 | 0 | 16,158 | 0 | 0 | |
| | | 3 | 225 | 225 | 225 | 0.01 | 0 | 16,158 | 25 | 25 | |
| | | 3B | 180 | 225 | 180 | 60 | 2700 | 22,858 | 25 | 25 | |
| | | 4 | 180 | 225 | 180 | 60 | 2700 | 9,143 | 25 | 25 | |
| | | 5 | 180 | 225 | 180 | 60 | 2700 | 4,572 | 25 | 25 | |
| | | 6 | 180 | 225 | 180 | 60 | 2700 | 4,572 | 25 | 25 | |
| | | 7A | 225 | 225 | 225 | 60 | 0 | 6,700 | 0 | 0 | |
| | | 7B | 150 | 150 | 150 | 0.01 | 0 | 6,700 | 0 | 0 | |
| | | 8 | 225 | 225 | 225 | 0.01 | 0 | 237 | 25 | 25 | |
| | | 9A | 70 | 225 | 70 | 60 | 9300 | 6,700 | 25 | 25 | |
| | | 9B | 70 | 150 | 70 | 60 | 9290 | 6,700 | 25 | 25 | |

**Table 4: Recirc/RHR Piping Size Information [3]**

| Regions | 1, 2 | 3 | 4 | 5 | 6 | 7A, 7B | 8 | 9A, 9B |
|---|---|---|---|---|---|---|---|---|
| Piping Nom. O.D. (in.) | 28.169 | 28.339 | 21.878 | 12.748 | 14.17 | 20 | 4.5 | 24 |
| Piping Nom. Wall (in.) | 1.244 | 1.339 | 1.043 | 0.685 | 1.395 | 1.031 | 0.3385 | 1.217 |
| Pipe Weight[1] (lb/ft) | 386.1 | 415.1 | 257.2 | 103.4 | 207.5 | 221.9 | 23.2 | 316.5 |

Note:

1. Weight of contents automatically added by the PIPESTRESS Program.

## 4.0 ANALYSIS

Through-wall thermal gradient terms were calculated by the PIPESTRESS program for all of the transients. Thermal transient cases were modeled for each transient, as shown in Table 3. Some transients were similar in nature and were lumped together and the number of cycles added together. Listings of the PIPESTRESS input files are included as Appendix A.

The forces and moments due to thermal expansion need to be included in the fatigue evaluation. The thermal expansion cases as analyzed by the piping program, PIPESTRESS, correspond to the end temperature and pressure of the transient. Table 5 lists the thermal expansion cases.

The material properties were obtained from the ASME Code Section III, 1998 Edition, Appendix I, with 2000 Addenda [1]. E and $\alpha$ are taken at 70°F, and k, $\rho$, and $c_p$ are taken at the average temperature over the range of the individual transients.

The internal heat transfer coefficient h for the transients with flow occurring in the pipe is calculated based on the following relation for forced convection [13]:

$$h = 0.023\, Re^{0.8}\, Pr^{0.4}\, k/D$$

Where Re = Reynolds number
Pr = Prandtl number
k = Thermal conductivity
D = Pipe diameter

The heat transfer coefficients were calculated by PIPESTRESS using the above relation. The flow rates described for each transient in Section 3 were used. For the transients where flow is stopped, the natural convection heat transfer coefficient was used. The formula for h is [13]:

$$h = 0.55\,(Gr\,Pr)^{0.25} k/L$$

Where Gr = Grashof Number
L = Pipe diameter

PIPESTRESS only has the forced convection heat transfer formula built in, so an equivalent flow rate was determined that would give the same heat transfer coefficient as the free convection coefficient.

Since the replacement of the Recirculation piping [10], HWC conditions exist for 39% of the time, and NWC conditions exist for 61% of the time. This is based on 17.5 years of operation with NWC between March and July 1986 when the piping was replaced and November 2003 when HWC was implemented and the 46 years from March 1986 to the end of the period of extended operation in March 2032. Using the bounding EAF multipliers (8.36 for HWC and 15.35 for NWC) [14], an overall multiplier may be calculated as follows:

$$(15.35)0.61 + (8.36)0.39 = 12.62$$

**Table 5: Thermal Cycle Load Sets**

| Load Set | Transient Case | Region Temperatures (°F) | | | | | | | | | | | | Region Pressures (psig) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 3B | 4 | 5 | 6 | 7A | 7B | 8 | 9A | 9B | 1, 2, 7A | 3, 4, 5, 6, 8, 9A, 9B | 7B | 3B |
| 1 | 1 | 100 | 100 | 100 | - | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1,100 | 1,100 | 120 | - |
| 2 | 2 | 100 | 100 | 100 | - | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50 | 50 | 50 | - |
| 3 | 3 | 549 | 549 | 549 | - | 549 | 549 | 549 | 549 | 150 | 549 | 549 | 150 | 1,010 | 1,035 | 120 | - |
| 4 | 4 | 542 | 542 | 542 | - | 542 | 542 | 542 | 542 | 150 | 542 | 542 | 150 | 1,010 | 1,035 | 120 | - |
| 5 | 5 | 526 | 526 | 526 | - | 526 | 526 | 526 | 526 | 150 | 526 | 526 | 150 | 1,010 | 1,035 | 120 | - |
| 6 | 6 | 542 | 542 | 542 | - | 542 | 542 | 542 | 542 | 150 | 542 | 542 | 150 | 1,010 | 1,035 | 120 | - |
| 7 | 7 | 526 | 526 | 526 | - | 526 | 526 | 526 | 526 | 150 | 526 | 526 | 150 | 1,010 | 1,035 | 120 | - |
| 8 | 8 | 516 | 516 | 516 | - | 516 | 516 | 516 | 516 | 150 | 516 | 516 | 150 | 1,010 | 1,035 | 120 | - |
| 9 | 9 | 526 | 526 | 526 | - | 526 | 526 | 526 | 526 | 150 | 526 | 526 | 150 | 1,010 | 1,035 | 120 | - |
| 10 | 10 | 300 | 300 | 300 | - | 300 | 300 | 300 | 300 | 150 | 300 | 300 | 150 | 1,135 | 1,160 | 120 | - |
| 11 | 11 | 500 | 500 | 500 | - | 500 | 500 | 500 | 500 | 150 | 500 | 500 | 150 | 1,135 | 1,160 | 120 | - |
| 12 | 12 | 300 | 300 | 300 | - | 300 | 300 | 300 | 300 | 150 | 300 | 300 | 150 | 675 | 700 | 121 | - |
| 13 | 13 | 549 | 549 | 549 | - | 549 | 549 | 549 | 549 | 150 | 549 | 549 | 150 | 1,010 | 1,035 | 120 | - |
| 14 | 14 | 549 | 549 | 549 | - | 549 | 549 | 549 | 549 | 150 | 549 | 549 | 150 | 1,010 | 1,035 | 120 | - |
| 15 | 15 | 375 | 375 | 375 | - | 375 | 375 | 375 | 375 | 150 | 375 | 375 | 150 | 170 | 195 | 120 | - |
| 16 | 16 | 330 | 330 | 330 | - | 330 | 330 | 330 | 330 | 150 | 330 | 330 | 150 | 90 | 115 | 90 | - |
| 17 | 17 | 225 | 225 | 225 | - | 225 | 225 | 225 | 225 | 150 | 225 | 225 | 150 | 0 | 25 | 0 | - |
| 18 | 18 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0 | 25 | 0 | 25 |
| 19 | 19 | 100 | 100 | 100 | - | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 1,563 | 1,563 | 450 | - |
| 20 | 20 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 225 | 0 | 25 | 0 | 25 |
| 21 | 21 | 225 | 225 | 225 | 180 | 180 | 180 | 180 | 225 | 150 | 225 | 70 | 70 | 0 | 25 | 0 | 25 |

## 5.0 RESULTS OF ANALYSIS

To perform the fatigue analysis, program PIPESTRESS [5] was used. PIPESTRESS calculates the thermal expansion and seismic moments, the ASME Code Equation 10, 12, and 13 stresses, performs the thermal stress ratchet check, and performs fatigue analysis per Equation 11 and 14. For each operating state of the recirculation/RHR piping, load sets are created. A load set includes the coincident pressure, thermal expansion moment, through-wall thermal gradient terms, number of cycles, and temperature at which the allowable $S_m$ is taken. In general, the pressures and thermal expansion moments are taken at the end point of the transient, the thermal gradients taken at the point of maximum total thermal gradient stress during the transient, and the $S_m$ allowable is initially conservatively taken at the highest temperature of the transient. Table 5 lists the inputs to the load sets.

In calculating fatigue, the range of stress in going from one load set to another is determined. Since the Code assumes that any transient could follow any other, all pairs of load sets are evaluated to determine the range of stresses for the Code stress equations. The number of allowable cycles for each load set pair is determined. The incremental fatigue usage is obtained by dividing the number of design cycles by the allowable cycles. The incremental fatigue usages for all load set pairs are then summed to obtain the total fatigue usage.

The cumulative fatigue usage for the Loop A recirculation RHR return isolation valve-to-pipe location (Node 641), prior to considering environmental effects, is 0.0128. Taking into account environmental effects, the bounding multiplier for stainless steel is 12.62. This results in a total fatigue usage of 0.1615. (Note that since the RHR carbon steel piping has not been replaced, these results represent the full projected 60 year cycle count.)

The cumulative fatigue usage for the RHR return tee (Node 600), prior to considering environmental effects, is 0.0590. Taking into account environmental effects, the bounding multiplier for stainless steel is 12.62. This results in a total fatigue usage of 0.7446.

Appendix A contains the PIPESTRESS input files. Appendix B contains the fatigue usage summary for both locations.

## 6.0 REFERENCES


1. ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition with 2000 Addenda.
2. ASME Boiler and Pressure Vessel Code, Section XI, 1998 Edition.
3. Vermont Yankee Calculation 23A5569, "Recirculation System Stress Analysis Loop A", Revision 0, SI File No. VY-05Q-227.
4. Email from Jim Fitzpatrick (Entergy) to Terry Herrmann (SI), "RE: RHR Thermal Transients," dated: June 29, 2007 11:19AM, SI File Number VY-09Q-209.
5. Program PIPESTRESS, Version 3.5.1+26, DST Computer Services, S.A., June 2004.
6. ADLPIPE Model Input Listing, Vermont Yankee Calculation VYC-2030, Rev. 0, "Temporary Shielding Recirculation & RHR Piping Loop A," File c2030n2, SI File No. W-VY-05Q-227.
7. "Reactor Thermal Cycles for 60 Years of Operation," Attachment 1 of Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," SI File No. VY-16Q-209.
8. "Nozzle Thermal Cycles (Recirculation Outlet)," Attachment 1, page 4, of Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," SI File No. VY-16Q-209.
9. Entergy Nuclear Report VY-RPT-05-00022, "Task T0100 Reactor Heat Balance EPU Task Report for ER-0401409", Revision 0, SI File No. VY-16Q-205.
10. Design Input Record (DIR) Revision 1, EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," SI File No. VY-16Q-209.
11. "RHR Shutdown Cooling Temperature Data," page 8, of Entergy Design Input Record (DIR) EC No. 1773, Revision 1, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," SI File No. VY-16Q-209.
12. "RHR Shutdown Cooling Flow Rate and Pressure Data," page 9, of Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," SI File No. VY-16Q-209.
13. Holman, J.P., *Heat Transfer*, Fifth Edition, McGraw-Hill, 1981.

14. SI Calculation, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head," Revision 0, SI File Number VY-16Q-303.
15. VY Drawings, SI File No. VY-16Q-205:
    a. 5920-6801, Sheet 1, Revision 1.
    b. 5920-6802, Sheet 1, Revision 2, Sheet2, Revision 2, Sheet 3, Revision 3, Sheet 4, Revision 2, Sheet 5, Revision 2, Sheet 6, Revision 2.
    c. 5920-6808 Sheet 1, Revision 0.

# APPENDIX A

## PIPESTRESS Input Files

| Input File | Description |
|---|---|
| Recirc_15.fre | Piping model and general input for reduced cycle count |
| RHR_15.fre | Piping model and general input for 60 year cycle count |
| Reg1.inp | Region 1 transient definitions |
| Reg2.inp | Region 2 transient definitions |
| Reg3.inp | Region 3 transient definitions |
| Reg4.inp | Region 4 transient definitions |
| Reg5.inp | Region 5 transient definitions |
| Reg6.inp | Region 6 transient definitions |
| Reg7A.inp | Region 7A transient definitions |
| Reg7B.inp | Region 7B transient definitions |
| Reg8.inp | Region 8 transient definitions |
| Reg9A.inp | Region 9A transient definitions |
| Reg9B.inp | Region 9B transient definitions |

**Recirc 15.fre**

```
IDEN JB=3    *Job number (1 to 9999)
     CD=1     *1=ASME Class 1
     GR=-Y    *Direction of gravity
     VA=0     *0=Calculate            2=Verify
     IU=1     *Input units            1=USA
     OU=1     *Output units           1=USA
     CH=$     *Delimiter character
     AB=T     *FREE errors = abort
     PL=$Vermont Yankee$
     EN=$RVP$
TITL BL=3     *Modeling option:
              *  3 = uniform mass for static analysis
              *      lumped mass for dynamic analysis
              *      rotational inertia ignored
     GL=1     *Report forces/moment          0=Global     1=Local     2=G et L
     SU=1     *Support summary               0=No         1=Yes
     CV=15    *Code version - See Manual
     HS=1     *Highest 20 stress ratios for each case
     MD=1     *Hot modulus
     J6=1     *File generated by program
     TI=$Vermont Yankee Recirculation $
        $Fatigue Analysis$
FREQ RF=1 RP=8 FR=36 MP=20 RC=0 MX=70 TI=$SEISMIC$
*
*************************************
**** THERMAL CYCLE LOAD CASES****
*************************************
LCAS RF=0 CA=1 TY=0 TI=$LC-1$     *TC-1
LCAS RF=0 CA=2 TY=0 TI=$LC-2$     *TC-2
LCAS RF=0 CA=3 TY=0 TI=$LC-3$     *TC-3
LCAS RF=0 CA=4 TY=0 TI=$LC-4$     *TC-4
LCAS RF=0 CA=5 TY=0 TI=$LC-5$     *TC-5
LCAS RF=0 CA=6 TY=0 TI=$LC-6$     *TC-6
LCAS RF=0 CA=7 TY=0 TI=$LC-7$     *TC-7
LCAS RF=0 CA=8 TY=0 TI=$LC-8$     *TC-8
LCAS RF=0 CA=9 TY=0 TI=$LC-9$     *TC-9
LCAS RF=0 CA=10 TY=0 TI=$LC-10$   *TC-10
LCAS RF=0 CA=11 TY=0 TI=$LC-11$   *TC-11
LCAS RF=0 CA=12 TY=0 TI=$LC-12$   *TC-12
LCAS RF=0 CA=13 TY=0 TI=$LC-13$   *TC-13
LCAS RF=0 CA=14 TY=0 TI=$LC-14$   *TC-14
LCAS RF=0 CA=15 TY=0 TI=$LC-15$   *TC-15
LCAS RF=0 CA=16 TY=0 TI=$LC-16$   *TC-16
LCAS RF=0 CA=17 TY=0 TI=$LC-17$   *TC-17
LCAS RF=0 CA=18 TY=0 TI=$LC-18$   *TC-18
LCAS RF=0 CA=19 TY=0 TI=$LC-19$   *TC-19
LCAS RF=0 CA=20 TY=0 TI=$LC-20$   *TC-20
LCAS RF=0 CA=21 TY=0 TI=$LC-21$   *TC-21
LCAS RF=0 CA=22 TY=0 TI=$LC-22$   *TC-22
LCAS RF=0 CA=23 TY=0 TI=$LC-23$   *TC-23
LCAS RF=0 CA=24 TY=0 TI=$LC-24$   *TC-24
LCAS RF=0 CA=25 TY=0 TI=$LC-25$   *TC-25
*
*********************
**** WEIGHT CASES****
*********************
LCAS CA=101  RF=1  TY=3  TI=$OPERATING WEIGHT$
LCAS CA=102  RF=2  TY=4  TI=$HYDROTEST WEIGHT$
*
```

```
*********************************
**** THERMAL TRANSIENT CASES****
*********************************
TCAS CA=201 TI=$Design Hydrotest (+) $
TCAS CA=202 TI=$Design Hydrotest (-) $
TCAS CA=203 TI=$Startup              $
TCAS CA=204 TI=$TRoll & Inc. PWR1    $
TCAS CA=205 TI=$TRoll & Inc. PWR2    $
TCAS CA=206 TI=$LOFWH+TT PWR1        $
TCAS CA=207 TI=$LOFWH+TT PWR2        $
TCAS CA=208 TI=$LOFWH+PFWHTR Byp1    $
TCAS CA=209 TI=$LOFWH+PFWHTR Byp2    $
TCAS CA=210 TI=$LOFWP, ISO Cl DN 1   $
TCAS CA=211 TI=$LOFWP, ISO Cl UP 1   $
TCAS CA=212 TI=$LOFWP, ISO Cl DN 2   $
TCAS CA=213 TI=$LOFWP, ISO Cl UP 2   $
TCAS CA=214 TI=$Reduction to 0% PWR  $
TCAS CA=215 TI=$Shutdown1            $
TCAS CA=216 TI=$Shutdown2            $
TCAS CA=217 TI=$Shutdown3            $
TCAS CA=218 TI=$Shutdown4            $
TCAS CA=219 TI=$Code Hydrotest       $
TCAS CA=220 TI=$RHR Initiation UP    $
TCAS CA=221 TI=$RHR Initiation DN    $
TCAS CA=222 TI=$Inadvert. Inj. DOWN  $
TCAS CA=223 TI=$Inadvert. Inj. UP    $
TCAS CA=224 TI=$Single Relief BD DN  $
TCAS CA=225 TI=$Single Relief BD UP  $
*
**********************
**** SEISMIC CASES****
**********************
RCAS CA=103 EQ=3 EV=1 TY=1 SU=1 LO=1 FX=1 FY=1 FZ=1 TI=$OBE INERTIA$
*
** *************************
**** LOAD COMBINATION CASES *
** *************************
CCAS RF=1 CA=104      ME=1 FL=1  C1=103 CY=10  TI=$OBE$
CCAS RF=1 CA=401 SS=1 ME=1 EQ=3  C1=101 C2=103 TI=$EQUATION 9 LEVEL B$
CCAS RF=1 CA=402 SS=1 ME=3 F1=1  C1=103 C2=1   TI=$NORMAL+OBE$
CCAS RF=1 CA=403 SS=1 ME=3 F1=-1 C1=103 C2=1   TI=$NORMAL-OBE$
*
******************
**** LOAD SETS****
******************
*
LSET RF=1  FC=0 RP=1 CY=60   PR=1  MO=1  TR=201  TI=$Design Hydrotest (+)LS-1$
LSET RF=2  FC=0 RP=1 CY=60   PR=2  MO=2  TR=-202 TI=$Design Hydrotest (-)LS-2$
LSET RF=3  FC=0 RP=1 CY=150  PR=3  MO=3  TR=203  TI=$Startup             LS-3$
LSET RF=3  FC=0 RP=1 CY=290  PR=4  MO=4  TR=-204 TI=$TRoll & Inc. PWR1   LS-4$
LSET RF=4  FC=0 RP=1 CY=290  PR=5  MO=5  TR=-205 TI=$TRoll & Inc. PWR2   LS-5$
LSET RF=4  FC=0 RP=1 CY=10   PR=6  MO=6  TR=206  TI=$LOFWH+TT PWR1       LS-6$
LSET RF=4  FC=0 RP=1 CY=10   PR=7  MO=7  TR=-207 TI=$LOFWH+TT PWR2       LS-7$
LSET RF=5  FC=0 RP=1 CY=35   PR=8  MO=8  TR=-208 TI=$LOFWH+PFWHTR Byp1   LS-8$
LSET RF=5  FC=0 RP=1 CY=35   PR=9  MO=9  TR=209  TI=$LOFWH+PFWHTR Byp2   LS-9$
LSET RF=5  FC=0 RP=1 CY=5    PR=10 MO=10 TR=-210 TI=$LOFWP, ISO Cl DN 1  LS-10$
LSET RF=11 FC=0 RP=1 CY=10   PR=11 MO=11 TR=211  TI=$LOFWP, ISO Cl UP 1  LS-11$
LSET RF=11 FC=0 RP=1 CY=10   PR=12 MO=12 TR=-212 TI=$LOFWP, ISO Cl DN 2  LS-12$
LSET RF=3  FC=0 RP=1 CY=5    PR=13 MO=13 TR=213  TI=$LOFWP, ISO Cl UP 2  LS-13$
LSET RF=3  FC=0 RP=1 CY=150  PR=14 MO=14 TR=214  TI=$Reduction to 0% PWR LS-14$
```

```
LSET RF=5  FC=0 RP=1 CY=150  PR=15 MO=15 TR=-215 TI=$Shutdown1          LS-15$
LSET RF=15 FC=0 RP=1 CY=150  PR=16 MO=16 TR=-216 TI=$Shutdown2          LS-16$
LSET RF=16 FC=0 RP=1 CY=150  PR=17 MO=17 TR=-217 TI=$Shutdown3          LS-17$
LSET RF=20 FC=0 RP=1 CY=150  PR=18 MO=18 TR=-218 TI=$Shutdown4          LS-18$
LSET RF=19 FC=0 RP=1 CY=1    PR=19 MO=19 TR=219  TI=$Code Hydrotest     LS-19$
LSET RF=20 FC=0 RP=1 CY=150  PR=20 MO=20 TR=220  TI=$RHR Initiation UP  LS-20$
LSET RF=20 FC=0 RP=1 CY=150  PR=21 MO=21 TR=-221 TI=$RHR Initiation DN  LS-21$
LSET RF=5  FC=0 RP=1 CY=0    PR=22 MO=22 TR=-222 TI=$Inadvert. Inj. DOWN LS-22$
LSET RF=5  FC=0 RP=1 CY=0    PR=23 MO=23 TR=223  TI=$Inadvert. Inj. UP  LS-23$
LSET RF=23 FC=0 RP=1 CY=0    PR=24 MO=24 TR=-224 TI=$Single Relief BD DN LS-24$
LSET RF=24 FC=0 RP=1 CY=0    PR=25 MO=25 TR=225  TI=$Single Relief BD UP LS-25$
*
LSET RF=2 FC=0 CY=5 FL=1 PR=2 MO=402 TI=$NORMAL+OBE  LS-26$
LSET RF=2 FC=0 CY=5 FL=1 PR=2 MO=403 TI=$NORMAL-OBE  LS-27$
******
*FATG AT=500 AF=502
*FATG AT=600 AF=602
*
**************************
**** RESPONSE SPECTRA****
*************************
SPEC FS=OBE EV=1 ME=3 FP=0  TI=$RESPONSE$
      LV=1 DX=1 DY=1 DZ=1
      DI=X
        0.30/0.100  0.40/0.100  0.90/0.200  1.25/0.400  2.25/0.450  2.30/0.700
        3.30/0.700  4.40/0.750  4.41/0.900  4.75/1.100  5.20/1.100  5.80/1.600
        8.70/1.600 12.00/0.650 17.00/0.400 20.00/0.350 30.00/0.350 36.00/0.350
      DI=Y
        0.30/0.030  0.40/0.030  0.50/0.050  0.60/0.075  1.00/0.075  1.20/0.100
        2.00/0.220  2.40/0.350  3.50/0.350  3.60/0.300  5.30/0.300  5.75/0.330
        8.25/0.330  8.75/0.250 17.50/0.250 25.00/0.120 30.00/0.120 36.00/0.120
      DI=Z
        0.30/0.100  0.40/0.100  0.50/0.130  0.90/0.150  1.00/0.250  1.60/0.250
        1.90/0.600  3.50/0.600  3.75/0.700  4.40/0.700  4.50/0.800  6.25/1.500
        8.50/1.500 12.50/0.500 20.00/0.350 30.00/0.350 36.00/0.350
*
*****************************
**** MATERIAL PROPERTIES ****
*****************************
* ASTM A-106 Grade B, PIPE *
MATH CD=106      EX=0      TY=1      *C-Si
MATD TE=70       EH=29.5   EX=0.0    SM=20.0   SY=35
MATD TE=100      EH=29.3   EX=0.20   SM=20.0   SY=35
MATD TE=200      EH=28.8   EX=1.00   SM=20.0   SY=32.1
MATD TE=300      EH=28.3   EX=1.90   SM=20.0   SY=31
MATD TE=400      EH=27.7   EX=2.80   SM=20.0   SY=29.9
MATD TE=500      EH=27.3   EX=3.70   SM=18.9   SY=28.5
MATD TE=600      EH=26.7   EX=4.70   SM=17.3   SY=26.8
* ASME SA-376 Grade TP316, PIPE *
MATH CD=376.316 EX=0       TY=4      *16Cr-12Ni-2Mo
MATD TE=70       EH=28.3   EX=0.0    SM=20.0   SY=30.0
MATD TE=100      EH=28.1   EX=0.30   SM=20.0   SY=30.0
MATD TE=200      EH=27.6   EX=1.40   SM=20.0   SY=25.9
MATD TE=300      EH=27.0   EX=2.50   SM=20.0   SY=23.4
MATD TE=400      EH=26.5   EX=3.70   SM=19.3   SY=21.4
MATD TE=500      EH=25.8   EX=5.00   SM=18.0   SY=20.0
MATD TE=600      EH=25.3   EX=6.30   SM=17.0   SY=18.9
* ASME SA-403 Grade WP316, ELBOWS *
MATH CD=403.316 EX=0       TY=4      *16Cr-12Ni-2Mo
MATD TE=70       EH=28.3   EX=0.0    SM=20.0   SY=30.0
```

```
MATD TE=100    EH=28.1    EX=0.30   SM=20.0   SY=30.0
MATD TE=200    EH=27.6    EX=1.40   SM=20.0   SY=25.9
MATD TE=300    EH=27.0    EX=2.50   SM=20.0   SY=23.4
MATD TE=400    EH=26.5    EX=3.70   SM=18.7   SY=21.4
MATD TE=500    EH=25.8    EX=5.00   SM=17.5   SY=20.0
MATD TE=600    EH=25.3    EX=6.30   SM=16.4   SY=18.9
*** Cross Sectional Properties
CROS CD=1  OD=50.0   WT=8.87   MA=3977.2 *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0              *RECIRCULATION OUTLET NOZZLE
CROS CD=2  OD=37.85  WT=6.1    MA=2122.2 *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=3  OD=28.875 WT=1.56   MA=484.9  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=4  OD=28.638 WT=1.45   MA=450.4  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=5  OD=28.169 WT=1.244  MA=386.1  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=7  OD=28.166 WT=2.125  MA=0.001  *VALVE
           SO=1      ST=1.0    KL=1
CROS CD=8  OD=42.507 WT=2.486  MA=0.001  *PUMP
           SO=.001   ST=.001   KL=1
CROS CD=11 OD=6.625  WT=0.432  MA=0.001  *PUMP RIGID STRUTS
           SO=0.001  ST=0.001  KL=1
CROS CD=13 OD=28.339 WT=1.339  MA=415.1  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1
CROS CD=14 OD=28.339 WT=2.67   MA=0.001  *VALVE
           SO=1      ST=1.0    KL=1
CROS CD=15 OD=12.748 WT=0.685  MA=103.4  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=16 OD=14.17  WT=1.395  MA=207.5  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=17 OD=15.5   WT=2      MA=307.7  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=18 OD=21.88  WT=4.06   MA=803.2  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=19 OD=28.25  WT=7.25   MA=1673.1 *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=20 OD=21.878 WT=1.043  MA=257.2  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=25 OD=20     WT=1.031  MA=221.9  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1
CROS CD=26 OD=20     WT=1.875  MA=0.001  *VALVE
           SO=1      ST=1      KL=1
CROS CD=27 OD=4.5    WT=0.3385 MA=23.2   *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1      KL=1      *4 inch bypass line
CROS CD=28 OD=4.5    WT=0.67   MA=0.001  *VALVE V2-54A
           SO=1      ST=1      KL=1
CROS CD=29 OD=24     WT=1.217  MA=316.5  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1
CROS CD=30 OD=24     WT=2.43   MA=0.001  *VALVE
           SO=1      ST=1      KL=1
CROS CD=40 OD=4.5    WT=0.3385 MA=0.001  *4 inch bypass STRUTS
           SO=0.001  ST=0.001  KL=1
CROS CD=41 OD=2.875  WT=0.276  MA=0.001  *STRUT RDA1, RDA5, & VBA1
           SO=0.001  ST=0.001  KL=1
CROS CD=42 OD=28.339 WT=1.339  MA=0.001  *RIGID FROM RECIRC ELBOW TO RDA1 STRUT
           SO=0.001  ST=0.001  KL=1
*********************
* STRUCTURE AND LOADS
*********************
```

```
*------------------------------------------------------------------------------
DESN  TE=575.0  PR=1250.0 *Reference 12 GE Design Requirements Rpt VY-05Q-227
*------------------------------------------------------------------------------
*-------------------------------------------------------------------
*BEGIN REGION 1 TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY TO TEE
*-------------------------------------------------------------------
*
INCL FN=Z:\SISJ~PROJECTS\VY-16Q\Rev0\REG1.INP
*
* RUN   1     FROM ANCHOR TO REACTOR VESSEL N3B
*GROUP 1 FROM ANCHOR TO REACTOR VESSEL N3B
*NOTE
*NOTE NODE 003 - RECIRC SUCTION NOZZLE N1A (EL. 279'5 INCH)
*NOTE NODE 003 IS AT THE SAFE END TO VESSEL NOZZLE CONNECTION
*NOTE
*NOTE SAFE END FROM NODES 003 TO 808
*NOTE CONNECTION TO VESSEL AT NODE 003
*NOTE OD AND WALL THICKNESS FOR SAFE END TAKEN FROM GE CALC
*NOTE WEIGHT FOR SAFE END BASED ON THICKNESS
*NOTE
MATL CD=376.316
CROS CD=1
COOR PT=3    AX=0  AY=0  AZ=0
ANCH PT=3
AMVT    CA=1    PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
AMVT    CA=2    PT=3    DX=0.0000   DY=0.3141   DZ=-0.3602
AMVT    CA=3    PT=3    DX=0.0000   DY=0.3112   DZ=-0.3568
AMVT    CA=4    PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=5    PT=3    DX=0.0000   DY=0.3112   DZ=-0.3568
AMVT    CA=6    PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=7    PT=3    DX=0.0000   DY=0.2922   DZ=-0.3350
AMVT    CA=8    PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=9    PT=3    DX=0.0000   DY=0.1422   DZ=-0.1630
AMVT    CA=10   PT=3    DX=0.0000   DY=0.2807   DZ=-0.3218
AMVT    CA=11   PT=3    DX=0.0000   DY=0.1422   DZ=-0.1630
AMVT    CA=12   PT=3    DX=0.0000   DY=0.3141   DZ=-0.3602
AMVT    CA=13   PT=3    DX=0.0000   DY=0.3141   DZ=-0.3602
AMVT    CA=14   PT=3    DX=0.0000   DY=0.1928   DZ=-0.2521
AMVT    CA=15   PT=3    DX=0.0000   DY=0.1624   DZ=-0.1986
AMVT    CA=16   PT=3    DX=0.0000   DY=0.0946   DZ=-0.1084
AMVT    CA=17   PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
AMVT    CA=18   PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
AMVT    CA=19   PT=3    DX=0.0000   DY=0.0946   DZ=-0.1084
AMVT    CA=20   PT=3    DX=0.0000   DY=0.0946   DZ=-0.1084
AMVT    CA=21   PT=3    DX=0.0000   DY=0.0361   DZ=-0.0413
AMVT    CA=22   PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=23   PT=3    DX=0.0000   DY=0.1928   DZ=-0.2521
AMVT    CA=24   PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201


*
TANG PT=805  DZ=-1.017  EW=1
CROS CD=2
TANG PT=806  DZ=-0.823  EW=1
CROS CD=3
TANG PT=807  DZ=-0.58  EW=1
CROS CD=4
TANG PT=808  DZ=-0.47
CROS CD=5
TANG PT=5    DZ=-5.59 EW=1
```

```
MATL CD=403.316
BRAD PT=7    RA=3.5 EW=1
MATL CD=376.316
TANG PT=9    DY=-6.69  EW=1
TANG PT=500  DY=-2.31
*-----------------------------------------
*END REGION 1 GEOMETRY FROM RHR SUPPLY TO TEE
*-----------------------------------------
*
*---------------------------------------------------------------------
*BEGIN REGION 2 TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY TEE TO PUMP
*---------------------------------------------------------------------
*GROUP 2 RHR SUPPLY TEE TO PUMP
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG2.INP
*
TANG PT=11   DY=-2.22  EW=1
CROS CD=5
TANG PT=12   DY=-1.78
TANG PT=20   DY=-6.77
TANG PT=22   DY=-3.25
TANG PT=25   DY=-15.49  EW=1
MATL CD=403.316
BRAD PT=26   RA=3.5  EW=1
MATL CD=376.316
TANG PT=27   DX=-3.3 DZ=1.27  EW=1
CROS CD=7
VALV PT=30   DX=-2.28 DZ=0.89 MA=10.368 PL=1
JUNC PT=30
VALV PT=40   DX=-2.31 DZ=0.9 PL=2  EW=1
JUNC PT=30
RIGD PT=35   DY=7
LUMP PT=35   MA=1.132
JUNC PT=40
CROS CD=5
TANG PT=42 DX=-1.18 DZ=0.46
TANG PT=43 DX=-0.55 DZ=0.21
TANG PT=44 DX=-3.31 DZ=1.28  EW=1
MATL CD=403.316
BRAD PT=46 RA=2.33  EW=1
MATL CD=376.316
CROS CD=8
TANG PT=50 DY=4.33  EW=0
LUMP PT=50 MA=28  *NOTE WEIGHT OF PUMP FLOODED 28K (EXCLUDING MOTOR)
TANG PT=75 DY=0.5
TANG PT=83 DY=2.13
TANG PT=86 DY=3.38
LUMP PT=86 MA=32  *NOTE TOTAL WEIGHT OF PUMP MOTOR 32000 LBS
TANG PT=90 DY=4.08 *TOP OF PUMP
*NOTE SNUBBERS ON TOP OF PUMPS WERE DELETED DURING
*NOTE THE RECIRC PIPE REPLACEMENT PROJECT
*NOTE - RIGID LINKS FOR CONSTANT SUPPORTS AT PUMP FOLLOW
*--------------------------
*END REGION 2 GEOMETRY FROM RHR SUPPLY TEE TO PUMP
*--------------------------
*
*----------------------------------------
*BEGIN REGION 3 TRANSIENT CARDS & GEOMETRY FROM PUMP DISCHARGE TO HEADER
*----------------------------------------
*GROUP 3 FROM PUMP DISCHARGE TO HEADER
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG3.INP
```

```
*
JUNC PT=50
CROS CD=8
RIGD PT=54 DX=1.06 DZ=1.06
RIGD PT=56 DX=1.06 DY=0.75 DZ=1.06  *NOTE CONSTANT SUPPORT HA3 AT NODE 56
JUNC PT=50
RIGD PT=66 DZ=-3.83
RIGD PT=69 DY=1                     *NOTE CONSTANT SUPPORT HA4 AT NODE 69
JUNC PT=50
CROS CD=8
RIGD PT=60 DX=-3.83
RIGD PT=63 DY=1                     *CONSTANT SUPPORT HA5 AT NODE 63
*
* *** CODING FOR PUMP RIGID STRUTS FOLLOW ***
*     CODED FROM PUMP CENTERLINE
CROS CD=11
JUNC PT=66
RIGD PT=15    DY=0.7071 DZ=-0.7071
*
JUNC PT=60
RIGD PT=16    DX=-0.7071 DY=0.7071
* *** END OF CODING FOR PUMP SUPPORTS ***
*PUMP INLET
CROS CD=8
JUNC PT=50
TANG PT=150 DX=-2.17
BRAN PT=151 DZ=2.333  TE=1
*NOTE PUMP DISCHARGE CONNECTION TO PIPE AT NODE 151
CROS CD=13
TANG PT=152 DZ=1.25
TANG PT=155 DZ=1  EW=1
CROS CD=14
VALV PT=160 PL=1 DX=0.0 DY=0.0  DZ=2.52 MA=6.8285
JUNC PT=160
RIGD PT=163 DX=0.0 DY=7.12 DZ=0.0
LUMP PT=163 MA=0.9715
JUNC PT=160
VALV PT=170 PL=2 DX=0.0 DY=0.0 DZ=6.18  EW=1
CROS CD=13
MATL CD=403.316
BRAD PT=175 RA=3.5  EW=1
MATL CD=376.316
TANG PT=176 DY=5.95
TANG PT=177 DY=4.42
*NOTE ***WEIGHT OF FLOW ELEMENT NOT INCLUDED***
*NOTE ***REF. DWG. 5920-6800 FOR DIMENSIONS***
TANG PT=184 DY=4.42
TANG PT=186 DY=3.02
TANG PT=188 DY=1.51
TANG PT=189 DY=0.74
TANG PT=190 DY=1.15  EW=1
TANG PT=600 DY=1.06

***INPUT FILE TO INCLUDE EFFECTS OF RHR INITIATION ON LINE NEAR RHR RETURN TO HEADER
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG3B.INP

JUNC PT=600
TANG PT=195 DY=2.08  EW=1
TANG PT=210 DX=0.0  DY=1.83 DZ=0.0  KL=1 *CENTER OF CROSS, RECIRC HEADER
*MUST HAVE INDI CARD FOR EACH MEMBER CONNECTED TO CROSS CENTER
```

```
*--------------------------
*END REGION 3 GEOMETRY FROM PUMP DISCHARGE TO HEADER
*--------------------------
*
*----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 336
*----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 336
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
*NOTE CROSS AND REDUCER DIMENSIONS TAKEN FROM 5920-6632 SHT.3
CROS CD=13
MATL CD=376.316
TANG PT=215 DX=0.0 DY=2.59  DZ=0.0  EW=0
CRED PT=220 DY=1.29  AN=30  EW=1  *AL=$CONC. REDUCER$
CROS CD=15
TANG PT=330 DY=4.58
TANG PT=335 DY=3.29  EW=1
MATL CD=403.316
BRAD PT=334 RA=1.5  EW=1
*--------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 336
*--------------------------
*
*----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 336
*----------------------------------------
*GROUP 6 TO NOZZLE NODE 336
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=838 DX=3.875
CROS CD=16
TANG PT=837 DX=0.875  EW=1
CROS CD=17
TANG PT=836 DX=0.37  EW=1
CROS CD=18
TANG PT=835 DX=0.53  EW=1
CROS CD=19
TANG PT=336 DX=0.704  EW=1
NOZZ PT=336
AMVT    CA=1    PT=336  DX=-0.0201  DY=0.0246  DZ=0.0000
AMVT    CA=2    PT=336  DX=-0.3602  DY=0.4398  DZ=0.0000
AMVT    CA=3    PT=336  DX=-0.3568  DY=0.4316  DZ=0.0000
AMVT    CA=4    PT=336  DX=-0.3434  DY=0.4152  DZ=0.0000
AMVT    CA=5    PT=336  DX=-0.3568  DY=0.4050  DZ=0.0000
AMVT    CA=6    PT=336  DX=-0.3434  DY=0.2940  DZ=0.0000
AMVT    CA=7    PT=336  DX=-0.3350  DY=0.3229  DZ=0.0000
AMVT    CA=8    PT=336  DX=-0.3434  DY=0.2700  DZ=0.0000
AMVT    CA=9    PT=336  DX=-0.1630  DY=0.1991  DZ=0.0000
AMVT    CA=10   PT=336  DX=-0.3218  DY=0.1626  DZ=0.0000
AMVT    CA=11   PT=336  DX=-0.1630  DY=0.0246  DZ=0.0000
AMVT    CA=12   PT=336  DX=-0.3602  DY=0.4398  DZ=0.0000
AMVT    CA=13   PT=336  DX=-0.3602  DY=0.4316  DZ=0.0000
AMVT    CA=14   PT=336  DX=-0.2193  DY=0.4152  DZ=0.0000
AMVT    CA=15   PT=336  DX=-0.1862  DY=0.4050  DZ=0.0000
AMVT    CA=16   PT=336  DX=-0.1084  DY=0.2940  DZ=0.0000
AMVT    CA=17   PT=336  DX=-0.0201  DY=0.3229  DZ=0.0000
AMVT    CA=18   PT=336  DX=-0.0201  DY=0.2700  DZ=0.0000
AMVT    CA=19   PT=336  DX=-0.1084  DY=0.1991  DZ=0.0000
```

```
AMVT    CA=20   PT=336  DX=-0.0201  DY=0.1626  DZ=0.0000
AMVT    CA=21   PT=336  DX=-0.0413  DY=0.3229  DZ=0.0000
AMVT    CA=22   PT=336  DX=-0.3434  DY=0.2700  DZ=0.0000
AMVT    CA=23   PT=336  DX=-0.2211  DY=0.1991  DZ=0.0000
AMVT    CA=24   PT=336  DX=-0.0201  DY=0.1626  DZ=0.0000

*NOTE SAFE END FROM NODES 838 TO 336
*NOTE CONNECTION TO VESSEL AT NODE 336
*NOTE OD AND WALL THICKNESS FOR SAFE END TAKEN FROM GE CALC
*NOTE WEIGHT BASED ON THICKNESS
*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 336
*---------------------------
*
*----------------------------------------
*BEGIN REGION 4 TRANSIENT CARDS & GEOMETRY HEADER TO NOZZLE NODE 366
*----------------------------------------
*GROUP 4 HEADER TO NOZZLE NODE 366
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG4.INP
*
JUNC PT=210
CROS CD=20
BRAN PT=240 DX=0.1786 DY=0.0 DZ=1.7
TANG PT=250 DX=0.3 DZ=2.853  EW=0
BRAD PT=255 RA=4.578  EW=0 *NOTE BEND RADIUS IS 4.578 FEET
TANG PT=340 DX=1.799 DZ=3.108
*---------------------------
*END REGION 4 GEOMETRY HEADER TO NOZZLE NODE 366
*---------------------------
*
*----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 366
*----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 366
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
TANG PT=349 DX=0.71 DZ=1.23  EW=0
CRED PT=347 DX=0.75 DZ=1.3  AN=30
CROS CD=15
TANG PT=343 DX=0.5525 DZ=0.957  EW=1
BRAD PT=410 RA=1.5  EW=1
TANG PT=360 DX=3.483 DZ=2.011  EW=1
MATL CD=403.316
BRAD PT=361 RA=1.5  EW=1
MATL CD=376.316
CROS CD=15
TANG PT=362 DY=3.18
TANG PT=364 DY=8.56  EW=1
MATL CD=403.316
BRAD PT=365 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 366
*---------------------------

*----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 366
*----------------------------------------
*GROUP 6 TO NOZZLE NODE 366
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
```

```
*
MATL CD=376.316
TANG PT=868 DX=1.8 DZ=-3.1
CROS CD=16
TANG PT=867 DX=0.4375 DZ=-0.76  EW=1
CROS CD=17
TANG PT=866 DX=0.185 DZ=-0.32  EW=1
CROS CD=18
TANG PT=865 DX=0.265 DZ=-0.46  EW=1
CROS CD=19
TANG PT=366 DX=0.352 DZ=-0.61  EW=1
NOZZ PT=366
AMVT    CA=1     PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=2     PT=366  DX=-0.1800  DY=0.4398  DZ=0.3120
AMVT    CA=3     PT=366  DX=-0.1783  DY=0.4357  DZ=0.3091
AMVT    CA=4     PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=5     PT=366  DX=-0.1783  DY=0.4357  DZ=0.3091
AMVT    CA=6     PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=7     PT=366  DX=-0.1674  DY=0.4091  DZ=0.2902
AMVT    CA=8     PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=9     PT=366  DX=-0.0815  DY=0.1991  DZ=0.1412
AMVT    CA=10    PT=366  DX=-0.1609  DY=0.3930  DZ=0.2788
AMVT    CA=11    PT=366  DX=-0.0815  DY=0.1991  DZ=0.1412
AMVT    CA=12    PT=366  DX=-0.1800  DY=0.4398  DZ=0.3120
AMVT    CA=13    PT=366  DX=-0.1800  DY=0.4398  DZ=0.3120
AMVT    CA=14    PT=366  DX=-0.1097  DY=0.2678  DZ=0.1899
AMVT    CA=15    PT=366  DX=-0.0931  DY=0.2275  DZ=0.1613
AMVT    CA=16    PT=366  DX=-0.0542  DY=0.1324  DZ=0.0939
AMVT    CA=17    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=18    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=19    PT=366  DX=-0.0542  DY=0.1324  DZ=0.0939
AMVT    CA=20    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=21    PT=366  DX=-0.0207  DY=0.0505  DZ=0.0358
AMVT    CA=22    PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=23    PT=366  DX=-0.1105  DY=0.2700  DZ=0.1915
AMVT    CA=24    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174

*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 366
*---------------------------

*----------------------------------------
*BEGIN REGION 4 TRANSIENT CARDS & GEOMETRY HEADER TO NOZZLES NODE 326 & 316
*----------------------------------------
*GROUP 4 HEADER TO NOZZLES NODE 326 & 316
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG4.INP
*
JUNC PT=210
CROS CD=20
BRAN PT=260 DX=0.1786 DY=0.0 DZ=-1.7 TE=2
TANG PT=270 DX=0.3 DZ=-2.853  EW=0
BRAD PT=275 RA=4.578  EW=0
TANG PT=320 DX=1.799 DZ=-3.108
*---------------------------
*END REGION 4 GEOMETRY HEADER TO NOZZLES NODE 326 & 316
*---------------------------

*----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 316
*----------------------------------------
```

```
*GROUP 5 RISER TO NOZZLE NODE 316
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
TANG PT=319 DX=0.71 DZ=-1.23  EW=1
CRED PT=317 DX=0.75 DZ=-1.3  AN=30
CROS CD=15
TANG PT=313 DX=0.5525 DZ=-0.957  EW=1
BRAD PT=400 RA=1.5  EW=1
TANG PT=310 DX=3.483 DZ=-2.011  EW=1
MATL CD=403.316
BRAD PT=311 RA=1.5  EW=1
MATL CD=376.316
CROS CD=15
TANG PT=312 DY=4.74
TANG PT=314 DY=6.99  EW=1
MATL CD=403.316
BRAD PT=315 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 316
*---------------------------
*
*----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 316
*----------------------------------------
*GROUP 6 TO NOZZLE NODE 316
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=818 DX=1.84 DZ=3.19
CROS CD=16
TANG PT=817 DX=0.4375 DZ=0.76  EW=1
CROS CD=17
TANG PT=816 DX=0.185 DZ=0.32  EW=1
CROS CD=18
TANG PT=815 DX=0.265 DZ=0.46  EW=1
CROS CD=19
TANG PT=316 DX=0.352 DZ=0.61  EW=1
NOZZ PT=316
AMVT    CA=1    PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT    CA=2    PT=316  DX=-0.1800  DY=0.4398  DZ=-0.3120
AMVT    CA=3    PT=316  DX=-0.1783  DY=0.4357  DZ=-0.3091
AMVT    CA=4    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT    CA=5    PT=316  DX=-0.1783  DY=0.4357  DZ=-0.3091
AMVT    CA=6    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT    CA=7    PT=316  DX=-0.1674  DY=0.4091  DZ=-0.2902
AMVT    CA=8    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT    CA=9    PT=316  DX=-0.0815  DY=0.1991  DZ=-0.1412
AMVT    CA=10   PT=316  DX=-0.1609  DY=0.3930  DZ=-0.2788
AMVT    CA=11   PT=316  DX=-0.0815  DY=0.1991  DZ=-0.1412
AMVT    CA=12   PT=316  DX=-0.1800  DY=0.4398  DZ=-0.3120
AMVT    CA=13   PT=316  DX=-0.1800  DY=0.4398  DZ=-0.3120
AMVT    CA=14   PT=316  DX=-0.1097  DY=0.2678  DZ=-0.1899
AMVT    CA=15   PT=316  DX=-0.0931  DY=0.2275  DZ=-0.1613
AMVT    CA=16   PT=316  DX=-0.0542  DY=0.1324  DZ=-0.0939
AMVT    CA=17   PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT    CA=18   PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT    CA=19   PT=316  DX=-0.0542  DY=0.1324  DZ=-0.0939
AMVT    CA=20   PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT    CA=21   PT=316  DX=-0.0207  DY=0.0505  DZ=-0.0358
AMVT    CA=22   PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
```

```
AMVT    CA=23   PT=316  DX=-0.1105  DY=0.2700  DZ=-0.1915
AMVT    CA=24   PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 316
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 346
*-----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 346
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
JUNC PT=340
CROS CD=15
BRAN PT=342 DY=1.36  TE=2
TANG PT=344 DY=10.39  EW=0
MATL CD=403.316
BRAD PT=345 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 346
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 346
*-----------------------------------------
*GROUP 6 TO NOZZLE NODE 346
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=848 DX=3.17 DZ=-1.83
CROS CD=16
TANG PT=847 DX=0.758 DZ=-0.4375  EW=1
CROS CD=17
TANG PT=846 DX=0.32 DZ=-0.185  EW=1
CROS CD=18
TANG PT=845 DX=0.46 DZ=-0.265  EW=1
CROS CD=19
TANG PT=346 DX=0.61 DZ=-0.352  EW=1
NOZZ PT=346
AMVT    CA=1    PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=2    PT=346  DX=-0.3120  DY=0.4398  DZ=0.1800
AMVT    CA=3    PT=346  DX=-0.3091  DY=0.4357  DZ=0.1783
AMVT    CA=4    PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT    CA=5    PT=346  DX=-0.3091  DY=0.4357  DZ=0.1783
AMVT    CA=6    PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT    CA=7    PT=346  DX=-0.2902  DY=0.4091  DZ=0.1674
AMVT    CA=8    PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT    CA=9    PT=346  DX=-0.1412  DY=0.1991  DZ=0.0815
AMVT    CA=10   PT=346  DX=-0.2788  DY=0.3930  DZ=0.1609
AMVT    CA=11   PT=346  DX=-0.1412  DY=0.1991  DZ=0.0815
AMVT    CA=12   PT=346  DX=-0.3120  DY=0.4398  DZ=0.1800
AMVT    CA=13   PT=346  DX=-0.3120  DY=0.4398  DZ=0.1800
AMVT    CA=14   PT=346  DX=-0.1899  DY=0.2678  DZ=0.1097
AMVT    CA=15   PT=346  DX=-0.1613  DY=0.2275  DZ=0.0931
AMVT    CA=16   PT=346  DX=-0.0939  DY=0.1324  DZ=0.0542
AMVT    CA=17   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=18   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=19   PT=346  DX=-0.0939  DY=0.1324  DZ=0.0542
AMVT    CA=20   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=21   PT=346  DX=-0.0358  DY=0.0505  DZ=0.0207
```

```
AMVT     CA=22    PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT     CA=23    PT=346  DX=-0.1915  DY=0.2700  DZ=0.1105
AMVT     CA=24    PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 346
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 326
*-----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 326
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
JUNC PT=320
CROS CD=15
BRAN PT=322 DY=1.42  TE=2
TANG PT=324 DY=10.33  EW=1
MATL CD=403.316
BRAD PT=325 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 326
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 326
*-----------------------------------------
*GROUP 6 TO NOZZLE NODE 326
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=828 DX=3.18 DZ=1.84
CROS CD=16
TANG PT=827 DX=0.758 DZ=0.4375  EW=1
CROS CD=17
TANG PT=826 DX=0.32 DZ=0.185  EW=1
CROS CD=18
TANG PT=825 DX=0.46 DZ=0.265  EW=1
CROS CD=19
TANG PT=326 DX=0.61 DZ=0.352  EW=1
NOZZ PT=326
AMVT     CA=1     PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT     CA=2     PT=326  DX=-0.3120  DY=0.4398  DZ=-0.1800
AMVT     CA=3     PT=326  DX=-0.3091  DY=0.4357  DZ=-0.1783
AMVT     CA=4     PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT     CA=5     PT=326  DX=-0.3091  DY=0.4357  DZ=-0.1783
AMVT     CA=6     PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT     CA=7     PT=326  DX=-0.2902  DY=0.4091  DZ=-0.1674
AMVT     CA=8     PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT     CA=9     PT=326  DX=-0.1412  DY=0.1991  DZ=-0.0815
AMVT     CA=10    PT=326  DX=-0.2788  DY=0.3930  DZ=-0.1609
AMVT     CA=11    PT=326  DX=-0.1412  DY=0.1991  DZ=-0.0815
AMVT     CA=12    PT=326  DX=-0.3120  DY=0.4398  DZ=-0.1800
AMVT     CA=13    PT=326  DX=-0.3120  DY=0.4398  DZ=-0.1800
AMVT     CA=14    PT=326  DX=-0.1899  DY=0.2678  DZ=-0.1097
AMVT     CA=15    PT=326  DX=-0.1613  DY=0.2275  DZ=-0.0931
AMVT     CA=16    PT=326  DX=-0.0939  DY=0.1324  DZ=-0.0542
AMVT     CA=17    PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT     CA=18    PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT     CA=19    PT=326  DX=-0.0939  DY=0.1324  DZ=-0.0542
AMVT     CA=20    PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
```

```
AMVT    CA=21   PT=326  DX=-0.0358  DY=0.0505  DZ=-0.0207
AMVT    CA=22   PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT    CA=23   PT=326  DX=-0.1915  DY=0.2700  DZ=-0.1105
AMVT    CA=24   PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
*--------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 326
*--------------------------
*
*----------------------------------------
*BEGIN REGION 7A TRANSIENT CARDS & GEOMETRY TO RHR SUPPLY VALVE NODE 550
*----------------------------------------
*GROUP 7 TO RHR SUPPLY VALVE NODE 550
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG7A.INP
*
MATL CD=376.316
JUNC PT=500
CROS CD=25
BRAN PT=502 DX=1.67  EW=0  TE=1
TANG PT=506 DX=2.53  EW=0
MATL CD=403.316
BRAD PT=507 RA=1.67  EW=1
MATL CD=376.316
TANG PT=508 DZ=-4.01
TANG PT=515 DZ=-4.53  EW=1
MATL CD=403.316
BRAD PT=520 RA=1.67  EW=1
MATL CD=376.316
CROS CD=26
VALV PT=525 DX=-3.34 PL=1
JUNC PT=525
VALV PT=530 DX=-1.99 PL=2  EW=1
JUNC PT=525
RIGD PT=526 DY=2.5
LUMP PT=526 MA=7.569
JUNC PT=530
CROS CD=25
TANG PT=540 DX=-1.13  EW=1
CROS CD=26
VALV PT=545 DX=-1.97 PL=1
JUNC PT=545
RIGD PT=547 DY=2.5
LUMP PT=547 MA=7.355
JUNC PT=545
VALV PT=550 DX=-1.98 PL=2  EW=1
*--------------------------
*END REGION 7A GEOMETRY TO RHR SUPPLY VALVE NODE 550
*--------------------------
*
*----------------------------------------
*BEGIN REGION 7B TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY VALVE TO PENET. NODE 565
*----------------------------------------
*GROUP 17 FROM RHR SUPPLY VALVE TO PENET. NODE 565
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG7B.INP
*
CROS CD=25
MATL CD=106
TANG PT=555 DX=-3.36  EW=1
BRAD PT=556 RA=1.67  EW=1
TANG PT=560 DY=-10.17  EW=1
BRAD PT=561 RA=1.67  EW=1
```

```
TANG PT=563 DZ=-6.92
TANG PT=565 DZ=-6.92
*---------------------------
*END REGION 7B GEOMETRY FROM RHR SUPPLY VALVE TO PENET. NODE 565
*---------------------------
*
*----------------------------------------
*BEGIN REGION 8 TRANSIENT CARDS & GEOMETRY FOR 4 INCH BYPASS
*----------------------------------------
*GROUP 8 4 INCH BYPASS
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG8.INP
*
*NOTE CODING FOR 4 INCH BYPASS STARTS HERE
JUNC PT=152
CROS CD=27
MATL CD=376.316
BRAN PT=700 DX=-1.19  TE=4
TANG PT=702 DX=-0.61
TANG PT=703 DX=-1.43  EW=0
MATL CD=403.316
BRAD PT=704 RA=0.5  EW=0
MATL CD=376.316
TANG PT=705 DZ=5.08
*NOTE CONSTANT SUPPORT HA11 AT NODE 705
TANG PT=721 DZ=1.12
TANG PT=706 DZ=2.47
TANG PT=707 DZ=1.03
TANG PT=708 DZ=0.34
TANG PT=709 DZ=0.38
JUNC PT=707
BRAN PT=710 DY=0.34 TE=1
CROS CD=28
VALV PT=712 DY=0.71 MA=0.3669 PL=1  *AL=$VALVE V2-54A$
VALV PT=715 DZ=-3.5 MA=0.1831 PL=3
JUNC PT=712
VALV PT=714 DY=0.71          PL=2
CROS CD=27
TANG PT=723 DY=4.19
MATL CD=403.316
BRAD PT=716 RA=0.5
MATL CD=376.316
TANG PT=718 DX=1.48
TANG PT=720 DX=0.56
BRAN PT=176 DX=1.19  TE=4
************CODING FOR STRUTS RDA5 AND VAB1 FOLLOW
JUNC PT=170
CROS CD=40  *OD=4.5 inch
RIGD PT=725 DP=0 DX=-0.583 DY=1.84  *AL=$RDA5$
CROS CD=41  *OD=2.875 inch
RIGD PT=715 DP=0 DX=-2.67 DY=-0.79
RIGD PT=721 DP=0 DY=-1.05  *AL=$VAB1$
*************CODING FOR RDA1 STRUT FOLLOWS
CROS CD=42  *OD=28.339 inch
JUNC PT=175
RIGD PT=173 DP=0 DY=-3.5 DZ=0.34
CROS CD=41  *OD=2.875 inch
RIGD PT=708 DP=0 DX=-3.21  *AL=$RDA1$
*---------------------------
*END REGION 8 GEOMETRY  FOR 4 INCH BYPASS
*---------------------------
```

```
*
*-----------------------------------------
*BEGIN REGION 9A TRANSIENT CARDS & GEOMETRY FOR RHR RETURN FROM TEE TO VALVE NODE 660
*-----------------------------------------
*GROUP 9 RHR RETURN FROM TEE TO VALVE NODE 660
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG9A.INP
*
*NOTE CODING FOR RHR RETURN STARTS HERE
CROS CD=29
JUNC PT=600
MATL CD=376.316
BRAN PT=602 DX=-3.8123  TE=1
MATL CD=403.316
BRAD PT=610 RA=2  EW=1
TANP        DY=4
BRAD PT=612 RA=2  EW=1
MATL CD=376.316
TANG PT=614 DZ=-10.38  EW=1
MATL CD=403.316
BRAD PT=615 RA=10  EW=1
MATL CD=376.316
TANG PT=620 DX=5.98 DZ=-3.45  EW=1
*NOTE
*NOTE VARIABLE SPRING H104 AT NODE 620
*NOTE
*NOTE VALVE V10-81A DATA FROM 5920-4590 WEIGHT - 6845.#
*NOTE WEIGHT APPLIED AT ESTIMATED CENTER OF GRAVITY (NODE 623)
CROS CD=30
VALV PT=622 DX=1.98 DZ=-1.15 PL=1  *AL=$VALVE V10-81A$
JUNC PT=622
VALV PT=624 DX=1.98 DZ=-1.15 PL=2  EW=1
JUNC PT=622
RIGD PT=623 DY=2.5
LUMP PT=623 MA=7.32 *VALVE ACTUATOR
CROS CD=29
JUNC PT=624
TANG PT=625 DX=1.867 DZ=-1.078
TANG PT=630 DX=2.598 DZ=-1.5  EW=1
MATL CD=403.316
BRAD PT=631 RA=3  EW=1
MATL CD=376.316
TANG PT=640 DZ=-4.54  EW=1
MATL CD=403.316
BRAD PT=641 RA=2  EW=1
MATL CD=376.316
*NOTE VALVE V10-46A DATA FROM 5920-4718 WEIGHT - 5295.#
CROS CD=30
VALV PT=655 DX=-3.79 PL=1 TA=2 *AL=$VALVE V10-46A$
LUMP PT=655 MA=5.77

*---------------------------
*END REGION 9A GEOMETRY FOR RHR RETURN FROM TEE TO VALVE NODE 660
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 9B TRANSIENT CARDS & GEOMETRY FOR RHR RETURN FROM VALVE NODE 660 TO PENET. NODE
675
*-----------------------------------------
*GROUP 19 RHR RETURN FROM VALVE NODE 660 TO PENET. NODE 675
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG9B.INP
```

```
*
*NOTE
*NOTE VARIABLE SPRING H105 AT NODE 655
*NOTE
VALV PT=660 DX=-1.79 PL=2  EW=1
*NOTE SPEC CHANGE TO CARBON STEEL
MATL CD=106
CROS CD=29
TANG PT=661 DX=-1
TANG PT=663 DX=-3.31  EW=1
BRAD PT=665 RA=2  EW=1
TANG PT=670 DY=-10.5 DZ=0.38  EW=1
BRAD PT=671 RA=2  EW=1
TANG PT=673 DZ=-7.74
TANG PT=675 DZ=-7.74
*---------------------------
*END REGION 9B GEOMETRY FOR RHR RETURN FROM VALVE NODE 660 TO PENET. NODE 675
*---------------------------
*
*---------------------------
***STRESS INDICES AT CROSS POINT
*---------------------------
*
INDI AT=210 AF=195 B1=0.5 C1=1 K1=4 B2=2.256 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
INDI AT=210 AF=215 B1=0.5 C1=1 K1=4 B2=2.256 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
INDI AT=210 AF=240 B1=0.5 C1=1 K1=4 B2=1.805 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
INDI AT=210 AF=260 B1=0.5 C1=1 K1=4 B2=1.805 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
*---------------------------
*** SUPPORTS
*---------------------------
RSTN PT=675  DX=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=675  DY=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=675  DZ=1  SP=23000          *RHR SUPPLY PENET.
ROTR PT=675  RX=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=675  RY=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=675  RZ=1  SP=340000         *RHR SUPPLY PENET.
RSTN PT=565  DX=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=565  DY=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=565  DZ=1  SP=23000          *RHR SUPPLY PENET.
ROTR PT=565  RX=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=565  RY=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=565  RZ=1  SP=340000         *RHR SUPPLY PENET.
*
SNUB PT=12   DZ=-1 SP=1000   *AL=$SNUBBER SS-7A-1$
SNUB PT=12   DX=1  SP=1000   *AL=$SNUBBER SS-7A-2$
SNUB PT=190  DX=-1 SP=1000   *AL=$SNUBBER SS-6-A1$
SNUB PT=190  DZ=1  SP=1000   *AL=$SNUBBER SS-6-A2$
*
VSUP PT=20   DY=1  FO=24.8  SP=2.664  *AL=$VARI. SUPT. HA-1$
*
CSUP PT=27   DY=1  FO=8.3   KP=0.01   *AL=$CONST. SUPT. H-8-A1$
CSUP PT=42   DY=1  FO=8.3   KP=0.01   *AL=$CONST. SUPT. H-8-A2$
CSUP PT=56   DY=1  FO=18.05 KP=0.01   *AL=$CONST. SUPT. HA3 FOR PUMP$
CSUP PT=69   DY=1  FO=18.0  KP=0.01   *AL=$CONST. SUPT. HA4 FOR PUMP$
CSUP PT=63   DY=1  FO=18.02 KP=0.01   *AL=$CONST. SUPT. HA5 FOR PUMP$
CSUP PT=160  DY=-1 FO=11.8  KP=0.01   *AL=$CONST. SUPT. HA-9 & HA-10$
CSUP PT=705  DY=1  FO=0.960 KP=0.01   *AL=$CONST. SUPT. HA-11 ON 4 INCH BYPASS$
*
VSUP PT=184  DY=1  FO=36.0 SP=3.542   *AL=$VARI. SUPT. HA-2$
VSUP PT=343  DY=1  FO=7.1  SP=3.014   *AL=$VARI. SUPT. HA13$
```

```
VSUP PT=313  DY=1  FO=7.1  SP=3.014    *AL=$VARI. SUPT. HA14$
*
VSUP PT=530  DY=1  SP=9.420 FO=26.0    *AL=$HANGER H109 RHR SUPPLY VALVE$
VSUP PT=620  DY=1  SP=7.084 FO=14.9    *AL=$HANGER H104 RHR RETURN VALVE$
VSUP PT=655  DY=1  SP=4.710 FO=22.0    *AL=$HANGER H105 RHR RETURN VALVE$
*
RSTN PT=15   DY=0.7071 DZ=-0.7071  SP=6000    *RECIRC PUMP
RSTN PT=16   DX=-0.7071 DY=0.7071  SP=6000    *RECIRC PUMP
ENDP
```

**RHR_15.inp**

```
IDEN JB=3    *Job number (1 to 9999)
     CD=1    *1=ASME Class 1
     GR=-Y   *Direction of gravity
     VA=0    *0=Calculate          2=Verify
     IU=1    *Input units          1=USA
     OU=1    *Output units         1=USA
     CH=$    *Delimiter character
     AB=T    *FREE errors = abort
     PL=$Vermont Yankee$
     EN=$RVP$
TITL BL=3    *Modeling option:
             *  3 = uniform mass for static analysis
             *      lumped mass for dynamic analysis
             *      rotational inertia ignored
     GL=1    *Report forces/moment       0=Global     1=Local     2=G et L
     SU=1    *Support summary            0=No         1=Yes
     CV=15   *Code version - See Manual
     HS=1    *Highest 20 stress ratios for each case
     MD=1    *Hot modulus
     J6=1    *File generated by program
     TI=$Vermont Yankee Recirculation $
        $Fatigue Analysis$
FREQ RF=1 RP=8 FR=36 MP=20 RC=0 MX=70 TI=$SEISMIC$
*
*************************************
**** THERMAL CYCLE LOAD CASES****
*************************************
LCAS RF=0 CA=1 TY=0 TI=$LC-1$     *TC-1
LCAS RF=0 CA=2 TY=0 TI=$LC-2$     *TC-2
LCAS RF=0 CA=3 TY=0 TI=$LC-3$     *TC-3
LCAS RF=0 CA=4 TY=0 TI=$LC-4$     *TC-4
LCAS RF=0 CA=5 TY=0 TI=$LC-5$     *TC-5
LCAS RF=0 CA=6 TY=0 TI=$LC-6$     *TC-6
LCAS RF=0 CA=7 TY=0 TI=$LC-7$     *TC-7
LCAS RF=0 CA=8 TY=0 TI=$LC-8$     *TC-8
LCAS RF=0 CA=9 TY=0 TI=$LC-9$     *TC-9
LCAS RF=0 CA=10 TY=0 TI=$LC-10$   *TC-10
LCAS RF=0 CA=11 TY=0 TI=$LC-11$   *TC-11
LCAS RF=0 CA=12 TY=0 TI=$LC-12$   *TC-12
LCAS RF=0 CA=13 TY=0 TI=$LC-13$   *TC-13
LCAS RF=0 CA=14 TY=0 TI=$LC-14$   *TC-14
LCAS RF=0 CA=15 TY=0 TI=$LC-15$   *TC-15
LCAS RF=0 CA=16 TY=0 TI=$LC-16$   *TC-16
LCAS RF=0 CA=17 TY=0 TI=$LC-17$   *TC-17
LCAS RF=0 CA=18 TY=0 TI=$LC-18$   *TC-18
LCAS RF=0 CA=19 TY=0 TI=$LC-19$   *TC-19
LCAS RF=0 CA=20 TY=0 TI=$LC-20$   *TC-20
LCAS RF=0 CA=21 TY=0 TI=$LC-21$   *TC-21
LCAS RF=0 CA=22 TY=0 TI=$LC-22$   *TC-22
```

```
LCAS RF=0 CA=23 TY=0 TI=$LC-23$    *TC-23
LCAS RF=0 CA=24 TY=0 TI=$LC-24$    *TC-24
LCAS RF=0 CA=25 TY=0 TI=$LC-25$    *TC-25
*
*********************
**** WEIGHT CASES****
*********************
LCAS CA=101  RF=1  TY=3  TI=$OPERATING WEIGHT$
LCAS CA=102  RF=2  TY=4  TI=$HYDROTEST WEIGHT$
*
*********************************
**** THERMAL TRANSIENT CASES****
*********************************
TCAS CA=201 TI=$Design Hydrotest (+) $
TCAS CA=202 TI=$Design Hydrotest (-) $
TCAS CA=203 TI=$Startup              $
TCAS CA=204 TI=$TRoll & Inc. PWR1    $
TCAS CA=205 TI=$TRoll & Inc. PWR2    $
TCAS CA=206 TI=$LOFWH+TT PWR1        $
TCAS CA=207 TI=$LOFWH+TT PWR2        $
TCAS CA=208 TI=$LOFWH+PFWHTR Byp1    $
TCAS CA=209 TI=$LOFWH+PFWHTR Byp2    $
TCAS CA=210 TI=$LOFWP, ISO Cl DN 1   $
TCAS CA=211 TI=$LOFWP, ISO Cl UP 1   $
TCAS CA=212 TI=$LOFWP, ISO Cl DN 2   $
TCAS CA=213 TI=$LOFWP, ISO Cl UP 2   $
TCAS CA=214 TI=$Reduction to 0% PWR  $
TCAS CA=215 TI=$Shutdown1            $
TCAS CA=216 TI=$Shutdown2            $
TCAS CA=217 TI=$Shutdown3            $
TCAS CA=218 TI=$Shutdown4            $
TCAS CA=219 TI=$Code Hydrotest       $
TCAS CA=220 TI=$RHR Initiation UP    $
TCAS CA=221 TI=$RHR Initiation DN    $
TCAS CA=222 TI=$Inadvert. Inj. DOWN  $
TCAS CA=223 TI=$Inadvert. Inj. UP    $
TCAS CA=224 TI=$Single Relief BD DN  $
TCAS CA=225 TI=$Single Relief BD UP  $
*
**********************
**** SEISMIC CASES****
**********************
RCAS CA=103 EQ=3 EV=1 TY=1 SU=1 LO=1 FX=1 FY=1 FZ=1 TI=$OBE INERTIA$
*
** **************************
**** LOAD COMBINATION CASES *
** **************************
CCAS RF=1 CA=104      ME=1 FL=1  C1=103 CY=10  TI=$OBE$
CCAS RF=1 CA=401 SS=1 ME=1 EQ=3  C1=101 C2=103 TI=$EQUATION 9 LEVEL B$
CCAS RF=1 CA=402 SS=1 ME=3 F1=1  C1=103 C2=1   TI=$NORMAL+OBE$
CCAS RF=1 CA=403 SS=1 ME=3 F1=-1 C1=103 C2=1   TI=$NORMAL-OBE$
*
*****************
**** LOAD SETS****
*****************
*
LSET RF=1  FC=0 RP=1 CY=120  PR=1  MO=1  TR=201  TI=$Design Hydrotest (+)LS-1$
LSET RF=2  FC=0 RP=1 CY=120  PR=2  MO=2  TR=-202 TI=$Design Hydrotest (-)LS-2$
LSET RF=3  FC=0 RP=1 CY=300  PR=3  MO=3  TR=203  TI=$Startup             LS-3$
LSET RF=3  FC=0 RP=1 CY=579  PR=4  MO=4  TR=-204 TI=$TRoll & Inc. PWR1   LS-4$
```

```
LSET RF=4  FC=0 RP=1 CY=579  PR=5  MO=5  TR=-205 TI=$TRoll & Inc. PWR2  LS-5$
LSET RF=4  FC=0 RP=1 CY=20   PR=6  MO=6  TR=206  TI=$LOFWH+TT PWR1      LS-6$
LSET RF=4  FC=0 RP=1 CY=20   PR=7  MO=7  TR=-207 TI=$LOFWH+TT PWR2      LS-7$
LSET RF=5  FC=0 RP=1 CY=70   PR=8  MO=8  TR=-208 TI=$LOFWH+PFWHTR Byp1  LS-8$
LSET RF=5  FC=0 RP=1 CY=70   PR=9  MO=9  TR=209  TI=$LOFWH+PFWHTR Byp2  LS-9$
LSET RF=5  FC=0 RP=1 CY=10   PR=10 MO=10 TR=-210 TI=$LOFWP, ISO Cl DN 1 LS-10$
LSET RF=11 FC=0 RP=1 CY=20   PR=11 MO=11 TR=211  TI=$LOFWP, ISO Cl UP 1 LS-11$
LSET RF=11 FC=0 RP=1 CY=20   PR=12 MO=12 TR=-212 TI=$LOFWP, ISO Cl DN 2 LS-12$
LSET RF=3  FC=0 RP=1 CY=10   PR=13 MO=13 TR=213  TI=$LOFWP, ISO Cl UP 2 LS-13$
LSET RF=3  FC=0 RP=1 CY=300  PR=14 MO=14 TR=214  TI=$Reduction to 0% PWR LS-14$
LSET RF=5  FC=0 RP=1 CY=300  PR=15 MO=15 TR=-215 TI=$Shutdown1          LS-15$
LSET RF=15 FC=0 RP=1 CY=300  PR=16 MO=16 TR=-216 TI=$Shutdown2          LS-16$
LSET RF=16 FC=0 RP=1 CY=300  PR=17 MO=17 TR=-217 TI=$Shutdown3          LS-17$
LSET RF=20 FC=0 RP=1 CY=300  PR=18 MO=18 TR=-218 TI=$Shutdown4          LS-18$
LSET RF=19 FC=0 RP=1 CY=1    PR=19 MO=19 TR=219  TI=$Code Hydrotest     LS-19$
LSET RF=20 FC=0 RP=1 CY=300  PR=20 MO=20 TR=220  TI=$RHR Initiation UP  LS-20$
LSET RF=20 FC=0 RP=1 CY=300  PR=21 MO=21 TR=-221 TI=$RHR Initiation DN  LS-21$
LSET RF=5  FC=0 RP=1 CY=0    PR=22 MO=22 TR=-222 TI=$Inadvert. Inj. DOWN LS-22$
LSET RF=5  FC=0 RP=1 CY=0    PR=23 MO=23 TR=223  TI=$Inadvert. Inj. UP  LS-23$
LSET RF=23 FC=0 RP=1 CY=0    PR=24 MO=24 TR=-224 TI=$Single Relief BD DN LS-24$
LSET RF=24 FC=0 RP=1 CY=0    PR=25 MO=25 TR=225  TI=$Single Relief BD UP LS-25$
*
LSET RF=2 FC=0 CY=5 FL=1 PR=2 MO=402 TI=$NORMAL+OBE  LS-26$
LSET RF=2 FC=0 CY=5 FL=1 PR=2 MO=403 TI=$NORMAL-OBE  LS-27$
******
*FATG AT=500 AF=502
*FATG AT=600 AF=602
*
***************************
**** RESPONSE SPECTRA****
*************************
SPEC FS=OBE EV=1 ME=3 FP=0  TI=$RESPONSE$
      LV=1 DX=1 DY=1 DZ=1
      DI=X
        0.30/0.100  0.40/0.100  0.90/0.200  1.25/0.400  2.25/0.450  2.30/0.700
        3.30/0.700  4.40/0.750  4.41/0.900  4.75/1.100  5.20/1.100  5.80/1.600
        8.70/1.600 12.00/0.650 17.00/0.400 20.00/0.350 30.00/0.350 36.00/0.350
      DI=Y
        0.30/0.030  0.40/0.030  0.50/0.050  0.60/0.075  1.00/0.075  1.20/0.100
        2.00/0.220  2.40/0.350  3.50/0.350  3.60/0.300  5.30/0.300  5.75/0.330
        8.25/0.330  8.75/0.250 17.50/0.250 25.00/0.120 30.00/0.120 36.00/0.120
      DI=Z
        0.30/0.100  0.40/0.100  0.50/0.130  0.90/0.150  1.00/0.250  1.60/0.250
        1.90/0.600  3.50/0.600  3.75/0.700  4.40/0.700  4.50/0.800  6.25/1.500
        8.50/1.500 12.50/0.500 20.00/0.350 30.00/0.350 36.00/0.350
*
******************************
**** MATERIAL PROPERTIES ****
******************************
* ASTM A-106 Grade B, PIPE *
MATH CD=106      EX=0      TY=1      *C-Si
MATD TE=70       EH=29.5   EX=0.0    SM=20.0   SY=35
MATD TE=100      EH=29.3   EX=0.20   SM=20.0   SY=35
MATD TE=200      EH=28.8   EX=1.00   SM=20.0   SY=32.1
MATD TE=300      EH=28.3   EX=1.90   SM=20.0   SY=31
MATD TE=400      EH=27.7   EX=2.80   SM=20.0   SY=29.9
MATD TE=500      EH=27.3   EX=3.70   SM=18.9   SY=28.5
MATD TE=600      EH=26.7   EX=4.70   SM=17.3   SY=26.8
* ASME SA-376 Grade TP316, PIPE *
MATH CD=376.316 EX=0       TY=4      *16Cr-12Ni-2Mo
```

```
MATD TE=70      EH=28.3   EX=0.0    SM=20.0   SY=30.0
MATD TE=100     EH=28.1   EX=0.30   SM=20.0   SY=30.0
MATD TE=200     EH=27.6   EX=1.40   SM=20.0   SY=25.9
MATD TE=300     EH=27.0   EX=2.50   SM=20.0   SY=23.4
MATD TE=400     EH=26.5   EX=3.70   SM=19.3   SY=21.4
MATD TE=500     EH=25.8   EX=5.00   SM=18.0   SY=20.0
MATD TE=600     EH=25.3   EX=6.30   SM=17.0   SY=18.9
* ASME SA-403 Grade WP316, ELBOWS *
MATH CD=403.316 EX=0      TY=4      *16Cr-12Ni-2Mo
MATD TE=70      EH=28.3   EX=0.0    SM=20.0   SY=30.0
MATD TE=100     EH=28.1   EX=0.30   SM=20.0   SY=30.0
MATD TE=200     EH=27.6   EX=1.40   SM=20.0   SY=25.9
MATD TE=300     EH=27.0   EX=2.50   SM=20.0   SY=23.4
MATD TE=400     EH=26.5   EX=3.70   SM=18.7   SY=21.4
MATD TE=500     EH=25.8   EX=5.00   SM=17.5   SY=20.0
MATD TE=600     EH=25.3   EX=6.30   SM=16.4   SY=18.9
*** Cross Sectional Properties
CROS CD=1  OD=50.0   WT=8.87    MA=3977.2 *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0               *RECIRCULATION OUTLET NOZZLE
CROS CD=2  OD=37.85  WT=6.1     MA=2122.2 *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=3  OD=28.875 WT=1.56    MA=484.9  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=4  OD=28.638 WT=1.45    MA=450.4  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=5  OD=28.169 WT=1.244   MA=386.1  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=7  OD=28.166 WT=2.125   MA=0.001  *VALVE
           SO=1      ST=1.0     KL=1
CROS CD=8  OD=42.507 WT=2.486   MA=0.001  *PUMP
           SO=.001   ST=.001    KL=1
CROS CD=11 OD=6.625  WT=0.432   MA=0.001  *PUMP RIGID STRUTS
           SO=0.001  ST=0.001   KL=1
CROS CD=13 OD=28.339 WT=1.339   MA=415.1  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1
CROS CD=14 OD=28.339 WT=2.67    MA=0.001  *VALVE
           SO=1      ST=1.0     KL=1
CROS CD=15 OD=12.748 WT=0.685   MA=103.4  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=16 OD=14.17  WT=1.395   MA=207.5  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=17 OD=15.5   WT=2       MA=307.7  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=18 OD=21.88  WT=4.06    MA=803.2  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=19 OD=28.25  WT=7.25    MA=1673.1 *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=20 OD=21.878 WT=1.043   MA=257.2  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1.0
CROS CD=25 OD=20     WT=1.031   MA=221.9  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1
CROS CD=26 OD=20     WT=1.875   MA=0.001  *VALVE
           SO=1      ST=1       KL=1
CROS CD=27 OD=4.5    WT=0.3385  MA=23.2   *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1       KL=1      *4 inch bypass line
CROS CD=28 OD=4.5    WT=0.67    MA=0.001  *VALVE V2-54A
           SO=1      ST=1       KL=1
CROS CD=29 OD=24     WT=1.217   MA=316.5  *CALC. PER GE SPEC. NO. 23A5569 [3]
           SO=1      ST=1
CROS CD=30 OD=24     WT=2.43    MA=0.001  *VALVE
```

```
            SO=1        ST=1       KL=1
CROS CD=40  OD=4.5      WT=0.3385  MA=0.001   *4 inch bypass STRUTS
            SO=0.001    ST=0.001   KL=1
CROS CD=41  OD=2.875    WT=0.276   MA=0.001   *STRUT RDA1, RDA5, & VBA1
            SO=0.001    ST=0.001   KL=1
CROS CD=42  OD=28.339   WT=1.339   MA=0.001   *RIGID FROM RECIRC ELBOW TO RDA1 STRUT
            SO=0.001    ST=0.001   KL=1
**********************
* STRUCTURE AND LOADS
**********************
*------------------------------------------------------------------------------
DESN  TE=575.0  PR=1250.0 *Reference 12 GE Design Requirements Rpt VY-05Q-227
*------------------------------------------------------------------------------
*--------------------------------------------------------------------
*BEGIN REGION 1 TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY TO TEE
*--------------------------------------------------------------------
*
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG1.INP
*
* RUN   1      FROM ANCHOR TO REACTOR VESSEL N3B
*GROUP 1 FROM ANCHOR TO REACTOR VESSEL N3B
*NOTE
*NOTE NODE 003 - RECIRC SUCTION NOZZLE N1A (EL. 279'5 INCH)
*NOTE NODE 003 IS AT THE SAFE END TO VESSEL NOZZLE CONNECTION
*NOTE
*NOTE SAFE END FROM NODES 003 TO 808
*NOTE CONNECTION TO VESSEL AT NODE 003
*NOTE OD AND WALL THICKNESS FOR SAFE END TAKEN FROM GE CALC
*NOTE WEIGHT FOR SAFE END BASED ON THICKNESS
*NOTE
MATL CD=376.316
CROS CD=1
COOR PT=3    AX=0  AY=0  AZ=0
ANCH PT=3
AMVT    CA=1    PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
AMVT    CA=2    PT=3    DX=0.0000   DY=0.3141   DZ=-0.3602
AMVT    CA=3    PT=3    DX=0.0000   DY=0.3112   DZ=-0.3568
AMVT    CA=4    PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=5    PT=3    DX=0.0000   DY=0.3112   DZ=-0.3568
AMVT    CA=6    PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=7    PT=3    DX=0.0000   DY=0.2922   DZ=-0.3350
AMVT    CA=8    PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=9    PT=3    DX=0.0000   DY=0.1422   DZ=-0.1630
AMVT    CA=10   PT=3    DX=0.0000   DY=0.2807   DZ=-0.3218
AMVT    CA=11   PT=3    DX=0.0000   DY=0.1422   DZ=-0.1630
AMVT    CA=12   PT=3    DX=0.0000   DY=0.3141   DZ=-0.3602
AMVT    CA=13   PT=3    DX=0.0000   DY=0.3141   DZ=-0.3602
AMVT    CA=14   PT=3    DX=0.0000   DY=0.1928   DZ=-0.2521
AMVT    CA=15   PT=3    DX=0.0000   DY=0.1624   DZ=-0.1986
AMVT    CA=16   PT=3    DX=0.0000   DY=0.0946   DZ=-0.1084
AMVT    CA=17   PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
AMVT    CA=18   PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
AMVT    CA=19   PT=3    DX=0.0000   DY=0.0946   DZ=-0.1084
AMVT    CA=20   PT=3    DX=0.0000   DY=0.0946   DZ=-0.1084
AMVT    CA=21   PT=3    DX=0.0000   DY=0.0361   DZ=-0.0413
AMVT    CA=22   PT=3    DX=0.0000   DY=0.2995   DZ=-0.3434
AMVT    CA=23   PT=3    DX=0.0000   DY=0.1928   DZ=-0.2521
AMVT    CA=24   PT=3    DX=0.0000   DY=0.0176   DZ=-0.0201
```

```
*
TANG PT=805  DZ=-1.017  EW=1
CROS CD=2
TANG PT=806  DZ=-0.823  EW=1
CROS CD=3
TANG PT=807  DZ=-0.58  EW=1
CROS CD=4
TANG PT=808  DZ=-0.47
CROS CD=5
TANG PT=5    DZ=-5.59 EW=1
MATL CD=403.316
BRAD PT=7    RA=3.5 EW=1
MATL CD=376.316
TANG PT=9    DY=-6.69  EW=1
TANG PT=500  DY=-2.31
*------------------------------------------
*END REGION 1 GEOMETRY FROM RHR SUPPLY TO TEE
*------------------------------------------
*
*----------------------------------------------------------------------
*BEGIN REGION 2 TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY TEE TO PUMP
*----------------------------------------------------------------------
*GROUP 2 RHR SUPPLY TEE TO PUMP
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG2.INP
*
TANG PT=11   DY=-2.22  EW=1
CROS CD=5
TANG PT=12   DY=-1.78
TANG PT=20   DY=-6.77
TANG PT=22   DY=-3.25
TANG PT=25   DY=-15.49  EW=1
MATL CD=403.316
BRAD PT=26   RA=3.5  EW=1
MATL CD=376.316
TANG PT=27   DX=-3.3 DZ=1.27  EW=1
CROS CD=7
VALV PT=30   DX=-2.28 DZ=0.89 MA=10.368 PL=1
JUNC PT=30
VALV PT=40   DX=-2.31 DZ=0.9 PL=2  EW=1
JUNC PT=30
RIGD PT=35   DY=7
LUMP PT=35   MA=1.132
JUNC PT=40
CROS CD=5
TANG PT=42 DX=-1.18 DZ=0.46
TANG PT=43 DX=-0.55 DZ=0.21
TANG PT=44 DX=-3.31 DZ=1.28  EW=1
MATL CD=403.316
BRAD PT=46 RA=2.33  EW=1
MATL CD=376.316
CROS CD=8
TANG PT=50 DY=4.33  EW=0
LUMP PT=50 MA=28  *NOTE WEIGHT OF PUMP FLOODED 28K (EXCLUDING MOTOR)
TANG PT=75 DY=0.5
TANG PT=83 DY=2.13
TANG PT=86 DY=3.38
LUMP PT=86 MA=32  *NOTE TOTAL WEIGHT OF PUMP MOTOR 32000 LBS
TANG PT=90 DY=4.08 *TOP OF PUMP
*NOTE SNUBBERS ON TOP OF PUMPS WERE DELETED DURING
*NOTE THE RECIRC PIPE REPLACEMENT PROJECT
```

```
*NOTE - RIGID LINKS FOR CONSTANT SUPPORTS AT PUMP FOLLOW
*---------------------------
*END REGION 2 GEOMETRY FROM RHR SUPPLY TEE TO PUMP
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 3 TRANSIENT CARDS & GEOMETRY FROM PUMP DISCHARGE TO HEADER
*-----------------------------------------
*GROUP 3 FROM PUMP DISCHARGE TO HEADER
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG3.INP
*
JUNC PT=50
CROS CD=8
RIGD PT=54 DX=1.06 DZ=1.06
RIGD PT=56 DX=1.06 DY=0.75 DZ=1.06  *NOTE CONSTANT SUPPORT HA3 AT NODE 56
JUNC PT=50
RIGD PT=66 DZ=-3.83
RIGD PT=69 DY=1                     *NOTE CONSTANT SUPPORT HA4 AT NODE 69
JUNC PT=50
CROS CD=8
RIGD PT=60 DX=-3.83
RIGD PT=63 DY=1                     *CONSTANT SUPPORT HA5 AT NODE 63
*
* *** CODING FOR PUMP RIGID STRUTS FOLLOW ***
*     CODED FROM PUMP CENTERLINE
CROS CD=11
JUNC PT=66
RIGD PT=15    DY=0.7071 DZ=-0.7071
*
JUNC PT=60
RIGD PT=16    DX=-0.7071 DY=0.7071
* *** END OF CODING FOR PUMP SUPPORTS ***
*PUMP INLET
CROS CD=8
JUNC PT=50
TANG PT=150 DX=-2.17
BRAN PT=151 DZ=2.333  TE=1
*NOTE PUMP DISCHARGE CONNECTION TO PIPE AT NODE 151
CROS CD=13
TANG PT=152 DZ=1.25
TANG PT=155 DZ=1  EW=1
CROS CD=14
VALV PT=160 PL=1 DX=0.0 DY=0.0  DZ=2.52 MA=6.8285
JUNC PT=160
RIGD PT=163 DX=0.0 DY=7.12 DZ=0.0
LUMP PT=163 MA=0.9715
JUNC PT=160
VALV PT=170 PL=2 DX=0.0 DY=0.0 DZ=6.18  EW=1
CROS CD=13
MATL CD=403.316
BRAD PT=175 RA=3.5  EW=1
MATL CD=376.316
TANG PT=176 DY=5.95
TANG PT=177 DY=4.42
*NOTE ***WEIGHT OF FLOW ELEMENT NOT INCLUDED***
*NOTE ***REF. DWG. 5920-6800 FOR DIMENSIONS***
TANG PT=184 DY=4.42
TANG PT=186 DY=3.02
TANG PT=188 DY=1.51
TANG PT=189 DY=0.74
```

```
TANG PT=190 DY=1.15  EW=1
TANG PT=600 DY=1.06

***INPUT FILE TO INCLUDE EFFECTS OF RHR INITIATION ON LINE NEAR RHR RETURN TO HEADER
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG3B.INP

JUNC PT=600
TANG PT=195 DY=2.08  EW=1
TANG PT=210 DX=0.0  DY=1.83 DZ=0.0  KL=1 *CENTER OF CROSS, RECIRC HEADER
*MUST HAVE INDI CARD FOR EACH MEMBER CONNECTED TO CROSS CENTER
*---------------------------
*END REGION 3 GEOMETRY FROM PUMP DISCHARGE TO HEADER
*---------------------------
*
*------------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 336
*------------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 336
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
*NOTE CROSS AND REDUCER DIMENSIONS TAKEN FROM 5920-6632 SHT.3
CROS CD=13
MATL CD=376.316
TANG PT=215 DX=0.0 DY=2.59  DZ=0.0  EW=0
CRED PT=220 DY=1.29  AN=30  EW=1  *AL=$CONC. REDUCER$
CROS CD=15
TANG PT=330 DY=4.58
TANG PT=335 DY=3.29  EW=1
MATL CD=403.316
BRAD PT=334 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 336
*---------------------------
*
*------------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 336
*------------------------------------------
*GROUP 6 TO NOZZLE NODE 336
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=838 DX=3.875
CROS CD=16
TANG PT=837 DX=0.875  EW=1
CROS CD=17
TANG PT=836 DX=0.37  EW=1
CROS CD=18
TANG PT=835 DX=0.53  EW=1
CROS CD=19
TANG PT=336 DX=0.704  EW=1
NOZZ PT=336
AMVT    CA=1    PT=336  DX=-0.0201  DY=0.0246  DZ=0.0000
AMVT    CA=2    PT=336  DX=-0.3602  DY=0.4398  DZ=0.0000
AMVT    CA=3    PT=336  DX=-0.3568  DY=0.4316  DZ=0.0000
AMVT    CA=4    PT=336  DX=-0.3434  DY=0.4152  DZ=0.0000
AMVT    CA=5    PT=336  DX=-0.3568  DY=0.4050  DZ=0.0000
AMVT    CA=6    PT=336  DX=-0.3434  DY=0.2940  DZ=0.0000
AMVT    CA=7    PT=336  DX=-0.3350  DY=0.3229  DZ=0.0000
AMVT    CA=8    PT=336  DX=-0.3434  DY=0.2700  DZ=0.0000
AMVT    CA=9    PT=336  DX=-0.1630  DY=0.1991  DZ=0.0000
```

```
AMVT     CA=10    PT=336   DX=-0.3218   DY=0.1626   DZ=0.0000
AMVT     CA=11    PT=336   DX=-0.1630   DY=0.0246   DZ=0.0000
AMVT     CA=12    PT=336   DX=-0.3602   DY=0.4398   DZ=0.0000
AMVT     CA=13    PT=336   DX=-0.3602   DY=0.4316   DZ=0.0000
AMVT     CA=14    PT=336   DX=-0.2193   DY=0.4152   DZ=0.0000
AMVT     CA=15    PT=336   DX=-0.1862   DY=0.4050   DZ=0.0000
AMVT     CA=16    PT=336   DX=-0.1084   DY=0.2940   DZ=0.0000
AMVT     CA=17    PT=336   DX=-0.0201   DY=0.3229   DZ=0.0000
AMVT     CA=18    PT=336   DX=-0.0201   DY=0.2700   DZ=0.0000
AMVT     CA=19    PT=336   DX=-0.1084   DY=0.1991   DZ=0.0000
AMVT     CA=20    PT=336   DX=-0.0201   DY=0.1626   DZ=0.0000
AMVT     CA=21    PT=336   DX=-0.0413   DY=0.3229   DZ=0.0000
AMVT     CA=22    PT=336   DX=-0.3434   DY=0.2700   DZ=0.0000
AMVT     CA=23    PT=336   DX=-0.2211   DY=0.1991   DZ=0.0000
AMVT     CA=24    PT=336   DX=-0.0201   DY=0.1626   DZ=0.0000

*NOTE SAFE END FROM NODES 838 TO 336
*NOTE CONNECTION TO VESSEL AT NODE 336
*NOTE OD AND WALL THICKNESS FOR SAFE END TAKEN FROM GE CALC
*NOTE WEIGHT BASED ON THICKNESS
*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 336
*---------------------------
*
*----------------------------------------
*BEGIN REGION 4 TRANSIENT CARDS & GEOMETRY HEADER TO NOZZLE NODE 366
*----------------------------------------
*GROUP 4 HEADER TO NOZZLE NODE 366
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG4.INP
*
JUNC PT=210
CROS CD=20
BRAN PT=240 DX=0.1786 DY=0.0 DZ=1.7
TANG PT=250 DX=0.3 DZ=2.853  EW=0
BRAD PT=255 RA=4.578  EW=0 *NOTE BEND RADIUS IS 4.578 FEET
TANG PT=340 DX=1.799 DZ=3.108
*---------------------------
*END REGION 4 GEOMETRY HEADER TO NOZZLE NODE 366
*---------------------------
*
*----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 366
*----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 366
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
TANG PT=349 DX=0.71 DZ=1.23  EW=0
CRED PT=347 DX=0.75 DZ=1.3  AN=30
CROS CD=15
TANG PT=343 DX=0.5525 DZ=0.957  EW=1
BRAD PT=410 RA=1.5  EW=1
TANG PT=360 DX=3.483 DZ=2.011  EW=1
MATL CD=403.316
BRAD PT=361 RA=1.5  EW=1
MATL CD=376.316
CROS CD=15
TANG PT=362 DY=3.18
TANG PT=364 DY=8.56  EW=1
MATL CD=403.316
```

```
BRAD PT=365 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 366
*---------------------------

*-----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 366
*-----------------------------------------
*GROUP 6 TO NOZZLE NODE 366
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=868 DX=1.8 DZ=-3.1
CROS CD=16
TANG PT=867 DX=0.4375 DZ=-0.76  EW=1
CROS CD=17
TANG PT=866 DX=0.185 DZ=-0.32  EW=1
CROS CD=18
TANG PT=865 DX=0.265 DZ=-0.46  EW=1
CROS CD=19
TANG PT=366 DX=0.352 DZ=-0.61  EW=1
NOZZ PT=366
AMVT    CA=1     PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=2     PT=366  DX=-0.1800  DY=0.4398  DZ=0.3120
AMVT    CA=3     PT=366  DX=-0.1783  DY=0.4357  DZ=0.3091
AMVT    CA=4     PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=5     PT=366  DX=-0.1783  DY=0.4357  DZ=0.3091
AMVT    CA=6     PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=7     PT=366  DX=-0.1674  DY=0.4091  DZ=0.2902
AMVT    CA=8     PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=9     PT=366  DX=-0.0815  DY=0.1991  DZ=0.1412
AMVT    CA=10    PT=366  DX=-0.1609  DY=0.3930  DZ=0.2788
AMVT    CA=11    PT=366  DX=-0.0815  DY=0.1991  DZ=0.1412
AMVT    CA=12    PT=366  DX=-0.1800  DY=0.4398  DZ=0.3120
AMVT    CA=13    PT=366  DX=-0.1800  DY=0.4398  DZ=0.3120
AMVT    CA=14    PT=366  DX=-0.1097  DY=0.2678  DZ=0.1899
AMVT    CA=15    PT=366  DX=-0.0931  DY=0.2275  DZ=0.1613
AMVT    CA=16    PT=366  DX=-0.0542  DY=0.1324  DZ=0.0939
AMVT    CA=17    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=18    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=19    PT=366  DX=-0.0542  DY=0.1324  DZ=0.0939
AMVT    CA=20    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174
AMVT    CA=21    PT=366  DX=-0.0207  DY=0.0505  DZ=0.0358
AMVT    CA=22    PT=366  DX=-0.1716  DY=0.4193  DZ=0.2974
AMVT    CA=23    PT=366  DX=-0.1105  DY=0.2700  DZ=0.1915
AMVT    CA=24    PT=366  DX=-0.0101  DY=0.0246  DZ=0.0174

*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 366
*---------------------------

*-----------------------------------------
*BEGIN REGION 4 TRANSIENT CARDS & GEOMETRY HEADER TO NOZZLES NODE 326 & 316
*-----------------------------------------
*GROUP 4 HEADER TO NOZZLES NODE 326 & 316
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG4.INP
*
JUNC PT=210
CROS CD=20
BRAN PT=260 DX=0.1786 DY=0.0 DZ=-1.7 TE=2
```

```
TANG PT=270 DX=0.3 DZ=-2.853  EW=0
BRAD PT=275 RA=4.578  EW=0
TANG PT=320 DX=1.799 DZ=-3.108
*---------------------------
*END REGION 4 GEOMETRY HEADER TO NOZZLES NODE 326 & 316
*---------------------------

*-----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 316
*-----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 316
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
TANG PT=319 DX=0.71 DZ=-1.23  EW=1
CRED PT=317 DX=0.75 DZ=-1.3  AN=30
CROS CD=15
TANG PT=313 DX=0.5525 DZ=-0.957  EW=1
BRAD PT=400 RA=1.5  EW=1
TANG PT=310 DX=3.483 DZ=-2.011  EW=1
MATL CD=403.316
BRAD PT=311 RA=1.5  EW=1
MATL CD=376.316
CROS CD=15
TANG PT=312 DY=4.74
TANG PT=314 DY=6.99  EW=1
MATL CD=403.316
BRAD PT=315 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 316
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 316
*-----------------------------------------
*GROUP 6 TO NOZZLE NODE 316
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=818 DX=1.84 DZ=3.19
CROS CD=16
TANG PT=817 DX=0.4375 DZ=0.76  EW=1
CROS CD=17
TANG PT=816 DX=0.185 DZ=0.32  EW=1
CROS CD=18
TANG PT=815 DX=0.265 DZ=0.46  EW=1
CROS CD=19
TANG PT=316 DX=0.352 DZ=0.61  EW=1
NOZZ PT=316
AMVT    CA=1    PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT    CA=2    PT=316  DX=-0.1800  DY=0.4398  DZ=-0.3120
AMVT    CA=3    PT=316  DX=-0.1783  DY=0.4357  DZ=-0.3091
AMVT    CA=4    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT    CA=5    PT=316  DX=-0.1783  DY=0.4357  DZ=-0.3091
AMVT    CA=6    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT    CA=7    PT=316  DX=-0.1674  DY=0.4091  DZ=-0.2902
AMVT    CA=8    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT    CA=9    PT=316  DX=-0.0815  DY=0.1991  DZ=-0.1412
AMVT    CA=10   PT=316  DX=-0.1609  DY=0.3930  DZ=-0.2788
AMVT    CA=11   PT=316  DX=-0.0815  DY=0.1991  DZ=-0.1412
AMVT    CA=12   PT=316  DX=-0.1800  DY=0.4398  DZ=-0.3120
```

```
AMVT     CA=13    PT=316  DX=-0.1800  DY=0.4398  DZ=-0.3120
AMVT     CA=14    PT=316  DX=-0.1097  DY=0.2678  DZ=-0.1899
AMVT     CA=15    PT=316  DX=-0.0931  DY=0.2275  DZ=-0.1613
AMVT     CA=16    PT=316  DX=-0.0542  DY=0.1324  DZ=-0.0939
AMVT     CA=17    PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT     CA=18    PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT     CA=19    PT=316  DX=-0.0542  DY=0.1324  DZ=-0.0939
AMVT     CA=20    PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
AMVT     CA=21    PT=316  DX=-0.0207  DY=0.0505  DZ=-0.0358
AMVT     CA=22    PT=316  DX=-0.1716  DY=0.4193  DZ=-0.2974
AMVT     CA=23    PT=316  DX=-0.1105  DY=0.2700  DZ=-0.1915
AMVT     CA=24    PT=316  DX=-0.0101  DY=0.0246  DZ=-0.0174
*----------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 316
*----------------------------
*
*------------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 346
*------------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 346
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
JUNC PT=340
CROS CD=15
BRAN PT=342 DY=1.36  TE=2
TANG PT=344 DY=10.39  EW=0
MATL CD=403.316
BRAD PT=345 RA=1.5  EW=1
*----------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 346
*----------------------------
*
*------------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 346
*------------------------------------------
*GROUP 6 TO NOZZLE NODE 346
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=848 DX=3.17 DZ=-1.83
CROS CD=16
TANG PT=847 DX=0.758 DZ=-0.4375  EW=1
CROS CD=17
TANG PT=846 DX=0.32 DZ=-0.185  EW=1
CROS CD=18
TANG PT=845 DX=0.46 DZ=-0.265  EW=1
CROS CD=19
TANG PT=346 DX=0.61 DZ=-0.352  EW=1
NOZZ PT=346
AMVT     CA=1     PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT     CA=2     PT=346  DX=-0.3120  DY=0.4398  DZ=0.1800
AMVT     CA=3     PT=346  DX=-0.3091  DY=0.4357  DZ=0.1783
AMVT     CA=4     PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT     CA=5     PT=346  DX=-0.3091  DY=0.4357  DZ=0.1783
AMVT     CA=6     PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT     CA=7     PT=346  DX=-0.2902  DY=0.4091  DZ=0.1674
AMVT     CA=8     PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT     CA=9     PT=346  DX=-0.1412  DY=0.1991  DZ=0.0815
AMVT     CA=10    PT=346  DX=-0.2788  DY=0.3930  DZ=0.1609
AMVT     CA=11    PT=346  DX=-0.1412  DY=0.1991  DZ=0.0815
```

```
AMVT    CA=12   PT=346  DX=-0.3120  DY=0.4398  DZ=0.1800
AMVT    CA=13   PT=346  DX=-0.3120  DY=0.4398  DZ=0.1800
AMVT    CA=14   PT=346  DX=-0.1899  DY=0.2678  DZ=0.1097
AMVT    CA=15   PT=346  DX=-0.1613  DY=0.2275  DZ=0.0931
AMVT    CA=16   PT=346  DX=-0.0939  DY=0.1324  DZ=0.0542
AMVT    CA=17   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=18   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=19   PT=346  DX=-0.0939  DY=0.1324  DZ=0.0542
AMVT    CA=20   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
AMVT    CA=21   PT=346  DX=-0.0358  DY=0.0505  DZ=0.0207
AMVT    CA=22   PT=346  DX=-0.2974  DY=0.4193  DZ=0.1716
AMVT    CA=23   PT=346  DX=-0.1915  DY=0.2700  DZ=0.1105
AMVT    CA=24   PT=346  DX=-0.0174  DY=0.0246  DZ=0.0101
*---------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 346
*---------------------------
*
*----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 326
*----------------------------------------
*GROUP 5 RISER TO NOZZLE NODE 326
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG5.INP
*
JUNC PT=320
CROS CD=15
BRAN PT=322 DY=1.42  TE=2
TANG PT=324 DY=10.33  EW=1
MATL CD=403.316
BRAD PT=325 RA=1.5  EW=1
*---------------------------
*END REGION 5 GEOMETRY RISER TO NOZZLE NODE 326
*---------------------------
*
*----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 326
*----------------------------------------
*GROUP 6 TO NOZZLE NODE 326
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG6.INP
*
MATL CD=376.316
TANG PT=828 DX=3.18 DZ=1.84
CROS CD=16
TANG PT=827 DX=0.758 DZ=0.4375  EW=1
CROS CD=17
TANG PT=826 DX=0.32 DZ=0.185  EW=1
CROS CD=18
TANG PT=825 DX=0.46 DZ=0.265  EW=1
CROS CD=19
TANG PT=326 DX=0.61 DZ=0.352  EW=1
NOZZ PT=326
AMVT    CA=1    PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT    CA=2    PT=326  DX=-0.3120  DY=0.4398  DZ=-0.1800
AMVT    CA=3    PT=326  DX=-0.3091  DY=0.4357  DZ=-0.1783
AMVT    CA=4    PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT    CA=5    PT=326  DX=-0.3091  DY=0.4357  DZ=-0.1783
AMVT    CA=6    PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT    CA=7    PT=326  DX=-0.2902  DY=0.4091  DZ=-0.1674
AMVT    CA=8    PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT    CA=9    PT=326  DX=-0.1412  DY=0.1991  DZ=-0.0815
AMVT    CA=10   PT=326  DX=-0.2788  DY=0.3930  DZ=-0.1609
```

```
AMVT    CA=11   PT=326  DX=-0.1412  DY=0.1991  DZ=-0.0815
AMVT    CA=12   PT=326  DX=-0.3120  DY=0.4398  DZ=-0.1800
AMVT    CA=13   PT=326  DX=-0.3120  DY=0.4398  DZ=-0.1800
AMVT    CA=14   PT=326  DX=-0.1899  DY=0.2678  DZ=-0.1097
AMVT    CA=15   PT=326  DX=-0.1613  DY=0.2275  DZ=-0.0931
AMVT    CA=16   PT=326  DX=-0.0939  DY=0.1324  DZ=-0.0542
AMVT    CA=17   PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT    CA=18   PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT    CA=19   PT=326  DX=-0.0939  DY=0.1324  DZ=-0.0542
AMVT    CA=20   PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
AMVT    CA=21   PT=326  DX=-0.0358  DY=0.0505  DZ=-0.0207
AMVT    CA=22   PT=326  DX=-0.2974  DY=0.4193  DZ=-0.1716
AMVT    CA=23   PT=326  DX=-0.1915  DY=0.2700  DZ=-0.1105
AMVT    CA=24   PT=326  DX=-0.0174  DY=0.0246  DZ=-0.0101
*--------------------------
*END REGION 6 GEOMETRY TO NOZZLE NODE 326
*--------------------------
*
*----------------------------------------
*BEGIN REGION 7A TRANSIENT CARDS & GEOMETRY TO RHR SUPPLY VALVE NODE 550
*----------------------------------------
*GROUP 7 TO RHR SUPPLY VALVE NODE 550
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG7A.INP
*
MATL CD=376.316
JUNC PT=500
CROS CD=25
BRAN PT=502 DX=1.67  EW=0  TE=1
TANG PT=506 DX=2.53  EW=0
MATL CD=403.316
BRAD PT=507 RA=1.67  EW=1
MATL CD=376.316
TANG PT=508 DZ=-4.01
TANG PT=515 DZ=-4.53  EW=1
MATL CD=403.316
BRAD PT=520 RA=1.67  EW=1
MATL CD=376.316
CROS CD=26
VALV PT=525 DX=-3.34 PL=1
JUNC PT=525
VALV PT=530 DX=-1.99 PL=2  EW=1
JUNC PT=525
RIGD PT=526 DY=2.5
LUMP PT=526 MA=7.569
JUNC PT=530
CROS CD=25
TANG PT=540 DX=-1.13  EW=1
CROS CD=26
VALV PT=545 DX=-1.97 PL=1
JUNC PT=545
RIGD PT=547 DY=2.5
LUMP PT=547 MA=7.355
JUNC PT=545
VALV PT=550 DX=-1.98 PL=2  EW=1
*--------------------------
*END REGION 7A GEOMETRY TO RHR SUPPLY VALVE NODE 550
*--------------------------
*
*----------------------------------------
*BEGIN REGION 7B TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY VALVE TO PENET. NODE 565
```

```
*---------------------------------------
*GROUP 17 FROM RHR SUPPLY VALVE TO PENET. NODE 565
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG7B.INP
*
CROS CD=25
MATL CD=106
TANG PT=555 DX=-3.36  EW=1
BRAD PT=556 RA=1.67  EW=1
TANG PT=560 DY=-10.17  EW=1
BRAD PT=561 RA=1.67  EW=1
TANG PT=563 DZ=-6.92
TANG PT=565 DZ=-6.92
*--------------------------
*END REGION 7B GEOMETRY FROM RHR SUPPLY VALVE TO PENET. NODE 565
*--------------------------
*
*---------------------------------------
*BEGIN REGION 8 TRANSIENT CARDS & GEOMETRY FOR 4 INCH BYPASS
*---------------------------------------
*GROUP 8 4 INCH BYPASS
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG8.INP
*
*NOTE CODING FOR 4 INCH BYPASS STARTS HERE
JUNC PT=152
CROS CD=27
MATL CD=376.316
BRAN PT=700 DX=-1.19  TE=4
TANG PT=702 DX=-0.61
TANG PT=703 DX=-1.43  EW=0
MATL CD=403.316
BRAD PT=704 RA=0.5  EW=0
MATL CD=376.316
TANG PT=705 DZ=5.08
*NOTE CONSTANT SUPPORT HA11 AT NODE 705
TANG PT=721 DZ=1.12
TANG PT=706 DZ=2.47
TANG PT=707 DZ=1.03
TANG PT=708 DZ=0.34
TANG PT=709 DZ=0.38
JUNC PT=707
BRAN PT=710 DY=0.34 TE=1
CROS CD=28
VALV PT=712 DY=0.71 MA=0.3669 PL=1  *AL=$VALVE V2-54A$
VALV PT=715 DZ=-3.5 MA=0.1831 PL=3
JUNC PT=712
VALV PT=714 DY=0.71           PL=2
CROS CD=27
TANG PT=723 DY=4.19
MATL CD=403.316
BRAD PT=716 RA=0.5
MATL CD=376.316
TANG PT=718 DX=1.48
TANG PT=720 DX=0.56
BRAN PT=176 DX=1.19  TE=4
************CODING FOR STRUTS RDA5 AND VAB1 FOLLOW
JUNC PT=170
CROS CD=40  *OD=4.5 inch
RIGD PT=725 DP=0 DX=-0.583 DY=1.84  *AL=$RDA5$
CROS CD=41  *OD=2.875 inch
RIGD PT=715 DP=0 DX=-2.67 DY=-0.79
```

```
RIGD PT=721 DP=0 DY=-1.05  *AL=$VAB1$
*************CODING FOR RDA1 STRUT FOLLOWS
CROS CD=42  *OD=28.339 inch
JUNC PT=175
RIGD PT=173 DP=0 DY=-3.5 DZ=0.34
CROS CD=41  *OD=2.875 inch
RIGD PT=708 DP=0 DX=-3.21  *AL=$RDA1$
*---------------------------
*END REGION 8 GEOMETRY  FOR 4 INCH BYPASS
*---------------------------
*
*-----------------------------------------
*BEGIN REGION 9A TRANSIENT CARDS & GEOMETRY FOR RHR RETURN FROM TEE TO VALVE NODE 660
*-----------------------------------------
*GROUP 9 RHR RETURN FROM TEE TO VALVE NODE 660
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG9A.INP
*
*NOTE CODING FOR RHR RETURN STARTS HERE
CROS CD=29
JUNC PT=600
MATL CD=376.316
BRAN PT=602 DX=-3.8123  TE=1
MATL CD=403.316
BRAD PT=610 RA=2  EW=1
TANP        DY=4
BRAD PT=612 RA=2  EW=1
MATL CD=376.316
TANG PT=614 DZ=-10.38  EW=1
MATL CD=403.316
BRAD PT=615 RA=10  EW=1
MATL CD=376.316
TANG PT=620 DX=5.98 DZ=-3.45  EW=1
*NOTE
*NOTE VARIABLE SPRING H104 AT NODE 620
*NOTE
*NOTE VALVE V10-81A DATA FROM 5920-4590 WEIGHT - 6845.#
*NOTE WEIGHT APPLIED AT ESTIMATED CENTER OF GRAVITY (NODE 623)
CROS CD=30
VALV PT=622 DX=1.98 DZ=-1.15 PL=1  *AL=$VALVE V10-81A$
JUNC PT=622
VALV PT=624 DX=1.98 DZ=-1.15 PL=2  EW=1
JUNC PT=622
RIGD PT=623 DY=2.5
LUMP PT=623 MA=7.32 *VALVE ACTUATOR
CROS CD=29
JUNC PT=624
TANG PT=625 DX=1.867 DZ=-1.078
TANG PT=630 DX=2.598 DZ=-1.5  EW=1
MATL CD=403.316
BRAD PT=631 RA=3  EW=1
MATL CD=376.316
TANG PT=640 DZ=-4.54  EW=1
MATL CD=403.316
BRAD PT=641 RA=2  EW=1
MATL CD=376.316
*NOTE VALVE V10-46A DATA FROM 5920-4718 WEIGHT - 5295.#
CROS CD=30
VALV PT=655 DX=-3.79 PL=1 TA=2 *AL=$VALVE V10-46A$
LUMP PT=655 MA=5.77
```

```
*---------------------------
*END REGION 9A GEOMETRY FOR RHR RETURN FROM TEE TO VALVE NODE 660
*---------------------------
*
*----------------------------------------
*BEGIN REGION 9B TRANSIENT CARDS & GEOMETRY FOR RHR RETURN FROM VALVE NODE 660 TO PENET. NODE
675
*----------------------------------------
*GROUP 19 RHR RETURN FROM VALVE NODE 660 TO PENET. NODE 675
INCL FN=Z:\SISJ-PROJECTS\VY-16Q\Rev0\REG9B.INP
*
*NOTE
*NOTE VARIABLE SPRING H105 AT NODE 655
*NOTE
VALV PT=660 DX=-1.79 PL=2  EW=1
*NOTE SPEC CHANGE TO CARBON STEEL
MATL CD=106
CROS CD=29
TANG PT=661 DX=-1
TANG PT=663 DX=-3.31  EW=1
BRAD PT=665 RA=2  EW=1
TANG PT=670 DY=-10.5 DZ=0.38  EW=1
BRAD PT=671 RA=2  EW=1
TANG PT=673 DZ=-7.74
TANG PT=675 DZ=-7.74
*---------------------------
*END REGION 9B GEOMETRY FOR RHR RETURN FROM VALVE NODE 660 TO PENET. NODE 675
*---------------------------
*
*---------------------------
***STRESS INDICES AT CROSS POINT
*---------------------------
*
INDI AT=210 AF=195 B1=0.5 C1=1 K1=4 B2=2.256 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
INDI AT=210 AF=215 B1=0.5 C1=1 K1=4 B2=2.256 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
INDI AT=210 AF=240 B1=0.5 C1=1 K1=4 B2=1.805 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
INDI AT=210 AF=260 B1=0.5 C1=1 K1=4 B2=1.805 C2=3.024 K2=1 C3=1 K3=1 CP=0.5
*---------------------------
*** SUPPORTS
*---------------------------
RSTN PT=675  DX=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=675  DY=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=675  DZ=1  SP=23000          *RHR SUPPLY PENET.
ROTR PT=675  RX=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=675  RY=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=675  RZ=1  SP=340000         *RHR SUPPLY PENET.
RSTN PT=565  DX=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=565  DY=1  SP=16000          *RHR SUPPLY PENET.
RSTN PT=565  DZ=1  SP=23000          *RHR SUPPLY PENET.
ROTR PT=565  RX=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=565  RY=1  SP=300000         *RHR SUPPLY PENET.
ROTR PT=565  RZ=1  SP=340000         *RHR SUPPLY PENET.
*
SNUB PT=12   DZ=-1 SP=1000    *AL=$SNUBBER SS-7A-1$
SNUB PT=12   DX=1  SP=1000    *AL=$SNUBBER SS-7A-2$
SNUB PT=190  DX=-1 SP=1000    *AL=$SNUBBER SS-6-A1$
SNUB PT=190  DZ=1  SP=1000    *AL=$SNUBBER SS-6-A2$
*
VSUP PT=20   DY=1  FO=24.8  SP=2.664  *AL=$VARI. SUPT. HA-1$
*
```

```
CSUP PT=27    DY=1  FO=8.3   KP=0.01   *AL=$CONST. SUPT. H-8-A1$
CSUP PT=42    DY=1  FO=8.3   KP=0.01   *AL=$CONST. SUPT. H-8-A2$
CSUP PT=56    DY=1  FO=18.05 KP=0.01   *AL=$CONST. SUPT. HA3 FOR PUMP$
CSUP PT=69    DY=1  FO=18.0  KP=0.01   *AL=$CONST. SUPT. HA4 FOR PUMP$
CSUP PT=63    DY=1  FO=18.02 KP=0.01   *AL=$CONST. SUPT. HA5 FOR PUMP$
CSUP PT=160   DY=-1 FO=11.8  KP=0.01   *AL=$CONST. SUPT. HA-9 & HA-10$
CSUP PT=705   DY=1  FO=0.960 KP=0.01   *AL=$CONST. SUPT. HA-11 ON 4 INCH BYPASS$
*
VSUP PT=184   DY=1  FO=36.0 SP=3.542   *AL=$VARI. SUPT. HA-2$
VSUP PT=343   DY=1  FO=7.1   SP=3.014  *AL=$VARI. SUPT. HA13$
VSUP PT=313   DY=1  FO=7.1   SP=3.014  *AL=$VARI. SUPT. HA14$
*
VSUP PT=530   DY=1  SP=9.420 FO=26.0   *AL=$HANGER H109 RHR SUPPLY VALVE$
VSUP PT=620   DY=1  SP=7.084 FO=14.9   *AL=$HANGER H104 RHR RETURN VALVE$
VSUP PT=655   DY=1  SP=4.710 FO=22.0   *AL=$HANGER H105 RHR RETURN VALVE$
*
RSTN PT=15    DY=0.7071 DZ=-0.7071  SP=6000    *RECIRC PUMP
RSTN PT=16    DX=-0.7071 DY=0.7071  SP=6000    *RECIRC PUMP
ENDP
```

## Reg1.inp

```
*-----------------------------------------------------------------------
*BEGIN REGION 1 TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY TO TEE
*-----------------------------------------------------------------------
*
OPER CA=1    TE=100   PR=1100
OPER CA=2    TE=100   PR=50
OPER CA=3    TE=549   PR=1010
OPER CA=4    TE=542   PR=1010
OPER CA=5    TE=526   PR=1010
OPER CA=6    TE=542   PR=1010
OPER CA=7    TE=526   PR=1010
OPER CA=8    TE=516   PR=1010
OPER CA=9    TE=526   PR=1010
OPER CA=10   TE=300   PR=1135
OPER CA=11   TE=500   PR=1135
OPER CA=12   TE=300   PR=675
OPER CA=13   TE=549   PR=1010
OPER CA=14   TE=549   PR=1010
OPER CA=15   TE=375   PR=170
OPER CA=16   TE=330   PR=90
OPER CA=17   TE=225   PR=0
OPER CA=18   TE=100   PR=0
OPER CA=19   TE=100   PR=1563
OPER CA=20   TE=225   PR=0
OPER CA=21   TE=225   PR=0
OPER CA=22   TE=130   PR=1010
OPER CA=23   TE=526   PR=1010
OPER CA=24   TE=375   PR=200
OPER CA=25   TE=100   PR=0
*
TRAN  CA=201  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=2262  IP=15   FP=1115  TP=0
TRAN  CA=202  IS=1 FS=1 IT=100 FT=100  TT=1800  FL=2262  IP=1115 FP=65  TP=0
TRAN  CA=203  IS=1 FS=1 IT=100 FT=549  TT=16164 FL=16158 IP=65   FP=1025  TP=0
TRAN   CA=204  IS=1 FS=1 IT=549 FT=542  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN   CA=205  IS=1 FS=1 IT=542 FT=526  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN   CA=206  IS=1 FS=1 IT=526 FT=542  TT=900   FL=32316 IP=1025 FP=1025  TP=0
TRAN   CA=207  IS=1 FS=1 IT=542 FT=526  TT=360   FL=32316 IP=1025 FP=1025  TP=0
TRAN   CA=208  IS=1 FS=1 IT=526 FT=516  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN   CA=209  IS=1 FS=1 IT=516 FT=526  TT=0     FL=32316 IP=1025 FP=1025  TP=0
```

```
TRAN   CA=210  IS=1 FS=1 IT=526 FT=300  TT=220   FL=600   IP=1205 FP=1150   TP=0
TRAN  CA=211  IS=1 FS=1 IT=300 FT=500  TT=1980  FL=600   IP=900  FP=1150  TP=0
TRAN   CA=212  IS=1 FS=1 IT=500 FT=300  TT=180   FL=600   IP=1150  FP=690  TP=0
TRAN  CA=213  IS=1 FS=1 IT=300 FT=549  TT=8964  FL=16158 IP=255  FP=1025  TP=0
TRAN   CA=214  IS=1 FS=1 IT=526 FT=549  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=215  IS=1 FS=1 IT=549 FT=375  TT=6264  FL=16158 IP=1025 FP=185   TP=0
TRAN   CA=216  IS=1 FS=1 IT=375 FT=330  TT=600   FL=16158 IP=185  FP=105   TP=0
TRAN  CA=217  IS=1 FS=1 IT=330 FT=225  TT=3780  FL=16158 IP=105  FP=15    TP=0
TRAN  CA=218  IS=1 FS=1 IT=225 FT=100  TT=4500  FL=22858 IP=15   FP=15    TP=0
TRAN   CA=219  IS=1 FS=1 IT=100 FT=100  TT=0     FL=2262  IP=40   FP=1578  TP=0
TRAN   CA=220
TRAN   CA=221
TRAN   CA=222  IS=1 FS=1 IT=526 FT=130  TT=0     FL=32316 IP=1025  FP=1025 TP=0
TRAN   CA=223  IS=1 FS=1 IT=130 FT=526  TT=0     FL=32316 IP=1025  FP=1025 TP=0
TRAN   CA=224  IS=1 FS=1 IT=526 FT=375  TT=600   FL=32316 IP=1025  FP=215  TP=0
TRAN  CA=225  IS=1 FS=1 IT=375 FT=100  TT=9900  FL=32316 IP=215   FP=15   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140  EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140  EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151  EX=8.5 *Tavg=324.5
PAIR   CA=204 CO=10.5 DI=0.162  EX=8.5 *Tavg=545.5
PAIR   CA=205 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR   CA=206 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR   CA=207 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR   CA=208 CO=10.3 DI=0.161  EX=8.5 *Tavg=521.0
PAIR   CA=209 CO=10.3 DI=0.161  EX=8.5 *Tavg=521.0
PAIR   CA=210 CO=9.9  DI=0.156  EX=8.5 *Tavg=413.0
PAIR  CA=211 CO=9.8  DI=0.155  EX=8.5 *Tavg=400.0
PAIR   CA=212 CO=9.8  DI=0.155  EX=8.5 *Tavg=400.0
PAIR  CA=213 CO=9.9  DI=0.156  EX=8.5 *Tavg=424.5
PAIR   CA=214 CO=10.4 DI=0.162  EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158  EX=8.5 *Tavg=462.0
PAIR   CA=216 CO=9.5  DI=0.152  EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149  EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143  EX=8.5 *Tavg=162.5
PAIR   CA=219 CO=8.3  DI=0.140  EX=8.5 *Tavg=100.0
*PAIR  CA=220 CO=9.0  DI=0.146  EX=8.5 *Tavg=225.0
*PAIR  CA=221 CO=9.0  DI=0.146  EX=8.5 *Tavg=225.0
PAIR   CA=222 CO=9.4  DI=0.151  EX=8.5 *Tavg=328.0
PAIR   CA=223 CO=9.4  DI=0.151  EX=8.5 *Tavg=328.0
PAIR   CA=224 CO=10.0 DI=0.157  EX=8.5 *Tavg=450.5
PAIR  CA=225 CO=9.0  DI=0.147  EX=8.5 *Tavg=237.5
```

**Reg2.inp**

```
*-----------------------------------------------------------------------
*BEGIN REGION 2 TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY TEE TO PUMP
*-----------------------------------------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1010
OPER CA=4   TE=542  PR=1010
OPER CA=5   TE=526  PR=1010
OPER CA=6   TE=542  PR=1010
OPER CA=7   TE=526  PR=1010
OPER CA=8   TE=516  PR=1010
OPER CA=9   TE=526  PR=1010
OPER CA=10  TE=300  PR=1135
OPER CA=11  TE=500  PR=1135
OPER CA=12  TE=300  PR=675
```

```
OPER CA=13  TE=549  PR=1010
OPER CA=14  TE=549  PR=1010
OPER CA=15  TE=375  PR=170
OPER CA=16  TE=330  PR=90
OPER CA=17  TE=225  PR=0
OPER CA=18  TE=100  PR=0
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=0
OPER CA=21  TE=225  PR=0
OPER CA=22  TE=130  PR=1010
OPER CA=23  TE=526  PR=1010
OPER CA=24  TE=375  PR=200
OPER CA=25  TE=100  PR=0
*
TRAN  CA=201  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=2262  IP=15   FP=1115  TP=0
TRAN  CA=202  IS=1 FS=1 IT=100 FT=100  TT=1800  FL=2262  IP=1115 FP=65    TP=0
TRAN  CA=203  IS=1 FS=1 IT=100 FT=549  TT=16164 FL=16158 IP=65   FP=1025  TP=0
TRAN  CA=204  IS=1 FS=1 IT=549 FT=542  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=205  IS=1 FS=1 IT=542 FT=526  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=206  IS=1 FS=1 IT=526 FT=542  TT=900   FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=207  IS=1 FS=1 IT=542 FT=526  TT=360   FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=208  IS=1 FS=1 IT=526 FT=516  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=209  IS=1 FS=1 IT=516 FT=526  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=210  IS=1 FS=1 IT=526 FT=300  TT=220   FL=600   IP=1205 FP=1150  TP=0
TRAN  CA=211  IS=1 FS=1 IT=300 FT=500  TT=1980  FL=600   IP=900  FP=1150  TP=0
TRAN  CA=212  IS=1 FS=1 IT=500 FT=300  TT=180   FL=600   IP=1150 FP=690   TP=0
TRAN  CA=213  IS=1 FS=1 IT=300 FT=549  TT=8964  FL=16158 IP=255  FP=1025  TP=0
TRAN  CA=214  IS=1 FS=1 IT=526 FT=549  TT=0     FL=32316 IP=1025 FP=1025  TP=0
TRAN  CA=215  IS=1 FS=1 IT=549 FT=375  TT=6264  FL=16158 IP=1025 FP=185   TP=0
TRAN  CA=216  IS=1 FS=1 IT=375 FT=330  TT=600   FL=16158 IP=185  FP=105   TP=0
TRAN  CA=217  IS=1 FS=1 IT=330 FT=225  TT=3780  FL=16158 IP=105  FP=15    TP=0
TRAN  CA=218  IS=1 FS=1 IT=225 FT=100  TT=4500  FL=16158 IP=15   FP=15    TP=0
TRAN  CA=219  IS=1 FS=1 IT=100 FT=100  TT=0     FL=2262  IP=40   FP=1578  TP=0
TRAN  CA=220
TRAN  CA=221
TRAN  CA=222  *IS=1 FS=1 IT=526 FT=130  TT=0    FL=32316 IP=1025  FP=1025 TP=0
TRAN  CA=223  IS=1 FS=1 IT=130 FT=526  TT=0     FL=32316 IP=1025  FP=1025 TP=0
TRAN  CA=224  IS=1 FS=1 IT=526 FT=375  TT=600   FL=32316 IP=1025  FP=215  TP=0
TRAN  CA=225  IS=1 FS=1 IT=375 FT=100  TT=9900  FL=32316 IP=215   FP=15   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140  EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140  EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151  EX=8.5 *Tavg=324.5
PAIR  CA=204 CO=10.5 DI=0.162  EX=8.5 *Tavg=545.5
PAIR  CA=205 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR  CA=206 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR  CA=207 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR  CA=208 CO=10.3 DI=0.161  EX=8.5 *Tavg=521.0
PAIR  CA=209 CO=10.3 DI=0.161  EX=8.5 *Tavg=521.0
PAIR  CA=210 CO=9.9  DI=0.156  EX=8.5 *Tavg=413.0
PAIR  CA=211 CO=9.8  DI=0.155  EX=8.5 *Tavg=400.0
PAIR  CA=212 CO=9.8  DI=0.155  EX=8.5 *Tavg=400.0
PAIR  CA=213 CO=9.9  DI=0.156  EX=8.5 *Tavg=424.5
PAIR  CA=214 CO=10.4 DI=0.162  EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158  EX=8.5 *Tavg=462.0
PAIR  CA=216 CO=9.5  DI=0.152  EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149  EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143  EX=8.5 *Tavg=162.5
PAIR  CA=219 CO=8.3  DI=0.140  EX=8.5 *Tavg=100.0
*PAIR CA=220 CO=9.0  DI=0.146  EX=8.5 *Tavg=225.0
```

```
*PAIR  CA=221 CO=9.0  DI=0.146  EX=8.5 *Tavg=225.0
*PAIR  CA=222 CO=9.4  DI=0.151  EX=8.5 *Tavg=328.0
PAIR   CA=223 CO=9.4  DI=0.151  EX=8.5 *Tavg=328.0
PAIR   CA=224 CO=10.0 DI=0.157  EX=8.5 *Tavg=450.5
PAIR   CA=225 CO=9.0  DI=0.147  EX=8.5 *Tavg=237.5
```

**Reg3.inp**

```
*----------------------------------------
*BEGIN REGION 3 TRANSIENT CARDS & GEOMETRY FROM PUMP DISCHARGE TO HEADER
*----------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1035
OPER CA=4   TE=542  PR=1035
OPER CA=5   TE=526  PR=1035
OPER CA=6   TE=542  PR=1035
OPER CA=7   TE=526  PR=1035
OPER CA=8   TE=516  PR=1035
OPER CA=9   TE=526  PR=1035
OPER CA=10  TE=300  PR=1160
OPER CA=11  TE=500  PR=1160
OPER CA=12  TE=300  PR=700
OPER CA=13  TE=549  PR=1035
OPER CA=14  TE=549  PR=1035
OPER CA=15  TE=375  PR=195
OPER CA=16  TE=330  PR=115
OPER CA=17  TE=225  PR=25
OPER CA=18  TE=100  PR=25
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=225  PR=25
OPER CA=22  TE=130  PR=1035
OPER CA=23  TE=526  PR=1035
OPER CA=24  TE=375  PR=225
OPER CA=25  TE=100  PR=25
*
TRAN  CA=201  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=2262  IP=15   FP=1115  TP=0
TRAN  CA=202  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=2262  IP=1115 FP=65    TP=0
TRAN  CA=203  IS=1 FS=1 IT=100 FT=549  TT=16164 FL=16158 IP=65   FP=1050  TP=0
TRAN  CA=204  IS=1 FS=1 IT=549 FT=542  TT=0     FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=205  IS=1 FS=1 IT=542 FT=526  TT=0     FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=206  IS=1 FS=1 IT=526 FT=542  TT=900   FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=207  IS=1 FS=1 IT=542 FT=526  TT=360   FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=208  IS=1 FS=1 IT=526 FT=516  TT=0     FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=209  IS=1 FS=1 IT=516 FT=526  TT=0     FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=210  IS=1 FS=1 IT=526 FT=300  TT=220   FL=600   IP=1230 FP=1175  TP=0
TRAN  CA=211  IS=1 FS=1 IT=300 FT=500  TT=1980  FL=600   IP=925  FP=1175  TP=0
TRAN  CA=212  IS=1 FS=1 IT=500 FT=300  TT=180   FL=600   IP=1175 FP=715   TP=0
TRAN  CA=213  IS=1 FS=1 IT=300 FT=549  TT=8964  FL=16158 IP=280  FP=1050  TP=0
TRAN  CA=214  IS=1 FS=1 IT=526 FT=549  TT=0     FL=32316 IP=1050 FP=1050  TP=0
TRAN  CA=215  IS=1 FS=1 IT=549 FT=375  TT=6264  FL=16158 IP=1050 FP=210   TP=0
TRAN  CA=216  IS=1 FS=1 IT=375 FT=330  TT=600   FL=16158 IP=210  FP=130   TP=0
TRAN  CA=217  IS=1 FS=1 IT=330 FT=225  TT=3780  FL=16158 IP=130  FP=40    TP=0
TRAN  CA=218  IS=1 FS=1 IT=225 FT=100  TT=4500  FL=16158 IP=40   FP=40    TP=0
TRAN  CA=219  IS=1 FS=1 IT=100 FT=100  TT=0     FL=2262  IP=40   FP=1578  TP=0
TRAN  CA=220
TRAN  CA=221
TRAN  CA=222 *IS=1 FS=1 IT=526 FT=130  TT=0     FL=32316 IP=1050 FP=1050 TP=0
TRAN  CA=223  IS=1 FS=1 IT=130 FT=526  TT=0     FL=32316 IP=1050 FP=1050 TP=0
```

```
TRAN   CA=224  IS=1 FS=1 IT=526 FT=375  TT=600   FL=32316 IP=1050  FP=240  TP=0
TRAN  CA=225  IS=1 FS=1 IT=375 FT=100  TT=9900  FL=32316 IP=240   FP=40   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140 EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151 EX=8.5 *Tavg=324.5
PAIR   CA=204 CO=10.5 DI=0.162 EX=8.5 *Tavg=545.5
PAIR   CA=205 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=206 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=207 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=208 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=209 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=210 CO=9.9  DI=0.156 EX=8.5 *Tavg=413.0
PAIR  CA=211 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR   CA=212 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR  CA=213 CO=9.9  DI=0.156 EX=8.5 *Tavg=424.5
PAIR   CA=214 CO=10.4 DI=0.162 EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158 EX=8.5 *Tavg=462.0
PAIR   CA=216 CO=9.5  DI=0.152 EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149 EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143 EX=8.5 *Tavg=162.5
PAIR   CA=219 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
*PAIR  CA=220 CO=9.0  DI=0.146 EX=8.5 *Tavg=225.0
*PAIR  CA=221 CO=9.0  DI=0.146 EX=8.5 *Tavg=225.0
*PAIR   CA=222 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR   CA=223 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR   CA=224 CO=10.0 DI=0.157 EX=8.5 *Tavg=450.5
PAIR  CA=225 CO=9.0  DI=0.147 EX=8.5 *Tavg=237.5
```

**Reg3B.inp**

```
*-----------------------------------------
*BEGIN REGION 3B TRANSIENT CARDS & GEOMETRY AFFECTED BY RHR INITIATION
*-----------------------------------------
*
OPER CA=20   TE=225  PR=25
OPER CA=21   TE=180  PR=25
*
TRAN CA=220 IS=1 FS=1 IT=180  FT=225 TT=60 FL=22858 IP=40 FP=40
TRAN CA=221 IS=1 FS=1 IT=225 FT=180  TT=60 FL=22858 IP=40 FP=40
PAIR  CA=220 CO=8.8 DI=0.145 EX=8.5 *Tavg=202.5
PAIR  CA=221 CO=8.8 DI=0.145 EX=8.5 *Tavg=202.5
```

**Reg4.inp**

```
*-----------------------------------------
*BEGIN REGION 4 TRANSIENT CARDS & GEOMETRY HEADER TO NOZZLE NODE 366
*-----------------------------------------
*
OPER  CA=1    TE=100  PR=1100
OPER  CA=2    TE=100  PR=50
OPER  CA=3    TE=549  PR=1035
OPER  CA=4    TE=542  PR=1035
OPER  CA=5    TE=526  PR=1035
OPER  CA=6    TE=542  PR=1035
OPER  CA=7    TE=526  PR=1035
OPER  CA=8    TE=516  PR=1035
OPER  CA=9    TE=526  PR=1035
OPER  CA=10   TE=300  PR=1160
OPER  CA=11   TE=500  PR=1160
OPER  CA=12   TE=300  PR=700
OPER  CA=13   TE=549  PR=1035
```

```
OPER CA=14  TE=549  PR=1035
OPER CA=15  TE=375  PR=195
OPER CA=16  TE=330  PR=115
OPER CA=17  TE=225  PR=25
OPER CA=18  TE=100  PR=25
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=180  PR=25
OPER CA=22  TE=130  PR=1035
OPER CA=23  TE=526  PR=1035
OPER CA=24  TE=375  PR=225
OPER CA=25  TE=100  PR=25
*
TRAN  CA=201 IS=1 FS=1 IT=70  FT=100 TT=1800  FL=905   IP=15   FP=1115 TP=0
TRAN  CA=202 IS=1 FS=1 IT=100 FT=100 TT=1800  FL=905   IP=1115 FP=65   TP=0
TRAN  CA=203 IS=1 FS=1 IT=100 FT=549 TT=16164 FL=6463  IP=65   FP=1050 TP=0
TRAN  CA=204 IS=1 FS=1 IT=549 FT=542 TT=0     FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=205 IS=1 FS=1 IT=542 FT=526 TT=0     FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=206 IS=1 FS=1 IT=526 FT=542 TT=900   FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=207 IS=1 FS=1 IT=542 FT=526 TT=360   FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=208 IS=1 FS=1 IT=526 FT=516 TT=0     FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=209 IS=1 FS=1 IT=516 FT=526 TT=0     FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=210 IS=1 FS=1 IT=526 FT=300 TT=220   FL=400   IP=1230 FP=1175 TP=0
TRAN  CA=211 IS=1 FS=1 IT=300 FT=500 TT=1980  FL=400   IP=925  FP=1175 TP=0
TRAN  CA=212 IS=1 FS=1 IT=500 FT=300 TT=180   FL=400   IP=1175 FP=715  TP=0
TRAN  CA=213 IS=1 FS=1 IT=300 FT=549 TT=8964  FL=6463  IP=280  FP=1050 TP=0
TRAN  CA=214 IS=1 FS=1 IT=526 FT=549 TT=0     FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=215 IS=1 FS=1 IT=549 FT=375 TT=6264  FL=6463  IP=1050 FP=210  TP=0
TRAN  CA=216 IS=1 FS=1 IT=375 FT=330 TT=600   FL=6463  IP=210  FP=130  TP=0
TRAN  CA=217 IS=1 FS=1 IT=330 FT=225 TT=3780  FL=6463  IP=130  FP=40   TP=0
TRAN  CA=218 IS=1 FS=1 IT=225 FT=100 TT=4500  FL=9143  IP=40   FP=40   TP=0
TRAN  CA=219 IS=1 FS=1 IT=100 FT=100 TT=0     FL=905   IP=40   FP=1578 TP=0
TRAN  CA=220 IS=1 FS=1 IT=180 FT=225 TT=60    FL=9143  IP=40   FP=40   TP=0
TRAN  CA=221 IS=1 FS=1 IT=225 FT=180 TT=60    FL=9143  IP=40   FP=40   TP=0
TRAN  *CA=222 IS=1 FS=1 IT=526 FT=130 TT=0    FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=223 IS=1 FS=1 IT=130 FT=526 TT=0     FL=12926 IP=1050 FP=1050 TP=0
TRAN  CA=224 IS=1 FS=1 IT=526 FT=375 TT=600   FL=12926 IP=1050 FP=240  TP=0
TRAN  CA=225 IS=1 FS=1 IT=375 FT=100 TT=9900  FL=12926 IP=240  FP=40   TP=0
*
PAIR CA=201 CO=8.3  DI=0.140 EX=8.5 *Tavg=85.0
PAIR CA=202 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR CA=203 CO=9.4  DI=0.151 EX=8.5 *Tavg=324.5
PAIR CA=204 CO=10.5 DI=0.162 EX=8.5 *Tavg=545.5
PAIR CA=205 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR CA=206 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR CA=207 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR CA=208 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR CA=209 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR CA=210 CO=9.9  DI=0.156 EX=8.5 *Tavg=413.0
PAIR CA=211 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR CA=212 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR CA=213 CO=9.9  DI=0.156 EX=8.5 *Tavg=424.5
PAIR CA=214 CO=10.4 DI=0.162 EX=8.5 *Tavg=537.5
PAIR CA=215 CO=10.0 DI=0.158 EX=8.5 *Tavg=462.0
PAIR CA=216 CO=9.5  DI=0.152 EX=8.5 *Tavg=352.5
PAIR CA=217 CO=9.2  DI=0.149 EX=8.5 *Tavg=277.5
PAIR CA=218 CO=8.7  DI=0.143 EX=8.5 *Tavg=162.5
PAIR CA=219 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR CA=220 CO=8.8  DI=0.145 EX=8.5 *Tavg=202.5
PAIR CA=221 CO=8.8  DI=0.145 EX=8.5 *Tavg=202.5
```

```
*PAIR  CA=222 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR  CA=223 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR  CA=224 CO=10.0 DI=0.157 EX=8.5 *Tavg=450.5
PAIR CA=225 CO=9.0  DI=0.147 EX=8.5 *Tavg=237.5
```

**Reg5.inp**

```
*----------------------------------------
*BEGIN REGION 5 TRANSIENT CARDS & GEOMETRY RISER TO NOZZLE NODE 336
*----------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1035
OPER CA=4   TE=542  PR=1035
OPER CA=5   TE=526  PR=1035
OPER CA=6   TE=542  PR=1035
OPER CA=7   TE=526  PR=1035
OPER CA=8   TE=516  PR=1035
OPER CA=9   TE=526  PR=1035
OPER CA=10  TE=300  PR=1160
OPER CA=11  TE=500  PR=1160
OPER CA=12  TE=300  PR=700
OPER CA=13  TE=549  PR=1035
OPER CA=14  TE=549  PR=1035
OPER CA=15  TE=375  PR=195
OPER CA=16  TE=330  PR=115
OPER CA=17  TE=225  PR=25
OPER CA=18  TE=100  PR=25
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=180  PR=25
OPER CA=22  TE=130  PR=1035
OPER CA=23  TE=526  PR=1035
OPER CA=24  TE=375  PR=225
OPER CA=25  TE=100  PR=25
*
TRAN  CA=201 IS=1 FS=1 IT=70  FT=100  TT=1800  FL=452   IP=15   FP=1115 TP=0
TRAN  CA=202 IS=1 FS=1 IT=100 FT=100  TT=1800  FL=452   IP=1115 FP=65   TP=0
TRAN  CA=203 IS=1 FS=1 IT=100 FT=549  TT=16164 FL=3232  IP=65   FP=1050 TP=0
TRAN   CA=204 IS=1 FS=1 IT=549 FT=542  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=205 IS=1 FS=1 IT=542 FT=526  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=206 IS=1 FS=1 IT=526 FT=542  TT=900   FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=207 IS=1 FS=1 IT=542 FT=526  TT=360   FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=208 IS=1 FS=1 IT=526 FT=516  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=209 IS=1 FS=1 IT=516 FT=526  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=210 IS=1 FS=1 IT=526 FT=300  TT=220   FL=200   IP=1230 FP=1175 TP=0
TRAN  CA=211 IS=1 FS=1 IT=300 FT=500  TT=1980  FL=200   IP=925  FP=1175 TP=0
TRAN   CA=212 IS=1 FS=1 IT=500 FT=300  TT=180   FL=200   IP=1175 FP=715  TP=0
TRAN  CA=213 IS=1 FS=1 IT=300 FT=549  TT=8964  FL=3232  IP=280  FP=1050 TP=0
TRAN   CA=214 IS=1 FS=1 IT=526 FT=549  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN  CA=215 IS=1 FS=1 IT=549 FT=375  TT=6264  FL=3232  IP=1050 FP=210  TP=0
TRAN   CA=216 IS=1 FS=1 IT=375 FT=330  TT=600   FL=3232  IP=210  FP=130  TP=0
TRAN  CA=217 IS=1 FS=1 IT=330 FT=225  TT=3780  FL=3232  IP=130  FP=40   TP=0
TRAN  CA=218 IS=1 FS=1 IT=225 FT=100  TT=4500  FL=4571  IP=40   FP=40   TP=0
TRAN   CA=219 IS=1 FS=1 IT=100 FT=100  TT=0     FL=452   IP=40   FP=1578 TP=0
TRAN   CA=220 IS=1 FS=1 IT=180 FT=225  TT=60    FL=4572  IP=40   FP=40   TP=0
TRAN   CA=221 IS=1 FS=1 IT=225 FT=180  TT=60    FL=4572  IP=40   FP=40   TP=0
TRAN   *CA=222 IS=1 FS=1 IT=526 FT=130  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=223 IS=1 FS=1 IT=130 FT=526  TT=0     FL=6463  IP=1050 FP=1050 TP=0
TRAN   CA=224 IS=1 FS=1 IT=526 FT=375  TT=600   FL=6463  IP=1050 FP=240  TP=0
```

```
TRAN   CA=225 IS=1 FS=1 IT=375 FT=100  TT=9900  FL=6463  IP=240  FP=40   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140 EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151 EX=8.5 *Tavg=324.5
PAIR   CA=204 CO=10.5 DI=0.162 EX=8.5 *Tavg=545.5
PAIR   CA=205 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=206 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=207 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=208 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=209 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=210 CO=9.9  DI=0.156 EX=8.5 *Tavg=413.0
PAIR   CA=211 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR   CA=212 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR  CA=213 CO=9.9  DI=0.156 EX=8.5 *Tavg=424.5
PAIR   CA=214 CO=10.4 DI=0.162 EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158 EX=8.5 *Tavg=462.0
PAIR   CA=216 CO=9.5  DI=0.152 EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149 EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143 EX=8.5 *Tavg=162.5
PAIR   CA=219 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR   CA=220 CO=8.8  DI=0.145 EX=8.5 *Tavg=202.5
PAIR   CA=221 CO=8.8  DI=0.145 EX=8.5 *Tavg=202.5
*PAIR   CA=222 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR   CA=223 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR   CA=224 CO=10.0 DI=0.157 EX=8.5 *Tavg=450.5
PAIR  CA=225 CO=9.0  DI=0.147 EX=8.5 *Tavg=237.5
```

**Reg6.inp**

```
*----------------------------------------
*BEGIN REGION 6 TRANSIENT CARDS & GEOMETRY TO NOZZLE NODE 336
*----------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1035
OPER CA=4   TE=542  PR=1035
OPER CA=5   TE=526  PR=1035
OPER CA=6   TE=542  PR=1035
OPER CA=7   TE=526  PR=1035
OPER CA=8   TE=516  PR=1035
OPER CA=9   TE=526  PR=1035
OPER CA=10  TE=300  PR=1160
OPER CA=11  TE=500  PR=1160
OPER CA=12  TE=300  PR=700
OPER CA=13  TE=549  PR=1035
OPER CA=14  TE=549  PR=1035
OPER CA=15  TE=375  PR=195
OPER CA=16  TE=330  PR=115
OPER CA=17  TE=225  PR=25
OPER CA=18  TE=100  PR=25
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=180  PR=25
OPER CA=22  TE=130  PR=1035
OPER CA=23  TE=526  PR=1035
OPER CA=24  TE=375  PR=225
OPER CA=25  TE=100  PR=25
*
TRAN CA=201  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=452  IP=15   FP=1115 TP=0
```

```
TRAN CA=202  IS=1 FS=1 IT=100 FT=100  TT=1800  FL=452  IP=1115 FP=65   TP=0
TRAN CA=203  IS=1 FS=1 IT=100 FT=549  TT=16164 FL=3232 IP=65   FP=1050 TP=0
TRAN  CA=204  IS=1 FS=1 IT=549 FT=542  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=205  IS=1 FS=1 IT=542 FT=526  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=206  IS=1 FS=1 IT=526 FT=542  TT=900   FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=207  IS=1 FS=1 IT=542 FT=526  TT=360   FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=208  IS=1 FS=1 IT=526 FT=516  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=209  IS=1 FS=1 IT=516 FT=526  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=210  IS=1 FS=1 IT=526 FT=300  TT=220   FL=200  IP=1230 FP=1175 TP=0
TRAN CA=211  IS=1 FS=1 IT=300 FT=500  TT=1980  FL=200  IP=925  FP=1175 TP=0
TRAN  CA=212  IS=1 FS=1 IT=500 FT=300  TT=180   FL=200  IP=1175 FP=715  TP=0
TRAN CA=213  IS=1 FS=1 IT=300 FT=549  TT=8964  FL=3232 IP=280  FP=1050 TP=0
TRAN  CA=214  IS=1 FS=1 IT=526 FT=549  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN CA=215  IS=1 FS=1 IT=549 FT=375  TT=6264  FL=3232 IP=1050 FP=210  TP=0
TRAN  CA=216  IS=1 FS=1 IT=375 FT=330  TT=600   FL=3232 IP=210  FP=130  TP=0
TRAN CA=217  IS=1 FS=1 IT=330 FT=225  TT=3780  FL=3232 IP=130  FP=40   TP=0
TRAN CA=218  IS=1 FS=1 IT=225 FT=100  TT=4500  FL=4572 IP=40   FP=40   TP=0
TRAN  CA=219  IS=1 FS=1 IT=100 FT=100  TT=0     FL=452  IP=40   FP=1578 TP=0
TRAN  CA=220  IS=1 FS=1 IT=180 FT=225  TT=60    FL=4572 IP=40   FP=40   TP=0
TRAN  CA=221  IS=1 FS=1 IT=225 FT=180  TT=60    FL=4572 IP=40   FP=40   TP=0
TRAN  CA=222  IS=1 FS=1 IT=526 FT=130  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=223  IS=1 FS=1 IT=130 FT=526  TT=0     FL=6463 IP=1050 FP=1050 TP=0
TRAN  CA=224  IS=1 FS=1 IT=526 FT=375  TT=600   FL=6463 IP=1050 FP=240  TP=0
TRAN CA=225  IS=1 FS=1 IT=375 FT=100  TT=9900  FL=6463 IP=240  FP=40   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140 EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151 EX=8.5 *Tavg=324.5
PAIR   CA=204 CO=10.5 DI=0.162 EX=8.5 *Tavg=545.5
PAIR   CA=205 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=206 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=207 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=208 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=209 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=210 CO=9.9  DI=0.156 EX=8.5 *Tavg=413.0
PAIR  CA=211 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR   CA=212 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR  CA=213 CO=9.9  DI=0.156 EX=8.5 *Tavg=424.5
PAIR   CA=214 CO=10.4 DI=0.162 EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158 EX=8.5 *Tavg=462.0
PAIR   CA=216 CO=9.5  DI=0.152 EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149 EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143 EX=8.5 *Tavg=162.5
PAIR   CA=219 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR   CA=220 CO=8.8  DI=0.145 EX=8.5 *Tavg=202.5
PAIR   CA=221 CO=8.8  DI=0.145 EX=8.5 *Tavg=202.5
PAIR   CA=222 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR   CA=223 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR   CA=224 CO=10.0 DI=0.157 EX=8.5 *Tavg=450.5
PAIR  CA=225 CO=9.0  DI=0.147 EX=8.5 *Tavg=237.5
```

**Reg7A.inp**

```
*----------------------------------------
*BEGIN REGION 7A TRANSIENT CARDS & GEOMETRY TO RHR SUPPLY VALVE NODE 550
*----------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1010
OPER CA=4   TE=542  PR=1010
```

```
OPER CA=5   TE=526  PR=1010
OPER CA=6   TE=542  PR=1010
OPER CA=7   TE=526  PR=1010
OPER CA=8   TE=516  PR=1010
OPER CA=9   TE=526  PR=1010
OPER CA=10  TE=300  PR=1135
OPER CA=11  TE=500  PR=1135
OPER CA=12  TE=300  PR=675
OPER CA=13  TE=549  PR=1010
OPER CA=14  TE=549  PR=1010
OPER CA=15  TE=375  PR=170
OPER CA=16  TE=330  PR=90
OPER CA=17  TE=225  PR=0
OPER CA=18  TE=100  PR=0
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=0
OPER CA=21  TE=225  PR=0
OPER CA=22  TE=130  PR=1010
OPER CA=23  TE=526  PR=1010
OPER CA=24  TE=375  PR=200
OPER CA=25  TE=100  PR=0
*
TRAN CA=201  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=143  IP=15   FP=1115 TP=0
TRAN CA=202  IS=1 FS=1 IT=100 FT=100  TT=1800  FL=143  IP=1115 FP=65   TP=0
TRAN CA=203  IS=1 FS=1 IT=100 FT=549  TT=16164 FL=300  IP=65   FP=1025 TP=0
TRAN  CA=204  IS=1 FS=1 IT=549 FT=542  TT=0     FL=364  IP=1025 FP=1025 TP=0
TRAN  CA=205  IS=1 FS=1 IT=542 FT=526  TT=0     FL=358  IP=1025 FP=1025 TP=0
TRAN  CA=206  IS=1 FS=1 IT=526 FT=542  TT=900   FL=358  IP=1025 FP=1025 TP=0
TRAN  CA=207  IS=1 FS=1 IT=542 FT=526  TT=360   FL=358  IP=1025 FP=1025 TP=0
TRAN  CA=208  IS=1 FS=1 IT=526 FT=516  TT=0     FL=351  IP=1025 FP=1025 TP=0
TRAN  CA=209  IS=1 FS=1 IT=516 FT=526  TT=0     FL=351  IP=1025 FP=1025 TP=0
TRAN  CA=210  IS=1 FS=1 IT=526 FT=300  TT=220   FL=306  IP=1205 FP=1150 TP=0
TRAN CA=211  IS=1 FS=1 IT=300 FT=500  TT=1980  FL=301  IP=900  FP=1150 TP=0
TRAN  CA=212  IS=1 FS=1 IT=500 FT=300  TT=180   FL=301  IP=1150 FP=690  TP=0
TRAN CA=213  IS=1 FS=1 IT=300 FT=549  TT=8964  FL=310  IP=255  FP=1025 TP=0
TRAN  CA=214  IS=1 FS=1 IT=526 FT=549  TT=0     FL=360  IP=1025 FP=1025 TP=0
TRAN CA=215  IS=1 FS=1 IT=549 FT=375  TT=6264  FL=320  IP=1050 FP=185  TP=0
TRAN  CA=216  IS=1 FS=1 IT=375 FT=330  TT=600   FL=282  IP=185  FP=105  TP=0
TRAN CA=217  IS=1 FS=1 IT=330 FT=225  TT=3780  FL=260  IP=105  FP=15   TP=0
TRAN CA=218  IS=1 FS=1 IT=225 FT=100  TT=4500  FL=6700 IP=15   FP=15   TP=0
TRAN  CA=219  IS=1 FS=1 IT=100 FT=100  TT=0     FL=158  IP=40   FP=1578 TP=0
TRAN  CA=220 *IS=1 FS=1 IT=225 FT=225  TT=60    FL=6700 IP=15   FP=15   TP=0
TRAN  CA=221 *IS=1 FS=1 IT=225 FT=225  TT=60    FL=6700 IP=15   FP=15   TP=0
TRAN  CA=222 *IS=1 FS=1 IT=526 FT=130  TT=0     FL=272  IP=1025 FP=1025 TP=0
TRAN  CA=223  IS=1 FS=1 IT=130 FT=526  TT=0     FL=272  IP=1025 FP=1025 TP=0
TRAN  CA=224  IS=1 FS=1 IT=526 FT=375  TT=600   FL=320  IP=1025 FP=215  TP=0
TRAN CA=225  IS=1 FS=1 IT=375 FT=100  TT=9900  FL=234  IP=215  FP=15   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140 EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151 EX=8.5 *Tavg=324.5
PAIR   CA=204 CO=10.5 DI=0.162 EX=8.5 *Tavg=545.5
PAIR   CA=205 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=206 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=207 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR   CA=208 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=209 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR   CA=210 CO=9.9  DI=0.156 EX=8.5 *Tavg=413.0
PAIR  CA=211 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR   CA=212 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
```

```
PAIR  CA=213 CO=9.9  DI=0.156 EX=8.5 *Tavg=424.5
PAIR  CA=214 CO=10.4 DI=0.162 EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158 EX=8.5 *Tavg=462.0
PAIR  CA=216 CO=9.5  DI=0.152 EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149 EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143 EX=8.5 *Tavg=162.5
PAIR  CA=219 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
*PAIR  CA=220 CO=9.0  DI=0.146 EX=8.5 *Tavg=225.0
*PAIR  CA=221 CO=9.0  DI=0.146 EX=8.5 *Tavg=225.0
*PAIR  CA=222 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR  CA=223 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR  CA=224 CO=10.0 DI=0.157 EX=8.5 *Tavg=450.5
PAIR  CA=225 CO=9.0  DI=0.147 EX=8.5 *Tavg=237.5
```

**Reg7B.inp**

```
*-----------------------------------------
*BEGIN REGION 7B TRANSIENT CARDS & GEOMETRY FROM RHR SUPPLY VALVE TO PENET. NODE 565
*-----------------------------------------
*
OPER CA=1   TE=100  PR=120
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=150  PR=120
OPER CA=4   TE=150  PR=120
OPER CA=5   TE=150  PR=120
OPER CA=6   TE=150  PR=120
OPER CA=7   TE=150  PR=120
OPER CA=8   TE=150  PR=120
OPER CA=9   TE=150  PR=120
OPER CA=10  TE=150  PR=120
OPER CA=11  TE=150  PR=120
OPER CA=12  TE=150  PR=120
OPER CA=13  TE=150  PR=120
OPER CA=14  TE=150  PR=120
OPER CA=15  TE=150  PR=120
OPER CA=16  TE=150  PR=120
OPER CA=17  TE=150  PR=100
OPER CA=18  TE=100  PR=0
OPER CA=19  TE=100  PR=450
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=150  PR=25
OPER CA=22  TE=150  PR=100
OPER CA=23  TE=150  PR=1035
OPER CA=24  TE=150  PR=100
OPER CA=25  TE=150  PR=100
*
TRAN CA=201 IS=1 FS=1 IT=70  FT=100 TT=1800  FL=143 IP=15  FP=135 TP=0
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=1800  FL=143 IP=135 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=300 IP=65  FP=135  TP=0
TRAN  CA=204
TRAN  CA=205
TRAN  CA=206
TRAN  CA=207
TRAN  CA=208
TRAN  CA=209
TRAN  CA=210
TRAN CA=211
TRAN  CA=212
TRAN CA=213
TRAN  CA=214
TRAN CA=215
```

```
TRAN  CA=216
TRAN CA=217
TRAN CA=218 IS=1 FS=1 IT=225 FT=100  TT=4500 FL=6700 IP=15  FP=15 TP=0
TRAN  CA=219  IS=1 FS=1 IT=100 FT=100  TT=0  FL=143  IP=15  FP=465 TP=0
TRAN  CA=220  IS=1 FS=1 IT=150 FT=225  TT=60 FL=6700 IP=40  FP=40 TP=0
TRAN  CA=221 *IS=1 FS=1 IT=150 FT=150   TT=0 FL=6700 IP=40  FP=40 TP=0
TRAN  CA=222
TRAN  CA=223
TRAN  CA=224
TRAN CA=225
*
PAIR  CA=201 CO=27.6 DI=0.529 EX=6.4 *Tavg=85.0
PAIR  CA=202 CO=27.6 DI=0.512 EX=6.4 *Tavg=100.0
PAIR  CA=203 CO=27.6 DI=0.506 EX=6.4 *Tavg=125.0
*PAIR  CA=204 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=205 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=206 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=207 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=208 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=209 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=210 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=211 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=212 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=213 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=214 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=215 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=216 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=217 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
PAIR  CA=218 CO=27.6 DI=0.496 EX=6.4 *Tavg=162.5
PAIR   CA=219 CO=27.6 DI=0.512 EX=6.4 *Tavg=100.0
PAIR   CA=220 CO=27.6 DI=0.489 EX=6.4 *Tavg=187.5
PAIR   CA=221 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=222 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=223 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=224 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=225 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
```

**Reg8.inp**

```
*----------------------------------------
*BEGIN REGION 8 TRANSIENT CARDS & GEOMETRY FOR 4 INCH BYPASS
*----------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1035
OPER CA=4   TE=542  PR=1035
OPER CA=5   TE=526  PR=1035
OPER CA=6   TE=542  PR=1035
OPER CA=7   TE=526  PR=1035
OPER CA=8   TE=516  PR=1035
OPER CA=9   TE=526  PR=1035
OPER CA=10  TE=300  PR=1160
OPER CA=11  TE=500  PR=1160
OPER CA=12  TE=300  PR=700
OPER CA=13  TE=549  PR=1035
OPER CA=14  TE=549  PR=1035
OPER CA=15  TE=375  PR=195
OPER CA=16  TE=330  PR=115
OPER CA=17  TE=225  PR=25
OPER CA=18  TE=100  PR=25
```

```
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=225  PR=25
OPER CA=22  TE=130  PR=1035
OPER CA=23  TE=526  PR=1035
OPER CA=24  TE=375  PR=225
OPER CA=25  TE=100  PR=25
*
TRAN CA=201 IS=1 FS=1 IT=70  FT=100  TT=1800  FL=23.5  IP=15   FP=1115 TP=0
TRAN CA=202 IS=1 FS=1 IT=100 FT=100  TT=1800  FL=23.5  IP=1115 FP=65   TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=549  TT=16164 FL=168   IP=65   FP=1050 TP=0
TRAN  CA=204 IS=1 FS=1 IT=549 FT=542  TT=0     FL=335   IP=1050 FP=1050 TP=0
TRAN  CA=205 IS=1 FS=1 IT=542 FT=526  TT=0     FL=335   IP=1050 FP=1050 TP=0
TRAN  CA=206 IS=1 FS=1 IT=526 FT=542  TT=900   FL=335   IP=1050 FP=1050 TP=0
TRAN  CA=207 IS=1 FS=1 IT=542 FT=526  TT=360   FL=335   IP=1050 FP=1050 TP=0
TRAN  CA=208 IS=1 FS=1 IT=526 FT=516  TT=0     FL=335   IP=1050 FP=1050 TP=0
TRAN  CA=209 IS=1 FS=1 IT=516 FT=526  TT=0     FL=335   IP=1050 FP=1050 TP=0
TRAN  CA=210 IS=1 FS=1 IT=526 FT=300  TT=220   FL=6     IP=1230 FP=1175 TP=0
TRAN CA=211 IS=1 FS=1 IT=300 FT=500  TT=1980  FL=6     IP=925  FP=1175 TP=0
TRAN  CA=212 IS=1 FS=1 IT=500 FT=300  TT=180   FL=6     IP=1175 FP=715  TP=0
TRAN CA=213 IS=1 FS=1 IT=300 FT=549  TT=8964  FL=167.5 IP=280  FP=1050 TP=0
TRAN  CA=214 IS=1 FS=1 IT=526 FT=549  TT=0     FL=335   IP=1050 FP=1050 TP=0
TRAN CA=215 IS=1 FS=1 IT=549 FT=375  TT=6264  FL=167.5 IP=1050 FP=210  TP=0
TRAN  CA=216 IS=1 FS=1 IT=375 FT=330  TT=600   FL=167.5 IP=210  FP=130  TP=0
TRAN CA=217 IS=1 FS=1 IT=330 FT=225  TT=3780  FL=167.5 IP=130  FP=40   TP=0
TRAN CA=218 IS=1 FS=1 IT=225 FT=100  TT=4500  FL=167.5 IP=40   FP=40   TP=0
TRAN  CA=219 IS=1 FS=1 IT=100 FT=100  TT=0     FL=23.5  IP=40   FP=1578 TP=0
TRAN  CA=220
TRAN  CA=221
TRAN  CA=222 *IS=1 FS=1 IT=526 FT=130  TT=0     FL=335 IP=1050  FP=1050 TP=0
TRAN  CA=223 IS=1 FS=1 IT=130 FT=526  TT=0     FL=335 IP=1050  FP=1050 TP=0
TRAN  CA=224 IS=1 FS=1 IT=526 FT=375  TT=600   FL=335 IP=1050  FP=240  TP=0
TRAN CA=225 IS=1 FS=1 IT=375 FT=100  TT=9900  FL=335 IP=240   FP=40   TP=0
*
PAIR CA=201 CO=8.3  DI=0.140 EX=8.5 *Tavg=85.0
PAIR CA=202 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
PAIR CA=203 CO=9.4  DI=0.151 EX=8.5 *Tavg=324.5
PAIR  CA=204 CO=10.5 DI=0.162 EX=8.5 *Tavg=545.5
PAIR  CA=205 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR  CA=206 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR  CA=207 CO=10.4 DI=0.161 EX=8.5 *Tavg=534.0
PAIR  CA=208 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR  CA=209 CO=10.3 DI=0.161 EX=8.5 *Tavg=521.0
PAIR  CA=210 CO=9.9  DI=0.156 EX=8.5 *Tavg=413.0
PAIR CA=211 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR  CA=212 CO=9.8  DI=0.155 EX=8.5 *Tavg=400.0
PAIR CA=213 CO=9.9  DI=0.156 EX=8.5 *Tavg=424.5
PAIR  CA=214 CO=10.4 DI=0.162 EX=8.5 *Tavg=537.5
PAIR CA=215 CO=10.0 DI=0.158 EX=8.5 *Tavg=462.0
PAIR  CA=216 CO=9.5  DI=0.152 EX=8.5 *Tavg=352.5
PAIR CA=217 CO=9.2  DI=0.149 EX=8.5 *Tavg=277.5
PAIR CA=218 CO=8.7  DI=0.143 EX=8.5 *Tavg=162.5
PAIR  CA=219 CO=8.3  DI=0.140 EX=8.5 *Tavg=100.0
*PAIR CA=220 CO=9.0  DI=0.146 EX=8.5 *Tavg=225.0
*PAIR CA=221 CO=9.0  DI=0.146 EX=8.5 *Tavg=225.0
*PAIR  CA=222 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR  CA=223 CO=9.4  DI=0.151 EX=8.5 *Tavg=328.0
PAIR  CA=224 CO=10.0 DI=0.157 EX=8.5 *Tavg=450.5
PAIR CA=225 CO=9.0  DI=0.147 EX=8.5 *Tavg=237.5
```

**Reg9A.inp**

```
*----------------------------------------
*BEGIN REGION 9A TRANSIENT CARDS & GEOMETRY FOR RHR RETURN FROM TEE TO VALVE NODE 660
*----------------------------------------
*
OPER CA=1   TE=100  PR=1100
OPER CA=2   TE=100  PR=50
OPER CA=3   TE=549  PR=1035
OPER CA=4   TE=542  PR=1035
OPER CA=5   TE=526  PR=1035
OPER CA=6   TE=542  PR=1035
OPER CA=7   TE=526  PR=1035
OPER CA=8   TE=516  PR=1035
OPER CA=9   TE=526  PR=1035
OPER CA=10  TE=300  PR=1160
OPER CA=11  TE=500  PR=1160
OPER CA=12  TE=300  PR=700
OPER CA=13  TE=549  PR=1035
OPER CA=14  TE=549  PR=1035
OPER CA=15  TE=375  PR=195
OPER CA=16  TE=330  PR=115
OPER CA=17  TE=225  PR=25
OPER CA=18  TE=100  PR=100
OPER CA=19  TE=100  PR=1563
OPER CA=20  TE=225  PR=25
OPER CA=21  TE=70   PR=25
OPER CA=22  TE=130  PR=1035
OPER CA=23  TE=526  PR=1035
OPER CA=24  TE=375  PR=225
OPER CA=25  TE=100  PR=25
*
TRAN  CA=201  IS=1 FS=1 IT=70  FT=100  TT=1800  FL=204  IP=15   FP=1115 TP=0
TRAN  CA=202  IS=1 FS=1 IT=100 FT=100  TT=1800  FL=204  IP=1115 FP=65   TP=0
TRAN  CA=203  IS=1 FS=1 IT=100 FT=549  TT=16164 FL=247  IP=65   FP=1050 TP=0
TRAN  CA=204  IS=1 FS=1 IT=549 FT=542  TT=0     FL=520  IP=1050 FP=1050 TP=0
TRAN  CA=205  IS=1 FS=1 IT=542 FT=526  TT=0     FL=511  IP=1050 FP=1050 TP=0
TRAN  CA=206  IS=1 FS=1 IT=526 FT=542  TT=900   FL=511  IP=1050 FP=1050 TP=0
TRAN  CA=207  IS=1 FS=1 IT=542 FT=526  TT=360   FL=511  IP=1050 FP=1050 TP=0
TRAN  CA=208  IS=1 FS=1 IT=526 FT=516  TT=0     FL=502  IP=1050 FP=1050 TP=0
TRAN  CA=209  IS=1 FS=1 IT=516 FT=526  TT=0     FL=502  IP=1050 FP=1050 TP=0
TRAN  CA=210  IS=1 FS=1 IT=526 FT=300  TT=220   FL=437  IP=1230 FP=1175 TP=0
TRAN  CA=211  IS=1 FS=1 IT=300 FT=500  TT=1980  FL=429  IP=925  FP=1175 TP=0
TRAN  CA=212  IS=1 FS=1 IT=500 FT=300  TT=180   FL=429  IP=1175 FP=715  TP=0
TRAN  CA=213  IS=1 FS=1 IT=300 FT=549  TT=8964  FL=443  IP=280  FP=1050 TP=0
TRAN  CA=214  IS=1 FS=1 IT=526 FT=549  TT=0     FL=514  IP=1050 FP=1050 TP=0
TRAN  CA=215  IS=1 FS=1 IT=549 FT=375  TT=6264  FL=458  IP=1050 FP=210  TP=0
TRAN  CA=216  IS=1 FS=1 IT=375 FT=330  TT=600   FL=403  IP=210  FP=130  TP=0
TRAN  CA=217  IS=1 FS=1 IT=330 FT=225  TT=3780  FL=260  IP=130  FP=40   TP=0
TRAN  CA=218  IS=1 FS=1 IT=225 FT=100  TT=4500  FL=6700 IP=115  FP=115  TP=0
TRAN  CA=219  IS=1 FS=1 IT=100 FT=100  TT=0     FL=226  IP=40   FP=1578 TP=0
TRAN  CA=220  IS=1 FS=1 IT=70  FT=225  TT=60    FL=6700 IP=40   FP=40   TP=0
TRAN  CA=221  IS=1 FS=1 IT=225 FT=70   TT=60    FL=6700 IP=40   FP=40   TP=0
TRAN  CA=222  *IS=1 FS=1 IT=526 FT=130  TT=0    FL=389  IP=1050 FP=1050 TP=0
TRAN  CA=223  IS=1 FS=1 IT=130 FT=526  TT=0     FL=389  IP=1050 FP=1050 TP=0
TRAN  CA=224  IS=1 FS=1 IT=526 FT=375  TT=600   FL=458  IP=1050 FP=240  TP=0
TRAN  CA=225  IS=1 FS=1 IT=375 FT=100  TT=9900  FL=334  IP=240  FP=40   TP=0
*
PAIR  CA=201 CO=8.3  DI=0.140  EX=8.5 *Tavg=85.0
PAIR  CA=202 CO=8.3  DI=0.140  EX=8.5 *Tavg=100.0
PAIR  CA=203 CO=9.4  DI=0.151  EX=8.5 *Tavg=324.5
```

```
PAIR   CA=204 CO=10.5 DI=0.162  EX=8.5 *Tavg=545.5
PAIR   CA=205 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR   CA=206 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR   CA=207 CO=10.4 DI=0.161  EX=8.5 *Tavg=534.0
PAIR   CA=208 CO=10.3 DI=0.161  EX=8.5 *Tavg=521.0
PAIR   CA=209 CO=10.3 DI=0.161  EX=8.5 *Tavg=521.0
PAIR   CA=210 CO=9.9  DI=0.156  EX=8.5 *Tavg=413.0
PAIR  CA=211 CO=9.8  DI=0.155  EX=8.5 *Tavg=400.0
PAIR   CA=212 CO=9.8  DI=0.155  EX=8.5 *Tavg=400.0
PAIR  CA=213 CO=9.9  DI=0.156  EX=8.5 *Tavg=424.5
PAIR   CA=214 CO=10.4 DI=0.162  EX=8.5 *Tavg=537.5
PAIR  CA=215 CO=10.0 DI=0.158  EX=8.5 *Tavg=462.0
PAIR   CA=216 CO=9.5  DI=0.152  EX=8.5 *Tavg=352.5
PAIR  CA=217 CO=9.2  DI=0.149  EX=8.5 *Tavg=277.5
PAIR  CA=218 CO=8.7  DI=0.143  EX=8.5 *Tavg=162.5
PAIR   CA=219 CO=8.3  DI=0.140  EX=8.5 *Tavg=100.0
PAIR  CA=220 CO=8.6  DI=0.142  EX=8.5 *Tavg=147.5
PAIR  CA=221 CO=8.6  DI=0.142  EX=8.5 *Tavg=147.5
*PAIR  CA=222 CO=9.4  DI=0.151  EX=8.5 *Tavg=328.0
PAIR   CA=223 CO=9.4  DI=0.151  EX=8.5 *Tavg=328.0
PAIR   CA=224 CO=10.0 DI=0.157  EX=8.5 *Tavg=450.5
PAIR  CA=225 CO=9.0  DI=0.147  EX=8.5 *Tavg=237.5
```

**Reg9B.inp**

```
*-----------------------------------------
*BEGIN REGION 9B TRANSIENT CARDS & GEOMETRY FOR RHR RETURN FROM VALVE NODE 660 TO PENET. NODE
675
*-----------------------------------------
*
OPER CA=1    TE=100  PR=1100
OPER CA=2    TE=100  PR=50
OPER CA=3    TE=150  PR=1035
OPER CA=4    TE=150  PR=1035
OPER CA=5    TE=150  PR=1035
OPER CA=6    TE=150  PR=1035
OPER CA=7    TE=150  PR=1035
OPER CA=8    TE=150  PR=1035
OPER CA=9    TE=150  PR=1035
OPER CA=10   TE=150  PR=1160
OPER CA=11   TE=150  PR=1160
OPER CA=12   TE=150  PR=700
OPER CA=13   TE=150  PR=1035
OPER CA=14   TE=150  PR=1035
OPER CA=15   TE=150  PR=195
OPER CA=16   TE=150  PR=115
OPER CA=17   TE=150  PR=25
OPER CA=18   TE=100  PR=100
OPER CA=19   TE=100  PR=1563
OPER CA=20   TE=225  PR=25
OPER CA=21   TE=70   PR=25
OPER CA=22   TE=150  PR=1035
OPER CA=23   TE=150  PR=1035
OPER CA=24   TE=150  PR=225
OPER CA=25   TE=150  PR=25
*
TRAN CA=201 IS=1 FS=1 IT=70  FT=100 TT=1800  FL=204  IP=15   FP=1115 TP=0
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=1800  FL=204  IP=1115 FP=65   TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=247  IP=65   FP=1050 TP=0
TRAN  CA=204
TRAN  CA=205
```

```
TRAN  CA=206
TRAN  CA=207
TRAN  CA=208
TRAN  CA=209
TRAN  CA=210
TRAN CA=211
TRAN  CA=212 IS=1 FS=1 IT=150 FT=150 TT=0      FL=429  IP=1175 FP=715  TP=0
TRAN CA=213
TRAN  CA=214
TRAN CA=215
TRAN  CA=216 IS=1 FS=1 IT=150 FT=150 TT=600    FL=403  IP=210  FP=130  TP=0
TRAN CA=217
TRAN CA=218 IS=1 FS=1 IT=225 FT=100 TT=4500  FL=6700 IP=115  FP=115  TP=0
TRAN  CA=219 IS=1 FS=1 IT=100 FT=100 TT=0      FL=247  IP=40   FP=1578 TP=0
TRAN  CA=220 IS=1 FS=1 IT=70  FT=225 TT=60     FL=6700 IP=40   FP=40   TP=0
TRAN  CA=221 IS=1 FS=1 IT=150 FT=70  TT=60     FL=6700 IP=40   FP=40   TP=0
TRAN  CA=222
TRAN  CA=223
TRAN  CA=224 IS=1 FS=1 IT=150 FT=150 TT=0      FL=458  IP=1040 FP=240  TP=0
TRAN  CA=225 IS=1 FS=1 IT=150 FT=150 TT=0      FL=334  IP=240  FP=40   TP=0
*
PAIR  CA=201 CO=27.6 DI=0.521 EX=6.4 *Tavg=85.0
PAIR  CA=202 CO=27.6 DI=0.512 EX=6.4 *Tavg=100.0
PAIR  CA=203 CO=27.6 DI=0.506 EX=6.4 *Tavg=125.0
*PAIR  CA=204 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=205 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=206 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=207 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=208 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=209 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=210 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=211 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
PAIR   CA=212 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=213 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=214 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=215 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
PAIR   CA=216 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=217 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
PAIR  CA=218 CO=27.6 DI=0.496 EX=6.4 *Tavg=162.5
PAIR   CA=219 CO=27.6 DI=0.512 EX=6.4 *Tavg=100.0
PAIR   CA=220 CO=27.6 DI=0.500 EX=6.4 *Tavg=147.5
PAIR   CA=221 CO=27.6 DI=0.509 EX=6.4 *Tavg=110.0
*PAIR  CA=222 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
*PAIR  CA=223 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
PAIR   CA=224 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
PAIR   CA=225 CO=27.6 DI=0.499 EX=6.4 *Tavg=150.0
```

# APPENDIX B

## PIPESTRESS Output

| Output File | Description |
|---|---|
| Recirc_15.prf | Fatigue results for reduced cycle count |
| RHR_15.prf | Fatigue results for full 60 year cycle count |

## Recirc 15.prf

D S T  C O M P U T E R  S E R V I C E S  S. A.  F-4.2  PAGE NO. 3947

++ DST/PIPESTRESS ++  Vermont Yankee  Version 3.5.1+026 PC-EXE  Release: Jun

CALCULATION NUMBER : 3  CODE SECTION III CLASS 1 ASME-1998  RVP  2007/07/26 08:42:12 [42
Vermont Yankee Recirculation Fatigue Analysis

FATIGUE ANALYSIS AT POINT 600, WELDING TEE 600 TO 602

******************************
INDIVIDUAL STRESS RANGE CHECK
******************************

DELTA T1 IN DEGREES F
STRESSES IN PSI

| LOAD SET PAIR I | J | SALT EQN.14 | OCCURENCES NI | OCCURENCES NJ | | NUMBER USED | SETS ELIMINATED DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 21 | 88675. | 10 | 150 | | 10 | 11 | 2801. | 0.0036 | |
| | | | 0 | 140 | | | | | | |
| 14 | 21 | 84491. | 150 | 140 | | 140 | 21 | 3359. | 0.0417 | |
| | | | 10 | 0 | | | | | | |
| 19 | 20 | 67184. | 1 | 150 | | 1 | 19 | 8221. | 0.0001 | |
| | | | 0 | 149 | | | | | | |
| 14 | 27 | 65876. | 10 | 5 | | 5 | 27 | 8900. | 0.0006 | |
| | | | 5 | 0 | 45 | | | | | |
| 10 | 20 | 62914. | 5 | 149 | | 5 | 10 | 10868. | 0.0005 | |
| | | | 0 | 144 | | | | | | |
| 14 | 20 | 55493. | 5 | 144 | | 5 | 14 | 20012. | 0.0002 | |
| | | | 0 | 139 | | | | | | |
| 9 | 20 | 54186. | 35 | 139 | | 35 | 9 | 22574. | 0.0016 | |
| | | | 0 | 104 | | | | | | |
| 5 | 20 | 53739. | 290 | 104 | | 104 | 20 | 23541. | 0.0044 | |
| | | | 186 | 0 | | | | | | |
| 2 | 3 | 46216. | 60 | 150 | | 60 | 2 | 50502. | 0.0012 | |
| | | | 0 | 90 | | | | | | |
| 1 | 26 | 46169. | 60 | 5 | | 5 | 26 | 50782. | 0.0001 | |
| | | | 55 | 0 | 45 | | | | | |
| 3 | 17 | 42799. | 90 | 150 | | 90 | 3 | 76939. | 0.0012 | |
| | | | 0 | 60 | | | | | | |
| 6 | 17 | 42219. | 10 | 60 | | 10 | 6 | 82911. | 0.0001 | |
| | | | 0 | 50 | | | | | | |
| 5 | 18 | 42196. | 186 | 150 | | 150 | 18 | 83156. | 0.0018 | |
| | | | 36 | 0 | | | | | | |
| 13 | 17 | 42131. | 5 | 50 | | 5 | 13 | 83864. | 0.0001 | |
| | | | 0 | 45 | | | | | | |
| 8 | 17 | 41392. | 35 | 45 | | 35 | 8 | 92408. | 0.0004 | |
| | | | 0 | 10 | | | | | | |

CALCULATION NUMBER 3   CODE SECTION III CLASS 1 ASME-1998   RVP   2007/07/26 08:42:12 [42
Vermont Yankee Recirculation Fatigue Analysis

FATIGUE ANALYSIS AT POINT 600, WELDING TEE 600 TO 602

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES F
STRESSES IN PSI

| LOAD SET I | PAIR J | SALT EQN.14 | OCCURENCES NI | OCCURENCES NJ | NUMBER USED | SETS ELIMINATED DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 17 | 41326. | 10 | 10 | 10 | 7,17 | 93222. | 0.0001 | |
| | | | 0 | 0 | | | | | |
| 1 | 15 | 38663. | 55 | 150 | 55 | 1 | 133841. | 0.0004 | |
| | | | 0 | 95 | | | | | |
| 4 | 16 | 35177. | 290 | 150 | 150 | 16 | 227086. | 0.0007 | |
| | | | 140 | 0 | | | | | |
| 4 | 15 | 34727. | 140 | 95 | 95 | 15 | 246096. | 0.0004 | |
| | | | 45 | 0 | | | | | |
| 4 | 12 | 25167. | 45 | 10 | 10 | 12 | 1449206. | 0.0000 | |
| | | | 35 | 0 | | | | | |
| 26 | 27 | 23758. | 45 | 45 | 45 | ,27 26 | 1748766. | 0.0000 | DYN. RANGE OF EVENT NO. 1 |
| | | | 0 | 0 | | | | | |
| 4 | 5 | 2773. | 35 | 36 | 35 | 4 | >100000000000. | 0.0000 | |
| | | | 0 | 1 | | | | | |

TOTAL USAGE FACTOR = 0.0590

Notes a: Fails
f: Weld ISI
j: Rupture Location

## RHR 15.prf

D S T  C O M P U T E R  S E R V I C E S  S. A.    F-4.2    PAGE NO. 4019

++ DST/PIPESTRESS ++    Vermont Yankee    Version 3.5.1+026  PC-EXE    Release: Jun

CALCULATION NUMBER 3    CODE SECTION III CLASS 1  ASME-1998    RVP    2007/07/26  08:44:06  [43
Vermont Yankee Recirculation Fatigue Analysis

FATIGUE ANALYSIS AT POINT 641, SR ELBOW    640 TO 641

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES F
STRESSES IN PSI

| LOAD SET PAIR I | J | SALT EQN.14 | OCCURENCES NI | OCCURENCES NJ | | NUMBER USED | SETS ELIMINATED DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 20 | 100252. | 10 | 300 | | 10 | 10 | 1788. | 0.0056 | |
| | | | 0 | 290 | | | | | | |
| 11 | 21 | 68706. | 20 | 300 | | 20 | 11 | 7511. | 0.0027 | |
| | | | 0 | 280 | | | | | | |
| 12 | 20 | 64893. | 20 | 290 | | 20 | 12 | 9456. | 0.0021 | |
| | | | 0 | 270 | | | | | | |
| 20 | 21 | 39947. | 270 | 280 | | 270 | 20 | 112120. | 0.0024 | |
| | | | 0 | 10 | | | | | | |
| 3 | 21 | 35368. | 300 | 10 | | 10 | 21 | 219528. | 0.0000 | |
| | | | 290 | 0 | | | | | | |
| 3 | 17 | 20439. | 290 | 300 | | 290 | 3 | 3190872. | 0.0000 | |
| | | | 0 | 10 | | | | | | |
| 13 | 17 | 19221. | 10 | 10 | | 10 | 13,17 | 4148766. | 0.0000 | |
| | | | 0 | 0 | | | | | | |
| 14 | 18 | 14925. | 300 | 300 | | 300 | 14,18 | >100000000000. | 0.0000 | |
| | | | 0 | 0 | | | | | | |
| 15 | 19 | 14877. | 300 | 1 | | 1 | 19 | >100000000000. | 0.0000 | |
| | | | 299 | 0 | | | | | | |
| 1 | 15 | 14434. | 120 | 299 | | 120 | 1 | >100000000000. | 0.0000 | |
| | | | 0 | 179 | | | | | | |
| 6 | 15 | 12896. | 20 | 179 | | 20 | 6 | >100000000000. | 0.0000 | |
| | | | 0 | 159 | | | | | | |
| 9 | 15 | 12506. | 70 | 159 | | 70 | 9 | >100000000000. | 0.0000 | |
| | | | 0 | 89 | | | | | | |
| 4 | 15 | 11542. | 579 | 89 | | 89 | 15 | >100000000000. | 0.0000 | |
| | | | 490 | 0 | | | | | | |
| 7 | 27 | 10017. | 20 | 5 | | 5 | 27 | >100000000000. | 0.0000 | |
| | | | 15 | 0 | 45 | | | | | |
| 4 | 16 | 9993. | 490 | 300 | | 300 | 16 | >100000000000. | 0.0000 | |
| | | | 190 | 0 | | | | | | |

CALCULATION NUMBER 3   CODE SECTION III CLASS 1 ASME-1998   RVP   2007/07/26 08:44:06 [4
Vermont Yankee Recirculation Fatigue Analysis

FATIGUE ANALYSIS AT POINT 641, SR ELBOW 640 TO 641

******************************
INDIVIDUAL STRESS RANGE CHECK
******************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR I | J | SALT EQN.14 | OCCURENCES NI | NJ | | NUMBER USED | SETS ELIMINATED | DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 7 | 9353. | 120 | 15 | | 15 | 7 | | >100000000000. | 0.0000 | |
| | | | 105 | 0 | | | | | | | |
| 2 | 5 | 9353. | 105 | 579 | | 105 | 2 | | >100000000000. | 0.0000 | |
| | | | 0 | 474 | | | | | | | |
| 5 | 26 | 8235. | 474 | 5 | | 5 | 26 | | >100000000000. | 0.0000 | |
| | | | 469 | 0 | 45 | | | | | | |
| 26 | 27 | 2019. | 45 | 45 | | 45 | ,27 | 26 | >100000000000. | 0.0000 | DYN. RANGE OF EVENT NO. 1 |
| | | | 0 | 0 | | | | | | | |
| 4 | 5 | 1570. | 190 | 469 | | 190 | 4 | | >100000000000. | 0.0000 | |
| | | | 0 | 279 | | | | | | | |
| 5 | 8 | 1512. | 279 | 70 | | 70 | 8 | | >100000000000. | 0.0000 | |
| | | | 209 | 0 | | | | | | | |

TOTAL USAGE FACTOR = 0.0128

Notes a: Fails
f: Weld ISI
j: Rupture Location

**Structural Integrity Associates, Inc.**

# CALCULATION PACKAGE

File No.: VY-16Q-308

~~NEC-JH_11~~

Project No.: VY-16Q

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Core Spray Nozzle Finite Element Model

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-7, Appendix: A1-A17 | Initial Issue | Terry J. Herrmann 07/19/2007 [signature] | Roland Horvath 07/12/2007 [signature]<br>John Staples 07/12/2007 [signature] |

## Table of Contents



## List of Tables



## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation is to create a finite element model of the Vermont Yankee Nuclear Power Station Core Spray Nozzle. This model will be used to develop a Green's Function to be used in a subsequent fatigue analysis.

## 2.0 GEOMETRY / MATERIAL PROPERTIES

A 2-D axisymmetric finite element model (FEM) of the nozzle was developed with element type PLANE82. The developed model includes the part of the pipe, the safe end, the nozzle forging, a portion of the vessel shell, and the cladding. The radius of the vessel in the finite element model was multiplied by a factor of 2 to account for the fact that the vessel portion of the 2D axisymmetric model is a sphere, but the true geometry is a cylinder. The equation for the membrane hoop stress for a sphere is:

$$\sigma = \frac{(pressure) \times (radius)}{2 \times thickness}$$

The equation for the membrane hoop stress in a cylinder is:

$$\sigma = \frac{(pressure) \times (radius)}{thickness}$$

The factor of two was verified in Reference [11] where actual stress results were compared to the results of this analytical form.

The 2-D axisymmetric FEM was constructed using the dimensions and information from References [1 -8] based on ANSYS [9] finite element software. Figure 1 shows the resulting finite element model.

The materials of the various components of the model are listed below:

- Safe End – SB 166 [1] (72Ni-15Cr-8Fe, N06600)
- 8Ø x 10Ø Conc. Reduction – SA312 TP304 [7] (18Cr-8Ni)
- Nozzle Forging – SA508 Class II [1] (¾ Ni-1/2Mo-1/3 Cr-V)
- Vessel – SA533 Grade B [7] (Mn-1/2Mo-1/2Ni)
- Cladding – SA240 TP 304 [7] (18Cr-8Ni)

Note: In the FEM, the 8Ø x 10Ø Conc. Reduction was modeled as a straight pipe with the material properties of the original design [7]. Later, this piping section was replaced by a new material (SA403 T316L) [10]. These two stainless steels have the same modulus of elasticity and thermal coefficient properties.

Material properties for these materials are based upon the 1998 ASME Code, Section II, Part D, with 2000 Addenda [8] and are shown in Table 1. The properties are taken at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F, which will be applied to the FEM model for Green's Function development.

## 3.0 PROGRAM INPUT

The input file, VY_CSN_GEOM.inp (included in Appendix A), creates the finite element model for the core spray nozzle.

## 4.0 REFERENCES


1. Reactor 8 In. Dia. Nozzles Mk. N5A & B, 5920-00624 Rev. 8, SI File No. VY-16Q-207.
2. Core Spray Nozzle Weld Overlay Profile N5A & N5B, 5920-06813, Sh. 1 of 2 Rev. 0, SI File No. VY-16Q-206.
3. N5A/B Thermal Sleeve Details, 5920-00898, Rev 1, SI File No. VY-16Q-206.
4. Special Safe End Forging for Nozzles N2A/B & N5A/B, 5920-00655, Rev. 6, SI File No. VY-16Q-206.
5. Special Forgings for Nozzles N5A & N5B, 5920-00069, Rev 1, SI File No. VY-16Q-206.
6. Core Spray Nozzle Weld Overlay Profile N5A & N5B, 5920-06813, Sh. 2 of 2 Rev. 0, SI File No. VY-16Q-204.
7. CB&I RPV Stress Report, Section S7, "Stress Analysis Core Spray and Flooding Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201, SI File No. VY-16Q-206.
8. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
9. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.
10. "10" x 8" SA403 T316L CONC REDUCER", Page 18 of Attachment 2 of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.
11. SI Calculation No. VY-16Q-309, Revision 0, "Core Spray Nozzle Green's Functions".

**Table 1: Material Properties @ 300°F [(1)]**

| Material ID | Part Description | Material | | Modulus of Elasticity, e+6 psi [EX] | Coefficient of Thermal Expansion, e-6, in/in/°F [ALPX] | Thermal Conductivity, Btu/hr-ft-°F [KXX] | Thermal Diffusivity, ft²/hr | Specific Heat, Btu/lb-°F [C] [(3)] |
|---|---|---|---|---|---|---|---|---|
| 2 | Safe End | SB 166 | 72Ni-15Cr-8Fe N06600 | 29.8 | 7.9 | 9.6 | 0.160 | 0.1157 |
| 2 | Weld Overlay | INCONEL 82 | 72Ni-15Cr-8Fe N06600 | 29.8 | 7.9 | 9.6 | 0.160 | 0.1157 |
| 1 | Nozzle | SA508 Class II | ¾ Ni-1/2Mo-1/3 Cr-V | 26.7 | 7.3 | 23.4 | 0.401 | 0.1193 |
| 3 | Vessel | SA533 Grade B | Mn-1/2Mo-1/2Ni | 28.0 | 7.7 | 23.4 | 0.401 | 0.1193 |
| 4 | 3/16 Clad | SA240 TP 304 | 18Cr-8Ni | 27.0 | 9.8 | 9.8 | 0.160 | 0.1252 |
| 4 | 8Ø x 10Ø Conc. Reduction[(2)] | SA312 TP304 | 18Cr-8Ni | 27.0 | 9.8 | 9.8 | 0.160 | 0.1252 |

Notes:

1. The material properties applied in the analyses are taken from ASME Code, Section II, Part D 1998 Edition, with 2000 information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a for the original design code is acceptable, since later editions typically reflect more accurate material properties than wa editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, 2000 Addenda, Section II, Part D, except for densi assumed typical values [8].
2. In the FEM, the 8Ø x 10Ø Conc. Reduction was modeled as a straight pipe with the material properties of the original d was replaced by a new material (SA403 T316L). These two stainless steels have the same modulus of elasticity and thei
3. Calculated as $[k/(\rho d)]/12^3$.

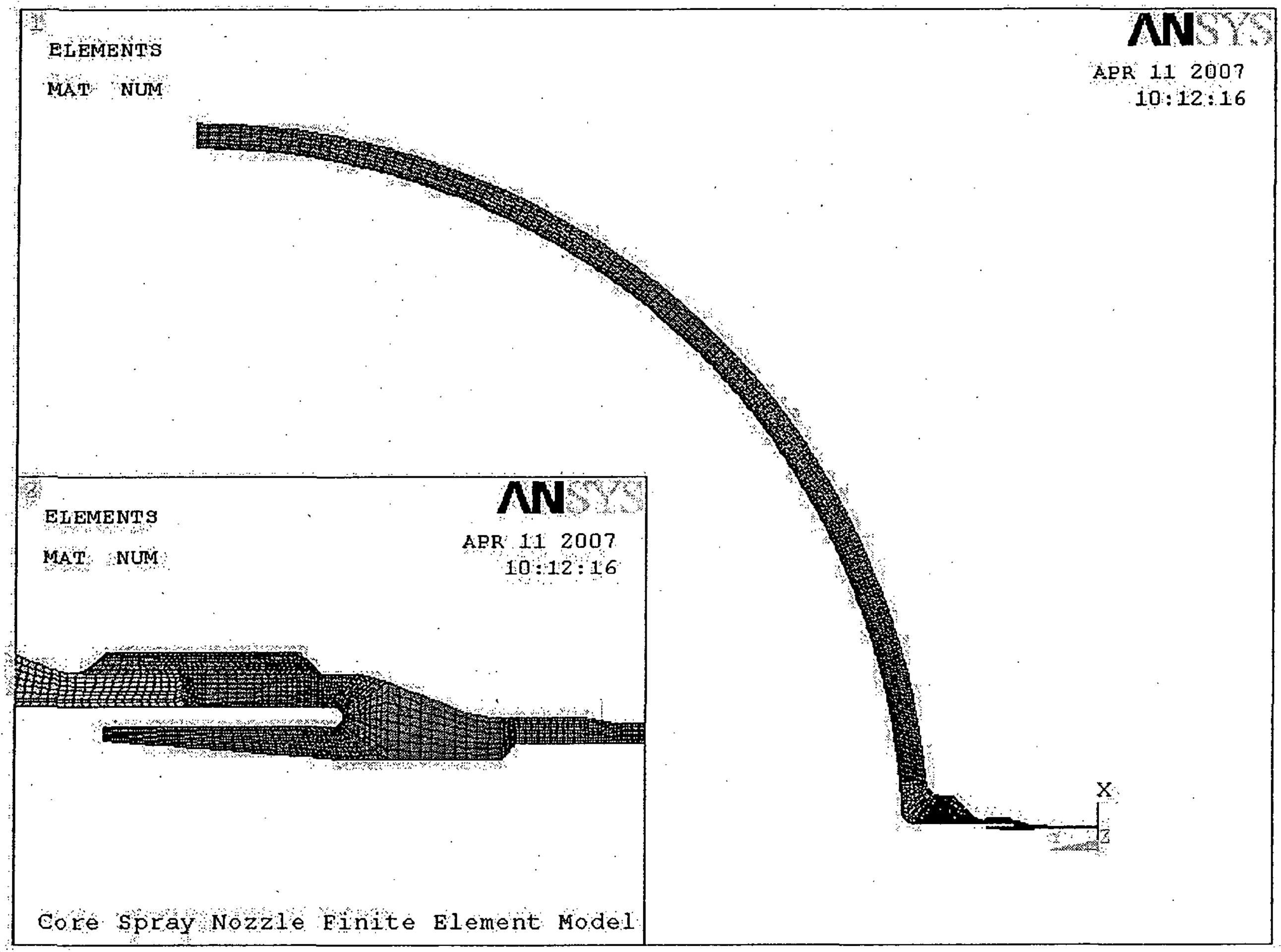



**Figure 1: ANSYS Finite Element Model**

# APPENDIX A

VY_CSN_GEOM.INP

```
!finish
!/clear,start
!/prep7

et,1,PLANE182,,,1   !Axisymmetric
/com, ****************************
/com, Material Properties @T=300F
/com, ****************************
/COM, Material #1 (Nozzle: SA-508 Class II, 3/4Ni-1/2Mo-1/3Cr-V)
mp,ex  ,1,26.7E+06
mp,alpx,1,7.3E-06
mp,kxx ,1,23.4   /3600/12
mp,c   ,1,0.1193277
mp,nuxy,1,0.3
mp,dens,1,0.283

/COM, Material #2 (Safe End: N06600, Inconel 82 Weld Overlay)
mp,ex  ,2,29.8E+06
mp,alpx,2,7.9E-06
mp,kxx ,2,9.6   /3600/12
mp,c   ,2,0.1157407
mp,nuxy,2,0.29
mp,dens,2,0.3

/COM, Material #3 (Vessel: SA-533 Grade B, Mn-1/2Mo-1/2Ni)
mp,ex  ,3,28.00E+06
mp,alpx,3,7.7E-06
mp,kxx ,3,23.4   /3600/12
mp,c   ,3,0.1193277
mp,nuxy,3,0.3
mp,dens,3,0.283

/COM, Material #4 (3/16 Clad: SA-240 TP304, 8-10 Diam. Conc. Red.: SA-312 TP 304, Thermal
Sleeve: SA-312 TP304)
mp,ex  ,4,27.0E+06
mp,alpx,4,9.8E-06
mp,kxx ,4,9.8   /3600/12
mp,c   ,4,0.1252495
mp,nuxy,4,0.3
mp,dens,4,0.283


/com, **********************
/com, Geometric Parameters
/com, **********************
*AFUN,deg
```

```
/com, pipe parameters
*set, pID, 9.834
*set, pOD, 10.815
*set, pL,        8

k, 1, pID/2, 0
k, 2, POD/2, 0
k, 3, POD/2, pL
k, 4, PID/2, pL

l, 1, 2
l, 2, 3
l, 3, 4
l, 4, 1


/com, ******************
/com, Safe End Parameters
/com, ******************
*set, seBX, pL
*set, seID01, 9.834
*set, seID02, 9
*set, seID03, 9 + 31/32
*set, seID04, 11+ 3/4

*set, seOD01, 10.815
*set, seOD02, 11 + 1/6
*set, seOD03, 13 + 27/64
*set, seOD04, 10 + 11/16

*set, seL01,  3 + 1/32
*set, seL02,  7/8
*set, seL03,  1+11/16
*set, seL04,  13/32
*set, seL05,  4
*set, seL06,  3+1/2
*set, seL07,  12+4+1/16
*set, seL08,  seL07-(seL01+seL02+seL03+seL04+seL05+seL06)
*set, seR01,  3
*set, seR02,  3/4
*set, seR03,  1/4
*set, seR04,  1/8


k, 5, seOD01/2, seBX+seL01
k, 6, seOD02/2, seBX+seL01+seL02
```

```
k, 7, seOD02/2, seBX+seL01+seL02+seL03+seL04 +.496
k, 8, (seOD02+seOD03)/4, seBX+seL01+seL02+seL03+seL04+seL05/2
k, 9, seOD03/2, seBX+seL01+seL02+seL03+seL04+seL05
k, 10, seOD03/2, seBX+seL01+seL02+seL03+seL04+seL05+seL06
k, 11, seID04/2, seBX+seL01+seL02+seL03+seL04+seL05+seL06
k, 12, seID04/2, seBX+seL01+seL02+seL03+seL04+seL05
k, 13, seOD04/2, seBX+seL01+seL02+seL03+seL04+seL05
k, 14, seOD04/2, seBX+seL07
k, 15, seID03/2, seBX+seL07
k, 16, seID02/2, seBX+seL01+seL02+seL03+seL04+seL05
k, 17, seID02/2, seBX+seL01+seL02+seL03+seL04
k, 18, seID01/2, seBX+seL01+seL02+seL03

l, 3, 5
l, 5, 6
l, 6, 7
l, 9, 10
l, 10, 11
l, 11, 12
l, 12, 13
l, 13, 14
l, 14, 15
l, 15, 16
l, 16, 17
l, 17, 18
l, 18, 4

k, 19, seOD02/2+seR01, seBX+seL01+seL02+seL03+seL04 +.496
k, 8, seOD02/2+seR01, seBX+seL01+seL02+seL03+seL04+seR01 +.496
larc, 7, 8, 19, seR01

k, 20, seOD03/2-seR01, seBX+seL01+seL02+seL03+seL04+seL05
k, 21, seOD03/2-seR01, seBX+seL01+seL02+seL03+seL04+seL05-seR01
larc, 9, 21, 20, seR01
L2ANG,19,18,0,0,,,
ldele, 20, 21, ,1

lfillt, 5, 6, seR02
lfillt, 6, 7, seR02
lfillt, 10, 11, seR03
lfillt, 11, 12, seR03
lfillt, 15, 16, seR04
lfillt, 16, 17, seR04

/com, weld 1/8 gap
*set, wgap, 1/8
```

```
k, 40, seOD03/2, seBX+seL01+seL02+seL03+seL04+seL05+seL06 + wgap
k, 41, seID04/2, seBX+seL01+seL02+seL03+seL04+seL05+seL06 + wgap

l, 10, 40
l, 40, 41
l, 41, 11

/com, *********************
/com, Nozzle
/com, *********************

*set, nID01, seOD01
*set, nOD01, seOD03
*set, nOD02, 24+1/4
*set, nOD03, 2*12+7.25
*set, nOD04, 2*12+7.25-1-1/8

*set, nL01, 4+5/16
*set, nL02, 5+3/8
*set, nL03, 5+1/8+5+5/8
*set, nW01, 1/16
*set, wClad, 3/16
*set, wReactor, 5+5/8-wClad
*set, nL04, 7/16
*set, nR01, 1/4
*set, nR02, 3/16
*set, nR03, (8*12+7)*2
*set, nR04, 2.5
*set, nR05, nR04-wClad
*set, nR06, 3.5
*set, nR07, 3 +7/8
*set, nR08, 0.5

K, 42, KX(11) + nW01, KY(11)
K, 43, KX(41) + wClad, KY(41)+nL04+nR01
K, 44, KX(43) + nR01, KY(43)
K, 46, KX(44) + nR01*sin(15), KY(44)-nR01*cos(15)
K, 47, KX(46) + 10*nR01*cos(15), KY(46)+10*nR01*sin(15)
K, 48, KX(43), KY(43) + 24
K, 49, KX(41), KY(41) + 24
K, 50, KX(40), KY(40) + nL01
K, 51, KX(44) + (nR01+wClad)*sin(15), KY(44)-(nR01+wClad)*cos(15)
K, 52, KX(51) + 10*nR01*cos(15), KY(51)+10*nR01*sin(15)
K, 53, KX(51) - 10*nR01*cos(15), KY(51)-10*nR01*sin(15)
K, 54, KX(42), KY(42)+wClad*2
larc, 43, 46, 44, nR01
```

```
L, 46, 47
L, 43, 48
L, 41, 49
L, 40, 50
L, 53, 52
L, 42, 54

LOVLAP, 35,36
LDELE, 39, 40,,0

LOVLAP, 31,34,38
LDELE, 40,42,2,0

lfillt, 37, 35, nR02

K, 60, nOD02/2, KY(40) + nL01+nL02
K, 61, nOD02/2, KY(40) + nL01+nL02+nL03
K, 62, 0, KY(40) + nL01+nL02+nL03+nR03
K, 63, 0, KY(62) - nR03
K, 64, nR03, KY(62)
K, 65, 0, KY(63)-wClad
K, 66, nR03+wClad, KY(62)
K, 67, 0, KY(65)-wReactor
K, 68, nR03+wReactor, KY(62)

LARC, 63, 64, 62, nR03
LARC, 65, 66, 62, nR03+wClad
LARC, 67, 68, 62, nR03+wReactor

L, 64, 66
L, 66, 68

LOVLAP, 34, 33
LDELE, 46,47

LOVLAP, 32, 38
LDELE, 34
LDELE, 46

LFILLT,45,48,nR04, ,
LFILLT,33,47,nR05, ,

L, 50, 60
L, 60, 61

LOVLAP, 40, 46
```

```
LDELE, 50, 51
LFILLT,49,52,nR06
LFILLT,38,41,nR07
LFILLT,49,38,nR08

/com, Nozzle and Vessel border
K,      80,     nOD03/2, KY(60)+2*nL03
K,      81, nOD03/2, KY(60)
K,      82,     nOD04/2, KY(60)+2*nL03
K,      83, nOD04/2, KY(60)
L,      80, 81
L,      82, 83

LPTN, 53, 48
LPTN, 51, 52
LDELE, 56, 59,1,0
LSTR,  76, 75
LPTN, 51, 47
KL,40,0.5, ,
KL,34,0.5, ,
KL,32,0.5, ,

LSTR,  78, 79
LSTR,  79, 84

K, 90, KX(73)+wReactor*2*cos(160), KY(73)+wReactor*2*sin(160)
L, 73, 90
LPTN, 59, 33
LPTN, 63, 45
LDELE, 65

K, 91, KX(71)+wReactor*2*cos(170), KY(71)+wReactor*2*sin(170)
L, 71, 91
LPTN, 45, 60
LPTN, 33, 67
LDELE, 69
KCENTER,KP,69,78,70,0
LSTR,     89,     58
LSTR,     89,     57

LPTN, 40, 33, 67
LDELE, 73, 74

L, 58, 56
L, 57, 55
```

```
/com, **********************
/com, Weld Overlay
/com, **********************
*set, woA, 3.100
*set, woB, 0.781
*set, woC, 2.500
*set, woD, 3.734
*set, woE, 3.480
*set, woF, 6.310
*set, woG, 8.313
*set, woH, 0.535
*set, woR01, 7/16

K, 80, KX(40), KY(40)-wgap/2-woA
K, 81, KX(80)+woH, KY(80)+woH
K, 83, KX(40), KY(40)-wgap/2+woB/2+woC
K, 82, KX(83)+woH, KY(83)-woH

L, 80, 81
L, 81, 82
L, 82, 83


LPTN, 74, 46
LDELE, 79
LFILLT,78,76,woR01, ,
LSTR,   94,   96

/com, *************************
/com, Heat transfer coef. points
/com, *************************
*set, tsL01, 2.25
*set, tsL02, 3.5

K, 100, KX(41),       KY(11)+seL08+tsL01
K, 101, KX(41)+wClad, KY(11)+seL08+tsL01

K, 102, KX(41),       KY(11)+seL08+tsL01+tsL02
K, 103, KX(41)+wClad, KY(11)+seL08+tsL01+tsL02
L, 100, 101
L, 102, 103

LDELE, 51
LDELE, 47
```

```
K, 104, KX(103)+wReactor*cos(-20), KY(103)+wReactor*sin(-20)
K, 105, KX(101)+wReactor*cos(-10), KY(101)+wReactor*sin(-10)
L, 103, 104
L, 101, 105
LPTN, 38, 47
LPTN, 76, 51

LDELE, 86
LDELE, 84
LDELE, 65
LDELE, 68

LDELE, 63
LDELE, 45
LDELE, 66
LDELE, 60

LSTR,    43,    101
LSTR,   101,    103
LSTR,   103,     85
LSTR,    86,    102
LSTR,   102,    100
LSTR,   100,     41

LDIV,30,0.5, ,2,0
K, 106, KX(99)+wReactor*cos(200), KY(99)+wReactor*sin(200)
K, 107, KX(38)+wReactor*cos(160), KY(38)+wReactor*sin(160)
L, 99, 106
L, 38, 107
LPTN, 66, 84
LPTN, 88, 76

LDELE, 89,90
LSTR,    99,     38
LDELE, 28
LSTR,    26,      9
LSTR,    29,     16

LCOMB,11,23,0
LCOMB,11,24,0
LDIV,11, , ,3,0

K, 110, KX(22)+wReactor*cos(180), KY(22)+wReactor*sin(180)
L, 110, 22
LPTN, 15, 89
LDELE, 94
```

```
LSTR,   28,   111
LSTR,   27,    22
LSTR,   17,     7
K, 112, KX(33)+wReactor, KY(33)
L, 33, 112
LPTN, 7, 95
LDELE, 99
K, 114, KX(25)+wReactor*cos(180), KY(25)+wReactor*sin(180)
L, 114,25
K, 115, KX(8)+wReactor*cos(180), KY(8)+wReactor*sin(180)
L, 115, 8
LPTN, 95,17
LPTN, 7,101
LDELE, 102,103


/com, *************************
/com, Creating Areas and Meshing
/com, *************************
allsel,all,all

MSHKEY,1    ! MAPPED MESHING
AL,1,2,3,4
MAT,4                      ! Pipe
LESIZE,1,,,8
LESIZE,3,,,8
LESIZE,2,,,20
LESIZE,4,,,20
AMESH, 1

MAT,2                      ! Safe End
AL, 3, 5, 100, 99
LESIZE,3,,,8
LESIZE,100,,,8
LESIZE,5,,,20
LESIZE,99,,,20
AMESH, 2

LCOMB, 20,6,0
LCOMB, 6,21,0
AL, 100, 6, 17, 104
LESIZE,100,,,8
LESIZE,17,,,8
LESIZE,6,,,10
LESIZE,104,,,10
AMESH, 3
```

```
AL, 17, 97, 98, 95
LESIZE,17,,,8
LESIZE,98,,,8
LESIZE,97,,,10
LESIZE,95,,,10
AMESH, 4

LDELE, 94
LSTR,     7,     30
LCOMB, 26,16,0
LCOMB, 16,25,0
AL, 98, 96, 7, 16
LESIZE,98,,,8
LESIZE,7,,,8
LESIZE,96,,,8
LESIZE,16,,,8
AMESH, 5


LCOMB, 18, 22
AL, 7, 18, 92, 93
LESIZE,7,,,8
LESIZE,92,,,8
LESIZE,18,,,10
LESIZE,93,,,10
AMESH, 6

AL, 92, 89, 23, 15
LESIZE,92,,,8
LESIZE,23,,,8
LESIZE,89,,,8
LESIZE,15,,,8
AMESH, 7

AL, 15, 24, 88, 90
LESIZE,15,,,8
LESIZE,24,,,8
LESIZE,88,,,8
LESIZE,90,,,8
AMESH, 8

AL, 89, 19, 28, 11
LESIZE,89,,,8
LESIZE,19,,,8
LESIZE,28,,,8
```

```
LESIZE,11,,,8
AMESH, 9


AL, 88, 12, 13, 14
LESIZE,88,,,8
LESIZE,13,,,8
LESIZE,12, , ,28,5, , , ,1
LESIZE,14, , ,28,0.2, , , ,1
AMESH, 10

K, 118, KX(80)+wReactor*cos(180), KY(80)+wReactor*sin(180)
L, 118, 80
LPTN, 10,20,8
LDELE, 101
AL, 28, 21, 94 , 26
LESIZE,28,,,8
LESIZE,94,,,8
LESIZE,21,,,6
LESIZE,26,,,6
AMESH, 11

LDELE, 9
LSTR,     42,     11
LSTR,     42,     10

LESIZE,8, , ,2, , , , ,1
LESIZE,9, , ,6, , , , ,1
LESIZE,22, , ,20,0.2, , , ,1
LESIZE,25, , ,20,0.2, , , ,1
AL, 94, 22, 9, 8, 25
AMAP,12,11,10,80,21


LCOMB, 37, 31
LCOMB, 27, 36
AL, 9, 27, 35, 31
LESIZE,35,,,6
LESIZE,27,,,4
LESIZE,31,,,4
AMESH, 13

MAT,4                          ! Clad
LCOMB, 68, 39
```

```
LCOMB, 29, 87
AL, 8, 31, 86, 29
LESIZE,8,,,2
LESIZE,86,,,2
LESIZE,31,,,4
LESIZE,29,,,4
AMESH, 14

AL, 35, 43, 39, 76
LESIZE,35,,,6
LESIZE,39,,,6
LESIZE,43,,,4
LESIZE,76,,,4
AMESH, 15


AL, 86, 76, 66, 91
LESIZE,86,,,2
LESIZE,66,,,2
LESIZE,76,,,4
LESIZE,91,,,4
AMESH, 16

MAT,1                    ! Nozzle
LCOMB, 41, 77,
LCOMB, 41, 74,
LCOMB, 41, 47,
LDELE, 41
LDELE, 47

LESIZE,45, , ,19, , , , ,1
LESIZE,30, , ,1, , , , ,1
LESIZE,10,,,20
LESIZE,85,,,6
AL, 39, 10, 85, 45, 30
AMAP,17,101,98,36,99

MAT,4                    ! Clad
LESIZE, 79,,,2
LESIZE,84,,,20
AL, 66, 30, 45, 79, 84
AMAP,18,100,101,99,109

MAT,1                    ! Nozzle
LCOMB, 38, 81
LESIZE, 38,,,14
```

```
LESIZE, 83,,,6
LESIZE, 51,,,14
AL, 85, 38, 83, 51
AMESH, 19

MAT,4                          ! Clad
LESIZE, 80,,,2
LESIZE, 65,,,14
AL, 79, 51, 80, 65
AMESH, 20

MAT,1                          ! Nozzle
LCOMB, 82, 50
LESIZE, 50,,,20
LESIZE, 62,,,6
LESIZE, 60,,,20
AL, 83, 50, 62, 60
AMESH, 21

MAT,4                          ! Clad
LESIZE, 64,,,2
LESIZE, 63,,,20
AL, 80, 60, 64, 63
AMESH, 22

MAT,1                          ! Nozzle
LCOMB, 49, 71
LESIZE, 49,,, 20
LESIZE, 69,,,6
LESIZE, 61,,,20
AL, 62,49,69,61
AMESH, 23

MAT,4                          ! Clad
LESIZE, 40,,,2
LESIZE, 59,,,20
AL, 64, 61, 40, 59
AMESH, 24

MAT,1                          ! Nozzle
LESIZE, 75,,,6
LESIZE, 70,,,6
LESIZE, 34,,,6
AL, 69, 75, 70, 34
AMESH, 25
```

```
MAT,4                                  ! Clad
LESIZE, 33,,,2
LESIZE, 32,,,6
AL, 40, 34, 33, 32
AMESH, 26

MAT,1                                  ! Nozzle
LCOMB, 53, 72
LESIZE, 53,,,8
LESIZE, 58,,,6
LESIZE, 52,,,8
AL, 70, 53, 58, 52
AMESH, 27

MAT,4                                  ! Clad
LESIZE, 57,,,2
LESIZE, 54,,,8
AL, 33, 52, 57, 54
AMESH, 28

MAT,3                                  ! Vessel
LESIZE, 57,,,2
LESIZE, 54,,,8
LESIZE, 48,,,100,0.2, , , ,1
LESIZE, 55,,,100,0.2, , , ,1
LESIZE, 56,,,100,0.2, , , ,1
AL, 48, 44, 56, 58
AMESH, 29

MAT,4                                  ! Clad
LESIZE, 42,,,2
AL, 57, 56, 42, 55
AMESH, 30


MAT,1                                  ! Nozzle
ACLEAR,     17
ADELE,      17
LOVLAP,10, 46
NUMMRG,KP, , , ,LOW
LCOMB,37,41 ,0
AL, 20, 37, 85, 45, 30, 39
AMAP,17,101,98,36,99
```

```
MAT,2                              ! Safe End
LCOMB, 36, 78
LESIZE, 67,,,6
LESIZE, 36,,,6, 0.2,,,1
AL, 67, 73,36,20,43,27,22
AMAP,31,23,82,81,80


/COM,*********************
/COM, HTC point of Region 3
/COM,*********************
ACLEAR, 4
ADELE,  4
LDELE,  95
LDELE,  97
K, 120, KX(18), KY(18) - 3/8
K, 121, KX(25), KY(120)
L, 25, 121
L, 121, 113
L, 117, 120
L, 120, 33
L, 120, 121

MAT,2                              ! Safe End
AL, 17, 10, 68, 46
LESIZE,10,,,12
LESIZE,68,,,8
LESIZE,46,,,12
AMESH, 4

AL, 68, 41, 98, 47
LESIZE,41,,,4
LESIZE,98,,,8
LESIZE,47,,,4
AMESH, 32


/COM,*********************
/COM, HTC point of Region 7
/COM,*********************
MAT,4                              ! Clad
ACLEAR,    18
ADELE,     18
K, 122, KX(14)+wReactor, KY(14)
L, 14,122
LSBL, 84, 71
```

```
LESIZE, 72,,,10
LESIZE, 74,,,10
AL, 66, 30,45,79,72,74
AMAP,18,100,101,99,109


/COM,***************************************
/COM, HTC point of Region 3
/COM,***************************************
MAT,2                          ! Safe End
ACLEAR, 2
ADELE, 2
K, 123, KX(120), KY(120)-3
K, 124, KX(4), KY(4)+1+1/16
LDELE, 99
L, 4, 124
L, 124, 123
L, 123, 116
AL, 3, 5, 100, 78, 77, 71
AMAP,2,116,8,3,4



/COM,*********************************
/COM, Define DOF constraints on lines
/COM,*********************************
DL,42, ,SYMM
DL,44, ,SYMM

FLST,4,9,1,ORDE,2
FITEM,4,1
FITEM,4,-9
CP,1,UY,P51X
```

**Structural Integrity Associates, Inc.**

# CALCULATION PACKAGE

**File No.:** VY-16Q-309

~~NEC-JH_12~~

**Project No.:** VY-16Q

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Core Spray Nozzle Green's Functions

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1-32, Appendix: A1-A2 | Initial Issue | Terry J. Herrmann 7/20/2007 [signature] | Roland Horvath 07/19/2007 [signature]<br>John F. Staples 07/19/2007 [signature] |

## Table of Contents



## List of Tables

## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation is to compute the pressure stresses, thermal stresses, and the Green's Functions for high (100%) and no (0%) flow thermal loading of the Vermont Yankee Nuclear Power Station Core Spray Nozzle.

## 2.0 CORE SPRAY NOZZLE MODEL DESCRIPTION

An axisymmetric finite element model of the core spray nozzle was developed in Reference [1] using ANSYS [2]. The geometry used in Reference [1] was utilized in this calculation. The material properties are taken at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F, which will be applied to the FE model for Green's Function development. Table 1 lists the material properties at 300°F. The meshed model is shown in Figure 1.

## Table 1: Material Properties @ 300°F [(1)]

| Part Description | Material | | Modulus of Elasticity, e+6 psi [EX] | Coefficient of Thermal Expansion, e-6, in/in/°F [ALPX] | Thermal Conductivity, Btu/hr-ft-°F [KXX] | Thermal Diffusivity, ft²/hr | Specific Heat, Btu/lb-°F [C] [(3)] | Poiss Ra [NU |
|---|---|---|---|---|---|---|---|---|
| Safe End | SB 166 | 72Ni-15Cr-8Fe N06600 | 29.8 | 7.9 | 9.6 | 0.160 | 0.1157 | 0.: |
| Weld Overlay | INCONEL 82 | | | | | | | |
| Nozzle | SA508 Class II | ¾ Ni-1/2Mo-1/3 Cr-V | 26.7 | 7.3 | 23.4 | 0.401 | 0.1193 | 0. |
| Vessel | SA533 Grade B | Mn-1/2Mo-1/2Ni | 28.0 | 7.7 | 23.4 | 0.401 | 0.1193 | 0. |
| 3/16 Clad | SA240 TP 304 | 18Cr-8Ni | 27.0 | 9.8 | 9.8 | 0.160 | 0.1252 | 0. |
| 8Ø x 10Ø Conc. Reduction[(2)] | SA312 TP304 | | | | | | | |
| Thermal Sleeve | SA312 TP304 | | | | | | | |

Notes:

1. The material properties applied in the analyses are taken from ASME Code, Section II, Part D 1998 Edition, with 2000 A information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a la for the original design code is acceptable, since later editions typically reflect more accurate material properties than was Material Properties are evaluated at 300°F from the 1998 ASME Code, 2000 Addenda, Section II, Part D, except for density and Poiss values [3].
2. In the FEM, the 8Ø x 10Ø Conc. Reduction was modeled as a straight pipe with the material properties of the original des was replaced by a new material (SA403 T316L). These two stainless steels have the same modulus of elasticity and therm
3. Calculated as $[k/(\rho d)]/12^3$.

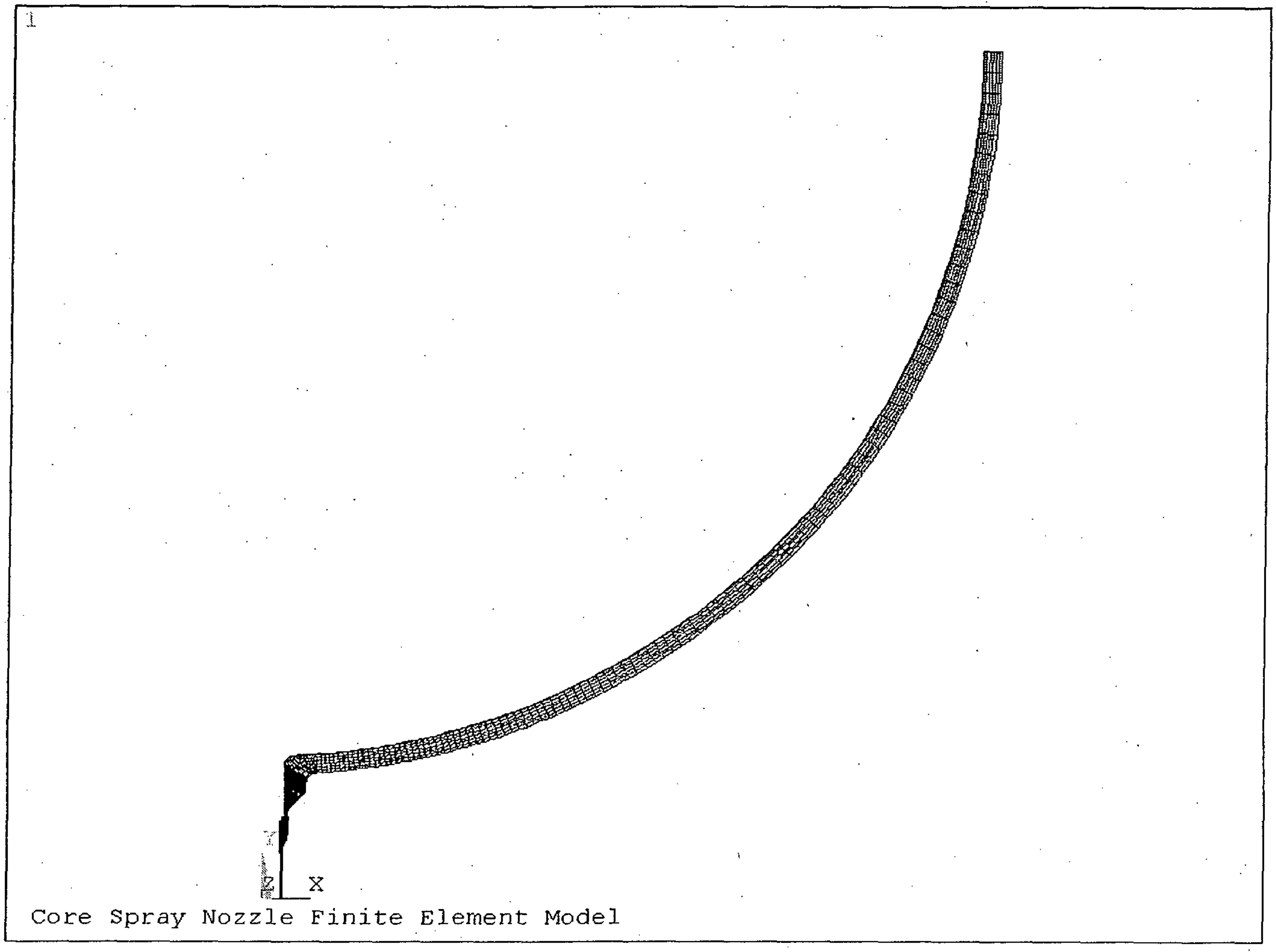



**Figure 1: ANSYS Finite Element Model**

## 3.0 APPLIED LOADS

Both pressure and thermal loads were applied to the finite element model.

### 3.1 Pressure Load

A uniform pressure of 1000 psi was applied along the inside surface of the core spray nozzle and the reactor vessel wall (Figure 2). A pressure load of 1000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the nozzle. This cap load was calculated as follows:

$$P_{CAP} = \frac{P \cdot D_i^2}{D_o^2 - D_i^2}$$

where:

P = Pressure = 1,000 psi

$D_i$ = Inside Diameter = 9.834 in

$D_o$ = Outside Diameter = 10.815 in

Therefore, the cap load is 4,774 psi. The calculated value was given a negative sign in order for it to exert tension on the end of the model. The nodes on the end of the safe end are coupled in the axial direction (UY, Figure 4) to ensure mutual displacement of the end of the nozzle due to attached piping. The boundary conditions at the end of the modeled portion of the reactor pressure vessel wall constructed to be "symmetric" (Figure 3).

The ANSYS input file VY_16Q_P.inp generates the core spray nozzle geometry from VY_CSN_Geom.inp [1] and performs the internal pressure load case just described. Figure 2, 3 and 4 show the internal pressure distribution, cap load, and symmetry conditions applied to the vessel end of the model, respectively.

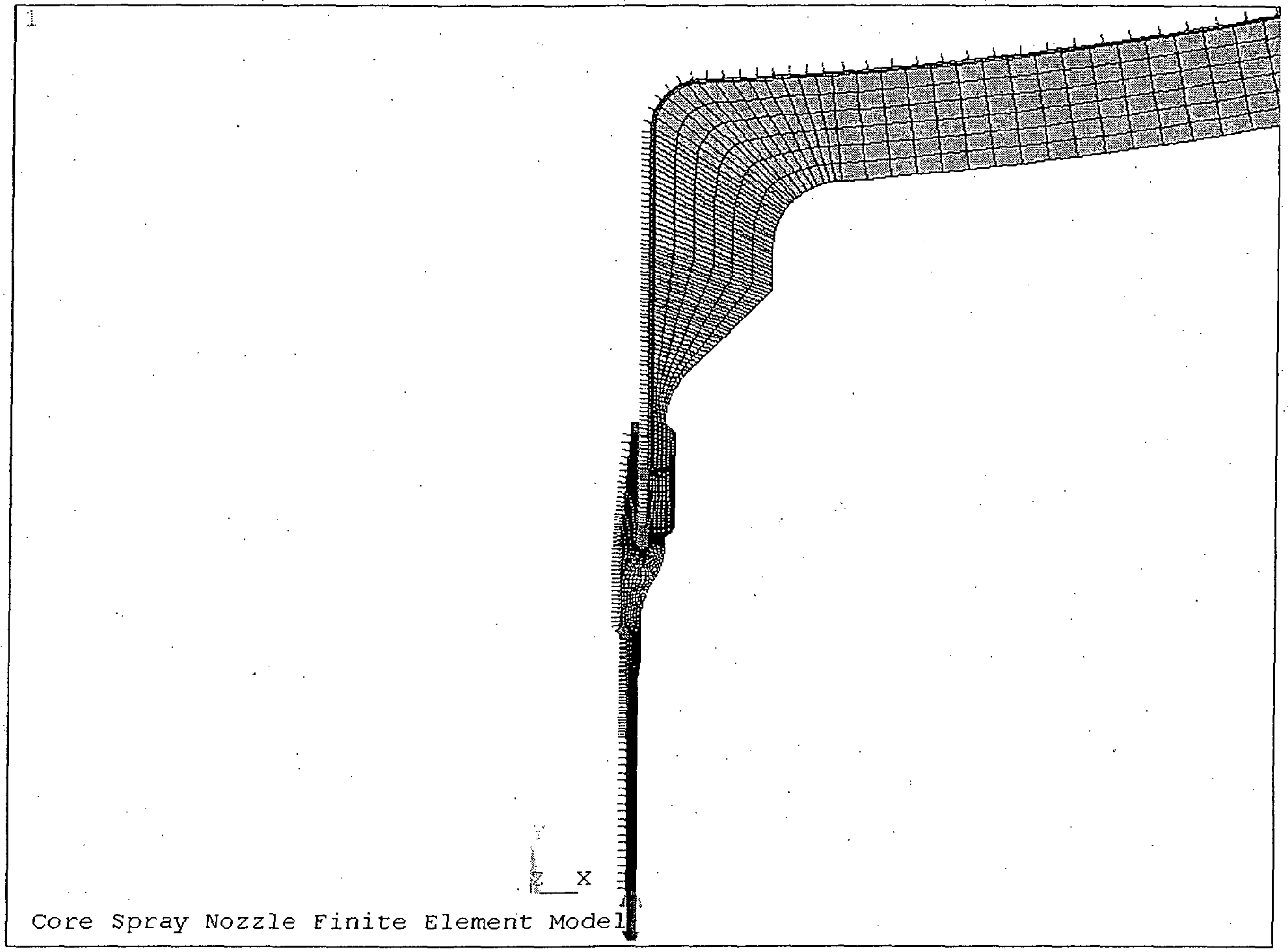



**Figure 2: Core Spray Nozzle Internal Pressure Distribution**

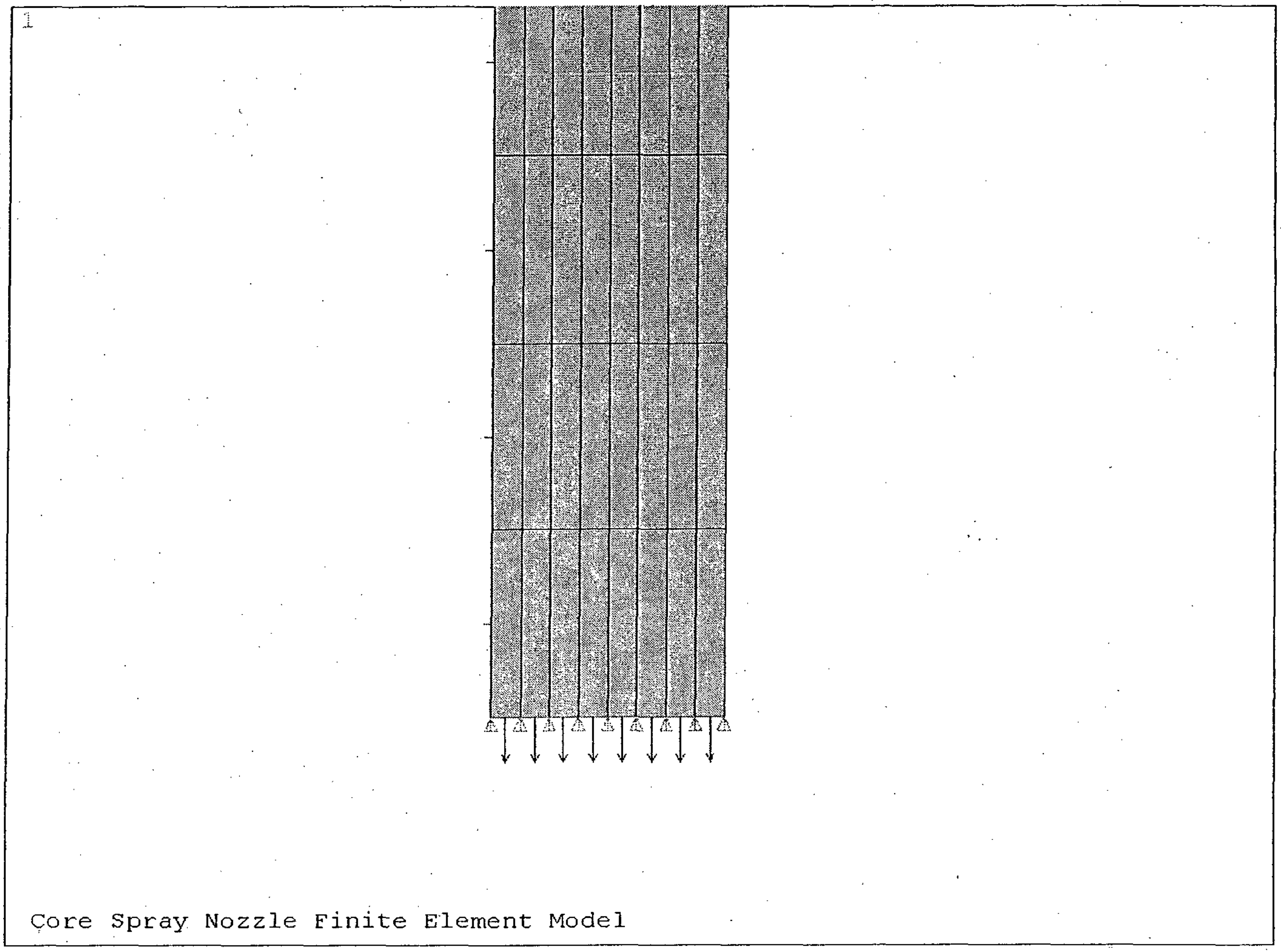



**Figure 3: Core Spray Nozzle Pressure Cap Load**

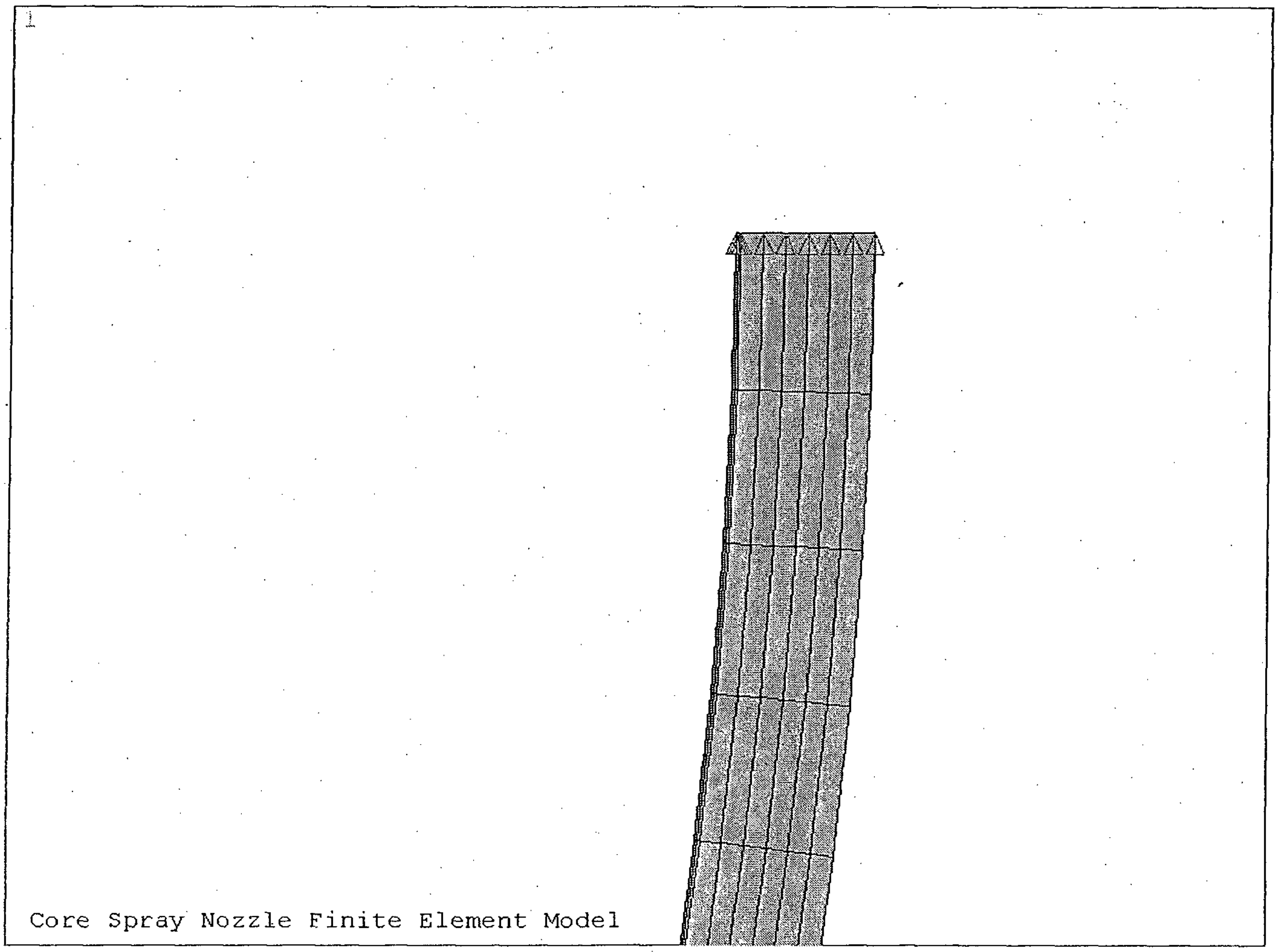



**Figure 4: Core Spray Nozzle Vessel Wall Boundary Conditions**

## 3.2 Thermal Load

Thermal loads are applied to the core spray nozzle model. The heat transfer coefficients (HTC) were determined using the methodology in the Excel spreadsheet "Heat Transfer Coefficients.xls", which is included in the project files. The HTCs were determined for various regions of the core spray FEM, (see Figure 5) for two different flow cases. The flow cases are for 100% (3200 gpm [6]) and 0% core spray flow through the nozzle.

The 0% flow case simulates a stagnant condition of the core spray nozzle when not in operation (i.e., the entire core spray nozzle is at the same temperature as the reactor pressure vessel due to reflooding). The HTCs for the no flow case are for free convection (stagnant) at the temperature of the reactor pressure vessel 500°F. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the core spray nozzle in the stagnant condition.

The 100% flow case simulates operational condition of the core spray nozzle (i.e., the entire core spray nozzle experiences 100°F water due to injection). The HTCs for the high flow case are for forced and free convection depending on the region of the FEM. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the core spray nozzle due to injection.

For both Green's Functions, a 500°F – 100°F thermal shock was run to determine the stress response. For the 0% flow case, the entire inside surface of the FEM was shocked. For the 100% flow case, only the nozzle flow path was shocked.

### 3.2.1 Boundary Fluid Temperatures

For the Green's Functions, a 500°F – 100°F thermal shock was run to determine the stress response to a degree change in temperature. The temperature on the exterior of the reactor, nozzle, safe end and the pipe is assumed to be 120 °F (ambient).

### 3.2.2 Heat Transfer Coefficients

Figure 5 shows where the heat transfer coefficients were applied to the FEM for the 0% (steady-state) and 100% core spray flow injection load case. For all the regions, the applied heat transfer coefficients and the initial temperatures are summarized in Table 2. The heat transfer coefficient for outside the reactor vessel wall is 0.2 BTU/hr-ft$^2$-°F and the heat transfer coefficient for inside the reactor vessel wall is 500 BTU/Hr-ft$^2$-°F, from page I-T7-5 of Reference [8].

Table 3 through Table 12 show the excel spreadsheets to calculate the HTC for regions 1, 3, 5, 7, and 9 respectively. These tables calculate the HTC for a certain part of the nozzle using the geometry of the bounding piping, the flow rate, and other physical fluid parameters. These tables calculate the Reynolds, Grashof and Rayleigh numbers in order to determine the HTC for inside surface/annulus forced and natural convection [4]. For several regions, the resultant HTCs had to be calculated from the partial heat transfer coefficients. These resultant HTCs are summarized in Table 13. In regions 2, 4, 6, 8, and 10 the HTCs are interpolated because of the complexity of the material profile.

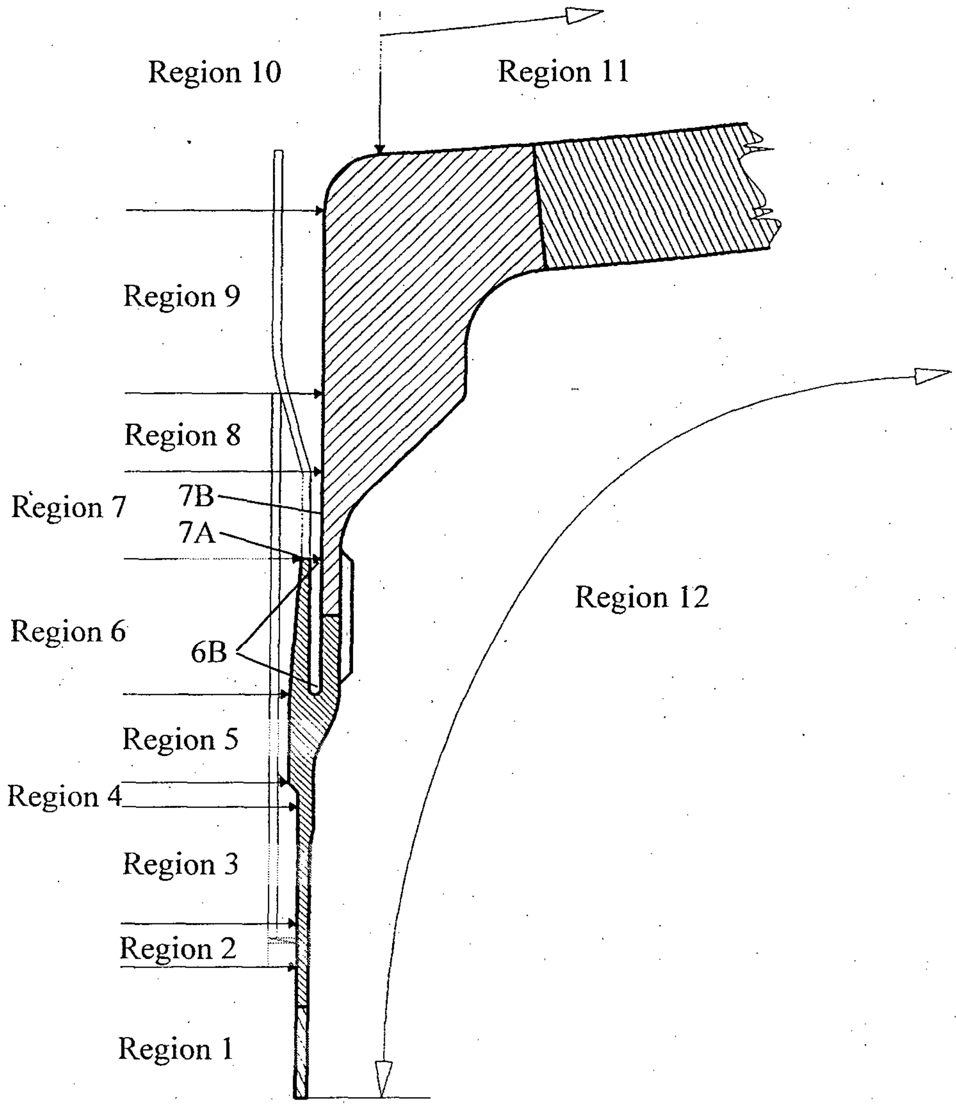



**Figure 5: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries (not to scale)**

**Table 2: Heat Transfer Coefficients**

| Regions | 0% Flow | | 100% Flow | |
|---|---|---|---|---|
| | Initial Temperature °F | HTC Btu/hr-ft$^2$-°F | Initial Temperature °F | HTC Btu/hr-ft$^2$-°F |
| R1 | 500 | 143 | 500 | 2693 |
| R2 | 500 | Interpolated | 500 | Interpolated |
| R3 (1) | 500 | 39 | 500 | 52 |
| R4 | 500 | Interpolated | 500 | Interpolated |
| R5 (1) | 500 | 47 | 500 | 66 |
| R6 | 500 | Interpolated | 500 | Interpolated |
| R6B | 500 | 97 | 500 | 97 |
| R7A (1) | 500 | 38 | 500 | 50 |
| R7B (1) | 500 | 20 | 500 | 23 |
| R8 | 500 | Interpolated | 500 | Interpolated |
| R9 (1) | 500 | 33 | 500 | 41 |
| R10 | 500 | Interpolated | 500 | Interpolated |
| R11 | 500 | 500 | 500 | 500 |
| R12 | 120 | 0.20 | 120 | 0.2 |

(1) See Table 13

# Table 3: Heat Transfer Coefficients for Region 1

| | | | | | | |
|---|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 9.834 | inches = | 0.820 | ft | | |
| | | = | 0.250 | m | | |
| Flow, % of rated = | 100% | | | | | |
| Fluid Velocity, V = | 13.517 | ft/sec = | 3,200.0 | gpm = | 1.234236214 | Mlb/hr |
| Characteristic Length, L = D = | 0.820 | ft = | 0.250 | m | | |

| | | |
|---|---|---|
| 100% rated flow = | 3,200 | gpm |
| @ T = | 549 | °F |
| Density, ρ = | 48.087 | $lbm/ft^3$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T_{fluid} - T_{surface}$, ΔT = assumed to be 12% of fluid temperature = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| *Note: The above assumption is based on experience with past RPV heat transfer analyses.* = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] | | | | | | | Units |
|---|---|---|---|---|---|---|---|---|---|
| | | 70 | 100 | 200 | 300 | 400 | 500 | 600 | °F |
| | | 21.11 | 37.78 | 93.33 | 148.89 | 204.44 | 260.00 | 315.56 | °C |
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| (Prandtl Number) | | | | | | | | | |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | ρVD/μ | 1.0307E+06 | 1.5019E+06 | 3.2317E+06 | 4.8825E+06 | 6.3843E+06 | 7.7540E+06 | 8.1118E+06 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 1.3522E+08 | 7.0314E+08 | 1.3383E+10 | 6.9351E+10 | 2.2021E+11 | 5.7264E+11 | 1.1964E+12 | --- |
| Rayleigh Number, Ra | GrPr | 9.4382E+08 | 3.1712E+09 | 2.5562E+10 | 8.4608E+10 | 2.0920E+11 | 4.9189E+11 | 1.2802E+12 | --- |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 7,765.07 | 9,257.25 | 13,050.72 | 15,291.12 | 16,581.64 | 16,999.27 | 16,154.74 | $W/m^2$-°C |
| | | 1,367.53 | 1,630.33 | 2,298.41 | 2,692.98 | 2,920.25 | 2,993.80 | 2,845.07 | $Btu/hr-ft^2$-°F |
| | | 2.638E-03 | 3.145E-03 | 4.434E-03 | 5.195E-03 | 5.633E-03 | 5.775E-03 | 5.488E-03 | $Btu/sec-in^2$-°F |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 256 of [4]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 231.44 | 329.18 | 597.32 | 811.84 | 984.52 | 1,113.82 | 1,187.70 | $W/m^2$-°C |
| | | 40.76 | 57.97 | 105.20 | 142.98 | 173.39 | 196.16 | 209.17 | $Btu/hr-ft^2$-°F |
| | | 7.863E-05 | 1.118E-04 | 2.029E-04 | 2.758E-04 | 3.345E-04 | 3.784E-04 | 4.035E-04 | $Btu/sec-in^2$-°F |

# Table 4: First Partial Heat Transfer Coefficients for Region 3

| | | | | | |
|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 7.981 | inches = | 0.665 | ft | |
| | | = | 0.203 | m | |
| Flow, % of rated = | 100% | | | | |
| Fluid Velocity, V = | 20.522 | ft/sec = | 3,200.0 | gpm = | 1.234236214 Mlb/hr |
| Characteristic Length, L = D = | 0.665 | ft = | 0.203 | m | |

| | | |
|---|---|---|
| 100% rated flow = | 3,200 | gpm |
| @ T = | 549 | °F |
| Density, ρ = | 48.087 | lbm/ft³ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T_{fluid} - T_{surface}$, ΔT = assumed to be 12% of fluid temperature = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| *Note: The above assumption is based on experience with past RPV heat transfer analyses.* = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | kg/m³ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | lbm/ft³ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | m³/m³-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | ft³/ft³-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | m/s² |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | ft/s² |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | — |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | **°F** |
| Reynold's Number, Re | ρVD/μ | 1.2700E+06 | 1.8507E+06 | 3.9821E+06 | 6.0161E+06 | 7.8665E+06 | 9.5543E+06 | 9.9952E+06 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 7.2279E+07 | 3.7586E+08 | 7.1540E+09 | 3.7071E+10 | 1.1771E+11 | 3.0610E+11 | 6.3954E+11 | --- |
| Rayleigh Number, Ra | GrPr | 5.0451E+08 | 1.6951E+09 | 1.3664E+10 | 4.5226E+10 | 1.1183E+11 | 2.6294E+11 | 6.8430E+11 | --- |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 11,307.23 | 13,480.10 | 19,004.02 | 22,266.42 | 24,145.63 | 24,753.78 | 23,524.01 | W/m²-°C |
| | | 1,991.36 | 2,374.03 | 3,346.87 | 3,921.42 | 4,252.38 | 4,359.48 | 4,142.90 | Btu/hr-ft²-°F |
| | | 3.841E-03 | 4.580E-03 | 6.456E-03 | 7.564E-03 | 8.203E-03 | 8.409E-03 | 7.992E-03 | Btu/sec-in²-°F |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 289 of [4]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 243.85 | 346.81 | 629.32 | 855.34 | 1,037.27 | 1,173.50 | 1,251.33 | W/m²-°C |
| | | 42.94 | 61.08 | 110.83 | 150.64 | 182.68 | 206.67 | 220.38 | Btu/hr-ft²-°F |
| | | 8.284E-05 | 1.178E-04 | 2.138E-04 | 2.906E-04 | 3.524E-04 | 3.987E-04 | 4.251E-04 | Btu/sec-in²-°F |

# Table 5: Second Partial Heat Transfer Coefficients for Region 3

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 9.834 | inches = | 0.820 | ft | | | | |
| | | = | 0.250 | m | | | | |
| Outer Pipe, Inside radius, $r_o$ = | 4.917 | inches = | 0.410 | ft | | | | |
| | | | 0.125 | m | | | | |
| Inner Pipe Outside Diameter, D = | 8.625 | inches = | 0.719 | ft | | | | |
| | | = | 0.219 | m | | | | |
| Inner Pipe, Outside radius, $r_i$ = | 4.3125 | inches = | 0.359 | ft | | | | |
| | | | 0.110 | m | | | | |
| Fluid Velocity, V = | 13.517 | ft/sec = | 3200.000 | gpm | | | | |
| Characteristic Length, L = D = | 0.820 | ft = | 0.250 | m | | | | |
| (Outside) $T_{fluid} - T_{surface}$, ΔT = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | $\rho VD/\mu$ | 1030724 | 1501950 | 3231741 | 4882481 | 6384268 | 7754027 | 8111787 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 135217684.2 | 703144247.6 | 13383382850 | 69350803914 | 2.2021E+11 | 5.72636E+11 | 1.19642E+12 | --- |
| Grashof Number, $Gr_\delta$ | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | 3.14E+04 | 1.63E+05 | 3.11E+06 | 1.61E+07 | 5.11E+07 | 1.33E+08 | 2.78E+08 | --- |
| Rayleigh Number, Ra | GrPr | 943819435.9 | 3171180557 | 25562261244 | 84607980776 | 2.092E+11 | 4.91894E+11 | 1.28017E+12 | --- |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 2.19E+05 | 7.37E+05 | 5.94E+06 | 1.97E+07 | 4.86E+07 | 1.14E+08 | 2.97E+08 | --- |

*From [4]:*

***Annulus Natural Convection Heat Transfer Coefficient:***

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Case: | Enclosed cylinder | | C = | 0.40 | n = | 0.20 | (see page 291 of [5]) | | |
| $H_{free}$ | $C(Gr_\delta Pr)^n k/(r_o-r_i)$ | 182.78 | 244.68 | 400.00 | 512.07 | 593.51 | 643.36 | 653.99 | $W/m^2$-°C |
| | | 32.19 | 43.09 | 70.45 | 90.18 | 104.53 | 113.30 | 115.18 | $Btu/hr\text{-}ft^2$-°F |

# Table 6: First Partial Heat Transfer Coefficients for Region 5

| | | | | | |
|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 7.981 | inches = | 0.665 | ft | |
| | | = | 0.203 | m | |
| Flow, % of rated = | 100% | | | | |
| Fluid Velocity, V = | 20.522 | ft/sec = | 3,200.0 | gpm = | 1.234236214 Mlb/hr |
| Characteristic Length, L = D = | 0.665 | ft = | 0.203 | m | |

| | | |
|---|---|---|
| 100% rated flow = | 3,200 | gpm |
| @ T = | 549 | °F |
| Density, $\rho$ = | 48.087 | $lbm/ft^3$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T_{fluid} - T_{surface}$, $\Delta T$ = assumed to be 12% of fluid temperature = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| *Note: The above assumption is based on experience with past RPV heat transfer analyses.* = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k (Thermal Conductivity) | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ (Specific Heat) | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| $\rho$ (Density) | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| $\beta$ (Volumetric Rate of Expansion) | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g (Gravitational Constant) | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| $\mu$ (Dynamic Viscosity) | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | $\rho VD/\mu$ | 1.2700E+06 | 1.8507E+06 | 3.9821E+06 | 6.0161E+06 | 7.8665E+06 | 9.5543E+06 | 9.9952E+06 | — |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 7.2279E+07 | 3.7586E+08 | 7.1540E+09 | 3.7071E+10 | 1.1771E+11 | 3.0610E+11 | 6.3954E+11 | — |
| Rayleigh Number, Ra | GrPr | 5.0451E+08 | 1.6951E+09 | 1.3664E+10 | 4.5226E+10 | 1.1183E+11 | 2.6294E+11 | 6.8430E+11 | — |
| *From [4]:* ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 11,307.23 | 13,480.10 | 19,004.02 | 22,266.42 | 24,145.63 | 24,753.78 | 23,524.01 | $W/m^2$-°C |
| | | 1,991.36 | 2,374.03 | 3,346.87 | 3,921.42 | 4,252.38 | 4,359.48 | 4,142.90 | $Btu/hr-ft^2$-°F |
| | | 3.841E-03 | 4.580E-03 | 6.456E-03 | 7.564E-03 | 8.203E-03 | 8.409E-03 | 7.992E-03 | $Btu/sec-in^2$-°F |
| *From [4]:* ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 289 of [4]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 243.85 | 346.81 | 629.32 | 855.34 | 1,037.27 | 1,173.50 | 1,251.33 | $W/m^2$-°C |
| | | 42.94 | 61.08 | 110.83 | 150.64 | 182.68 | 206.67 | 220.38 | $Btu/hr-ft^2$-°F |
| | | 8.284E-05 | 1.178E-04 | 2.138E-04 | 2.906E-04 | 3.524E-04 | 3.987E-04 | 4.251E-04 | $Btu/sec-in^2$-°F |

# Table 7: Second Partial Heat Transfer Coefficients for Region 5

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Title = | No Flow Region between nozzle and thermal sleeve | | | | | | | |
| Pipe Inside Diameter, D = | 9.000 | inches = | 0.750 | ft | | | | |
| | | = | 0.229 | m | | | | |
| Outer Pipe, Inside radius, $r_o$ = | 4.5 | inches = | 0.375 | ft | | | | |
| | | | 0.114 | m | | | | |
| Inner Pipe Outside Diameter, D = | 8.625 | inches = | 0.719 | ft | | | | |
| | | = | 0.219 | m | | | | |
| Inner Pipe, Outside radius, $r_i$ = | 4.3125 | inches = | 0.359 | ft | | | | |
| | | | 0.110 | m | | | | |
| Fluid Velocity, V = | 16.138 | ft/sec = | 3200.000 | gpm | | | | |
| Characteristic Length, L = D = | 0.750 | ft = | 0.229 | m | | | | |
| (Outside) $T_{fluid} - T_{surface}$, ΔT = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k (Thermal Conductivity) | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ (Specific Heat) | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ (Density) | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β (Volumetric Rate of Expansion) | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g (Gravitational Constant) | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ (Dynamic Viscosity) | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | **°F** |
| Reynold's Number, Re | $\rho VD/\mu$ | 1126238 | 1641130 | 3531215 | 5334924 | 6975877 | 8472567 | 8863480 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 103650263.4 | 538990790.5 | 10258947757 | 53160421562 | 1.68801E+11 | 4.3895E+11 | 9.17108E+11 | --- |
| Grashof Number, $Gr_\delta$ | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | 9.37E+02 | 4.87E+03 | 9.28E+04 | 4.81E+05 | 1.53E+06 | 3.97E+06 | 8.29E+06 | --- |
| Rayleigh Number, Ra | GrPr | 723478838.9 | 2430848465 | 19594590215 | 64855714305 | 1.60361E+11 | 3.77058E+11 | 9.81306E+11 | --- |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 6.54E+03 | 2.20E+04 | 1.77E+05 | 5.86E+05 | 1.45E+06 | 3.41E+06 | 8.87E+06 | --- |
| *From [4]:* | | | | | | | | | |
| ***Annulus Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.40 | n = | 0.20 | (see page 291 of [5]) | | |
| $H_{free}$ | $C(Gr_\delta Pr)^n k/(r_o-r_i)$ | 291.94 | 390.80 | 638.87 | 817.88 | 947.95 | 1,027.56 | 1,044.55 | $W/m^2$-°C |
| | | 51.41 | 68.83 | 112.51 | 144.04 | 166.95 | 180.97 | 183.96 | Btu/hr-$ft^2$-°F |

# Table 8: First Partial Heat Transfer Coefficients for Region 7

| | | | | | | |
|---|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 7.981 | inches = | 0.665 | ft | | |
| | | = | 0.203 | m | | |
| Flow, % of rated = | 100% | | | | | |
| Fluid Velocity, V = | 20.522 | ft/sec = | 3,200.0 | gpm = | 1.234236214 | Mlb/hr |
| Characteristic Length, L = D = | 0.665 | ft = | 0.203 | m | | |

| | | |
|---|---|---|
| 100% rated flow = | 3,200 | gpm |
| @ T = | 549 | °F |
| Density, ρ = | 48.087 | $lbm/ft^3$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T_{fluid} - T_{surface}$, ΔT = assumed to be 12% of fluid temperature = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

*Note: The above assumption is based on experience with past RPV heat transfer analyses.*

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | ρVD/μ | 1.2700E+06 | 1.8507E+06 | 3.9821E+06 | 6.0161E+06 | 7.8665E+06 | 9.5543E+06 | 9.9952E+06 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 7.2279E+07 | 3.7586E+08 | 7.1540E+09 | 3.7071E+10 | 1.1771E+11 | 3.0610E+11 | 6.3954E+11 | --- |
| Rayleigh Number, Ra | GrPr | 5.0451E+08 | 1.6951E+09 | 1.3664E+10 | 4.5226E+10 | 1.1183E+11 | 2.6294E+11 | 6.8430E+11 | --- |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 11,307.23 | 13,480.10 | 19,004.02 | 22,266.42 | 24,145.63 | 24,753.78 | 23,524.01 | $W/m^2$-°C |
| | | 1,991.36 | 2,374.03 | 3,346.87 | 3,921.42 | 4,252.38 | 4,359.48 | 4,142.90 | $Btu/hr-ft^2$-°F |
| | | 3.841E-03 | 4.580E-03 | 6.456E-03 | 7.564E-03 | 8.203E-03 | 8.409E-03 | 7.992E-03 | $Btu/sec-in^2$-°F |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 289 of [4]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 243.85 | 346.81 | 629.32 | 855.34 | 1,037.27 | 1,173.50 | 1,251.33 | $W/m^2$-°C |
| | | 42.94 | 61.08 | 110.83 | 150.64 | 182.68 | 206.67 | 220.38 | $Btu/hr-ft^2$-°F |
| | | 8.284E-05 | 1.178E-04 | 2.138E-04 | 2.906E-04 | 3.524E-04 | 3.987E-04 | 4.251E-04 | $Btu/sec-in^2$-°F |

# Table 9: Second Partial Heat Transfer Coefficients for Region 7

| | | | | | |
|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 10.020 | inches = | 0.835 | ft | |
| | | = | 0.255 | m | |
| Outer Pipe, Inside radius, $r_o$ = | 5.01 | inches = | 0.418 | ft | |
| | | | 0.127 | m | |
| Inner Pipe Outside Diameter, D = | 8.625 | inches = | 0.719 | ft | |
| | | = | 0.219 | m | |
| Inner Pipe, Outside radius, $r_i$ = | 4.3125 | inches = | 0.359 | ft | |
| | | | 0.110 | m | |
| Fluid Velocity, V = | 13.020 | ft/sec = | 3200.000 | gpm | |
| Characteristic Length, L = D = | 0.835 | ft = | 0.255 | m | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Outside) $T_{fluid} - T_{surface}$, $\Delta T$ = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70. / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | kg/m$^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | lbm/ft$^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | m$^3$/m$^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | ft$^3$/ft$^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | m/s$^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | ft/s$^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | **°F** |
| Reynold's Number, Re | $\rho VD/\mu$ | 1011591 | 1474069 | 3171750 | 4791848 | 6265758 | 7610090 | 7961209 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 143036227.2 | 743801381.9 | 14157235436 | 73360798959 | 2.32943E+11 | 6.05747E+11 | 1.2656E+12 | --- |
| *Grashof Number, $Gr_\delta$* | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | *4.82E+04* | *2.51E+05* | *4.78E+06* | *2.47E+07* | *7.86E+07* | *2.04E+08* | *4.27E+08* | --- |
| Rayleigh Number, Ra | GrPr | 998392866.2 | 3354544233 | 27040319682 | 89500174730 | 2.21296E+11 | 5.20336E+11 | 1.35419E+12 | --- |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 3.37E+05 | 1.13E+06 | 9.12E+06 | 3.02E+07 | 7.46E+07 | 1.76E+08 | 4.57E+08 | --- |

*From [4]:*

***Annulus Natural Convection Heat Transfer Coefficient:***

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Case: | Enclosed cylinder | | C = | 0.40 | n = | 0.20 | (see page 291 of [5]) | | |
| $H_{free}$ | $C(Gr_\delta Pr)^n k/(r_o-r_i)$ | 172.61 | 231.07 | 377.74 | 483.58 | 560.49 | 607.56 | 617.61 | W/m$^2$-°C |
| | | 30.40 | 40.69 | 66.53 | 85.17 | 98.71 | 107.00 | 108.77 | Btu/hr-ft$^2$-°F |

# Table 10: Third Partial Heat Transfer Coefficients for Region 7

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 11.750 | inches = | 0.979 | ft | | | | | |
| | | = | 0.298 | m | | | | | |
| Outer Pipe, Inside radius, $r_o$ = | 5.875 | inches = | 0.490 | ft | | | | | |
| | | | 0.149 | m | | | | | |
| Inner Pipe Outside Diameter, D = | 10.750 | inches = | 0.896 | ft | | | | | |
| | | = | 0.273 | m | | | | | |
| Inner Pipe, Outside radius, $r_i$ = | 5.375 | inches = | 0.448 | ft | | | | | |
| | | | 0.137 | m | | | | | |
| Fluid Velocity, V = | 9.468 | ft/sec = | 3200.000 | gpm | | | | | |
| Characteristic Length, L = D = | 0.979 | ft = | 0.298 | m | | | | | |
| (Outside) $T_{fluid} - T_{surface}$, ΔT = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F | |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C | |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] | | | | | | | Units |
|---|---|---|---|---|---|---|---|---|---|
| | | 70 | 100 | 200 | 300 | 400 | 500 | 600 | °F |
| | | 21.11 | 37.78 | 93.33 | 148.89 | 204.44 | 260.00 | 315.56 | °C |
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | **°F** |
| Reynold's Number, Re | $\rho VD/\mu$ | 862650 | 1257036 | 2704761 | 4086325 | 5343225 | 6489626 | 6789048 | — |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 230651605.4 | 1199409312 | 22829105215 | 1.18297E+11 | 3.75631E+11 | 9.76791E+11 | 2.04083E+12 | — |
| Grashof Number, $Gr_\delta$ | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | 1.78E+04 | 9.24E+04 | 1.76E+06 | 9.12E+06 | 2.89E+07 | 7.53E+07 | 1.57E+08 | --- |
| Rayleigh Number, Ra | GrPr | 1609948206 | 5409335995 | 43603590961 | 1.44323E+11 | 3.56849E+11 | 8.39063E+11 | 2.18369E+12 | — |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 1.24E+05 | 4.17E+05 | 3.36E+06 | 1.11E+07 | 2.75E+07 | 6.47E+07 | 1.68E+08 | — |
| *From [4]:* | | | | | | | | | |
| ***Annulus Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.40 | n = | 0.20 | (see page 291 of [5]) | | |
| $H_{free}$ | $C(Gr_\delta Pr)^n k/(r_o-r_i)$ | 197.20 | 263.98 | 431.55 | 552.46 | 640.32 | 694.10 | 705.57 | $W/m^2$-°C |
| | | 34.73 | 46.49 | 76.00 | 97.30 | 112.77 | 122.24 | 124.26 | Btu/hr-$ft^2$-°F |

# Table 11: First Partial Heat Transfer Coefficients for Region 9

| | | | | | |
|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 7.981 | inches = | 0.665 | ft | |
| | | = | 0.203 | m | |
| Flow, % of rated = | 100% | | | | |
| Fluid Velocity, V = | 20.522 | ft/sec = | 3,200.0 | gpm = | 1.234236214 Mlb/hr |
| Characteristic Length, L = D = | 0.665 | ft = | 0.203 | m | |

| | | |
|---|---|---|
| 100% rated flow = | 3,200 | gpm |
| @ T = | 549 | °F |
| Density, ρ = | 48.087 | lbm/ft³ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $T_{fluid} - T_{surface}$, ΔT = assumed to be 12% of fluid temperature = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C |

*Note: The above assumption is based on experience with past RPV heat transfer analyses.*

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7]: 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units: °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k (Thermal Conductivity) | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ (Specific Heat) | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.962 | 6.322 | kJ/kg-°C |
| | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ (Density) | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | kg/m³ |
| | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | lbm/ft³ |
| β (Volumetric Rate of Expansion) | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | m³/m³-°C |
| | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | ft³/ft³-°F |
| g (Gravitational Constant) | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | m/s² |
| | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | ft/s² |
| μ (Dynamic Viscosity) | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | — |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | **°F** |
| Reynold's Number, Re | ρVD/μ | 1.2700E+06 | 1.8507E+06 | 3.9821E+06 | 6.0161E+06 | 7.8665E+06 | 9.5543E+06 | 9.9952E+06 | — |
| Grashof Number, Gr | $g\beta\Delta T L^3/(\mu/\rho)^2$ | 7.2279E+07 | 3.7586E+08 | 7.1540E+09 | 3.7071E+10 | 1.1771E+11 | 3.0610E+11 | 6.3954E+11 | — |
| Rayleigh Number, Ra | GrPr | 5.0451E+08 | 1.6951E+09 | 1.3664E+10 | 4.5226E+10 | 1.1183E+11 | 2.6294E+11 | 6.8430E+11 | — |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Forced Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 11,307.23 | 13,480.10 | 19,004.02 | 22,266.42 | 24,145.63 | 24,753.78 | 23,524.01 | W/m²-°C |
| | | 1,991.36 | 2,374.03 | 3,346.87 | 3,921.42 | 4,252.38 | 4,359.48 | 4,142.90 | Btu/hr-ft²-°F |
| | | 3.841E-03 | 4.580E-03 | 6.456E-03 | 7.564E-03 | 8.203E-03 | 8.409E-03 | 7.992E-03 | Btu/sec-in²-°F |
| *From [4]:* | | | | | | | | | |
| ***Inside Surface Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 289 of [4]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 243.85 | 346.81 | 629.32 | 855.34 | 1,037.27 | 1,173.50 | 1,251.33 | W/m²-°C |
| | | 42.94 | 61.08 | 110.83 | 160.64 | 182.68 | 206.67 | 220.38 | Btu/hr-ft²-°F |
| | | 8.284E-05 | 1.178E-04 | 2.138E-04 | 2.906E-04 | 3.524E-04 | 3.987E-04 | 4.251E-04 | Btu/sec-in²-°F |

# Table 12: Second Partial Heat Transfer Coefficients for Region 9

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pipe Inside Diameter, D = | 11.750 | inches = | 0.979 | ft | | | | | |
| | | = | 0.298 | m | | | | | |
| Outer Pipe, Inside radius, $r_o$ = | 5.875 | inches = | 0.490 | ft | | | | | |
| | | | 0.149 | m | | | | | |
| Inner Pipe Outside Diameter, D = | 8.625 | inches = | 0.719 | ft | | | | | |
| | | = | 0.219 | m | | | | | |
| Inner Pipe, Outside radius, $r_i$ = | 4.3125 | inches = | 0.359 | ft | | | | | |
| | | | 0.110 | m | | | | | |
| Fluid Velocity, V = | 9.468 | ft/sec = | 3200.000 | gpm | | | | | |
| Characteristic Length, L = D = | 0.979 | ft = | 0.298 | m | | | | | |
| (Outside) $T_{fluid} - T_{surface}$, $\Delta T$ = | 8.40 | 12.00 | 24.00 | 36.00 | 48.00 | 60.00 | 72.00 | °F | |
| = | 4.67 | 6.67 | 13.33 | 20.00 | 26.67 | 33.33 | 40.00 | °C | |

| Water Property | Conversion Factor [4] | Value at Fluid Temperature, T [7] 70 / 21.11 | 100 / 37.78 | 200 / 93.33 | 300 / 148.89 | 400 / 204.44 | 500 / 260.00 | 600 / 315.56 | Units °F / °C |
|---|---|---|---|---|---|---|---|---|---|
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| $\rho$ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | kg/m³ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | lbm/ft³ |
| $\beta$ | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | m³/m³-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | ft³/ft³-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | m/s² |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | ft/s² |
| $\mu$ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | **70** | **100** | **200** | **300** | **400** | **500** | **600** | °F |
| Reynold's Number, Re | $\rho VD/\mu$ | 862650 | 1257036 | 2704761 | 4086325 | 5343225 | 6489626 | 6789048 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 230651605.4 | 1199409312 | 22829105215 | 1.18297E+11 | 3.75631E+11 | 9.76791E+11 | 2.04083E+12 | --- |
| Grashof Number, $Gr_\delta$ | $g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$ | 5.42E+05 | 2.82E+06 | 5.37E+07 | 2.78E+08 | 8.83E+08 | 2.30E+09 | 4.80E+09 | --- |
| Rayleigh Number, Ra | GrPr | 1609948206 | 5409335995 | 43603590961 | 1.44323E+11 | 3.56849E+11 | 8.39063E+11 | 2.18369E+12 | --- |
| Rayleigh Number, Ra | $Gr_\delta Pr$ | 3.79E+06 | 1.27E+07 | 1.03E+08 | 3.39E+08 | 8.39E+08 | 1.97E+09 | 5.13E+09 | --- |
| *From [4]:* | | | | | | | | | |
| ***Annulus Natural Convection Heat Transfer Coefficient:*** | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.40 | n = | 0.20 (see page 291 of [5]) | | | |
| $H_{free}$ | $C(Gr_\delta Pr)^n k/(r_o-r_i)$ | 125.02 | 167.35 | 273.58 | 350.24 | 405.94 | 440.03 | 447.30 | W/m²-°C |
| | | 22.02 | 29.47 | 48.18 | 61.68 | 71.49 | 77.50 | 78.78 | Btu/hr-ft²-°F |

Although the thermal sleeve was excluded from the analysis, its effect had to be included in the finite element model. For several thermal regions, the resultant HTCs had to be calculated from the partial heat transfer coefficients ($HTC_i$ in Table 13). These are generated by "Heat Transfer Coefficients.xls".

$$\frac{1}{HTC_{Res}} = \left(\frac{1}{HTC_I} + \frac{T_I}{TC_I}\right) + \left(\frac{1}{HTC_{II}} + \frac{T_{II}}{TC_{II}}\right) + \left(\frac{1}{HTC_{III}} + \frac{T_{III}}{TC_{III}}\right)$$

Where:

$HTC_{Res}$ = Resultant HTC
$HTC_i$ = HTC of i[th] material
$T_i$ = Thickness of i[th] material
$TC_i$ = Thermal Conductivity of i[th] material

The reference for this equation is [4].

**Table 13: Resultant Heat Transfer Coefficients for the Regions**

**100% Flow**

| Regions | HTC I | Material | | HTCII | Material | | HTCIII | HTC resultant |
|---|---|---|---|---|---|---|---|---|
| | | Thermal Conductivity, Btu/hr-ft-°F | Thickness [ft] | | Thermal Conductivity, Btu/hr-ft-°F | Thickness [ft] | | |
| R1 | 2,692.98 | | | | | | | 2693 |
| R2 | | | | | | | | |
| R3 | 3,921.42 | 9.8 | 0.0268 | 90.18 | | | | 71 |
| R4 | | | | | | | | |
| R5 | 3,921.42 | 9.8 | 0.0268 | 144.04 | | | | 101 |
| R6 | | | | | | | | |
| R6B | | | | | | | 97.30 | 97 |
| R7A | 3,921.42 | 9.8 | 0.0268 | 85.17 | | | | 68 |
| R7B | 3,921.42 | 9.8 | 0.0268 | 85.17 | 9.8 | 0.0304 | 97.30 | 36 |
| R8 | | | | | | | | |
| R9 | 3,921.42 | 9.8 | 0.0268 | 61.68 | | | | 52 |
| R10 | | | | | | | | |
| R11 | 500 | | | | | | | 500 |
| R12 | 0.2 | | | | | | | 0.2 |

**0% Flow**

| Regions | HTC I | Material | | HTCII | Material | | HTCIII | HTC resultant |
|---|---|---|---|---|---|---|---|---|
| | | Thermal Conductivity, Btu/hr-ft-°F | Thickness [ft] | | Thermal Conductivity, Btu/hr-ft-°F | Thickness [ft] | | |
| R1 | 142.98 | | | | | | | 143 |
| R2 | | | | | | | | |
| R3 | 150.64 | 9.8 | 0.0268 | 90.18 | | | | 49 |
| R4 | | | | | | | | |
| R5 | 150.64 | 9.8 | 0.0268 | 144.04 | | | | 61 |
| R6 | | | | | | | | |
| R6B | | | | | | | 97.30 | 97 |
| R7A | 150.64 | 9.8 | 0.0268 | 85.17 | | | | 47 |
| R7B | 150.64 | 9.8 | 0.0268 | 85.17 | 9.8 | 0.0304 | 97.30 | 29 |
| R8 | | | | | | | | |
| R9 | 150.64 | 9.8 | 0.0268 | 61.68 | | | | 39 |
| R10 | | | | | | | | |
| R11 | 500 | | | | | | | 500 |
| R12 | 0.2 | | | | | | | 0.2 |

## 4.0 THERMAL AND PRESSURE LOAD RESULTS

The two flow dependent thermal load cases outlined in previous section were run on the core spray FEM. For ANSYS, the thermal transient input files "VY_16Q_T100.inp," "VY_16Q_T0.inp," for 100% and 0% flow, respectively. The stress input filenames are "VY_16Q_ST100.inp"and "VY_16Q_ST0.inp," respectively.

The limiting safe end location was chosen based on the highest thermal stress intensity at 100% flow. Node 3719 on the inside surface of the core spray nozzle was selected for the safe end analysis and shown in Figure 6.

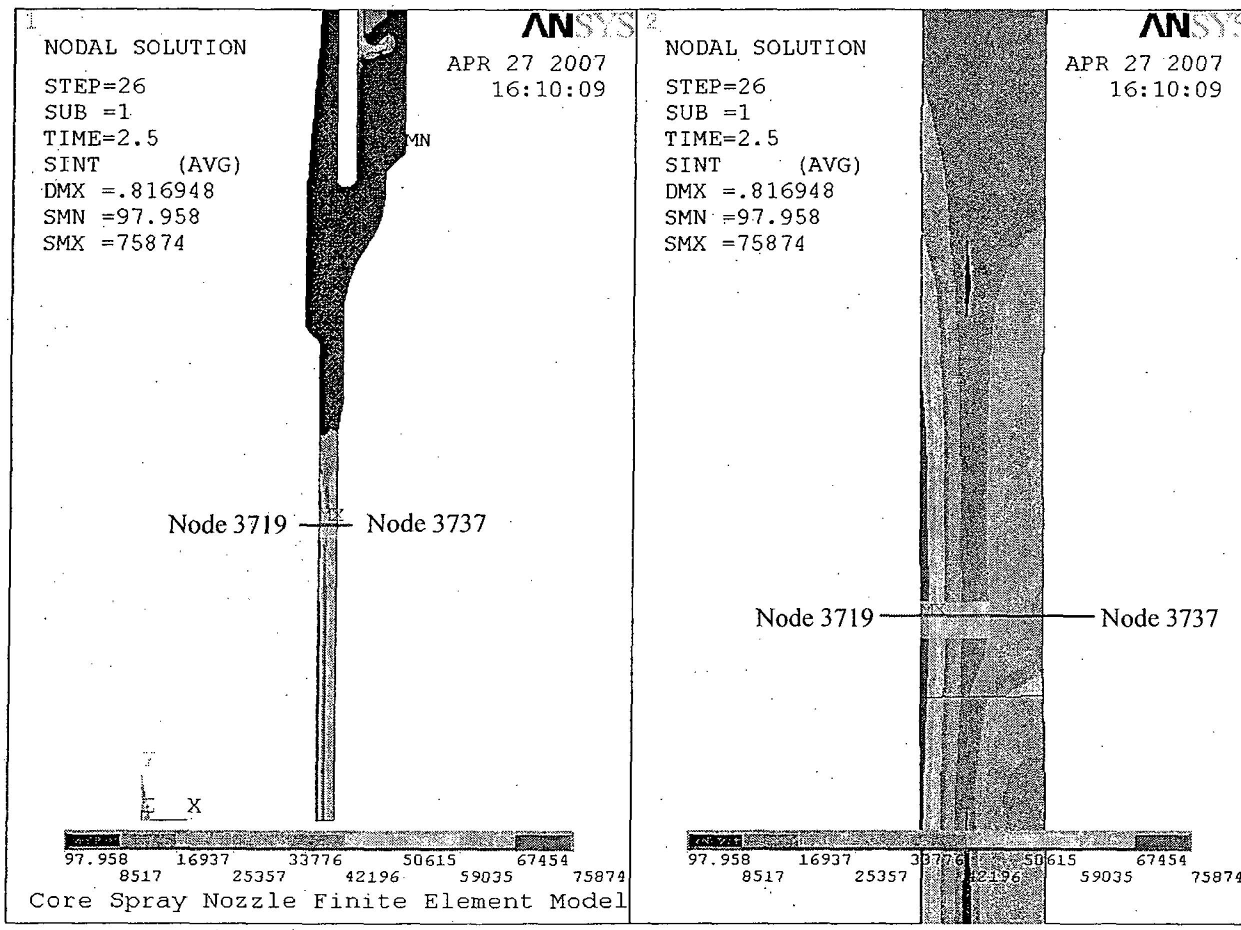



**Figure 6: Safe End Critical Thermal Stress Location, Node 3719**

The limiting blend radius location was chosen based upon the highest pressure stress intensity. Node 2166 on the inside surface of the blend radius was therefore selected for the nozzle forging analysis and shown in Figure 7. The highest thermal stress and pressure stress occur very close to the same location in the nozzle forging region. Therefore, this location is a reasonable choice for the limiting location.

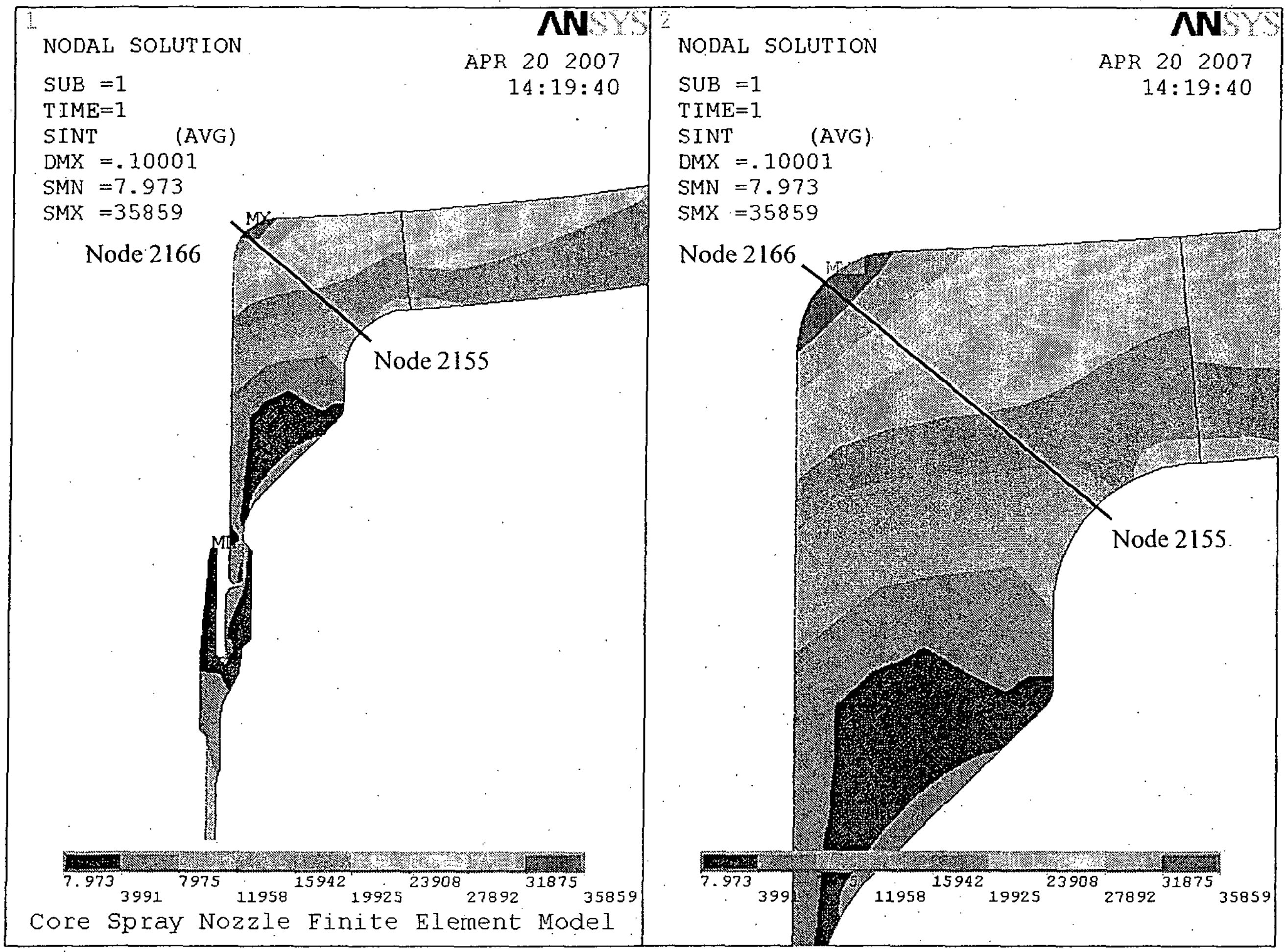



**Figure 7: Blend Radius Limiting Pressure Stress Location, Node 2166**

The stress intensity time history for the critical safe end and blend radius paths were extracted using the ANSYS post-processing file "extract100.inp" for 100% flow. This produced the two files, "SE_F100.out" and "BR_F100.out," which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the four files "SE_F100.cln, BR_F100.cln" and "SE_F100_INSIDE.RED, BR_F100_ INSIDE.RED."

The stress intensity time history for the critical safe end and blend radius paths were extracted using the ANSYS post-processing file "extract0.inp" for 0% flow. This produced the two files, "SE_F0.out" and "BR_F0.out," which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the four files "SE_F0.cln, BR_F0.cln" and "SE_F0_INSIDE.RED, BR_F0_ INSIDE.RED."

As the models were run with a 400°F step change in temperature, and the Green's Functions are for a 1°F step change in temperature, all data values were divided by 400. The governing Green's Functions for the core spray nozzle during 100% flow and 0% flow are shown in Figure 8 through Figure 11. The data for the Green's Functions is included in the files:

**0% Flow Rate:**

SE_Flow0_T_Green.xls
SE_Flow0_M+B-Green.xls
BLEND_Flow0_M+B_Green.xls
BLEND_Flow0_T_Green.xls

**100 Flow Rate:**

SE_Flow100_T_Green.xls
SE_Flow100_M+B-Green.xls
BLEND_Flow100_M+B_Green.xls
BLEND_Flow100_T_Green.xls

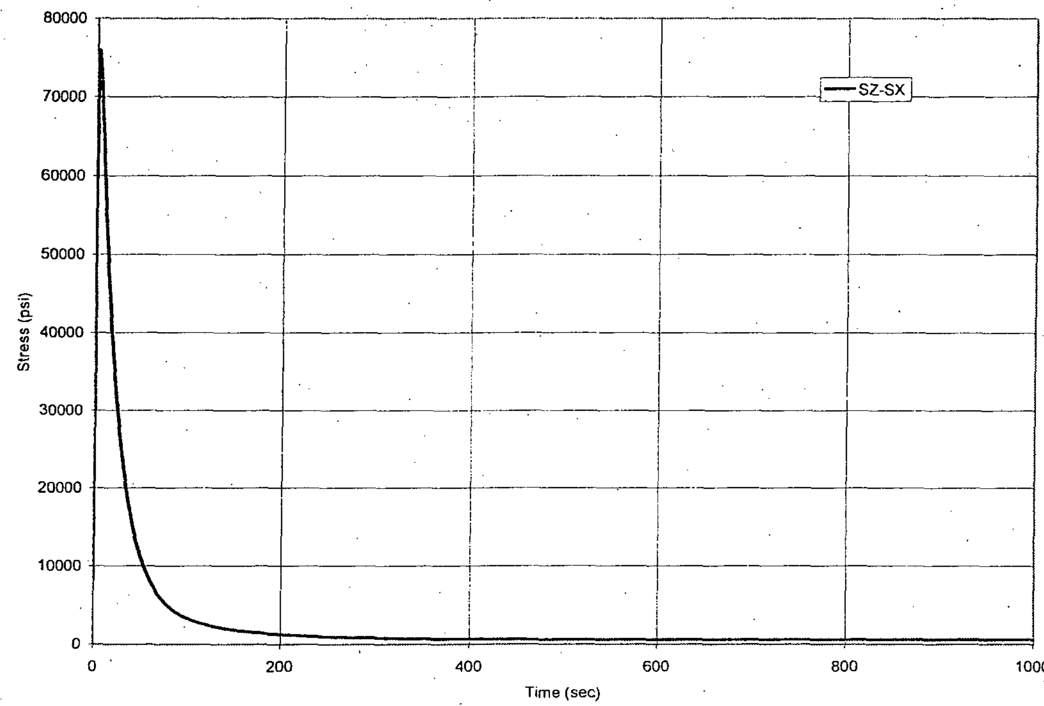



**Figure 8: Safe End Total Stress History, 100% Flow**

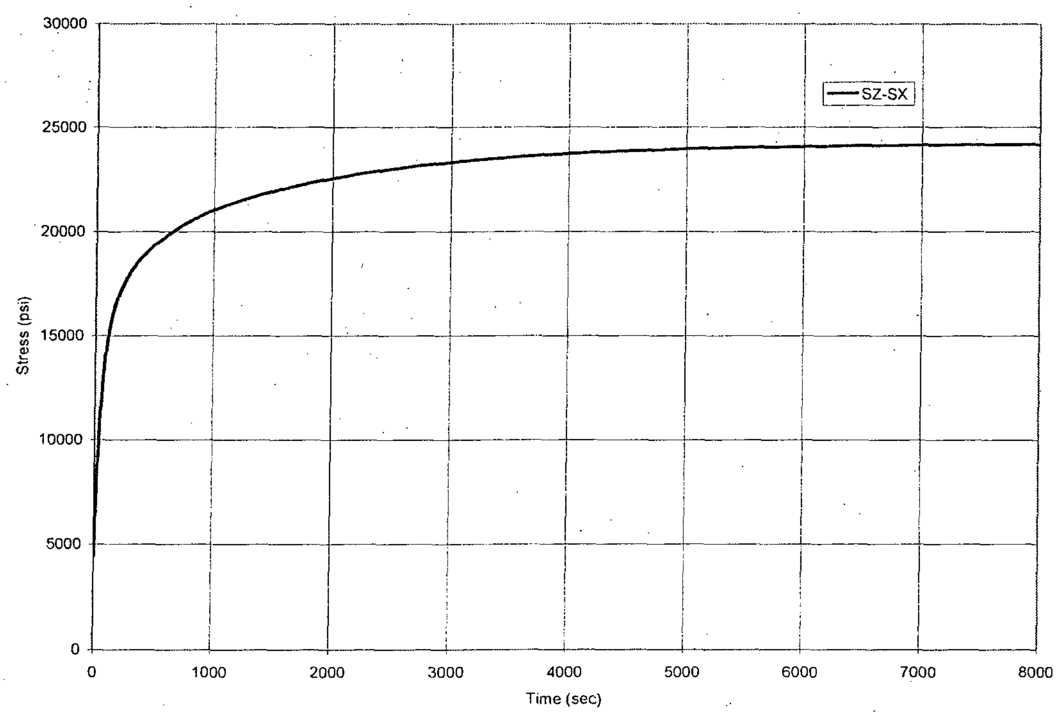



**Figure 9: Blend Radius Total Stress History, 100% Flow**

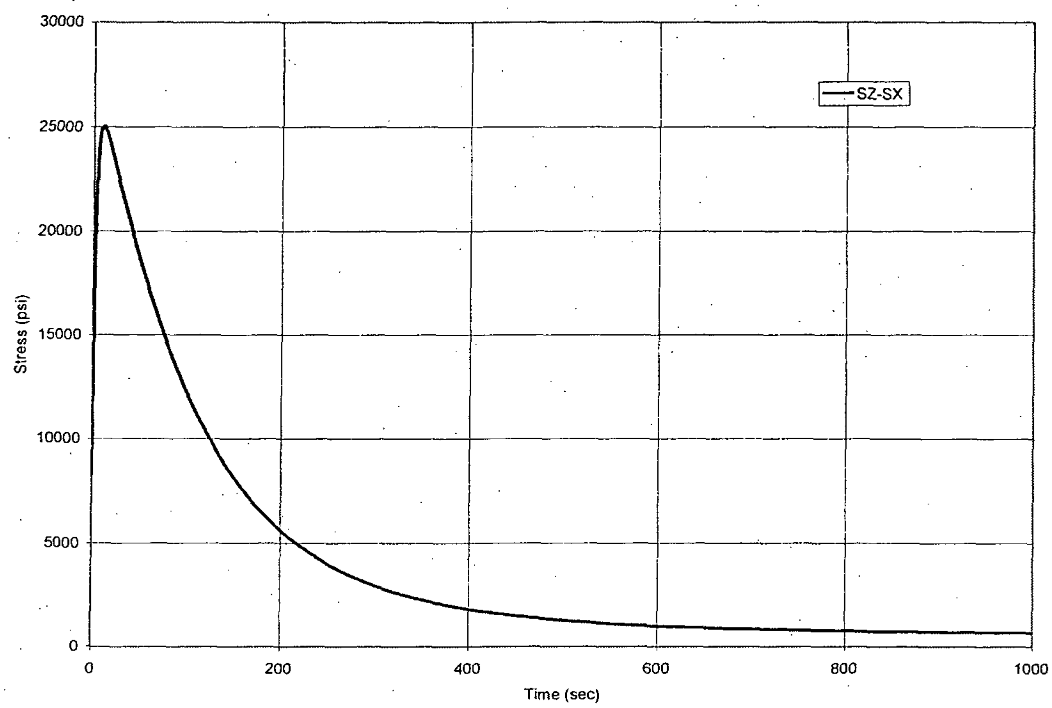



**Figure 10: Safe End Total Stress History, 0% Flow**

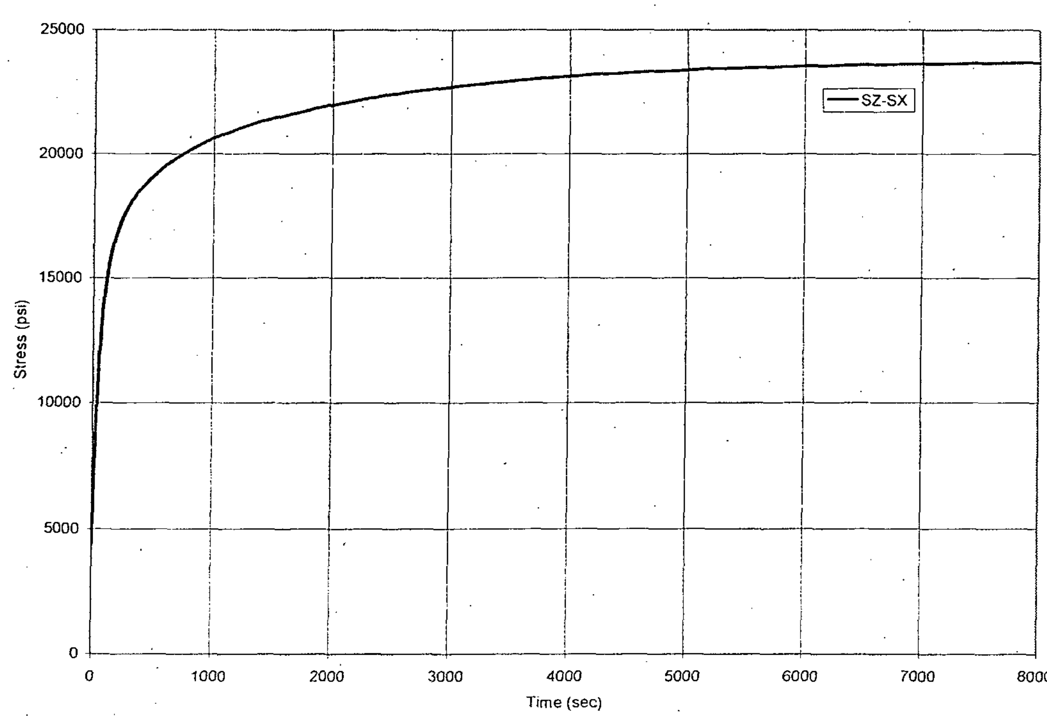



**Figure 11: Blend Radius Total Stress History, 0% Flow**

The pressure stress intensities for the safe end and blend radius paths were extracted using the ANSYS post-processing file "extractP.inp." This produced two files, SE_P.OUT for the safe end and BR_P.OUT for the blend radius.

Results of the internal pressure load case for Node 2166 (blend radius) is a total stress intensity of 35,860 psi and for Node 3719 (safe end), a total stress intensity of 12,030 psi. The membrane plus bending stress intensity at Node 2166 and Node 3719 are 34970 psi and 12,020 psi, respectively. Table 14 shows the final pressure results for the safe end and blend radius.

**Table 14: Pressure Results (1,000 psi)**

| Location | Membrane plus Bending Stress Intensity (psi) | Total Stress Intensity (psi) |
|---|---|---|
| Safe End | 12,020 | 12,030 |
| Blend Radius | 34,970 | 35,860 |

Results were also extracted from the vessel portion of the model to verify the accuracy of the results obtained from the ANSYS model, and to check the results due to the use of the 2.0 multiplier on the vessel radius. These results are contained in the file VESSEL_P.OUT. The radius of the finite element model (FEM) was multiplied by a factor of 2.0 [1] to account for the fact that the vessel portion of the 2D axisymmetric model is a sphere, but the true geometry is the intersection of two cylinders.

The equation for the membrane hoop stress in a sphere is:

$$\sigma = \left( \frac{(pressure) \times (radius)}{2 \times thickness} \right)$$

Considering a vessel base metal radius, R, of 105.906 inches increased by a factor of 2.0, a vessel base metal thickness, t, of 5.4375 inches, and an applied pressure, P, of 1,000 psi, the calculated stress for a sphere is PR/(2t) = 19,477 psi. This compares very well with the remote vessel wall membrane hoop stress from the ANSYS result file, VESSEL_P.OUT, of 18,530 psi. Thus, considering the peak total pressure stress of 35,860 psi reported above, the stress concentrating effect of the nozzle corner is 35,860/19,477 = 1.84. In other words, the peak nozzle corner stress is 1.84 times higher than nominal vessel wall stress for the 2D axisymmetric model.

The equation for the membrane hoop stress in a cylinder is:

$$\sigma = \left( \frac{(pressure) \times (radius)}{thickness} \right).$$

Based on the previous dimensions, the calculated stress for a cylinder without the 2.0 factor is 19,477 psi. Increasing this by a factor of 1.84 yields an expected peak nozzle corner stress of 35,838 psi, which would be expected from a cylindrical geometry that is representative of the nozzle configuration. Therefore, the result from the ANSYS file for the peak nozzle corner stress (35,860 psi) is close to the peak nozzle corner stress for a cylindrical geometry because of the use of the 2.0 multiplier. This is consistent with SI's experience where a factor of two increase in radius is typical for representing the three-dimensional (3D) effect in a 2D axisymmetric model.

## 5.0 REFERENCES


1. SI Calculation No. VY-16Q-308, Revision 0, "Core Spray Nozzle Finite Element Model".

2. ANSYS, Release 8.1A1 (w/Service Pack 1), ANSYS, Inc., June 2004.

3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.

4. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.

5. J. P. Holman, "Heat Transfer," 5th Edition, 1981.

6. Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.

7. N. P. Cheremisinoff, "Heat Transfer Pocket Handbook," Gulf Publishing Co., 1984.

8. CB&I RPV Stress Report, Section T7, "Thermal Analysis of Core Spray Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201, SI File No. VY-16Q-206.

# APPENDIX A

# FINITE ELEMENT ANALYSIS FILES

## ANSYS Input Files

| File Name | Description |
|---|---|
| vy_csn_geom.inp | ANSYS input file includes the geometry and material properties |
| Heat Transfer Coefficients.xls | Excel file to calculate Heat Transfer coefficients |
| VY_16Q_P.inp | ANSYS input file for the pressure stress analysis |
| VY_16Q_T100.inp | ANSYS input file for the thermal analysis, 100% flow rate |
| VY_16Q_T0.inp | ANSYS input file for the thermal analysis, 0% flow rate |
| VY_16Q_ST100.inp | ANSYS input file for the thermal stress analysis, 100% flow rate |
| VY_16Q_ST0.inp | ANSYS input file for the thermal stress analysis, 0% flow rate |
| extract100.inp | ANSYS input file to extract the limiting paths, 100% flow rate |
| extract0.inp | ANSYS input file to extract the limiting paths, 100% flow rate |
| extractP.inp | ANSYS input file to extract the limiting paths |
| extractVessel.inp | ANSYS input file to extract the membrane stress in the vessel wall |

## ANSYS Output Files

| File Name | Description |
|---|---|
| BR_F100.out | ANSYS output file, Results of running: extract100.inp, Blend Radius 100% Flow |
| SE_F100.out | ANSYS output file, Results of running: extract100.inp, Safe End 100% Flow |
| BR_F100.cln | Reduced ANSYS output file, contains the stress values in time, Blend Radius 100% Flow |
| SE_F100.cln | Reduced ANSYS output file, contains the stress values in time, Safe End 100% Flow |
| BR_F100_ INSIDE.RED | Reduced ANSYS output file, contains detailed stress values in time, Blend Radius 100% Flow |
| SE_F100_INSIDE.RED | Reduced ANSYS output file, contains detailed stress values in time, Safe End 100% Flow |
| | |
| BR_F0.out | ANSYS output file, Results of running: extract0.inp, Blend Radius 0% Flow |
| SE_F0.out | ANSYS output file, Results of running: extract0.inp, Safe End 0% Flow |
| BR_F100.cln | Reduced ANSYS output file, contains the stress values in time, Blend Radius 0% Flow |
| SE_F100.cln | Reduced ANSYS output file, contains the stress values in time, Safe End 0% Flow |
| BR_F0_ INSIDE.RED | Reduced ANSYS output file, contains detailed stress values in time, Blend Radius 0% Flow |
| SE_F0_INSIDE.RED | Reduced ANSYS output file, contains detailed stress values in time, Safe End 0% Flow |

**Structural Integrity Associates, Inc.**

# CALCULATION PACKAGE

File No.: VY-16Q-310

NEC-JH_13

Project No.: VY-16Q

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Fatigue Analysis of Core Spray Nozzle

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
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## Table of Contents



## List of Tables

List of Figures

## 1.0 OBJECTIVE

The purpose of this calculation is to perform a revised fatigue analysis for the core spray nozzle. Two locations will be analyzed for fatigue acceptance: the blend radius (SA508 Class II) and the safe end (SB 166 N06600). Both locations are chosen based on the highest overall stress of the analysis performed in Reference [1]. A revised fatigue usage will be determined for both locations, the nozzle forging and safe end, respectively. In the end, the environmental fatigue usage factors will be determined for the limiting locations.

## 2.0 METHODOLOGY

In order to provide an overall approach and strategy for evaluating the core spray nozzle, the Green's Function methodology and associated ASME Code stress and fatigue analyses are described in this section.

Revised stress and fatigue analyses are being performed for the core spray nozzle using ASME Code, Section III methodology. These analyses are being performed to address license renewal requirements to evaluate environmental fatigue for this component in response to Generic Aging Lessons Learned (GALL), Report [12] requirements. The revised analysis is being performed to refine the fatigue usage so that an environmental fatigue factor can be determined for subsequent license renewal efforts.

Two sets of rules are available under ASME Code, Section III, Class 1 [8]. Subparagraph NB-3600 of Section III provides simplified rules for analysis of piping components, and NB-3200 allows for more detailed analysis of vessel components. The NB-3600 piping equations combine by absolute sum the stresses due to pressure, moments and through wall thermal gradient effects, regardless of where within the pipe cross-section the maximum value of the components of stress are located. By considering stress signs, affected surface (inside or outside) and azimuthal position, the stress ranges may be significantly reduced. In addition, NB-3600 assigns stress indices by which the stresses are multiplied to conservatively incorporate the effects of geometric discontinuities. In NB-3200, stress indices are not required, as the stresses are calculated by finite element analysis and consider applicable stress concentration factors. In addition, NB-3200 methodology accounts for the different locations within a component where stresses due to thermal, pressure or other mechanical loading are a maximum. This generally results in a net reduction of the stress ranges and consequently, in the calculated fatigue usage. Article 4 [14] methodology was originally used to evaluate the core spray nozzle. NB-3200 methodology, which is the modern day equivalent to Article 4, is used in this analysis to be consistent with the Section III design bases for this component, as well as to allow a more detailed analysis of this component. In addition, several of the conservatisms originally used in the original core spray nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve a more refined CUF.

For the core spray nozzle evaluated as a part of this work, stress histories will be computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's Function integration scheme is similar in concept to the well-known Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [11]. A general outline is provided in this section.

The steps involved in the evaluation are as follows:

- Develop finite element model
- Develop heat transfer coefficients and boundary conditions for the finite element model
- Develop Green's Functions
- Develop thermal transient definitions
- Perform stress analysis to determine stresses for all thermal transients
- Perform fatigue analysis

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 8 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 9. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 9. These five step changes produce the five successive stress responses in the lower plot shown in Figure 9. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY core spray nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.

Fatigue calculations are performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology. Fatigue analysis is performed for the two limiting locations (one in the safe end and one in the nozzle forging, representing the two materials of the nozzle assembly) using the Green's Functions developed for these two locations and 60-year projected cycle counts.

Three Structural Integrity utility programs will be used to perform the fatigue analysis. The first two calculate stresses in response to transients. The transients analyzed are those described in the thermal cycle diagrams [2] for the core spray nozzle. These transients are shown in Figure 1– Figure 6. The temperatures and pressures for these transients have been modified to account for power uprate [3]. The power uprate pressures and temperatures were used for this analysis. The last program calculates fatigue based on the stress output. The three programs are STRESS.EXE, P-V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys, as required by ASME Code fatigue evaluation methods. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III range-pair methodology. All three programs are explained in detail and have been independently verified for generic use in the Reference [4] calculation.

In order to perform the fatigue analysis, Green's Functions are developed using the finite element model. Then, input files with the necessary data are prepared and the three utility computer programs are run. The first program (STRESS.EXE) requires the following three input files:

- Input file "GREEN.DAT": This file contains the Green's Function for the location being evaluated. For each flow condition, two Green's Functions are determined: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function. This allows computation of total stress, as well as membrane plus bending stress, which is necessary to compute $K_e$ per ASME Code, Section III requirements.
- Input file "GREEN.CFG": This file is a configuration file containing parameters that define the Green's Function (i.e., number of points, temperature drop analyzed, etc.).
- Input file "TRANSNT.INP": This file contains the input transient definition for all thermal transients to be analyzed for the location being evaluated.

Pressure and piping stress intensities are also included for each transient case, based on pressure stress results from finite element analysis and attached piping load calculations.

The second program (P-V.EXE) simply extracts only the maxima and minima stress (i.e., the peaks and valleys) from the stress histories generated by program STRESS.EXE.

The third program (FATIGUE.EXE) performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data consists of the output peak and valley history from program P-V.EXE, and a configuration input file that provides ASME Code configuration data relevant to the fatigue analysis (i.e., $K_e$ parameters, $S_m$, Young's modulus, etc.). The output is the final fatigue calculation for the location being evaluated.

The Green's Function methodology described above uses standard industry stress and fatigue analysis practices, and is the same as the methodology used in typical stress reports. Special approval for the use of this methodology is therefore not required.

## 3.0 ANALYSIS

The transients analyzed for the core spray nozzle were developed based on the definitions in the original RPV Design Specification [10], as modified for EPU [3], as well as more recent definitions based on BWR operating experience [2] for BWR. The final transients evaluated in the stress and fatigue analyses are shown in Figure 1 thru Figure 6.

The fatigue analysis involves the preparing of input files for, and running of three programs [4]. The programs STRESS.EXE and P-V.EXE are run together through the use of a batch file. The program FATIGUE.EXE is run after processing the output from P_V.EXE.

The steps associated with this process are described in the following sub-sections.

### 3.1 Transient Definitions (for program STRESS.EXE)

The program STRESS.EXE requires the following three input files for analyzing an individual transient:

- Green.dat. There are 8 stress history functions obtained from References [1]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. Both of the blend radius and the safe end have two stress history functions for flow condition of 0% and 100%.
- Green.cfg is configured as described in Reference [4].
- Transnt.inp. These files are created to represent the selected transients obtained from the thermal cycle diagrams [2] and redefined by power uprate [3]. Table 1 and Table 2 contain the loading defined for each transient. Based upon the thermal cycle diagram for the RPV and the core spray nozzle, the transients are split into the following groups based upon flow rate:
  - Transients 02, 03, 11, 14, 21-23 and 24 are run at 0% flow.
  - Transient 30 runs at 100% flow rate per [3]. The transient of emergency shutdown is numbered as 30.

The remaining transients are not included in this analysis, as temperature changes from them are considered negligible to have impact on the results.

### 3.2 Peak and Valley Points of the Stress History (for program P-V.EXE)

The program P-V.exe is then run to extract the peaks and valleys from the STRESS.OUT file produced by the STRESS.EXE program. The only input required for this program is STRESS.OUT and it outputs all the peaks and valleys to P-V.OUT. Columns 2 through 5 of Table 5 (for the blend radius) and Table 6 (for the safe end) show the final peak and valley output. The pressure for column six is then filled in using the thermal cycle diagrams. Pressure and piping loads have to be added to the peak and valley points to calculate the final stress values used for fatigue analysis.

### 3.3 Pressure Load

The pressure stress associated with a 1000 psi internal pressure was determined in Reference [1]. These values are as follows:

| Location | Membrane plus Bending Stress Intensity (psi) | Total Stress Intensity (psi) |
|---|---|---|
| Safe End | 12,020 | 12,030 |
| Blend Radius | 34,970 | 35,860 |

These pressure stress values for each location were linearly scaled according to the pressure of the transient. The actual pressure for column 6 of Table 5 and Table 6 is obtained from Reference [2] and shown in Tables 1 and 2. The scaled pressure stress values are shown in columns 7 and 8 of Table 5 (for the blend radius) and Table 6 (for the safe end).

The pressure stress is combined with the peak and valley points to calculate the final stress values used for fatigue analysis.

### 3.4 Attached Piping Loads

Additionally, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 7.

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first cut (blend radius) and second cut (safe end) locations using the following equations:

For Cut I:

$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:

$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:

$$M_{xy} = \sqrt{(M_x)_1^{\,2} + (M_y)_1^{\,2}}$$
$$F_{xy} = \sqrt{(F_x)_1^{\,2} + (F_y)_1^{\,2}}$$

For Cut II:

$$M_{xy} = \sqrt{(M_x)_2^{\,2} + (M_y)_2^{\,2}}$$
$$F_{xy} = \sqrt{(F_x)_2^{\,2} + (F_y)_2^{\,2}}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, PM, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$
$$(P_M)_\theta = \frac{Pa_N}{t_N}$$
$$(P_M)_R = -P$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^{\,2}}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^{\,2}}$$

Where:

$L_1$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.

| | | |
|---|---|---|
| $L_2$ | = | The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end. |
| $M_{xy}$ | = | The maximum bending moment in the xy plane. |
| $F_{yx}$ | = | The maximum shear force in the xy plane. |
| $N_z$ | = | The normal force per inch of circumference applied to the end of the nozzle in the z direction. |
| $q_N$ | = | The shear force per inch of circumference applied to the nozzle. |
| $R_N$ | = | The mid-wall nozzle radius. |

Because pressure was not considered in this analysis, the equations used for Cut I are valid for Cut II. In addition, the equations can be simplified as follows:

$$(P_M)_z = \frac{Nz}{t_N}$$

$$(P_M)_\theta = 0$$

$$(P_M)_R = 0$$

$$\tau_M = \frac{q_N}{t_N}$$

$$SI_{MAX} = 2(\tau_M)_{z\theta}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{Nz}{2t_N}\right)^2 + (\tau_M)_{z\theta}^{\;2}}$$

Per Reference [5], the core spray nozzle piping loads are as follows:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $F_x$ = | 2,500 | lbs | $M_x$ = | 22,000 | ft-lb | = | 264,000 | in-lb |
| $F_y$ = | 4,600 | lbs | $M_y$ = | 7,100 | ft-lb | = | 85,200 | in-lb |
| $F_z$ = | 1,700 | lbs | $M_z$ = | 8,800 | ft-lb | = | 150,600 | in-lb |

The location of the nozzle piping loads is assumed to be at the end of the connection of the safe end and the attached pipe. Therefore, the L1 is equal to 30.817 inches and the L2 is equal to 0.303 inches. The calculations for the blend radius and safe end are shown in Table 3 and Table 4. The first cut location is the middle of Green's Function cross section for the blend radius (Node 2181) per [1], and the second cut is from Node 3719 (inside) to Node 3737 (outside). The maximum stress intensities, due to piping loads are 322.52 psi at the blend radius and 6949.94 psi at the safe end, respectively. The piping load sign is set as the same as the thermal stress sign.

These piping stress values are scaled assuming no stress occurs at an ambient temperature of 70°F and the full values are reached at reactor design temperature, 575°F [2]. The scaled piping stress values are shown in columns 9 and 10 of Table 5 and Table 6. Columns 11 and 12 of Table 5 and Table 6 show the summation of all stresses for each thermal peak and valley stress point.

### 3.5 Fatigue Analysis (for program FATIGUE.EXE)

The number of cycles projected for the 60-year operating life is used for each transient, as obtained from Reference [2]. Column 13 in Table 5 and Table 6 shows the number of cycles associated with each transient.

The program FATIGUE.EXE performs the "ASME Code style" peak event pairing required to calculate a fatigue usage value. The input data for FATIGUE.CFG is as follows:

| | Blend Radius (SA508 Class II) | Safe End (N06600) | Piping (Stainless Steel) |
|---|---|---|---|
| Parameters *m* and *n* for Computing $K_e$ | 2.0 & 0.2 (low alloy steel) [8] | 1.7 & 0.3 [8] | 1.7 & 0.3 [8] |
| Design Stress Intensity Values, $S_m$ | 26,700 psi [6] @ 600°F | 23,300 psi [6] @ 600°F | 17,000 psi [6] @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi [8] | $28.3 \times 10^6$ psi [8] | $28.3 \times 10^6$ psi [8] |
| Elastic Modulus Used in Finite Element Model (300°F) | $26.7 \times 10^6$ psi [1] | $29.8 \times 10^6$ psi [1] | $27.0 \times 10^6$ psi [1] |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 4.0 See Note | 1.8 [14] |

Note: Conservative bounding value per ASME Code, Section NB-3600 to cover thread and weld regions.

The results of the fatigue analyses are presented in Table 7 through Table 9 for the blend radius, safe end and stainless steel piping for 60 years, respectively.

The Core Spray piping adjacent to the safe end was also analyzed because of its proximity to the maximum safe end thermal stress location. For this fatigue analysis, the stress results of the safe end were used with stainless steel material properties and a value of 1.8 was selected for $K_t$ at the weld location, based on the maximum value given in ASME Code, Section III, table NB-3681(a)-1 [8].

The results described are contained in EXCEL files BRresults.xls and SEresults.xls, which are contained in the computer files.

## 4.0 FATIGUE USAGE RESULTS

The blend radius Cumulative Usage Factor (CUF) from system cycling is 0.0043 for 60 years. The safe end CUF is 0.0184 and the CUF of stainless steel piping is 0.0005 for 60 years.

## 5.0 ENVIRONMENTAL FATIGUE ANALYSIS

Per Reference [7], the dissolved Oxygen (DO) calculation shows the overall HWC availability is 47%. It means the pre-HWC is 53%.

The fatigue calculation will be re-performed for the nozzle base material, since cladding is structurally neglected in modern-day fatigue analyses, per ASME Code, Section III, NB-3122.3 [8]. This is also consistent with Sections 5.7.1 and 5.7.4 of NUREG/CR-6260 [9]. Therefore, the cladding will be neglected and EAF assessment of the nozzle base material is performed.

For the blend radius location, the environmental fatigue factors for pre-HWC and post-HWC are 11.14 and 8.82 from Table 4 of Reference [7]. It results in an EAF adjusted CUF of (11.14 x 53% + 8.82 x 47%) x 0.0043 = 0.0432 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 10.05.

For the safe end location, the environmental fatigue factors for post-HWC and pre-HWC are all 1.49 from Reference [13]. It results in an EAF adjusted CUF of 1.49 x 0.0184 = 0.0274 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 1.49.

For the stainless steel piping, the environmental fatigue factors for post-HWC and pre-HWC are all 8.36 from Table 4 of Reference [7]. It results in an EAF adjusted CUF of 8.36 x 0.0005 = 0.00418 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0). The overall environmental multiplier is 8.36.

A Fatigue Environmental Multiplier of 1.49 for Ni-Cr-Fe was applied to the safe end fatigue usage and 8.36 for stainless steel to the piping. This results in the safe end being the limiting location for fatigue.

## 6.0 REFERENCES


1 SI Calculation No. VY-16Q-309, Revision 0, "Core Spray Nozzle Green's Functions."

2 "Reactor Thermal Cycles for 60 Years of Operation," Attachment 1 of Entergy Design Input Record (DIR), Revision 1, EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/07, SI File No. VY-16Q-209.

3 GE Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," August 29, 2003, SI File No. VY-05Q-236.

4 Structural Integrity Associates Calculation (Generic) No. SW-SPVF-01Q-301, Revision 0, "STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification."

5 VY Drawing 5920-0024, Revision 11, Sht. No. 7, "Reactor Vessel," (GE Drawing No. 919D294), SI File No. VY-05Q-241.

6 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.

7 SI Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell Bottom Head."

8 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III Subsection NB, 1998 Edition, 2000 Addenda.

9 NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

10 GE Design Specification No. 21A1115, Revision 4, "Vermont Yankee Reactor Pressure Vessel," October 21, 1969, SI File No. VY-05Q-210.

11 Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green's Functions," ASME PVP Conference, Chicago, 1986.

12 NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.

13 EPRI Report No. TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," December 1995.

14 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection A, Article 4, 1965 Edition with Winter 1966 Addenda.

**Table 1: Blend Radius Transients [1,2,3]**

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 2. Design HYD Test | --- | 100 | --- | 0 | |
| | | | | 1100 | |
| 120 Cycles | | | | 50 | |
| 3. Startup | 0 | 100 | | 0 | 0 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 | (0%) |
| | 24164 | 549 | 8000 | 1010 | |
| 11. Loss of Feedwater | 0 | 526 | | 1010 | 0 |
| Pumps | 3 | 526 | 3 | 1190 | (0%) |
| 10 Cycles | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6893 | 500 | 4500 | 1135 | |
| | 7313 | 300 | 420 | 675 | |
| | 7613 | 300 | 300 | 675 | |
| | 11213 | 400 | 3600 | 240 | |
| | 16577 | 549 | 5364 | 1010 | |
| | 16637 | 549 | 60 | 1010 | |
| | 16638 | 542 | 1 | 1010 | |
| | 16698 | 542 | 60 | 1010 | |
| | 16699 | 526 | 1 | 1010 | |
| | 24699 | 526 | 8000 | 1010 | |
| 14. SRV Blowdown | 0 | 526 | | 1010 | 0 |
| 1 Cycle | 600 | 375 | 600 | 400 | (0%) |
| | 11580 | 70 | 10980 | 50 | |
| | 19580 | 70 | 8000 | 50 | |
| 21-23. Shutdown | 0 | 549 | | 1010 | 0 |
| 300 Cycles | 6264 | 375 | 6264 | 50 | (0%) |
| | 6864 | 330 | 600 | 50 | |
| | 16224 | 100 | 9360 | 50 | |
| | 24224 | 100 | 8000 | 50 | |
| 24. Hydrostatic Test | --- | 100 | --- | 50 | |
| 1 Cycle | | | | 1563 | |
| | | | | 50 | |
| 30. Emergency Shut Down | 0 | 549 | | 1010 | 3200 |
| 1 Cycle | 10 | 406 | 10 | 250 | (100%) |
| | 11 | 70 | 1 | 250 | |
| | 8011 | 70 | 8000 | 0 | |

Note:

1. Instant temperature change is 1 sec.
2. This is due to the length of the Green's Function. The transients are plotted using an 8000 second steady state increment.
3. The number of cycles for 60 years is from Reference [2].

**Table 2: Safe End Transients [1, 2, 3]**

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 2. Design HYD Test | --- | 100 | --- | 0 | |
| 120 Cycles | | | | 1100 | |
| | | | | 50 | |
| 3. Startup | 0 | 100 | | 0 | 0 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 | (0%) |
| | 17164 | 549 | 1000 | 1010 | |
| 11. Loss of Feedwater | 0 | 526 | | 1010 | 0 |
| Pumps | 3 | 526 | 3 | 1190 | (0%) |
| 10 Cycles | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6893 | 500 | 4500 | 1135 | |
| | 7313 | 300 | 420 | 675 | |
| | 7613 | 300 | 300 | 675 | |
| | 11213 | 400 | 3600 | 240 | |
| | 16577 | 549 | 5364 | 1010 | |
| | 16637 | 549 | 60 | 1010 | |
| | 16638 | 542 | 1 | 1010 | |
| | 16698 | 542 | 60 | 1010 | |
| | 16699 | 526 | 1 | 1010 | |
| | 17699 | 526 | 1000 | 1010 | |
| 14. SRV Blowdown | 0 | 526 | | 1010 | 0 |
| 1 Cycle | 600 | 375 | 600 | 400 | (0%) |
| | 11580 | 70 | 10980 | 50 | |
| | 12580 | 70 | 1000 | 50 | |
| 21-23. Shutdown | 0 | 549 | | 1010 | 0 |
| 300 Cycles | 6264 | 375 | 6264 | 50 | (0%) |
| | 6864 | 330 | 600 | 50 | |
| | 16224 | 100 | 9360 | 50 | |
| | 17224 | 100 | 1000 | 50 | |
| 12. Hydrostatic Test | --- | 100 | --- | 50 | |
| 1 cycle | | | | 1563 | |
| | | | | 50 | |
| 30. Emergency Shut Down | 0 | 549 | | 1010 | 3200 |
| 1 Cycle | 10 | 406 | 10 | 250 | (100%) |
| | 11 | 70 | 1 | 250 | |
| | 1011 | 70 | 1000 | 0 | |

Note:

1. Instant temperature change is 1 sec.
2. The transients are plotted using a 1000 second steady state increment. The difference is due to the length of the Green's Function for the safe end.
3. The number of cycles for 60 years is from Reference [2].

**Table 3: Maximum Piping Stress Intensity Calculations for Blend Radius**

| Blend Radius External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 2.50 | kips |
| $F_y$ = | 4.60 | kips |
| $F_Z$ = | 1.70 | kips |
| $M_x$ = | 264.00 | in-kips |
| $M_y$ = | 85.20 | in-kips |
| $M_Z$ = | 105.60 | in-kips |
| OD= | 18.87 | in |
| ID= | 11.750 | in |
| $R_N$ = | 7.65 | in |
| L = | 30.82 | in |
| $t_N$ = | 3.56 | in |
| $(M_x)_2$ = | 122.24 | in-kips |
| $(M_y)_2$ = | 162.24 | in-kips |
| $M_{xy}$ = | 203.14 | in-kips |
| $F_{xy}$ = | 5.24 | kips |
| $N_Z$ = | 1.14 | kips/in |
| $q_N$ = | -0.07 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 0.32 | ksi |
| τ = | -0.02 | ksi |
| $SI_{max}$ = | 0.32 | ksi |
| $SI_{max}$ = | 322.52 | psi |

Note: The locations for Cut I and Cut II were defined in Reference [1] for safe end and blend radius paths, respectively.

**Table 4: Maximum Piping Stress Intensity Calculations for Safe End**

| Safe End External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 2.50 | kips |
| $F_y$ = | 4.60 | kips |
| $F_Z$ = | 1.70 | kips |
| $M_x$ = | 264.00 | in-kips |
| $M_y$ = | 85.20 | in-kips |
| $M_Z$ = | 105.60 | in-kips |
| OD= | 10.82 | in |
| ID= | 9.834 | in |
| $R_N$ = | 5.16 | in |
| L = | 0.30 | in |
| $t_N$ = | 0.49 | in |
| $(M_x)_1$ = | 262.60 | in-kips |
| $(M_y)_1$ = | 85.96 | in-kips |
| $M_{xy}$ = | 276.31 | in-kips |
| $F_{xy}$ = | 5.24 | kips |
| $N_Z$ = | 3.35 | kips/in |
| $q_N$ = | -0.31 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 6.84 | ksi |
| $\tau$ = | -0.63 | ksi |
| $SI_{max}$ = | 6.95 | ksi |
| $SI_{max}$ = | 6949.94 | psi |

Note: The locations for Cut I and Cut II were defined in Reference [1] for safe end and blend radius paths, respectively.

# Table 5: Blend Radius Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 2 | | | | 100 | 0 | 0 | 0 | 19 | 19 | 19 | 19 | 120 |
| | | | | 100 | 1100 | 39446 | 38467 | 19 | 19 | 39465 | 38486 | 120 |
| | | | | 100 | 50 | 1793 | 1749 | 19 | 19 | 1812 | 1768 | 120 |
| 3 | 0 | 23700 | 12600 | 100 | 0 | 0 | 0 | 19 | 19 | 23719 | 12619 | 300 |
| | 24164 | 2100 | 3180 | 549 | 1010 | 36219 | 35320 | 306 | 306 | 38625 | 38806 | 300 |
| 11 | 0 | 3209 | 3644 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39719 | 39255 | 10 |
| | 3 | 3209 | 3644 | 526 | 1190 | 42673 | 41614 | 291 | 291 | 46174 | 45550 | 10 |
| | 526 | 10458 | 5374 | 330 | 1135 | 40701 | 39691 | 166 | 166 | 51325 | 45231 | 10 |
| | 2222 | 5488 | 1664 | 490 | 1122 | 40235 | 39236 | 268 | 268 | 45991 | 41168 | 10 |
| | 2860 | 11776 | 7444 | 321 | 911 | 32668 | 31858 | 160 | 160 | 44605 | 39462 | 10 |
| | 6903 | 5435 | 3621 | 495 | 1124 | 40307 | 39306 | 272 | 272 | 46013 | 43199 | 10 |
| | 8012 | 12577 | 6791 | 390 | 627 | 22484 | 21926 | 204 | 204 | 35265 | 28921 | 10 |
| | 16640 | 2772 | 4370 | 542 | 1010 | 36219 | 35320 | 301 | 301 | 39292 | 39991 | 10 |
| | 16991 | 3389 | 4115 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39899 | 39726 | 10 |
| | 24699 | 3209 | 3644 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39719 | 39255 | 10 |
| 14 | 0 | 3209 | 3644 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39719 | 39255 | 1 |
| | 19580 | 25122 | 13197 | 70 | 50 | 1793 | 1749 | 0 | 0 | 26915 | 14946 | 1 |
| 21-23 | 0 | 2103 | 3161 | 549 | 1010 | 36219 | 35320 | 306 | 306 | 38628 | 38787 | 300 |
| | 24224 | 23680 | 12568 | 100 | 50 | 1793 | 1749 | 19 | 19 | 25492 | 14336 | 300 |
| 24 | | | | 100 | 50 | 1793 | 1749 | 19 | 19 | 1812 | 1768 | 1 |
| | | | | 100 | 1563 | 56049 | 54658 | 19 | 19 | 56068 | 54677 | 1 |
| | | | | 100 | 50 | 1793 | 1749 | 19 | 19 | 1812 | 1768 | 1 |
| 30 | 0 | 2040 | 2950 | 549 | 1010 | 36219 | 35320 | 306 | 306 | 38565 | 38576 | 1 |
| | 8011 | 25700 | 14900 | 70 | 0 | 0 | 0 | 0 | 0 | 25700 | 14900 | 1 |

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 1.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 35,860)/1000 [1].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 34,970)/1000 [1].
Column 9: Total external stress from calculation in Table 3, 322.52 x (Column 5 -70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

## Table 6: Safe End Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| ***2*** | | | | 100 | 0 | 0 | 0 | 413 | 413 | 413 | 413 | **120** |
| | | | | 100 | 1100 | 13233 | 13222 | 413 | 413 | 13646 | 13635 | **120** |
| | | | | 100 | 50 | 602 | 601 | 413 | 413 | 1014 | 1014 | **120** |
| ***3*** | 0 | 661 | 759 | 100 | 0 | 0 | 0 | 413 | 413 | 1074 | 1172 | **300** |
| | 17164 | 9240 | 10700 | 549 | 1010 | 12150 | 12140 | 6592 | 6592 | 27982 | 29432 | **300** |
| ***11*** | 0 | 8802 | 10236 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 27228 | 28652 | **10** |
| | 3 | 8802 | 10236 | 526 | 1190 | 14316 | 14304 | 6276 | 6276 | 29393 | 30815 | **10** |
| | 13 | 8802 | 10236 | 526 | 1135 | 13654 | 13643 | 6276 | 6276 | 28732 | 30154 | **10** |
| | 164 | 11645 | 11598 | 408 | 1135 | 13654 | 13643 | 4657 | 4657 | 29956 | 29898 | **10** |
| | 672 | 4808 | 5791 | 344 | 1135 | 13654 | 13643 | 3775 | 3775 | 22237 | 23209 | **10** |
| | 2374 | 11140 | 10841 | 361 | 912 | 10971 | 10962 | 4005 | 4005 | 26116 | 25808 | **10** |
| | 2955 | 4722 | 5577 | 325 | 916 | 11019 | 11010 | 3509 | 3509 | 19250 | 20096 | **10** |
| | 7054 | 9518 | 10162 | 441 | 959 | 11537 | 11527 | 5100 | 5100 | 26155 | 26789 | **10** |
| | 7930 | 4491 | 5276 | 309 | 637 | 7663 | 7657 | 3287 | 3287 | 15441 | 16219 | **10** |
| | 16709 | 9960 | 11116 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 28386 | 29532 | **10** |
| | 17699 | 8802 | 10236 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 27228 | 28652 | **10** |
| ***14*** | 0 | 8802 | 10236 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 27228 | 28652 | **1** |
| | 152 | 9499 | 10570 | 497 | 855 | 10286 | 10277 | 5880 | 5880 | 25664 | 26727 | **1** |
| | 12580 | 91 | 95 | 70 | 50 | 602 | 601 | 0 | 0 | 693 | 696 | **1** |
| ***21-23*** | 0 | 9242 | 0 | 549 | 1010 | 12150 | 12140 | 6592 | 6592 | 27984 | 18732 | **300** |
| | 17224 | 664 | 0 | 100 | 50 | 602 | 601 | 413 | 413 | 1678 | 1014 | **300** |
| ***24*** | | | | 100 | 50 | 602 | 601 | 413 | 413 | 1014 | 1014 | **1** |
| | | | | 100 | 1563 | 18803 | 18787 | 413 | 413 | 19216 | 19200 | **1** |
| | | | | 100 | 50 | 602 | 601 | 413 | 413 | 1014 | 1014 | **1** |
| ***30*** | 0 | 9280 | 10800 | 549 | 1010 | 12150 | 12140 | 6592 | 6592 | 28022 | 29532 | **1** |
| | 13 | 85600 | 44694 | 162 | 250 | 3002 | 3000 | 1260 | 1260 | 89862 | 48953 | **1** |
| | 1011 | -12 | -10 | 70 | 0 | 0 | 0 | 0 | 0 | -12 | -10 | **1** |

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 2.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 12,030)/1000.
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 12,020)/1000.
Column 9: Total external stress from calculation in Table 4, 6949.94 x (Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

## Table 7: Fatigue Results for Blend Radius (60 Years)

```
     LOCATION = LOCATION NO. 2 -- BLEND RADIUS
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
            m = 2.0
            n =  .2
           Sm = 26700. psi
       Ecurve = 3.000E+07 psi
    Eanalysis = 2.670E+07 psi
           Kt = 1.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 56068. | 19. | 56049. | 54658. | 1.000 | 31488. | 1.000E+00 | 1.896E+04 | .0001 |
| 51325. | 19. | 51306. | 45212. | 1.000 | 28824. | 1.000E+01 | 2.501E+04 | .0004 |
| 46174. | 19. | 46155. | 45531. | 1.000 | 25930. | 1.000E+01 | 3.460E+04 | .0003 |
| 46013. | 19. | 45994. | 43180. | 1.000 | 25839. | 1.000E+01 | 3.498E+04 | .0003 |
| 45991. | 19. | 45972. | 41149. | 1.000 | 25827. | 1.000E+01 | 3.503E+04 | .0003 |
| 44605. | 19. | 44586. | 39443. | 1.000 | 25048. | 1.000E+01 | 3.848E+04 | .0003 |
| 39899. | 19. | 39880. | 39707. | 1.000 | 22404. | 1.000E+01 | 5.695E+04 | .0002 |
| 39719. | 19. | 39700. | 39236. | 1.000 | 22303. | 1.000E+01 | 5.824E+04 | .0002 |
| 39719. | 19. | 39700. | 39236. | 1.000 | 22303. | 1.000E+01 | 5.824E+04 | .0002 |
| 39719. | 19. | 39700. | 39236. | 1.000 | 22303. | 1.000E+00 | 5.824E+04 | .0000 |
| 39465. | 19. | 39446. | 38467. | 1.000 | 22161. | 3.800E+01 | 6.012E+04 | .0006 |
| 39465. | 1812. | 37653. | 36718. | 1.000 | 21153. | 8.200E+01 | 7.572E+04 | .0011 |
| 39292. | 1812. | 37480. | 38223. | 1.000 | 21056. | 1.000E+01 | 7.747E+04 | .0001 |
| 38628. | 1812. | 36816. | 37019. | 1.000 | 20683. | 2.800E+01 | 8.466E+04 | .0003 |
| 38628. | 1812. | 36816. | 37019. | 1.000 | 20683. | 1.000E+00 | 8.466E+04 | .0000 |
| 38628. | 1812. | 36816. | 37019. | 1.000 | 20683. | 1.000E+00 | 8.466E+04 | .0000 |
| 38628. | 23719. | 14909. | 26168. | 1.000 | 8376. | 2.700E+02 | 5.366E+07 | .0000 |
| 38625. | 23719. | 14906. | 26187. | 1.000 | 8374. | 3.000E+01 | 5.375E+07 | .0000 |
| 38625. | 25492. | 13133. | 24470. | 1.000 | 7378. | 2.700E+02 | 3.042E+08 | .0000 |
| 38565. | 25492. | 13073. | 24240. | 1.000 | 7344. | 1.000E+00 | 3.374E+08 | .0000 |
| 35265. | 25492. | 9773. | 14585. | 1.000 | 5490. | 1.000E+01 | 1.000E+20 | .0000 |
| 26915. | 25492. | 1423. | 610. | 1.000 | 799. | 1.000E+00 | 1.000E+20 | .0000 |
| 25700. | 25492. | 208. | 564. | 1.000 | 117. | 1.000E+00 | 1.000E+20 | .0000 |
| | | | | | | | TOTAL USAGE FACTOR = | .0043 |

## Table 8: Fatigue Results for Safe End (60 Years)

```
      LOCATION = LOCATION NO. 1 -- SAFE END
 FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 1.7
             n =  .3
            Sm = 23300. psi
        Ecurve = 2.830E+07 psi
     Eanalysis = 2.980E+07 psi
            Kt = 4.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 89862. | -12. | 89874. | 48963. | 1.000 | 112423. | 1.000E+00 | 1.213E+03 | .0008 |
| 29956. | 413. | 29543. | 29485. | 1.000 | 56029. | 1.000E+01 | 1.910E+04 | .0005 |
| 29393. | 413. | 28980. | 30402. | 1.000 | 57068. | 1.000E+01 | 1.746E+04 | .0006 |
| 28732. | 413. | 28319. | 29741. | 1.000 | 55813. | 1.000E+01 | 1.946E+04 | .0005 |
| 28386. | 413. | 27973. | 29119. | 1.000 | 54762. | 1.000E+01 | 2.140E+04 | .0005 |
| 28022. | 413. | 27609. | 29119. | 1.000 | 54590. | 1.000E+00 | 2.174E+04 | .0000 |
| 27984. | 413. | 27571. | 18319. | 1.000 | 39187. | 7.900E+01 | 1.244E+05 | .0006 |
| 27984. | 693. | 27291. | 18036. | 1.000 | 38651. | 1.000E+00 | 1.341E+05 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 38045. | 1.200E+02 | 1.460E+05 | .0008 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 38045. | 1.000E+00 | 1.460E+05 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 38045. | 1.000E+00 | 1.460E+05 | .0000 |
| 27984. | 1074. | 26910. | 17560. | 1.000 | 37792. | 9.800E+01 | 1.514E+05 | .0006 |
| 27982. | 1074. | 26908. | 28260. | 1.000 | 53033. | 2.020E+02 | 2.517E+04 | .0080 |
| 27982. | 1678. | 26304. | 28418. | 1.000 | 52971. | 9.800E+01 | 2.532E+04 | .0039 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 51502. | 1.000E+01 | 2.919E+04 | .0003 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 51502. | 1.000E+01 | 2.919E+04 | .0003 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 51502. | 1.000E+00 | 2.919E+04 | .0000 |
| 26155. | 1678. | 24477. | 25775. | 1.000 | 48339. | 1.000E+01 | 4.021E+04 | .0002 |
| 26116. | 1678. | 24438. | 24794. | 1.000 | 46923. | 1.000E+01 | 4.673E+04 | .0002 |
| 25664. | 1678. | 23986. | 25713. | 1.000 | 48017. | 1.000E+00 | 4.159E+04 | .0000 |
| 22237. | 1678. | 20559. | 22195. | 1.000 | 41379. | 1.000E+01 | 9.257E+04 | .0001 |
| 19250. | 1678. | 17572. | 19082. | 1.000 | 35526. | 1.000E+01 | 2.135E+05 | .0000 |
| 19216. | 1678. | 17538. | 18186. | 1.000 | 34234. | 1.000E+00 | 2.691E+05 | .0000 |
| 15441. | 1678. | 13763. | 15205. | 1.000 | 28195. | 1.000E+01 | 1.001E+06 | .0000 |
| 13646. | 1678. | 11968. | 12621. | 1.000 | 23661. | 1.200E+02 | 1.772E+06 | .0001 |
| | | | | | | | TOTAL USAGE FACTOR = | .0184 |

## Table 9: Fatigue Results for Stainless Steel Piping (60 Years)

```
      LOCATION = LOCATION NO. 1 -- SS Piping
 FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 1.7
             n =  .3
            Sm = 17000. psi
        Ecurve = 2.830E+07 psi
     Eanalysis = 2.700E+07 psi
            Kt = 1.80
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 89862. | -12. | 89874. | 48963. | 1.000 | 67629. | 1.000E+00 | 8.006E+03 | .0001 |
| 29956. | 413. | 29543. | 29485. | 1.000 | 27845. | 1.000E+01 | 1.042E+06 | .0000 |
| 29393. | 413. | 28980. | 30402. | 1.000 | 27934. | 1.000E+01 | 1.031E+06 | .0000 |
| 28732. | 413. | 28319. | 29741. | 1.000 | 27310. | 1.000E+01 | 1.110E+06 | .0000 |
| 28386. | 413. | 27973. | 29119. | 1.000 | 26868. | 1.000E+01 | 1.171E+06 | .0000 |
| 28022. | 413. | 27609. | 29119. | 1.000 | 26678. | 1.000E+00 | 1.198E+06 | .0000 |
| 27984. | 413. | 27571. | 18319. | 1.000 | 22130. | 7.900E+01 | 2.272E+06 | .0000 |
| 27984. | 693. | 27291. | 18036. | 1.000 | 21864. | 1.000E+00 | 2.392E+06 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 21563. | 1.200E+02 | 2.539E+06 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 21563. | 1.000E+00 | 2.539E+06 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 21563. | 1.000E+00 | 2.539E+06 | .0000 |
| 27984. | 1074. | 26910. | 17560. | 1.000 | 21465. | 9.800E+01 | 2.588E+06 | .0000 |
| 27982. | 1074. | 26908. | 28260. | 1.000 | 25950. | 2.020E+02 | 1.311E+06 | .0002 |
| 27982. | 1678. | 26304. | 28418. | 1.000 | 25700. | 9.800E+01 | 1.354E+06 | .0001 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 24978. | 1.000E+01 | 1.485E+06 | .0000 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 24978. | 1.000E+01 | 1.485E+06 | .0000 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 24978. | 1.000E+00 | 1.485E+06 | .0000 |
| 26155. | 1678. | 24477. | 25775. | 1.000 | 23634. | 1.000E+01 | 1.779E+06 | .0000 |
| 26116. | 1678. | 24438. | 24794. | 1.000 | 23202. | 1.000E+01 | 1.889E+06 | .0000 |
| 25664. | 1678. | 23986. | 25713. | 1.000 | 23351. | 1.000E+00 | 1.850E+06 | .0000 |
| 22237. | 1678. | 20559. | 22195. | 1.000 | 20080. | 1.000E+01 | 3.442E+06 | .0000 |
| 19250. | 1678. | 17572. | 19082. | 1.000 | 17209. | 1.000E+01 | 7.481E+06 | .0000 |
| 19216. | 1678. | 17538. | 18186. | 1.000 | 16816. | 1.000E+00 | 8.600E+06 | .0000 |
| 15441. | 1678. | 13763. | 15205. | 1.000 | 13588. | 1.000E+01 | 1.000E+20 | .0000 |
| 13646. | 1678. | 11968. | 12621. | 1.000 | 11564. | 1.200E+02 | 1.000E+20 | .0000 |
| | | | | | | | TOTAL USAGE FACTOR = | .0005 |

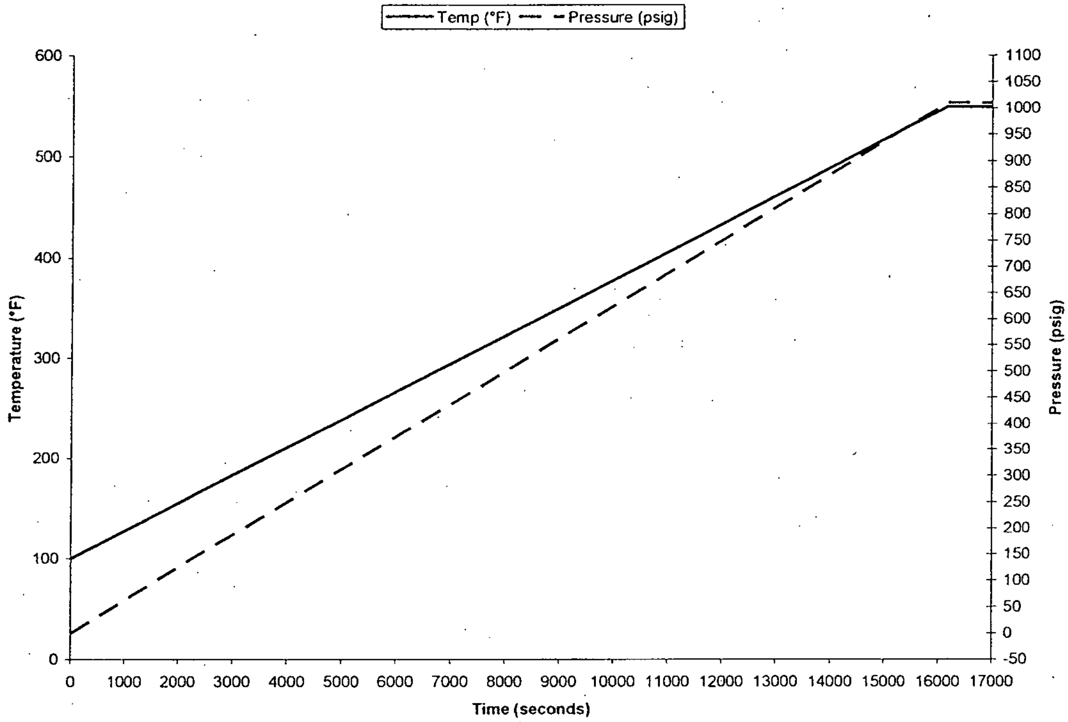


**Figure 1: Transient 03: Start Up**

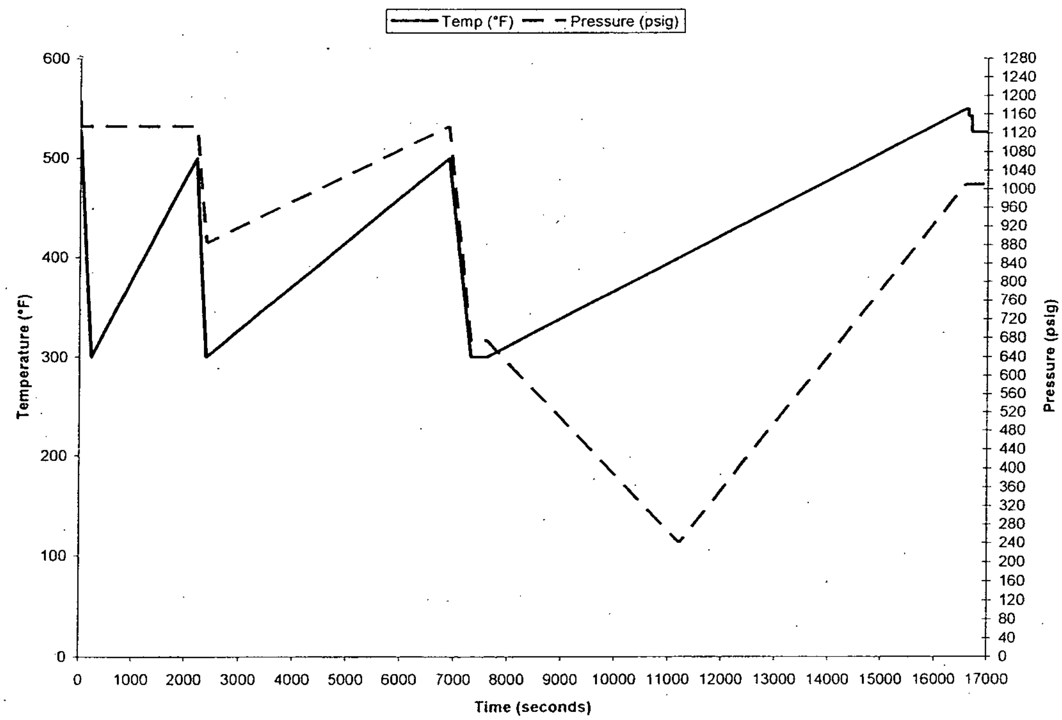


**Figure 2: Transient 11: Loss of Feedwater Pumps, Isolation Valves Close**

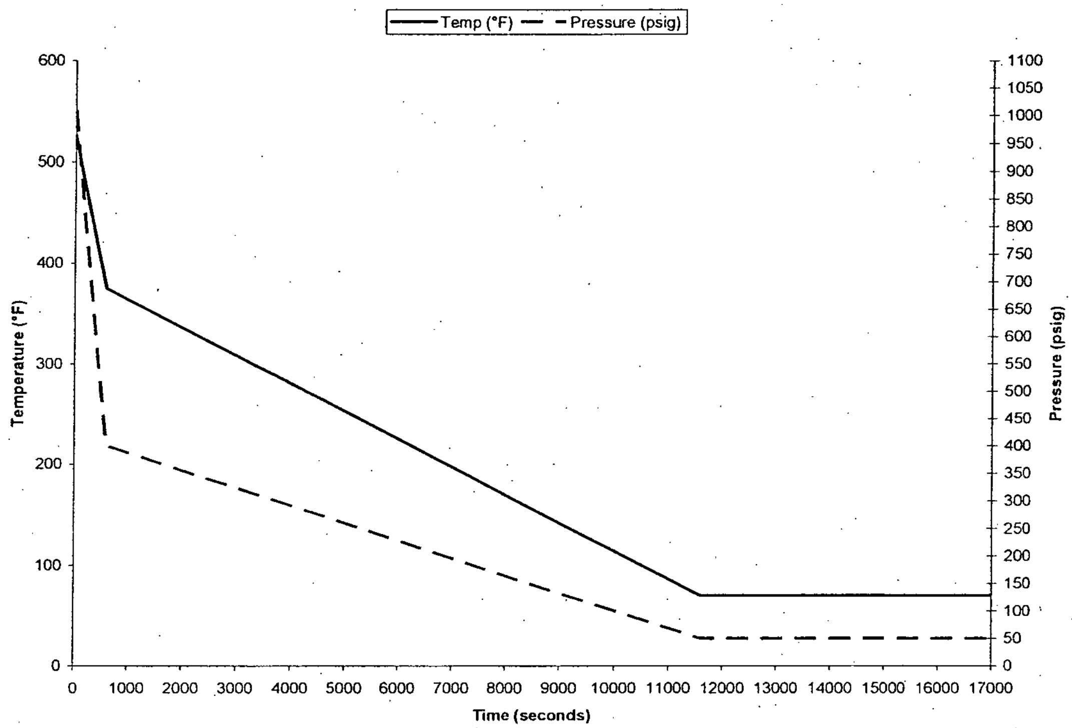


**Figure 3: Transient 14: Single Relief of Safety Valve Blow Down**

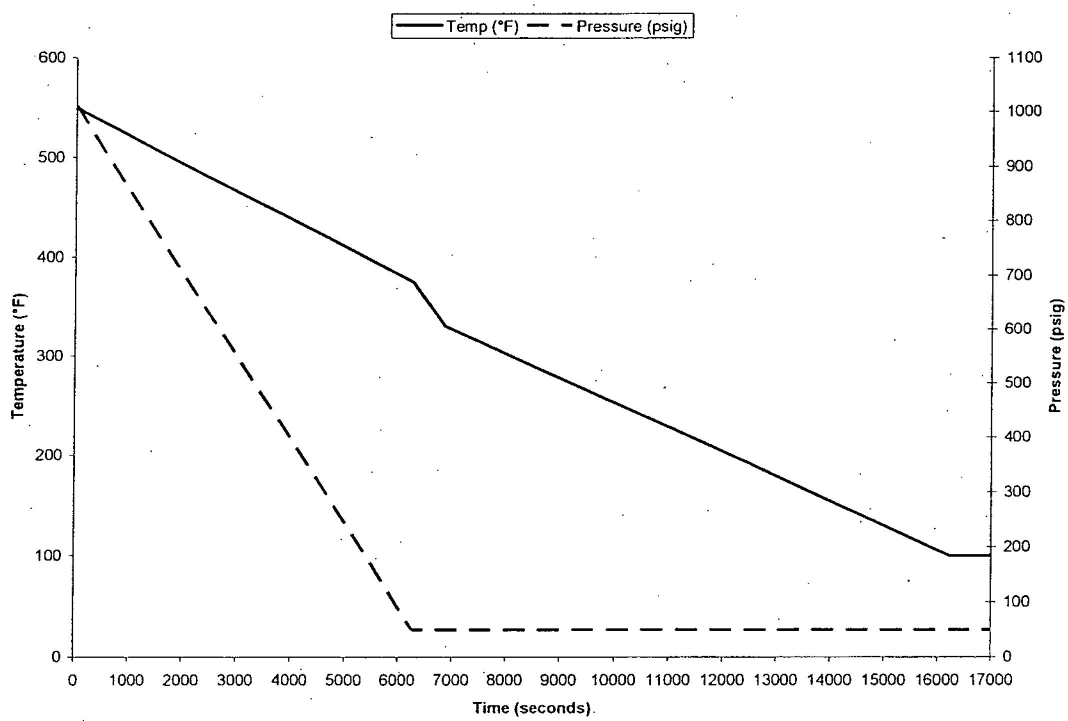


**Figure 4: Transient 21-23: Shut Down Vessel Flooding**

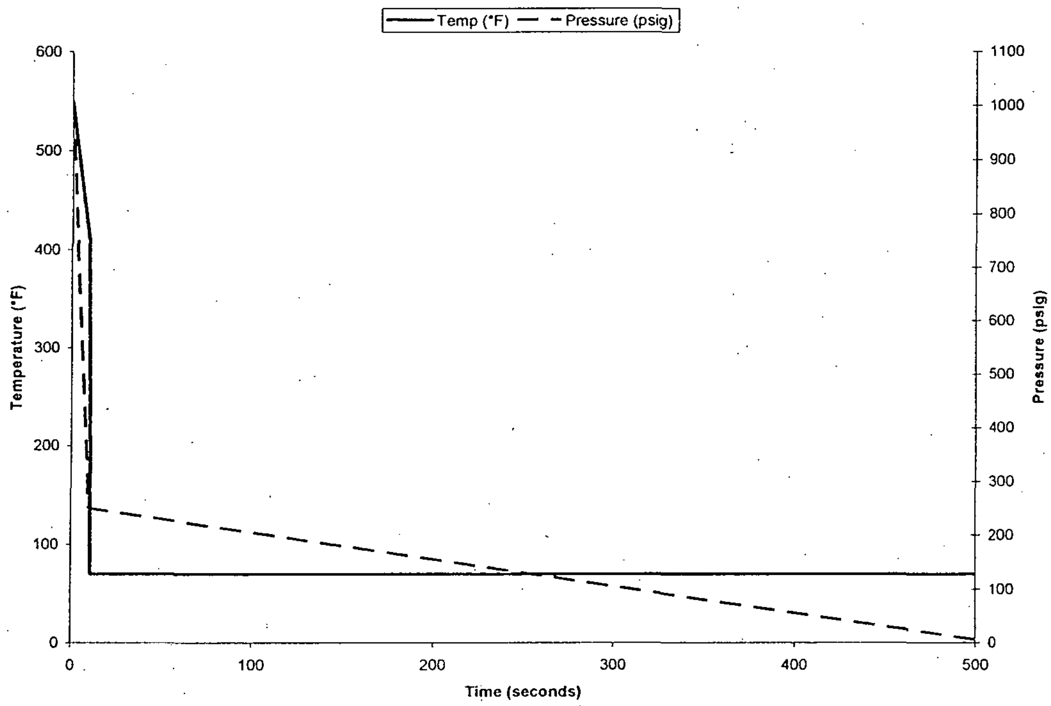


Figure 5: Transient 30: Emergency Shut Down 100% Flow (Safe End)

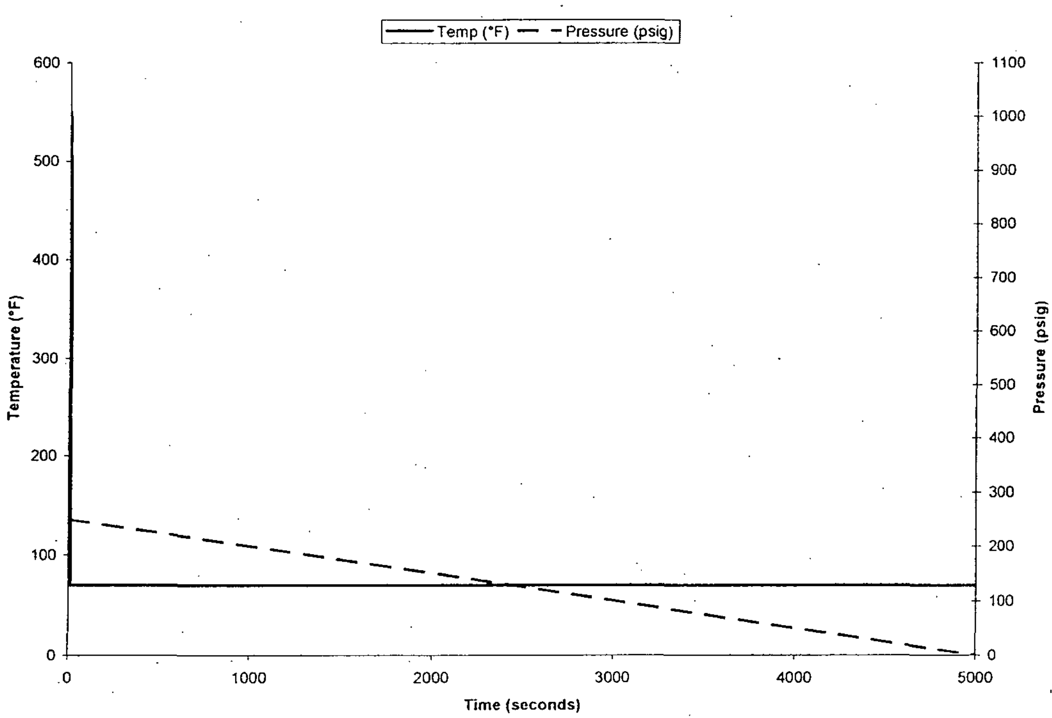


Figure 6: Transient 30: Emergency Shut Down 100% Flow (Blend Radius)

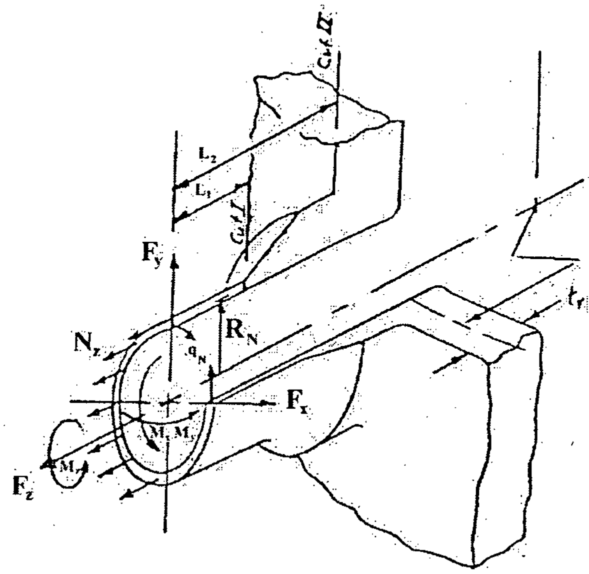


**Figure 7: External Forces and Moments on the Core Spray Nozzle**

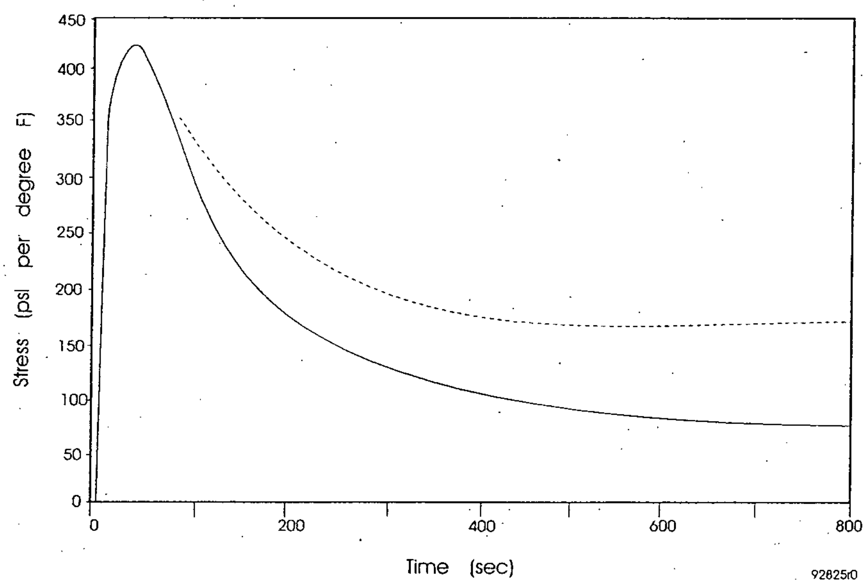


**Figure 8: Typical Green's Functions for Thermal Transient Stress**

Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

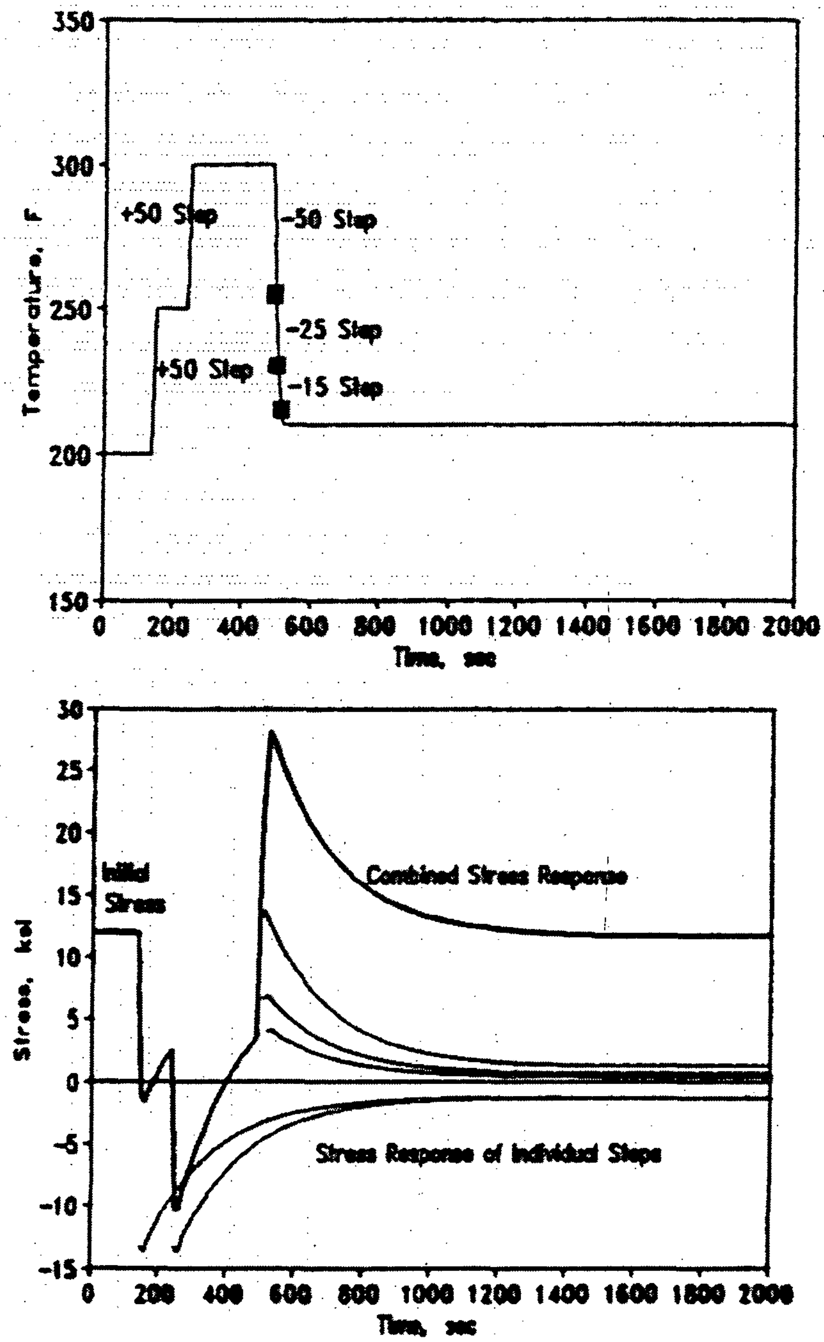


**Figure 9: Typical Stress Response Using Green's Functions**

# APPENDIX A

## INPUT AND OUTPUT FILES

## Input Files

| File Name | Description |
|---|---|
| TRANSNT_03.INP | Text file describing transient 03 for STRESS.EXE |
| TRANSNT_11.INP | Text file describing transient 11 for STRESS.EXE |
| TRANSNT_14.INP | Text file describing transient 14 for STRESS.EXE |
| TRANSNT_21_22_23.INP | Text file describing transients 21-23 for STRESS.EXE |
| TRANSNT_30.INP | Text file describing transient 30 for STRESS.EXE |

## Output Files

| File Name | Description |
|---|---|
| P-V_03.OUT | Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 03 |
| P-V_11.OUT | Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 11 |
| P-V_14.OUT | Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 14 |
| P-V_21_22_23.OUT | Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transients 21-23 |
| P-V_30.OUT | Output text file of STRESS.EXE and P-V.EXE, Stress peaks and valleys of transient 30 |

Structural Integrity Associates, Inc.

# CALCULATION PACKAGE

File No.: VY-16Q-311

NEC-JH_14

Project No.: VY-16Q

**PROJECT NAME:**

Environmental Fatigue Analysis of VYNPS

**CONTRACT NO.:**

10150394

**CLIENT:**

Entergy Nuclear Operations, Inc.

**PLANT:**

Vermont Yankee Nuclear Power Station

**CALCULATION TITLE:**

Feedwater Class 1 Piping Fatigue Analysis

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
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| 0 | 1-17, A1 – A38, B1 – B45 In Computer Files | Initial Issue | Terry J. Herrmann 7/20/2007 [signature] | Keith R. Evon 7/16/2007 [signature] Ryan V. Perry 7/16/2007 [signature] |

## Table of Contents



## List of Tables



## List of Figures

## 1.0 OBJECTIVE

The purpose of this calculation is to perform an ASME Section III, NB-3600 fatigue calculation (Including environmental fatigue) of the Vermont Yankee (VY) Class 1 feedwater piping located inside the drywell (originally analyzed to B31.1 requirements). This section of piping was originally identified in the Recommendation Report [6] for installing a fatigue monitoring system at VY.

The fatigue calculation performed herein is not a certified ASME Code NB-3600 stress and fatigue analysis. Rather, it is an evaluation for the purposes of establishing fatigue usage to accommodate fatigue monitoring of the subject B31.1 piping. Although the PIPESTRESS program implements all ASME Code NB-3600 equations, only the fatigue usage results are utilized. All stress limit checks, although calculated by the program, are ignored since satisfactory stress limit checks were performed as a part of the already existing governing B31.1 stress analyses for all piping systems.

## 2.0 METHODOLOGY

The Class 1 Loop A feedwater piping system line extending from anchor HD-36 to reactor pressure vessel (RPV) nozzles N-4A and N-4B was evaluated. This includes a portion of the HPCI line to support HPCI-HD35A [7], so that the appropriate stiffness affects of this line on the feedwater piping are included. This evaluation is also considered valid for the Loop B line extending from anchor HD-39 to RPV nozzles N-4C and N-4D for the following reasons:

1. The Class 1 sections of Loop A and Loop B are mirror images of each other. This evaluation includes piping beyond the Class 1 boundary check valve so that its influence on the Class 1 piping is taken into account. The final fatigue analysis will only consider points on the Class 1 portion of the piping.
2. A 14" HPCI line tees into Loop A and a 4" RCIC line tees into Loop B. The HPCI line is more than three times the size of the RCIC line and will therefore have a greater influence on the feedwater piping.
3. The transients defined in this calculation are the bounding set for the two loops.

The operating conditions for the Class 1 portion of the feedwater line were defined based on References [11 and 12]. The resulting piping transient definitions are specified in Table 1. For each thermal cycle, the operating temperatures for Regions I through V define the conditions to be applied to the model.

Region boundaries are defined at branches, transitions, or locations where temperature and flow conditions change. These boundary locations are also shown in Figure 1. A listing of the PIPESTRESS input file "FWHPCI.FRE" is given in Appendix A and is also included in the project computer files.

# Table 1: Thermal Cycle Definitions for Feedwater Line

| Transient Cycle | Description (1) | Piping Region (3) | Thermal Conditions (2) Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | $T_{avg}$ (°F) | Flow (%) | Ratio | (gpm)(4) | Pressure Conditions Pinit (psig) | Pfinal (psig) | No. of Cycles (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Design Hydrotest (Leak Test) (+) | I | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1 | 200.0 | 0.0 | 1100 | 120 |
| | | IIa | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1 | 150.0 | 0.0 | 1100 | |
| | | IIb | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1 | 150.0 | 0.0 | 1100 | |
| | | II | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1 | 150.0 | 0.0 | 50 | |
| | | III | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1 | 200.0 | 0.0 | 1100 | |
| | | IV | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1/2 | 100.0 | 0.0 | 1100 | |
| | | IVa | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1/2 | 100.0 | 0.0 | 1100 | |
| | | IVb | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1/2 | 100.0 | 0.0 | 1100 | |
| | | V | 100 | 70 | 100 | 1800 | 60 | 85 | 0 | 1/2 | 100.0 | 0.0 | 1100 | |
| 2 | Design Hydrotest (Leak Test) (-) | I | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 200.0 | 1100.0 | 50 | 120 |
| | | IIa | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 1100.0 | 50 | |
| | | IIb | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 1100.0 | 50 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 200.0 | 1100.0 | 50 | |
| | | IV | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 1100.0 | 50 | |
| | | IVa | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 1100.0 | 50 | |
| | | IVb | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 1100.0 | 50 | |
| | | V | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 1100.0 | 50 | |
| 3 | Startup (+) | I | 150 | 100 | 150 | 16164 | 11.1 | 125 | 0 | 1 | 200.0 | 50.0 | 1010 | 300 |
| | | IIa | 150 | 100 | 150 | 16164 | 11.1 | 125 | 0 | 1 | 150.0 | 50.0 | 1010 | |
| | | IIb | 125 | 100 | 125 | 16164 | 5.6 | 113 | 0 | 1 | 150.0 | 50.0 | 1010 | |
| | | II | 100 | 100 | 100 | 16164 | 0.0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 100 | 150 | 16164 | 11.1 | 125 | 0 | 1 | 200.0 | 50.0 | 1010 | |
| | | IV | 150 | 100 | 150 | 16164 | 11.1 | 125 | 0 | 1/2 | 100.0 | 50.0 | 1010 | |
| | | IVa | 283 | 100 | 283 | 16164 | 40.8 | 192 | 0 | 1/2 | 100.0 | 50.0 | 1010 | |
| | | IVb | 416 | 100 | 416 | 16164 | 70.4 | 258 | 0 | 1/2 | 100.0 | 50.0 | 1010 | |
| | | V | 549 | 100 | 549 | 16164 | 100 | 325 | 0 | 1/2 | 100.0 | 50.0 | 1010 | |
| 4 | Turbine Roll & Increase to Rated Power 1 (-) (Includes 10 SCRAM, Loss of Feedwater Pumps and 300 Hot Standby - Feedwater Cycling) | I | 100 | 150 | 100 | 0 | STEP | 125 | 15 | 1 | 1377.0 | 1010.0 | 1010 | 610 |
| | | IIa | 100 | 150 | 100 | 0 | STEP | 125 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 100 | 125 | 100 | 0 | STEP | 113 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 0 | STEP | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 150 | 100 | 0 | STEP | 125 | 15 | 1 | 1377.0 | 1010.0 | 1010 | |
| | | IV | 100 | 150 | 100 | 0 | STEP | 125 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVa | 100 | 283 | 100 | 0 | STEP | 192 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVb | 100 | 416 | 100 | 0 | STEP | 258 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | V | 100 | 549 | 100 | 0 | STEP | 325 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| 5 | Turbine Roll & Increase to Rated Power 2 (+) (Includes 10 SCRAM, Loss of Feedwater Pumps, 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 260 | 100 | 260 | 0 | STEP | 180 | 15 | 1 | 1377.0 | 1010.0 | 1010 | 599 |
| | | IIa | 260 | 100 | 260 | 0 | STEP | 180 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 180 | 100 | 180 | 0 | STEP | 140 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 0 | STEP | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 260 | 100 | 260 | 0 | STEP | 180 | 15 | 1 | 1377.0 | 1010.0 | 1010 | |
| | | IV | 260 | 100 | 260 | 0 | STEP | 180 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVa | 260 | 100 | 260 | 0 | STEP | 180 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVb | 260 | 100 | 260 | 0 | STEP | 180 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | V | 260 | 100 | 260 | 0 | STEP | 180 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| 6 | Turbine Roll & Increase to Rated Power 3 (+) (Includes 10 SCRAM, Loss of Feedwater Pumps, 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 392 | 260 | 392 | 1800 | 264 | 326 | 100 | 1 | 9180.0 | 1010.0 | 1010 | 599 |
| | | IIa | 392 | 260 | 392 | 1800 | 264 | 326 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 246 | 180 | 246 | 1800 | 132 | 213 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 1800 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 260 | 392 | 1800 | 264 | 326 | 100 | 1 | 9180.0 | 1010.0 | 1010 | |
| | | IV | 392 | 260 | 392 | 1800 | 264 | 326 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | IVa | 392 | 260 | 392 | 1800 | 264 | 326 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | IVb | 392 | 260 | 392 | 1800 | 264 | 326 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | V | 392 | 260 | 392 | 1800 | 264 | 326 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| 7 | Daily Reduction to 75% Power (-) | I | 310 | 392 | 310 | 900 | -328 | 351 | 75 | 1 | 6885.0 | 1010.0 | 1010 | 10000 |
| | | IIa | 310 | 392 | 310 | 900 | -328 | 351 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 205 | 246 | 205 | 900 | -164 | 226 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 310 | 392 | 310 | 900 | -328 | 351 | 75 | 1 | 6885.0 | 1010.0 | 1010 | |
| | | IV | 310 | 392 | 310 | 900 | -328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| | | IVa | 310 | 392 | 310 | 900 | -328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| | | IVb | 310 | 392 | 310 | 900 | -328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| | | V | 310 | 392 | 310 | 900 | -328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| 8 | Daily Reduction to 75% Power (+) | I | 392 | 310 | 392 | 900 | 328 | 351 | 75 | 1 | 6885.0 | 1010.0 | 1010 | 10000 |
| | | IIa | 392 | 310 | 392 | 900 | 328 | 351 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 246 | 205 | 246 | 900 | 164 | 226 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 310 | 392 | 900 | 328 | 351 | 75 | 1 | 6885.0 | 1010.0 | 1010 | |
| | | IV | 392 | 310 | 392 | 900 | 328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| | | IVa | 392 | 310 | 392 | 900 | 328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| | | IVb | 392 | 310 | 392 | 900 | 328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| | | V | 392 | 310 | 392 | 900 | 328 | 351 | 75 | 1/2 | 3442.5 | 1010.0 | 1010 | |
| 9 | Weekly Reduction to 50% Power (-) | I | 280 | 392 | 280 | 1800 | -224 | 336 | 50 | 1 | 4590.0 | 1010.0 | 1010 | 2000 |
| | | IIa | 280 | 392 | 280 | 1800 | -224 | 336 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 190 | 246 | 190 | 1800 | -112 | 218 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 1800 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 280 | 392 | 280 | 1800 | -224 | 336 | 50 | 1 | 4590.0 | 1010.0 | 1010 | |
| | | IV | 280 | 392 | 280 | 1800 | -224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVa | 280 | 392 | 280 | 1800 | -224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVb | 280 | 392 | 280 | 1800 | -224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | V | 280 | 392 | 280 | 1800 | -224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |

For notes, see last page of table.

## Table 1: Thermal Cycle Definitions for Feedwater Line (continued)

| Transient Cycle | Description (1) | Piping Region (3) | Thermal Conditions (2) Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | $T_{avg}$ (°F) | Flow (%) | Ratio | (gpm)(4) | Pressure Conditions Pinit (psig) | Pfinal (psig) | No. of Cycles (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Weekly Reduction to 50% Power (+) | I | 392 | 280 | 392 | 1800 | 224 | 336 | 50 | 1 | 4590.0 | 1010.0 | 1010 | 2000 |
| | | IIa | 392 | 280 | 392 | 1800 | 224 | 336 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 246 | 190 | 246 | 1800 | 112 | 218 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 1800 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 280 | 392 | 1800 | 224 | 336 | 50 | 1 | 4590.0 | 1010.0 | 1010 | |
| | | IV | 392 | 280 | 392 | 1800 | 224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVa | 392 | 280 | 392 | 1800 | 224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVb | 392 | 280 | 392 | 1800 | 224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | V | 392 | 280 | 392 | 1800 | 224 | 336 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| 11 | Loss of Feedwater Heater, Turbine Trip 1 (-) (Includes 10 Loss of Feedwater Heater Turbine Trip, and 300 Reduction to 0% Power) | I | 265 | 392 | 265 | 1800 | -254 | 329 | 50 | 1 | 4590.0 | 1010.0 | 1010 | 310 |
| | | IIa | 265 | 392 | 265 | 1800 | -254 | 329 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 182.5 | 246 | 182.5 | 1800 | -127 | 214 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 1800 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 265 | 392 | 265 | 1800 | -254 | 329 | 50 | 1 | 4590.0 | 1010.0 | 1010 | |
| | | IV | 265 | 392 | 265 | 1800 | -254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVa | 265 | 392 | 265 | 1800 | -254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVb | 265 | 392 | 265 | 1800 | -254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | V | 265 | 392 | 265 | 1800 | -254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| 12 | Loss of Feedwater Heater, Turbine Trip 2 (-) | I | 90 | 265 | 90 | 360 | -1750 | 178 | 15 | 1 | 1377.0 | 1010.0 | 1010 | 10 |
| | | IIa | 90 | 265 | 90 | 360 | -1750 | 178 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 95 | 182.5 | 95 | 360 | -875 | 139 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 360 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 90 | 265 | 90 | 360 | -1750 | 178 | 15 | 1 | 1377.0 | 1010.0 | 1010 | |
| | | IV | 90 | 265 | 90 | 360 | -1750 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVa | 90 | 265 | 90 | 360 | -1750 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVb | 90 | 265 | 90 | 360 | -1750 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | V | 90 | 265 | 90 | 360 | -1750 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| 13 | Loss of Feedwater Heater, Turbine Trip 3 (+) | I | 265 | 90 | 265 | 900 | 700 | 178 | 15 | 1 | 1377.0 | 1010.0 | 1010 | 10 |
| | | IIa | 265 | 90 | 265 | 900 | 700 | 178 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 182.5 | 95 | 182.5 | 900 | 350 | 139 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 265 | 90 | 265 | 900 | 700 | 178 | 15 | 1 | 1377.0 | 1010.0 | 1010 | |
| | | IV | 265 | 90 | 265 | 900 | 700 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVa | 265 | 90 | 265 | 900 | 700 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | IVb | 265 | 90 | 265 | 900 | 700 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| | | V | 265 | 90 | 265 | 900 | 700 | 178 | 15 | 1/2 | 688.5 | 1010.0 | 1010 | |
| 14 | Loss of Feedwater Heater, Turbine Trip 4 (+) | I | 392 | 265 | 392 | 1800 | 254 | 329 | 50 | 1 | 4590.0 | 1010.0 | 1010 | 10 |
| | | IIa | 392 | 265 | 392 | 1800 | 254 | 329 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 246 | 182.5 | 246 | 1800 | 127 | 214 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 1800 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 265 | 392 | 1800 | 254 | 329 | 50 | 1 | 4590.0 | 1010.0 | 1010 | |
| | | IV | 392 | 265 | 392 | 1800 | 254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVa | 392 | 265 | 392 | 1800 | 254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | IVb | 392 | 265 | 392 | 1800 | 254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| | | V | 392 | 265 | 392 | 1800 | 254 | 329 | 50 | 1/2 | 2295.0 | 1010.0 | 1010 | |
| 15 | Loss of Feedwater Heater, FW Heater Bypass (-) | I | 265 | 392 | 265 | 90 | -5080 | 329 | 100 | 1 | 9180.0 | 1010.0 | 1010 | 70 |
| | | IIa | 265 | 392 | 265 | 90 | -5080 | 329 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 182.5 | 246 | 182.5 | 90 | -2540 | 214 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 90 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 265 | 392 | 265 | 90 | -5080 | 329 | 100 | 1 | 9180.0 | 1010.0 | 1010 | |
| | | IV | 265 | 392 | 265 | 90 | -5080 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | IVa | 265 | 392 | 265 | 90 | -5080 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | IVb | 265 | 392 | 265 | 90 | -5080 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | V | 265 | 392 | 265 | 90 | -5080 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| 16 | Loss of Feedwater Heater, FW Heater Bypass (+) | I | 392 | 265 | 392 | 180 | 2540 | 329 | 100 | 1 | 9180.0 | 1010.0 | 1010 | 70 |
| | | IIa | 392 | 265 | 392 | 180 | 2540 | 329 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 246 | 182.5 | 246 | 180 | 1270 | 214 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 180 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 265 | 392 | 180 | 2540 | 329 | 100 | 1 | 9180.0 | 1010.0 | 1010 | |
| | | IV | 392 | 265 | 392 | 180 | 2540 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | IVa | 392 | 265 | 392 | 180 | 2540 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | IVb | 392 | 265 | 392 | 180 | 2540 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| | | V | 392 | 265 | 392 | 180 | 2540 | 329 | 100 | 1/2 | 4590.0 | 1010.0 | 1010 | |
| 17 | SCRAM, T.G. Trip, Reactor Overpressure, and All Other Scrams 1 (-) (Includes 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1 | 10098.0 | 1010.0 | 1010 | 289 |
| | | IIa | 275 | 392 | 275 | 60 | -7020 | 334 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 187.5 | 246 | 187.5 | 60 | -3510 | 217 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 60 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1 | 10098.0 | 1010.0 | 1010 | |
| | | IV | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 1010 | |
| | | IVa | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 1010 | |
| | | IVb | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 1010 | |
| | | V | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 1010 | |
| 18 | SCRAM, T.G. Trip, Reactor Overpressure, and All Other Scrams 2 (-) (Includes 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1 | 275.4 | 1010.0 | 1010 | 289 |
| | | IIa | 100 | 275 | 100 | 900 | -700 | 188 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 100 | 187.5 | 100 | 900 | -350 | 144 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1 | 275.4 | 1010.0 | 1010 | |
| | | IV | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 1010.0 | 1010 | |
| | | IVa | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 1010.0 | 1010 | |
| | | IVb | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 1010.0 | 1010 | |
| | | V | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 1010.0 | 1010 | |

For notes, see last page of table.

## Table 1: Thermal Cycle Definitions for Feedwater Line (continued)

| Transient Cycle | Description (1) | Piping Region (3) | Thermal Conditions (2) Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | $T_{avg}$ (°F) | Flow (%) | Ratio | (gpm)(4) | Pressure Conditions Pinit (psig) | Pfinal (psig) | No. of Cycles (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Hot Standby 1 (+) | I | 265 | 265 | 265 | 0 | STEP | 265 | 0 | 1 | 200.0 | 1010.0 | 1010 | 300 |
| | | IIa | 265 | 265 | 265 | 0 | STEP | 265 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 182.5 | 182.5 | 182.5 | 0 | STEP | 183 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 0 | STEP | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 265 | 265 | 265 | 0 | STEP | 265 | 0 | 1 | 200.0 | 1010.0 | 1010 | |
| | | IV | 265 | 265 | 265 | 0 | STEP | 265 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVa | 323 | 265 | 323 | 0 | STEP | 294 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVb | 382 | 265 | 382 | 0 | STEP | 324 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | V | 440 | 265 | 440 | 0 | STEP | 353 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| 20 | Hot Standby 2 (+) | I | 265 | 265 | 265 | 0 | 0 | 265 | 0 | 1 | 200.0 | 1010.0 | 1010 | 300 |
| | | IIa | 265 | 265 | 265 | 0 | 0 | 265 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 182.5 | 182.5 | 182.5 | 0 | 0 | 183 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 265 | 265 | 265 | 0 | 0 | 265 | 0 | 1 | 200.0 | 1010.0 | 1010 | |
| | | IV | 265 | 265 | 265 | 0 | 0 | 265 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVa | 360 | 323 | 360 | 3924 | 34 | 342 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVb | 454 | 382 | 454 | 3924 | 66 | 418 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | V | 549 | 440 | 549 | 3924 | 100 | 495 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| 21 | Hot Standby 3 (-) | I | 150 | 265 | 150 | 4140 | -100 | 208 | 0 | 1 | 200.0 | 1010.0 | 1010 | 300 |
| | | IIa | 150 | 265 | 150 | 4140 | -100 | 208 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 125 | 182.5 | 125 | 4140 | -50 | 154 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 265 | 150 | 4140 | -100 | 208 | 0 | 1 | 200.0 | 1010.0 | 1010 | |
| | | IV | 150 | 265 | 150 | 4140 | -100 | 208 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVa | 283 | 360 | 283 | 4140 | -67 | 322 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVb | 416 | 454 | 416 | 4140 | -33 | 435 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | V | 549 | 549 | 549 | 0 | 0 | 549 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| 22 | Shutdown 1 (-) | I | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1 | 200.0 | 1010.0 | 170 | 300 |
| | | IIa | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1 | 150.0 | 1010.0 | 170 | |
| | | IIb | 125 | 125 | 125 | 0 | 0 | 125 | 0 | 1 | 150.0 | 1010.0 | 170 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1 | 200.0 | 1010.0 | 170 | |
| | | IV | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1/2 | 100.0 | 1010.0 | 170 | |
| | | IVa | 225 | 283 | 225 | 6264 | -33 | 254 | 0 | 1/2 | 100.0 | 1010.0 | 170 | |
| | | IVb | 300 | 416 | 300 | 6264 | -67 | 358 | 0 | 1/2 | 100.0 | 1010.0 | 170 | |
| | | V | 375 | 549 | 375 | 6264 | -100 | 462 | 0 | 1/2 | 100.0 | 1010.0 | 170 | |
| 23 | Shutdown 2 (-) | I | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1 | 200.0 | 170.0 | 88 | 300 |
| | | IIa | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1 | 150.0 | 170.0 | 88 | |
| | | IIb | 125 | 125 | 125 | 0 | 0 | 125 | 0 | 1 | 150.0 | 170.0 | 88 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1 | 200.0 | 170.0 | 88 | |
| | | IV | 150 | 150 | 150 | 0 | 0 | 150 | 0 | 1/2 | 100.0 | 170.0 | 88 | |
| | | IVa | 210 | 225 | 210 | 600 | -90 | 218 | 0 | 1/2 | 100.0 | 170.0 | 88 | |
| | | IVb | 270 | 300 | 270 | 600 | -180 | 285 | 0 | 1/2 | 100.0 | 170.0 | 88 | |
| | | V | 330 | 375 | 330 | 600 | -270 | 353 | 0 | 1/2 | 100.0 | 170.0 | 88 | |
| 24 | Shutdown 3 (-) | I | 100 | 150 | 100 | 8280 | -22 | 125 | 0 | 1 | 200.0 | 88.0 | 50 | 300 |
| | | IIa | 100 | 150 | 100 | 8280 | -22 | 125 | 0 | 1 | 150.0 | 88.0 | 50 | |
| | | IIb | 100 | 125 | 100 | 8280 | -11 | 113 | 0 | 1 | 150.0 | 88.0 | 50 | |
| | | II | 100 | 100 | 100 | 8280 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 150 | 100 | 8280 | -22 | 125 | 0 | 1 | 200.0 | 88.0 | 50 | |
| | | IV | 100 | 150 | 100 | 8280 | -22 | 125 | 0 | 1/2 | 100.0 | 88.0 | 50 | |
| | | IVa | 100 | 210 | 100 | 8280 | -48 | 155 | 0 | 1/2 | 100.0 | 88.0 | 50 | |
| | | IVb | 100 | 270 | 100 | 8280 | -74 | 185 | 0 | 1/2 | 100.0 | 88.0 | 50 | |
| | | V | 100 | 330 | 100 | 8280 | -100 | 215 | 0 | 1/2 | 100.0 | 88.0 | 50 | |
| 25 | SCRAM, Loss of Feedwater Pumps 1 (+) | I | 392 | 392 | 392 | 12 | 0 | 392 | 0 | 1 | 200.0 | 1010.0 | 1190 | 10 |
| | | IIa | 392 | 392 | 392 | 12 | 0 | 392 | 0 | 1 | 150.0 | 1010.0 | 1190 | |
| | | IIb | 246 | 246 | 246 | 12 | 0 | 246 | 0 | 1 | 150.0 | 1010.0 | 1190 | |
| | | II | 100 | 100 | 100 | 12 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 392 | 392 | 12 | 0 | 392 | 0 | 1 | 200.0 | 1010.0 | 1190 | |
| | | IV | 392 | 392 | 392 | 12 | 0 | 392 | 0 | 1/2 | 100.0 | 1010.0 | 1190 | |
| | | IVa | 450 | 392 | 450 | 12 | 17400 | 421 | 0 | 1/2 | 100.0 | 1010.0 | 1190 | |
| | | IVb | 507 | 392 | 507 | 12 | 34500 | 450 | 0 | 1/2 | 100.0 | 1010.0 | 1190 | |
| | | V | 565 | 392 | 565 | 12 | 51900 | 479 | 0 | 1/2 | 100.0 | 1010.0 | 1190 | |
| 26 | SCRAM, Loss of Feedwater Pumps 2 (-) (First HPCI) | I | 50 | 392 | 50 | 0 | STEP | 221 | 40 | 1 | 3672.0 | 1190.0 | 1135 | 10 |
| | | IIa | 50 | 392 | 50 | 0 | STEP | 221 | 40 | 1 | 3672.0 | 1190.0 | 1135 | |
| | | IIb | 50 | 246 | 50 | 0 | STEP | 148 | 40 | 1 | 3672.0 | 1190.0 | 1135 | |
| | | II | 50 | 100 | 50 | 0 | STEP | 75 | 40 | 1 | 3672.0 | 50.0 | 1135 | |
| | | III | 50 | 392 | 50 | 0 | STEP | 221 | 40 | 1 | 3672.0 | 1190.0 | 1135 | |
| | | IV | 50 | 392 | 50 | 0 | STEP | 221 | 40 | 1/2 | 1836.0 | 1190.0 | 1135 | |
| | | IVa | 50 | 450 | 50 | 0 | STEP | 250 | 40 | 1/2 | 1836.0 | 1190.0 | 1135 | |
| | | IVb | 50 | 507 | 50 | 0 | STEP | 279 | 40 | 1/2 | 1836.0 | 1190.0 | 1135 | |
| | | V | 50 | 565 | 50 | 0 | STEP | 308 | 40 | 1/2 | 1836.0 | 1190.0 | 1135 | |
| 27 | SCRAM, Loss of Feedwater Pumps 3 (+) | I | 150 | 50 | 150 | 1380 | 261 | 100 | 0 | 1 | 200.0 | 1135.0 | 1135 | 10 |
| | | IIa | 150 | 50 | 150 | 1380 | 261 | 100 | 0 | 1 | 150.0 | 1135.0 | 1135 | |
| | | IIb | 125 | 50 | 125 | 1380 | 196 | 88 | 0 | 1 | 150.0 | 1135.0 | 1135 | |
| | | II | 100 | 50 | 100 | 1380 | 130 | 75 | 0 | 1 | 150.0 | 1135.0 | 50 | |
| | | III | 150 | 50 | 150 | 1380 | 261 | 100 | 0 | 1 | 200.0 | 1135.0 | 1135 | |
| | | IV | 150 | 50 | 150 | 1380 | 261 | 100 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| | | IVa | 247 | 50 | 247 | 1380 | 514 | 149 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| | | IVb | 343 | 50 | 343 | 1380 | 764 | 197 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| | | V | 440 | 50 | 440 | 1380 | 1017 | 245 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |

For notes, see last page of table.

## Table 1: Thermal Cycle Definitions for Feedwater Line (continued)

| Transient Cycle | Description (1) | Piping Region (3) | Thermal Conditions (2) Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | $T_{avg}$ (°F) | Flow (%) | Ratio | (gpm)(4) | Pressure Conditions Pinit (psig) | Pfinal (psig) | No. of Cycles (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | SCRAM, Loss of Feedwater Pumps 4 (+) | I | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1 | 200.0 | 1135.0 | 1135 | 10 |
| | | IIa | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1 | 150.0 | 1135.0 | 1135 | |
| | | IIb | 125 | 125 | 125 | 0 | STEP | 125 | 0 | 1 | 150.0 | 1135.0 | 1135 | |
| | | II | 100 | 100 | 100 | 0 | STEP | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1 | 200.0 | 1135.0 | 1135 | |
| | | IV | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| | | IVa | 288 | 247 | 288 | 0 | STEP | 268 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| | | IVb | 427 | 343 | 427 | 0 | STEP | 385 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| | | V | 565 | 440 | 565 | 0 | STEP | 503 | 0 | 1/2 | 100.0 | 1135.0 | 1135 | |
| 29 | SCRAM, Loss of Feedwater Pumps 5 (-) (Second HPCI) | I | 50 | 150 | 50 | 0 | STEP | 100 | 30 | 1 | 2754.0 | 1135.0 | 885 | 10 |
| | | IIa | 50 | 150 | 50 | 0 | STEP | 100 | 30 | 1 | 2754.0 | 1135.0 | 885 | |
| | | IIb | 50 | 125 | 50 | 0 | STEP | 88 | 30 | 1 | 2754.0 | 1135.0 | 885 | |
| | | II | 50 | 100 | 50 | 0 | STEP | 75 | 30 | 1 | 2754.0 | 1135.0 | 885 | |
| | | III | 50 | 150 | 50 | 0 | STEP | 100 | 30 | 1 | 2754.0 | 1135.0 | 885 | |
| | | IV | 50 | 150 | 50 | 0 | STEP | 100 | 30 | 1/2 | 1377.0 | 1135.0 | 885 | |
| | | IVa | 50 | 288 | 50 | 0 | STEP | 169 | 30 | 1/2 | 1377.0 | 1135.0 | 885 | |
| | | IVb | 50 | 427 | 50 | 0 | STEP | 239 | 30 | 1/2 | 1377.0 | 1135.0 | 885 | |
| | | V | 50 | 565 | 50 | 0 | STEP | 308 | 30 | 1/2 | 1377.0 | 1135.0 | 885 | |
| 30 | SCRAM, Loss of Feedwater Pumps 6 (+) | I | 150 | 50 | 150 | 3060 | 118 | 100 | 0 | 1 | 200.0 | 885.0 | 1060 | 10 |
| | | IIa | 150 | 50 | 150 | 3060 | 118 | 100 | 0 | 1 | 150.0 | 885.0 | 1060 | |
| | | IIb | 125 | 50 | 125 | 3060 | 88 | 88 | 0 | 1 | 150.0 | 885.0 | 1060 | |
| | | II | 100 | 50 | 100 | 3060 | 59 | 75 | 0 | 1 | 150.0 | 885.0 | 50 | |
| | | III | 150 | 50 | 150 | 3060 | 118 | 100 | 0 | 1 | 200.0 | 885.0 | 1060 | |
| | | IV | 150 | 50 | 150 | 3060 | 118 | 100 | 0 | 1/2 | 100.0 | 885.0 | 1060 | |
| | | IVa | 247 | 50 | 247 | 3060 | 232 | 149 | 0 | 1/2 | 100.0 | 885.0 | 1060 | |
| | | IVb | 343 | 50 | 343 | 3060 | 345 | 197 | 0 | 1/2 | 100.0 | 885.0 | 1060 | |
| | | V | 440 | 50 | 440 | 3060 | 459 | 245 | 0 | 1/2 | 100.0 | 885.0 | 1060 | |
| 31 | SCRAM, Loss of Feedwater Pumps 7 (+) | I | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1 | 200.0 | 1060.0 | 1135 | 10 |
| | | IIa | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1 | 150.0 | 1060.0 | 1135 | |
| | | IIb | 125 | 125 | 125 | 0 | STEP | 125 | 0 | 1 | 150.0 | 1060.0 | 1135 | |
| | | II | 100 | 100 | 100 | 0 | STEP | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1 | 200.0 | 1060.0 | 1135 | |
| | | IV | 150 | 150 | 150 | 0 | STEP | 150 | 0 | 1/2 | 100.0 | 1060.0 | 1135 | |
| | | IVa | 283 | 247 | 283 | 0 | STEP | 265 | 0 | 1/2 | 100.0 | 1060.0 | 1135 | |
| | | IVb | 416 | 343 | 416 | 0 | STEP | 380 | 0 | 1/2 | 100.0 | 1060.0 | 1135 | |
| | | V | 549 | 440 | 549 | 0 | STEP | 495 | 0 | 1/2 | 100.0 | 1060.0 | 1135 | |
| 32 | SCRAM, Loss of Feedwater Pumps 8 (-) (Third HPCI) | I | 50 | 150 | 50 | 0 | STEP | 100 | 17 | 1 | 1560.6 | 1135.0 | 675 | 10 |
| | | IIa | 50 | 150 | 50 | 0 | STEP | 100 | 17 | 1 | 1560.6 | 1135.0 | 675 | |
| | | IIb | 50 | 125 | 50 | 0 | STEP | 88 | 17 | 1 | 1560.6 | 1135.0 | 675 | |
| | | II | 50 | 100 | 50 | 0 | STEP | 75 | 17 | 1 | 1560.6 | 50.0 | 675 | |
| | | III | 50 | 150 | 50 | 0 | STEP | 100 | 17 | 1 | 1560.6 | 1135.0 | 675 | |
| | | IV | 50 | 150 | 50 | 0 | STEP | 100 | 17 | 1/2 | 780.3 | 1135.0 | 675 | |
| | | IVa | 50 | 283 | 50 | 0 | STEP | 167 | 17 | 1/2 | 780.3 | 1135.0 | 675 | |
| | | IVb | 50 | 416 | 50 | 0 | STEP | 233 | 17 | 1/2 | 780.3 | 1135.0 | 675 | |
| | | V | 50 | 549 | 50 | 0 | STEP | 300 | 17 | 1/2 | 780.3 | 1135.0 | 675 | |
| 33 | SCRAM, Loss of Feedwater Pumps 9 (+) | I | 150 | 50 | 150 | 300 | 1200 | 100 | 0 | 1 | 200.0 | 675.0 | 675 | 10 |
| | | IIa | 150 | 50 | 150 | 300 | 1200 | 100 | 0 | 1 | 150.0 | 675.0 | 675 | |
| | | IIb | 125 | 50 | 125 | 300 | 900 | 88 | 0 | 1 | 150.0 | 675.0 | 675 | |
| | | II | 100 | 50 | 100 | 300 | 600 | 75 | 0 | 1 | 150.0 | 675.0 | 50 | |
| | | III | 150 | 50 | 150 | 300 | 1200 | 100 | 0 | 1 | 200.0 | 675.0 | 675 | |
| | | IV | 150 | 50 | 150 | 300 | 1200 | 100 | 0 | 1/2 | 100.0 | 675.0 | 675 | |
| | | IVa | 200 | 50 | 200 | 300 | 1800 | 125 | 0 | 1/2 | 100.0 | 675.0 | 675 | |
| | | IVb | 250 | 50 | 250 | 300 | 2400 | 150 | 0 | 1/2 | 100.0 | 675.0 | 675 | |
| | | V | 300 | 50 | 300 | 300 | 3000 | 175 | 0 | 1/2 | 100.0 | 675.0 | 675 | |
| 34 | SCRAM, Loss of Feedwater Pumps 10 (+) | I | 150 | 150 | 150 | 8964 | 0 | 150 | 0 | 1 | 200.0 | 240.0 | 1010 | 10 |
| | | IIa | 150 | 150 | 150 | 8964 | 0 | 150 | 0 | 1 | 150.0 | 240.0 | 1010 | |
| | | IIb | 125 | 125 | 125 | 8964 | 0 | 125 | 0 | 1 | 150.0 | 240.0 | 1010 | |
| | | II | 100 | 100 | 100 | 8964 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 150 | 150 | 8964 | 0 | 150 | 0 | 1 | 200.0 | 240.0 | 1010 | |
| | | IV | 150 | 150 | 150 | 8964 | 0 | 150 | 0 | 1/2 | 100.0 | 240.0 | 1010 | |
| | | IVa | 283 | 200 | 283 | 8964 | 33 | 242 | 0 | 1/2 | 100.0 | 240.0 | 1010 | |
| | | IVb | 416 | 250 | 416 | 8964 | 67 | 333 | 0 | 1/2 | 100.0 | 240.0 | 1010 | |
| | | V | 549 | 300 | 549 | 8964 | 100 | 425 | 0 | 1/2 | 100.0 | 240.0 | 1010 | |
| 35 | SCRAM, SRV Blowdown 1 (-) | I | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1 | 10098.0 | 1010.0 | 885 | 1 |
| | | IIa | 275 | 392 | 275 | 60 | -7020 | 334 | 0 | 1 | 150.0 | 1010.0 | 885 | |
| | | IIb | 187.5 | 246 | 187.5 | 60 | -3510 | 217 | 0 | 1 | 150.0 | 1010.0 | 885 | |
| | | II | 100 | 100 | 100 | 60 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1 | 10098.0 | 1010.0 | 885 | |
| | | IV | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 885 | |
| | | IVa | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 885 | |
| | | IVb | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 885 | |
| | | V | 275 | 392 | 275 | 60 | -7020 | 334 | 110 | 1/2 | 5049.0 | 1010.0 | 885 | |
| 36 | SCRAM, SRV Blowdown 2 (-) | I | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1 | 275.4 | 885.0 | 50 | 1 |
| | | IIa | 100 | 275 | 100 | 900 | -700 | 188 | 0 | 1 | 150.0 | 885.0 | 50 | |
| | | IIb | 100 | 187.5 | 100 | 900 | -350 | 144 | 0 | 1 | 150.0 | 885.0 | 50 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1 | 275.4 | 885.0 | 50 | |
| | | IV | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 885.0 | 50 | |
| | | IVa | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 885.0 | 50 | |
| | | IVb | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 885.0 | 50 | |
| | | V | 100 | 275 | 100 | 900 | -700 | 188 | 3 | 1/2 | 137.7 | 885.0 | 50 | |

For notes, see last page of table.

Structural Integrity Associates, Inc.

## Table 1: Thermal Cycle Definitions for Feedwater Line (continued)

| Transient Cycle | Description (1) | Piping Region (3) | Thermal Conditions (2): Oper. Temp. (°F) | $T_{init}$ (°F) | $T_{final}$ (°F) | Time (sec.) | Rate (°F/hr) | $T_{avg}$ (°F) | Flow (%) | Ratio | (gpm)(4) | Pressure Conditions: Pinit (psig) | Pfinal (psig) | No. of Cycles (1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Hydrostatic Test (+) | I | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 200.0 | 50.0 | 1563 | 1 |
| | | IIa | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 1563 | |
| | | IIb | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 1563 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 200.0 | 50.0 | 1563 | |
| | | IV | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 50.0 | 1563 | |
| | | IVa | 100 | 100 | 100 | 0 | 0.0 | 100 | 0 | 1/2 | 100.0 | 50.0 | 1563 | |
| | | IVb | 100 | 100 | 100 | 0 | 0.0 | 100 | 0 | 1/2 | 100.0 | 50.0 | 1563 | |
| | | V | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 50.0 | 1563 | |
| 38 | Hydrostatic Test (-) | I | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 200.0 | 1563.0 | 50 | 1 |
| | | IIa | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 1563.0 | 50 | |
| | | IIb | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 1563.0 | 50 | |
| | | II | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1 | 200.0 | 1563.0 | 50 | |
| | | IV | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 1563.0 | 50 | |
| | | IVa | 100 | 100 | 100 | 0 | 0.0 | 100 | 0 | 1/2 | 100.0 | 1563.0 | 50 | |
| | | IVb | 100 | 100 | 100 | 0 | 0.0 | 100 | 0 | 1/2 | 100.0 | 1563.0 | 50 | |
| | | V | 100 | 100 | 100 | 0 | 0 | 100 | 0 | 1/2 | 100.0 | 1563.0 | 50 | |
| 39 | SCRAM, T.G. Trip, Reactor Overpressure, and All Other Scrams 1 (-) (Includes 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 392 | 392 | 392 | 60 | 0 | 392 | 110 | 1 | 10098.0 | 1010.0 | 1375 | 289 |
| | | IIa | 392 | 392 | 392 | 60 | 0 | 392 | 0 | 1 | 150.0 | 1010.0 | 1375 | |
| | | IIb | 246 | 246 | 246 | 60 | 0 | 246 | 0 | 1 | 150.0 | 1010.0 | 1375 | |
| | | II | 100 | 100 | 100 | 60 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 392 | 392 | 60 | 0 | 392 | 110 | 1 | 10098.0 | 1010.0 | 1375 | |
| | | IV | 392 | 392 | 392 | 60 | 0 | 392 | 110 | 1/2 | 5049.0 | 1010.0 | 1375 | |
| | | IVa | 392 | 392 | 392 | 60 | 0 | 392 | 110 | 1/2 | 5049.0 | 1010.0 | 1375 | |
| | | IVb | 392 | 392 | 392 | 60 | 0 | 392 | 110 | 1/2 | 5049.0 | 1010.0 | 1375 | |
| | | V | 392 | 392 | 392 | 60 | 0 | 392 | 110 | 1/2 | 5049.0 | 1010.0 | 1375 | |
| 40 | SCRAM, T.G. Trip, Reactor Overpressure, and All Other Scrams 2 (-) (Includes 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1 | 275.4 | 1375.0 | 940 | 289 |
| | | IIa | 392 | 392 | 392 | 900 | 0 | 392 | 0 | 1 | 150.0 | 1375.0 | 940 | |
| | | IIb | 246 | 246 | 246 | 900 | 0 | 246 | 0 | 1 | 150.0 | 1375.0 | 940 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1 | 275.4 | 1375.0 | 940 | |
| | | IV | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 1375.0 | 940 | |
| | | IVa | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 1375.0 | 940 | |
| | | IVb | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 1375.0 | 940 | |
| | | V | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 1375.0 | 940 | |
| 41 | SCRAM, T.G. Trip, Reactor Overpressure, and All Other Scrams 3 (-) (Includes 1 Reactor Overpressure, 228 Other SCRAMS and 60 Turbine Generator Trip) | I | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1 | 275.4 | 940.0 | 1010 | 289 |
| | | IIa | 392 | 392 | 392 | 900 | 0 | 392 | 0 | 1 | 150.0 | 940.0 | 1010 | |
| | | IIb | 246 | 246 | 246 | 900 | 0 | 246 | 0 | 1 | 150.0 | 940.0 | 1010 | |
| | | II | 100 | 100 | 100 | 900 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1 | 275.4 | 940.0 | 1010 | |
| | | IV | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 940.0 | 1010 | |
| | | IVa | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 940.0 | 1010 | |
| | | IVb | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 940.0 | 1010 | |
| | | V | 392 | 392 | 392 | 900 | 0 | 392 | 3 | 1/2 | 137.7 | 940.0 | 1010 | |
| 42 | Hot Standby, Feedwater Cycling 1 (+) | I | 125 | 100 | 125 | 60 | 1500 | 113 | 0 | 1 | 200.0 | 1010.0 | 1010 | 300 |
| | | IIa | 125 | 100 | 125 | 60 | 1500 | 113 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 112.5 | 100 | 112.5 | 60 | 750 | 106 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 60 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 125 | 100 | 125 | 60 | 1500 | 113 | 0 | 1 | 200.0 | 1010.0 | 1010 | |
| | | IV | 125 | 100 | 125 | 60 | 1500 | 113 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVa | 180 | 100 | 180 | 60 | 4800 | 140 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVb | 235 | 100 | 235 | 60 | 8100 | 168 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | V | 290 | 100 | 290 | 60 | 11400 | 195 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| 43 | Hot Standby, Feedwater Cycling 2 (+) | I | 150 | 125 | 150 | 210 | 429 | 138 | 0 | 1 | 200.0 | 1010.0 | 1010 | 300 |
| | | IIa | 150 | 125 | 150 | 210 | 429 | 138 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | IIb | 125 | 112.5 | 125 | 210 | 214 | 119 | 0 | 1 | 150.0 | 1010.0 | 1010 | |
| | | II | 100 | 100 | 100 | 210 | 0 | 100 | 0 | 1 | 150.0 | 50.0 | 50 | |
| | | III | 150 | 125 | 150 | 210 | 429 | 138 | 0 | 1 | 200.0 | 1010.0 | 1010 | |
| | | IV | 150 | 125 | 150 | 210 | 429 | 138 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVa | 283 | 180 | 283 | 210 | 1766 | 232 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | IVb | 416 | 235 | 416 | 210 | 3103 | 326 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |
| | | V | 549 | 290 | 549 | 210 | 4440 | 420 | 0 | 1/2 | 100.0 | 1010.0 | 1010 | |

For notes, see next page.

**Table 1: Thermal Cycle Definitions for Feedwater Line (concluded)**

Notes:

1. From Reference [13].
2. Normal operating conditions are 1,010 psig, 549°F (steam dome), 392°F (feedwater), and 4590 gpm (feedwater nozzle) [14].
3. See Figure 1.
4. For the transients where flow is stopped, the natural convection heat transfer coefficient was used. The same approximate value was used within each region. These values are:
   - 200 gpm for Regions I and III.
   - 150 gpm for Regions II, IIa, and IIb.
   - 100 gpm for Regions IV and V.

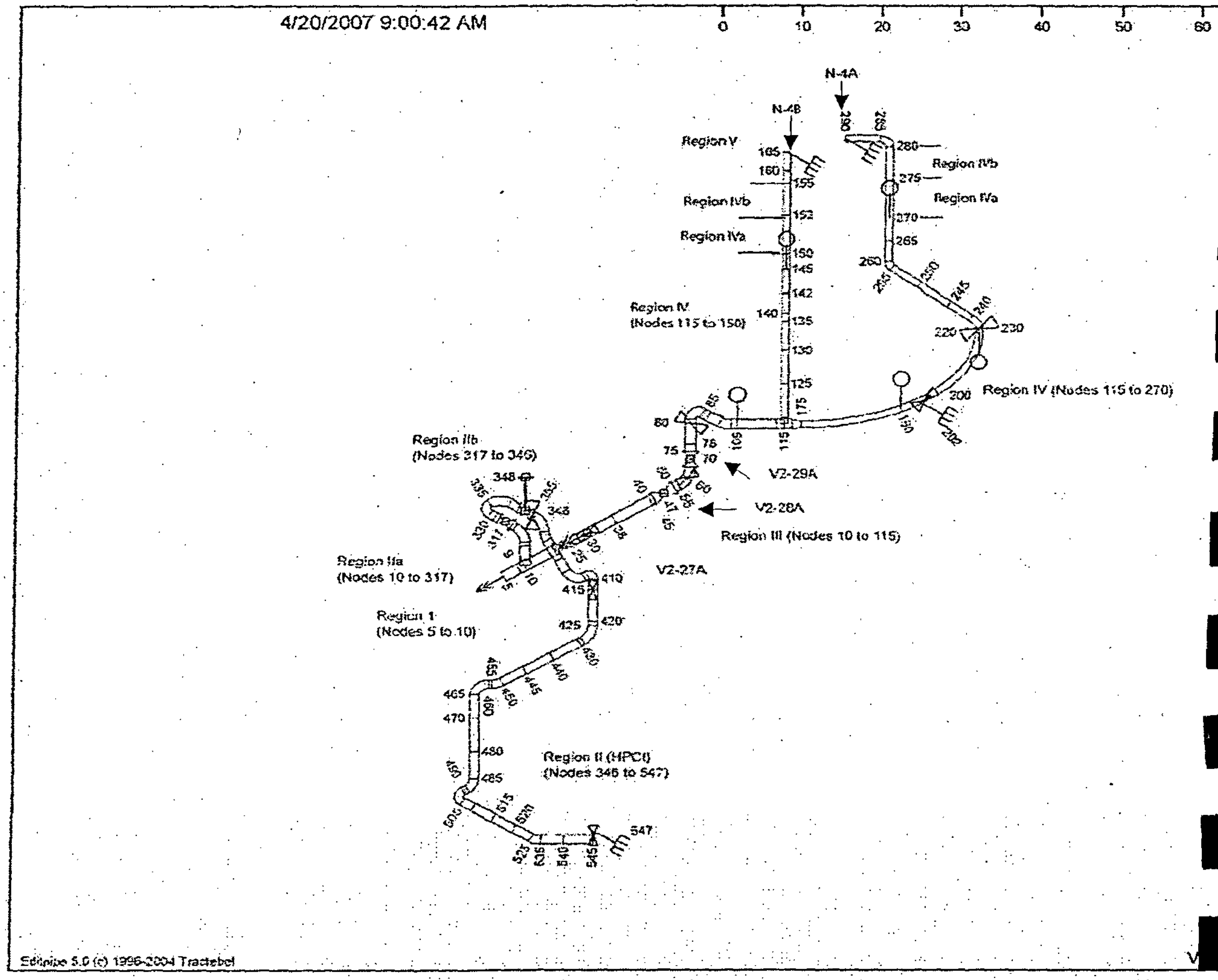


**Figure 1: Feedwater/HPCI Piping from Anchor HD-36 to RPV Nozzles N-4A an**

## 3.0 ASSUMPTIONS/DESIGN INPUT

In order to take advantage of improvements in the ASME Code that result in a lower calculated fatigue usage, this evaluation is done to the ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition with 2000 Addenda [9]. The 1998 Edition of Section III (with 2000 Addenda) has been accepted by the US NRC for use in design analyses. Although there are a few restrictions on the application of this Edition, they involve the use of optional increased allowables that are not being used in this calculation.

A piping model was created using PIPESTRESS [1]. The calculation [2] that had previously analyzed the subject Class 1 feedwater piping contains the ADLPIPE input file used to create the PIPESTRESS input file for this evaluation. Valve dimensions and properties were also obtained from the ADLPIPE input file. The piping model is composed of one carbon steel grade (maximum carbon content of 0.30 %) [2]. Temperature dependent material properties were used with values obtained from Reference [5]. Table 2 summarizes these values. The resulting PIPESTRESS model (including boundary conditions) is shown in Figure 1. The drawings for both feedwater loops [3, 4] and the HPCI line [7] were also consulted to aid in building the PIPESTRESS model.

Assumptions:

1) The weight of insulation is included in the analysis and PIPESTRESS calculates the heat transfer effects of insulation.
2) Node 545 is the end of the as-modeled HPCI piping system. This is appropriate because of the distance from the HPCI/Feedwater tee, six pipe supports in the segment and multiple pipe direction changes.

The feedwater and HPCI line sizes are specified in the previous calculation [2] and are shown in Table 3.

**Table 2: Material Properties for Feedwater System Class 1 Piping [2 App. E, 5]**

| SA 106 B and SA-234 WPB (Carbon Silicon Steel, C-Si) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Temperature (°F) | Young's Modulus (x10[6] psi) | Coefficient of Linear Thermal Expansion (in/100 ft) | Mean Coefficient of Thermal Expansion[(1)] (10[-6] /in/in/°F) | Thermal Conductivity[(1)] (btu/hr/ft/°F) | Thermal Diffusivity[(1)] (ft[2]/hr) | Yield Stress $S_y$ (ksi) | Design Stress Intensity $S_m$ (ksi) |
| 50 | 29.6 | 0[(2)] | | | | 35.0 | 20.0 |
| 70 | 29.5 | 0 | 6.4 | 27.5 | 0.529 | 35.0 | 20.0 |
| 100 | 29.3 | 0.2 | | 27.6 | 0.512 | 35.0 | 20.0 |
| 150 | | | | 27.6 | 0.496 | | |
| 200 | 28.8 | 1.0 | | 27.6 | 0.486 | 32.1 | 20.0 |
| 250 | | | | 27.4 | 0.467 | | |
| 300 | 28.3 | 1.9 | | 27.2 | 0.453 | 31.0 | 20.0 |
| 350 | | | | 27.0 | 0.440 | | |
| 400 | 27.7 | 2.8 | | 26.7 | 0.428 | 29.9 | 20.0 |
| 450 | | | | 26.3 | 0.413 | | |
| 500 | 27.3 | 3.7 | | 25.9 | 0.398 | 28.5 | 18.9 |
| 550 | | | | 25.5 | 0.387 | | |
| 600 | 26.7 | 4.7 | | 25.0 | 0.374 | 26.8 | 17.3 |

Notes:
1. These properties are used for the transient analysis only.
2. Assumed equivalent to the value at 70°F.

***The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions.***

**Table 3: Feedwater/HPCI Piping Size Information [2]**

| | 16" FW Downstream of V2-29A | 16" FW Upstream of V2-29A | 10" FW | 14" HPCI |
|---|---|---|---|---|
| Pipe Schedule | 80 | 120 | 120 | 120 |
| Fittings Schedule | 120 | --- | 120 | --- |
| Piping O.D. (in.) | 16.0 | 16.0 | 10.75 | 14.0 |
| Piping Nom. Wall (in.) | 0.843 | 1.218 | 0.843 | 1.093 |
| Fitting Nom. Wall (in.) | 1.218 | --- | 0.843 | --- |
| Pipe Weight[1] (lb/ft) | 136.46 | 192.3 | 89.20 | 150.7 |
| Insulation Weight (lb/ft) | 14.64 | 11.98 | 8.92 | 10.65[2] |

Note:

1. Weight of contents automatically added by the PIPESTRESS Program.
2. Insulation weight assumed to be consistent with thickness (2 inches) and composition of insulation on the 16" FW upstream of V2-29A.

## 4.0 ANALYSIS

Through-wall thermal gradient terms were calculated by the PIPESTRESS program for all of the transients. Table 1 defines each thermal cycle definition (i.e., transient load case) and the region of the modeled piping those conditions are applicable.

The forces and moments due to differential thermal expansion need to be included in the fatigue evaluation. The differential thermal expansion cases as analyzed by the piping program, PIPESTRESS, correspond to the end temperature and pressure of the transient. Table 4 lists the thermal expansion cases.

The material properties were obtained from the ASME Code Section II, 1998 Edition, Part D, with 2000 Addenda [5]. E and $\alpha$ are taken at 70°F, and k, $\rho$, and $c_p$ are taken at the average temperature over the range of the individual transients.

The internal heat transfer coefficient h for the transients with flow occurring in the pipe is calculated based on the following relation for forced convection [8]:

$$h = 0.023\ Re^{0.8}\ Pr^{0.4}\ k/D$$

Where Re = Reynolds number
Pr = Prandtl number

The heat transfer coefficients were calculated by PIPESTRESS using the above relation. The flow rates described for each transient in Table 1 were used. For the transients where flow is stopped, the natural convection heat transfer coefficient was used. The formula for h is [8]:

$$h = 0.55\ (Gr\ Pr)^{0.25} k/L$$

Where Gr = Grashof Number
L = pipe diameter

PIPESTRESS only has the forced convection heat transfer formula built in, so an equivalent flow rate was determined that would give the same heat transfer coefficient as the free convection coefficient.

As discussed in the next section, the PIPESTRESS input file "FWHPCI.FRE" will be run and analyzed to Section III, Subsection NB-3600 of ASME 1998 Edition [9] in order to evaluate acceptable fatigue usage values for the Class 1 feedwater loop A system. The code option available in PIPESTRESS is the 1998 edition without addenda. This is acceptable as the 1999 and 2000 addenda to the 1998 code did not change the fatigue analysis method which PIPESTRESS uses.

A Listing of the PIPESTRESS input is included as Appendix A.

## Table 4: Thermal Cycle Load Cases

| Load Set | Transients Represented | Region I Temp. (°F) | Region IIa Temp. (°F) | Region IIb Temp. (°F) | Region II Temp. (°F) | Region III Temp. (°F) | Region IV Temp. (°F) | Region IVa Temp. (°F) | Region IVb Temp. (°F) | Region V Temp. (°F) | Vessel Temp. (°F) | Region II Pressure (psig) | All other Regions Pressure (psig) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50 | 1100 |
| 2 | 2, 24, 36, 38 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50 | 50 |
| 3 | 3, 21, 34, 43 | 150 | 150 | 125 | 100 | 150 | 150 | 283 | 416 | 549 | 549 | 50 | 1010 |
| 4 | 5 | 260 | 260 | 180 | 100 | 260 | 260 | 260 | 260 | 260 | 549 | 50 | 1010 |
| 5 | 6, 8, 10, 14, 16 | 392 | 392 | 246 | 100 | 392 | 392 | 392 | 392 | 392 | 549 | 50 | 1010 |
| 6 | 7 | 310 | 310 | 205 | 100 | 310 | 310 | 310 | 310 | 310 | 549 | 50 | 1010 |
| 7 | 9 | 280 | 280 | 190 | 100 | 280 | 280 | 280 | 280 | 280 | 549 | 50 | 1010 |
| 8 | 11, 13, 15 | 265 | 265 | 182.5 | 100 | 265 | 265 | 265 | 265 | 265 | 549 | 50 | 1010 |
| 9 | 12 | 90 | 90 | 95 | 100 | 90 | 90 | 90 | 90 | 90 | 549 | 50 | 1010 |
| 10 | 20 | 265 | 265 | 182.5 | 100 | 265 | 265 | 360 | 454 | 549 | 549 | 50 | 1010 |
| 11 | 22 | 150 | 150 | 125 | 100 | 150 | 150 | 225 | 300 | 375 | 375 | 50 | 170 |
| 12 | 23 | 150 | 150 | 125 | 100 | 150 | 150 | 210 | 270 | 330 | 330 | 50 | 88 |
| 13 | 25 | 392 | 392 | 246 | 100 | 392 | 392 | 450 | 507 | 565 | 565 | 50 | 1190 |
| 14 | 26 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 565 | 1135 | 1135 |
| 15 | 27 | 150 | 150 | 125 | 100 | 150 | 150 | 247 | 343 | 440 | 565 | 50 | 1135 |
| 16 | 28 | 150 | 150 | 125 | 100 | 150 | 150 | 288 | 427 | 565 | 565 | 50 | 1135 |
| 17 | 30 | 150 | 150 | 125 | 100 | 150 | 150 | 247 | 343 | 440 | 555 | 50 | 1060 |
| 18 | 31 | 150 | 150 | 125 | 100 | 150 | 150 | 283 | 416 | 549 | 565 | 50 | 1135 |
| 19 | 32 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 502 | 675 | 675 |
| 20 | 33 | 150 | 150 | 125 | 100 | 150 | 150 | 200 | 250 | 300 | 502 | 50 | 675 |
| 21 | 35 | 275 | 275 | 187.5 | 100 | 275 | 275 | 275 | 275 | 275 | 549 | 50 | 885 |
| 22 | 37 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50 | 1563 |
| 23 | 39 | 392 | 392 | 246 | 100 | 392 | 392 | 392 | 392 | 392 | 600 | 50 | 1375 |
| 24 | 40 | 392 | 392 | 246 | 100 | 392 | 392 | 392 | 392 | 392 | 539 | 50 | 940 |
| 25 | 41 | 392 | 392 | 246 | 100 | 392 | 392 | 392 | 392 | 392 | 549 | 50 | 1010 |
| 26 | 17 | 275 | 275 | 187.5 | 100 | 275 | 275 | 275 | 275 | 275 | 539 | 50 | 1010 |
| 27 | 19 | 265 | 265 | 182.5 | 100 | 265 | 265 | 323 | 382 | 440 | 549 | 50 | 1010 |
| 28 | 4 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 549 | 50 | 1010 |
| 29 | 18 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 539 | 50 | 1010 |
| 30 | 42 | 125 | 125 | 112.5 | 100 | 125 | 125 | 180 | 235 | 290 | 549 | 50 | 1010 |
| 31 | 29 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 532 | 885 | 885 |

## 5.0 RESULTS OF ANALYSIS

Since the piping at VY was designed in accordance with USAS B31.1 methodology, fatigue analysis does not exist for the piping. Therefore, fatigue calculations are being developed for selected locations in the Class 1 piping systems at VY. This will result in detailed, Class 1 fatigue calculations for each selected location. Piping models and transient definitions have been developed for the Class 1 portion of the feedwater system, as documented in the previous sections of this calculation.

The limiting total fatigue usage for the analyzed feedwater/HPCI piping system occurs at Node 155 on the riser to the feedwater nozzle. The total usage at this location is U = 0.1661 (per the PIPESTRESS report FWHPCI.PRF) which passes Class 1 fatigue evaluation. The second highest total fatigue usage for the analyzed feedwater/HPCI piping system occurs at Node 175, the 16" to 10" reducer on the feedwater piping. The total usage at this location is U = 0.1114 (per the PIPESTRESS report FWHPCI.PRF) which passes Class 1 fatigue evaluation. The environmental fatigue multiplier to use from Reference [10] is 1.74. The total usage including environmental effects is therefore 0.289.

Appendix B contains the fatigue usage summary for node 155.

## 6.0 REFERENCES


1. PIPESTRESS, Version 3.5.1+0.26, DST Computer Services S.A., QA-1670-301, June, 2004.
2. HPCI/FW Piping Stress Information. ADLPIPE listing for FDW & HPCI piping from Calculation No. VYC-551, Rev. 2, Appendix A, SI File No. VY-05Q-229.
3. Vermont Yankee Nuclear Power Corp. Drawing No. VYI-FDW-Part 5, Rev. 1, "Piping Isometric Feedwater: Drywell-Main Steam Tunnel (FDW) Part 5," SI File No. VY-05Q-221.
4. Vermont Yankee Nuclear Power Corp. Drawing No. VYI-FDW-Part 5A, Rev. 1, "Piping Isometric Feedwater: Main Steam Tunnel and Drywell FDW-Part 5A," SI File No. VY-05Q-221.
5. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Materials, Part D, "Properties (Customary)," 1998 Edition including the 2000 Addenda.
6. Structural Integrity Associates Report No. SIR-01-130, Revision 0, "System Review and Recommendations for a Transient and Fatigue Monitoring System at the Vermont Yankee Nuclear Power Station," February 2002, SI File No. VY-05Q-401.
7. Vermont Yankee Nuclear Power Corp. Drawing No. VYI-HPCI-Part 5, Rev. 0, "Piping Isometric Drawing High Pressure Coolant Injection Main Steam Tunnel-Torus Area (HPCI) Part 5," SI File No. VY-05Q-223.
8. Holman, J.P., *Heat Transfer*, Fifth Edition, McGraw-Hill, 1981.
9. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, 1998 Edition including the 2000 Addenda.
10. Structural Integrity Associates Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head."
11. "Reactor Thermal Cycles," Attachment 1, page 2, of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.
12. "Nozzle Thermal Cycles (Feedwater)," Attachment 1, page 3, of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.
13. "Reactor Thermal Cycles for 60 Years of Operation," Attachment 1 of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.
14. GE Certified Design Specification No. 26A6019, Revision 1, "REACTOR VESSEL – EXTENDED POWER UPRATE," August 29, 2003, SI File No. VY-05Q-236.

APPENDIX A

PIPESTRESS INPUT FILE ("FWHPCI.FRE")

(Pages A1 – A38)

```
IDEN JB=2     *Job number (1 to 9999)
     CD=1     *1=ASME Section III
     VA=0     *0=Calculate             2=Verify
     GR=-Y    *Direction of gravity
     IU=1     *Input units             0=SIU        1=USA
     OU=1     *Output units            0=SIU        1=USA
     CH=$     *Delimiter character
     AB=T     *FREE errors =abort
     PL=$Vermont Yankee$
     EN=$KRE$
TITL BL=3     *Modeling option:
              *  3 =uniform mass for static analysis
              *      lumped mass for dynamic analysis
              *      rotational inertia ignored
     GL=1     *Report forces/moment          0=Global     1=Local     2=G et L
     SU=1     *Support summary               0=No         1=Yes
     CV=15    *Code version - See Manual
     HS=1     *Highest 20 stress ratios for each case
     MD=1     *Hot modulus
     TI=$Vermont Yankee Feedwater Piping$
        $SI Fatigue Analysis$
FREQ RF=1 RP=8 FR=33 MP=20 MX=70 TI=$SEISMIC$
*
*************************************
**** THERMAL CYCLE LOAD CASES****
*************************************
LCAS RF=0 CA=1 TY=0 TI=$LC-1$      *TC-1
LCAS RF=0 CA=2 TY=0 TI=$LC-2$      *TC-2,24,36,38
LCAS RF=0 CA=3 TY=0 TI=$LC-3$      *TC-3,21,34,43
LCAS RF=0 CA=4 TY=0 TI=$LC-4$      *TC-5
LCAS RF=0 CA=5 TY=0 TI=$LC-5$      *TC-6,8,10,14,16
LCAS RF=0 CA=6 TY=0 TI=$LC-6$      *TC-7
LCAS RF=0 CA=7 TY=0 TI=$LC-7$      *TC-9
LCAS RF=0 CA=8 TY=0 TI=$LC-8$      *TC-11,13,15
LCAS RF=0 CA=9 TY=0 TI=$LC-9$      *TC-12
LCAS RF=0 CA=10 TY=0 TI=$LC-10$    *TC-20
LCAS RF=0 CA=11 TY=0 TI=$LC-11$    *TC-22
LCAS RF=0 CA=12 TY=0 TI=$LC-12$    *TC-23
LCAS RF=0 CA=13 TY=0 TI=$LC-13$    *TC-25
LCAS RF=0 CA=14 TY=0 TI=$LC-14$    *TC-26, 29
LCAS RF=0 CA=15 TY=0 TI=$LC-15$    *TC-27
LCAS RF=0 CA=16 TY=0 TI=$LC-16$    *TC-28
LCAS RF=0 CA=17 TY=0 TI=$LC-17$    *TC-30
LCAS RF=0 CA=18 TY=0 TI=$LC-18$    *TC-31
LCAS RF=0 CA=19 TY=0 TI=$LC-19$    *TC-32
LCAS RF=0 CA=20 TY=0 TI=$LC-20$    *TC-33
LCAS RF=0 CA=21 TY=0 TI=$LC-21$    *TC-35
LCAS RF=0 CA=22 TY=0 TI=$LC-22$    *TC-37
LCAS RF=0 CA=23 TY=0 TI=$LC-23$    *TC-39
LCAS RF=0 CA=24 TY=0 TI=$LC-24$    *TC-40
LCAS RF=0 CA=25 TY=0 TI=$LC-25$    *TC-41
LCAS RF=0 CA=26 TY=0 TI=$LC-26$    *TC-17
LCAS RF=0 CA=27 TY=0 TI=$LC-27$    *TC-19
LCAS RF=0 CA=28 TY=0 TI=$LC-28$    *TC-4
LCAS RF=0 CA=29 TY=0 TI=$LC-29$    *TC-18
LCAS RF=0 CA=30 TY=0 TI=$LC-30$    *TC-42
```

```
LCAS RF=0 CA=31 TY=0 TI=$LC-31    *TC-29
LCAS RF=6 CA=32 TY=6 TI=$SAM$
*********************
**** WEIGHT CASES****
*********************
LCAS CA=101  RF=1  TY=3  TI=$OPERATING WEIGHT$
LCAS CA=102  RF=2  TY=4  TI=$HYDROTEST WEIGHT$
*
*********************************
**** THERMAL TRANSIENT CASES****
*********************************
TCAS CA=201 RP=1 TI=$Design Hydrotest +$
TCAS CA=202 RP=1 TI=$Design Hydrotest -$
TCAS CA=203 RP=1 TI=$Startup +$
TCAS CA=204 RP=1 TI=$TRoll & Inc. PWR1 -$
TCAS CA=205 RP=1 TI=$TRoll & Inc. PWR2 +$
TCAS CA=206 RP=1 TI=$TRoll & Inc. PWR3 +$
TCAS CA=207 RP=1 TI=$DlyReduction to 75% -$
TCAS CA=208 RP=1 TI=$DlyReduction to 75% +$
TCAS CA=209 RP=1 TI=$WklyReduct to 50% -$
TCAS CA=210 RP=1 TI=$WklyReduct to 50% +$
TCAS CA=211 RP=1 TI=$LOFWH+TT 1 -$
TCAS CA=212 RP=1 TI=$LOFWH+TT 2 -$
TCAS CA=213 RP=1 TI=$LOFWH+TT 3 +$
TCAS CA=214 RP=1 TI=$LOFWH+TT 4 +$
TCAS CA=215 RP=1 TI=$LOFWH+PFWHTR Byp -$
TCAS CA=216 RP=1 TI=$LOFWH+PFWHTR Byp +$
TCAS CA=217 RP=1 TI=$SCRAM+TT+AllOtrScm -$
TCAS CA=218 RP=1 TI=$SCRAM+TT+AllOtrScm -$
TCAS CA=219 RP=1 TI=$HotStandby 1 +$
TCAS CA=220 RP=1 TI=$HotStandby 2 +$
TCAS CA=221 RP=1 TI=$HotStandby 3 -$
TCAS CA=222 RP=1 TI=$Shutdown 1 -$
TCAS CA=223 RP=1 TI=$Shutdown 2 -$
TCAS CA=224 RP=1 TI=$Shutdown 3 -$
TCAS CA=225 RP=1 TI=$SCRAM+LOFWP1 +$
TCAS CA=226 RP=1 TI=$SCRAM+LOFWP2 -$
TCAS CA=227 RP=1 TI=$SCRAM+LOFWP3 +$
TCAS CA=228 RP=1 TI=$SCRAM+LOFWP4 +$
TCAS CA=229 RP=1 TI=$SCRAM+LOFWP5 -$
TCAS CA=230 RP=1 TI=$SCRAM+LOFWP6 +$
TCAS CA=231 RP=1 TI=$SCRAM+LOFWP7 +$
TCAS CA=232 RP=1 TI=$SCRAM+LOFWP8 -$
TCAS CA=233 RP=1 TI=$SCRAM+LOFWP9 +$
TCAS CA=234 RP=1 TI=$SCRAM+LOFWP10+$
TCAS CA=235 RP=1 TI=$SCRAM+SRVBLDN1-$
TCAS CA=236 RP=1 TI=$SCRAM+SRVBLDN2-$
TCAS CA=237 RP=1 TI=$Hydro Test +$
TCAS CA=238 RP=1 TI=$Hydro Test -$
TCAS CA=239 RP=1 TI=$SCRAM+TG+OPres1 -$
TCAS CA=240 RP=1 TI=$SCRAM+TG+OPres2 -$
TCAS CA=241 RP=1 TI=$SCRAM+TG+OPres3 -$
TCAS CA=242 RP=1 TI=$HotSby_FWcyc +$
TCAS CA=243 RP=1 TI=$HotSby_FWcyc +$
*********************
**** SEISMIC CASES****
```

```
**********************
RCAS CA=103 EQ=3 EV=1 TY=1 SU=1 LO=1 FX=1 FY=1 FZ=1 TI=$OBE INERTIA$
*
** **************************
**** LOAD COMBINATION CASES *
** **************************
CCAS RF=1 CA=104      ME=1 FL=1  C1=103 CY=10  TI=$OBE$
CCAS RF=1 CA=401 SS=1 ME=1 EQ=3  C1=102 C2=103 TI=$EQUATION 9 LEVEL B$
CCAS RF=1 CA=402 SS=1 ME=3 F1=1  C1=103 C2=6 C3=32 TI=$NORMAL+OBE$
CCAS RF=1 CA=403 SS=1 ME=3 F1=-1 C1=103 C2=6 C3=32 TI=$NORMAL-OBE$
*
******************
**** LOAD SETS****
******************
*RF field is the highest temperature and pressure of the transient
*PR and MO fields are the final temperature and pressure of the transient
LSET RF=1  RP=1 CY=120   PR=1  MO=1  TR=+201 TI=$Design Hydrotest +    LS-1$
LSET RF=2  RP=1 CY=120   PR=2  MO=2  TR=-202 TI=$Design Hydrotest -    LS-2$
LSET RF=3  RP=1 CY=300   PR=3  MO=3  TR=+203 TI=$Startup +             LS-3$
LSET RF=3  RP=1 CY=610   PR=28 MO=28 TR=-204 TI=$TRoll & Inc. PWR1 -   LS-4$
LSET RF=4  RP=1 CY=599   PR=4  MO=4  TR=+205 TI=$TRoll & Inc. PWR2 +   LS-5$
LSET RF=5  RP=1 CY=599   PR=5  MO=5  TR=+206 TI=$TRoll & Inc. PWR3 +   LS-6$
LSET RF=5  RP=1 CY=10000 PR=6  MO=6  TR=-207 TI=$DlyReduction to 75% - LS-7$
LSET RF=5  RP=1 CY=10000 PR=5  MO=5  TR=+208 TI=$DlyReduction to 75% + LS-8$
LSET RF=5  RP=1 CY=2000  PR=7  MO=7  TR=-209 TI=$WklyReduct to 50% -   LS-9$
LSET RF=5  RP=1 CY=2000  PR=5  MO=5  TR=+210 TI=$WklyReduct to 50% +   LS-10$
LSET RF=5  RP=1 CY=310   PR=8  MO=8  TR=-211 TI=$LOFWH+TT 1 -          LS-11$
LSET RF=8  RP=1 CY=10    PR=9  MO=9  TR=-212 TI=$LOFWH+TT 2 -          LS-12$
LSET RF=8  RP=1 CY=10    PR=8  MO=8  TR=+213 TI=$LOFWH+TT 3 +          LS-13$
LSET RF=5  RP=1 CY=10    PR=5  MO=5  TR=+214 TI=$LOFWH+TT 4 +          LS-14$
LSET RF=5  RP=1 CY=70    PR=8  MO=8  TR=-215 TI=$LOFWH+PFWHTR Byp -    LS-15$
LSET RF=5  RP=1 CY=70    PR=5  MO=5  TR=+216 TI=$LOFWH+PFWHTR Byp +    LS-16$
LSET RF=5  RP=1 CY=289   PR=26 MO=26 TR=-217 TI=$SCRAM+TT+AllOtrScm -  LS-17$
LSET RF=26 RP=1 CY=289   PR=29 MO=29 TR=-218 TI=$SCRAM+TT+AllOtrScm -  LS-18$
LSET RF=27 RP=1 CY=300   PR=27 MO=27 TR=+219 TI=$HotStandby 1 +        LS-19$
LSET RF=10 RP=1 CY=300   PR=10 MO=10 TR=+220 TI=$HotStandby 2 +        LS-20$
LSET RF=10 RP=1 CY=300   PR=3  MO=3  TR=-221 TI=$HotStandby 3 -        LS-21$
LSET RF=3  RP=1 CY=300   PR=11 MO=11 TR=-222 TI=$Shutdown 1 -          LS-22$
LSET RF=11 RP=1 CY=300   PR=12 MO=12 TR=-223 TI=$Shutdown 2 -          LS-23$
LSET RF=12 RP=1 CY=300   PR=2  MO=2  TR=-224 TI=$Shutdown 3 -          LS-24$
LSET RF=13 RP=1 CY=10    PR=13 MO=13 TR=+225 TI=$SCRAM+LOFWP1 +        LS-25$
LSET RF=13 RP=1 CY=10    PR=14 MO=14 TR=-226 TI=$SCRAM+LOFWP2 -        LS-26$
LSET RF=15 RP=1 CY=10    PR=15 MO=15 TR=+227 TI=$SCRAM+LOFWP3 +        LS-27$
LSET RF=16 RP=1 CY=10    PR=16 MO=16 TR=+228 TI=$SCRAM+LOFWP4 +        LS-28$
LSET RF=16 RP=1 CY=10    PR=31 MO=31 TR=-229 TI=$SCRAM+LOFWP5 -        LS-29$
LSET RF=17 RP=1 CY=10    PR=17 MO=17 TR=+230 TI=$SCRAM+LOFWP6 +        LS-30$
LSET RF=18 RP=1 CY=10    PR=18 MO=18 TR=+231 TI=$SCRAM+LOFWP7 +        LS-31$
LSET RF=18 RP=1 CY=10    PR=19 MO=19 TR=-232 TI=$SCRAM+LOFWP8 -        LS-32$
LSET RF=20 RP=1 CY=10    PR=20 MO=20 TR=+233 TI=$SCRAM+LOFWP9 +        LS-33$
LSET RF=3  RP=1 CY=10    PR=3  MO=3  TR=+234 TI=$SCRAM+LOFWP10+        LS-34$
LSET RF=5  RP=1 CY=1     PR=21 MO=21 TR=-235 TI=$SCRAM+SRVBLDN1-       LS-35$
LSET RF=21 RP=1 CY=1     PR=2  MO=2  TR=-236 TI=$SCRAM+SRVBLDN2-       LS-36$
LSET RF=22 RP=1 CY=1     PR=22 MO=22 TR=+237 TI=$Hydro Test +          LS-37$
LSET RF=2  RP=1 CY=1     PR=2  MO=2  TR=-238 TI=$Hydro Test -          LS-38$
LSET RF=23 RP=1 CY=289   PR=23 MO=23 TR=-239 TI=$SCRAM+TG+OPres1 -     LS-39$
LSET RF=24 RP=1 CY=289   PR=24 MO=24 TR=-240 TI=$SCRAM+TG+OPres2 -     LS-40$
```

```
LSET RF=25 RP=1 CY=289   PR=25 MO=25 TR=-241 TI=$SCRAM+TG+OPres3 -     LS-41$
LSET RF=30 RP=1 CY=300   PR=30 MO=30 TR=+242 TI=$HotSbyFWcyc +         LS-42$
LSET RF=3  RP=1 CY=300   PR=3  MO=3  TR=+243 TI=$HotSbyFWcyc +         LS-43$
*
LSET RF=6 CY=5 FL=1 PR=6 MO=402 TI=$NORMAL+OBE  LS-132$
LSET RF=6 CY=5 FL=1 PR=6 MO=403 TI=$NORMAL-OBE  LS-133$

**************************
**** RESPONSE SPECTRA****
*************************
*SSE response spectra conservatively used
SPEC FS=OBE EV=1 ME=3 FP=1 TI=$RESPONSE$
      LV=1 DX=1 DY=1 DZ=1
       DI=X
         0.30/0.125  0.80/0.300  2.00/0.650  3.00/0.725  3.50/1.000  4.40/1.200
         5.00/1.900  5.75/2.850  6.00/3.375  8.25/3.375  9.00/3.000 10.00/2.400
        14.00/1.325 19.00/1.600 21.00/1.000 22.00/0.800 30.00/0.700 36.00/0.650
       DI=Y
         0.30/0.075  1.25/0.250  1.75/0.325  2.40/0.450  2.75/0.475  3.80/0.500
         4.40/0.500  4.80/0.600  7.25/0.600  7.50/0.700  8.50/0.700 10.00/0.925
        12.00/1.450 16.00/1.900 18.00/1.700 20.00/0.750 25.00/0.450 30.00/0.350
        36.00/0.325 36.10/0.325 36.20/0.325 36.30/0.325 36.40/0.325 36.50/0.325
       DI=Z
         0.30/0.150  1.00/0.350  2.00/0.625  4.00/1.000  4.50/1.400  5.00/2.000
         5.75/2.950  6.00/3.450  6.25/3.800  8.75/3.800 10.00/2.625  12.0/2.150
        15.00/1.300 17.50/1.450 20.00/0.875 30.00/0.650 36.00/0.650 36.10/0.650
*****************************
**** MATERIAL PROPERTIES ****
*****************************
* SA-106 Grade B and SA-234 WPB
MATH CD=106 EX=0 TY=1 *C-Si
*MATD TE=-100 EH=30.2 EX=0 SM=20 SY=35
MATD TE=50   EH=29.6 EX=0 SM=20 SY=35
MATD TE=70   EH=29.5 EX=0   SM=20   SY=35
MATD TE=100  EH=29.3 EX=0.2 SM=20.0 SY=35
MATD TE=200  EH=28.8 EX=1.0 SM=20.0 SY=32.1
MATD TE=300  EH=28.3 EX=1.9 SM=20.0 SY=31
MATD TE=400  EH=27.7 EX=2.8 SM=20.0 SY=29.9
MATD TE=500  EH=27.3 EX=3.7 SM=18.9 SY=28.5
MATD TE=600  EH=26.7 EX=4.7 SM=17.3 SY=26.8
*** Cross Sectional Properties
*REGION I- LINE 16 INCH FDW-16 SCH. 120 Run from 5 to 10
*Anchor HD36 to HPCI brnch
CROS CD=1 OD=16.0  WT=1.218 MA=204.28
          SO=1  ST=1  IN=0
*FEEDWATER Valves - V2-27A, V2-28A, V2-29A
CROS CD=2 OD=24.0  WT=2.436 MA=0.12
          SO=1  ST=1  IN=0  KL=1
*REGION III- LINE 16 INCH FDW-16 SCH. 80
*Piping Downstream of Valve V2-29A TO FW TEE
CROS CD=3 OD=16.0  WT=0.843 MA=151.1
          SO=1  ST=1  IN=0
*REGION III- LINE 16 INCH FDW-16 SCH. 120
*Fittings Downstream of Valve V2-29A TO FW TEE
CROS CD=4 OD=16.0  WT=1.218 MA=204.28
          SO=1  ST=1  IN=0
```

```
*REGION IV & V- LINES 10 INCH INCH FDW-21 AND 10 INCH FDW-19 SCH. 120
*Piping Downstream of FW TEE TO NOZZLES
CROS CD=5 OD=10.75 WT=0.843 MA=98.12
          SO=1  ST=1  IN=0
*REGION II- LINE 14 INCH HPCI-15A SCH. 120 FROM NODE 10 TO 547
CROS CD=6 OD=14.0  WT=1.093 MA=161.35
          SO=1  ST=1  IN=1
*REGION II- HPCI Valves
CROS CD=7 OD=21.0  WT=2.186 MA=0.12
          SO=1  ST=1  IN=1  KL=1
*
**********************
* STRUCTURE AND LOADS
*------------------------------------------------------------------------------
DESN  TE=400.0  PR=1900.0 *FEEDWATER AND HPCI PIPING
*------------------------------------------------------------------------------
*BEGIN REGION 1
*--------------
*Same for all regions except II
OPER CA=1  TE=100 PR=1100
OPER CA=22 TE=100 PR=1563
OPER CA=28 TE=100 PR=1010
OPER CA=29 TE=100 PR=1010

*Same for all regions
OPER CA=2  TE=100 PR=50
OPER CA=19 TE=50  PR=675
OPER CA=31 TE=50  PR=885

*Unique
OPER CA=3  TE=150 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=265 PR=1010
OPER CA=11 TE=150 PR=170
OPER CA=12 TE=150 PR=88
OPER CA=13 TE=392 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=150 PR=1135
OPER CA=16 TE=150 PR=1135
OPER CA=17 TE=150 PR=1060
OPER CA=18 TE=150 PR=1135

OPER CA=20 TE=150 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=265 PR=1010
```

```
OPER CA=30 TE=125 PR=1010

*
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=200 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=200 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=200 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=150 FT=100 TT=0 FL=1377 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=1377 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=9180 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=6885 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=6885 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=1377 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=1377 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=9180 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=9180 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=10098 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=275.4 IP=1025 FP=1025 TP=900
TRAN CA=219 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=200 IP=1025 FP=1025 TP=0
TRAN CA=220 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=200 IP=1025 FP=1025 TP=0
TRAN CA=221 IS=1 FS=1 IT=265 FT=150 TT=4140 FL=200 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=1025 FP=185 TP=0
TRAN CA=223 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=185 FP=103 TP=0
TRAN CA=224 IS=1 FS=1 IT=150 FT=100 TT=8280 FL=200 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=392 TT=12 FL=200 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=392 FT=50 TT=0 FL=3672 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=150 TT=1380 FL=200 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=150 FT=50 TT=0 FL=2754 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=150 TT=3060 FL=200 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=150 FT=50 TT=0 FL=1560.6 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=150 TT=300 FL=200 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=150 FT=150 TT=8964 FL=200 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=10098 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=275.4 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=200 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=200 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=10098 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=275.4 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=275.4 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=125 TT=60 FL=200 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=125 FT=150 TT=210 FL=200 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=204 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
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PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=220 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=221 CO=27.6 DI=0.483 EX=6.4 * Tavg=208
PAIR CA=222 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=223 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=224 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=225 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=226 CO=27.5 DI=0.478 EX=6.4 * Tavg=221
PAIR CA=227 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=228 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=229 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=230 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=231 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=232 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=233 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=234 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=243 CO=27.6 DI=0.500 EX=6.4 * Tavg=138
*
*REGION I GEOMETRY
* RUN 1 FROM ANCHOR HD36 TO HPCI brnCH- FDW-16 LINE A
MATL CD=106
CROS CD=1
COOR PT=5   AX=0 AY=0 AZ=0 *ANCHOR HD36
JUNC PT=5
TANG PT=9   DZ=-2.75  EW=1
TANG PT=10  DZ=-1 *WELDING TEE PER ANSI B16.9
*---------------------------------------------------------------------------
*END REGION I
*---------------------------------------------------------------------------
*BEGIN REGION 3
*---------------
*OPER cards same as those for region I
*
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=200 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=200 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=200 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=150 FT=100 TT=0 FL=1377 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=1377 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=9180 IP=1025 FP=1025 TP=1800
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TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=6885 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=6885 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=1377 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=1377 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=9180 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=9180 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=10098 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=275.4 IP=1025 FP=1025 TP=900
TRAN CA=219 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=200 IP=1025 FP=1025 TP=0
TRAN CA=220 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=200 IP=1025 FP=1025 TP=0
TRAN CA=221 IS=1 FS=1 IT=265 FT=150 TT=4140 FL=200 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=1025 FP=185 TP=0
TRAN CA=223 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=185 FP=103 TP=0
TRAN CA=224 IS=1 FS=1 IT=150 FT=100 TT=8280 FL=200 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=392 TT=12 FL=200 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=392 FT=50 TT=0 FL=3672 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=150 TT=1380 FL=200 IP=1150 FP=1150 TP=1380
TRAN CA=228 *IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=150 FT=50 TT=0 FL=2754 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=150 TT=3060 FL=200 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=150 FT=150 TT=0 FL=200 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=150 FT=50 TT=0 FL=1560.6 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=150 TT=300 FL=200 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=150 FT=150 TT=8964 FL=200 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=10098 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=275.4 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=200 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=200 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=10098 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=275.4 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=275.4 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=125 TT=60 FL=200 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=125 FT=150 TT=210 FL=200 IP=1025 FP=1025 TP=210

*
PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=204 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
```

```
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=220 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=221 CO=27.6 DI=0.483 EX=6.4 * Tavg=208
PAIR CA=222 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=223 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=224 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=225 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=226 CO=27.5 DI=0.478 EX=6.4 * Tavg=221
PAIR CA=227 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=228 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=229 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=230 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=231 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=232 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=233 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=234 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=243 CO=27.6 DI=0.500 EX=6.4 * Tavg=138

*
*REGION III GEOMETRY
CROS CD=1
*JUNC PT=10
TANG PT=11  DZ=-1  EW=1
TANG PT=15  DZ=-4.17
TANG PT=20  DZ=-0.333  EW=1  *TA=1
CROS CD=2
VALV PT=22  DZ=-1.333 PL=1 MA=2.7  *VALVE V2-27A
VALV PT=25  DZ=-1.333 PL=2  EW=1  *TA=1
CROS CD=1
TANG PT=30  DZ=-2.792
LUMP PT=30  MA=1.285
TANG PT=38  DZ=-4.6
TANG PT=40  DZ=-6.317
TANG PT=45  DZ=-0.625  EW=1  *TA=1
CROS CD=2
VALV PT=47  DZ=-1.792 PL=1 MA=2.7  *VALVE V2-28A
VALV PT=50  DZ=-1.792 PL=2  EW=1  *TA=1
CROS CD=1
*TANG PT=55  DZ=-2.791  EW=1
TANG PT=55  DZ=-.791 EW=1
*BRAD PT=65  RA=2  SD=2  EW=1 Used this to determine midpoint viw .prd output
BEND PT=60 X1=0 Y1=0 Z1=-.828 X2=0 Y2=.586 Z2=-.586
BEND PT=65 X1=0 Y1=.586 Z1=-.586 X2=0 Y2=.828 Z2=0
*TANG PT=67  DY=2.084  EW=1  *TA=1
TANG PT=67  DY=.084
CROS CD=2
VALV PT=70  DY=1.333 PL=1 MA=3.25  *VALVE V2-29A
```

```
VALV PT=75  DY=1.333 PL=2  EW=1  *TA=1
CROS CD=3
TANG PT=78  DY=1.25
TANG PT=80  DY=3.5
TANG PT=82  DY=2.667  EW=1
CROS CD=4
BRAD PT=85  RA=2  EW=1
CROS CD=3
TANG PT=90  DX=2.875
TANG PT=95  DX=2.875  EW=1
CROS CD=4
BRAD PT=100 RA=2  EW=1
CROS CD=3
TANG PT=105 DX=1.12  DZ=-1.12
TANG PT=110 DX=3.477 DZ=-3.477  EW=1
CROS CD=4
TANG PT=115 DX=0.7071 DZ=-0.7071 EW=1
*
*----------------------------------------------------------------------------
*END REGION III
*----------------------------------------------------------------------------
*BEGIN REGION IV
*---------------
*OPER cards same as those for regions I and III
*
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=150 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=221 IS=1 FS=1 IT=265 FT=150 TT=4140 FL=100 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=1025 FP=185 TP=0
TRAN CA=223 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=185 FP=103 TP=0
TRAN CA=224 IS=1 FS=1 IT=150 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=392 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=392 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=150 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 *IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=150 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=150 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=1075 FP=1150 TP=0
```

```
TRAN CA=232 IS=1 FS=1 IT=150 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=150 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=150 FT=150 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=125 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=125 FT=150 TT=210 FL=100 IP=1025 FP=1025 TP=210

*
PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=204 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=220 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=221 CO=27.6 DI=0.483 EX=6.4 * Tavg=208
PAIR CA=222 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=223 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=224 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=225 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=226 CO=27.5 DI=0.478 EX=6.4 * Tavg=221
PAIR CA=227 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=228 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=229 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=230 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=231 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=232 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=233 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=234 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
```

```
PAIR CA=243 CO=27.6 DI=0.500 EX=6.4 * Tavg=138

*
*REGION IV GEOMETRY DOWNSTREAM OF FW brnCH TEE/REDUCER - 10 INCH PIPING
*RUN FROM FW TEE TO ELBOW BEFORE NOZZLE NBA, NODE 275
CROS CD=4
TANG PT=170  DX=0.7071  DZ=-0.7071  EW=1
ERED PT=175  DX=0.825 DZ=-0.825  AN=30
CROS CD=5
*RUN FROM FW TEE TO ELBOW BEFORE NOZZLE N4B, NODE 152
BEND PT=190  X1=4.813  Y1=0  Z1=-4.813  X2=1.283  Y2=0  Z2=-6.685
BEND PT=200  X1=0.449  Y1=0  Z1=-2.342  X2=-0.059  Y2=0  Z2=-2.384
STRU PT=201 DX=.198 DZ=.9802
STRU PT=202 DX=.198 DZ=.9802
ANCH PT=202
JUNC PT=200
BEND PT=220  X1=-0.2196  Y1=0  Z1=-8.859  X2=-6.266  Y2=0  Z2=-6.266
TANG PT=225  DX=-0.3388  DZ=-0.3388
TANG PT=230  DX=-0.3388  DZ=-0.3388
TANG PT=235  DX=-1.002  DZ=-1.002
BRAD PT=240  RA=1.25
TANG PT=245  DX=-2.693  DY=3.196  DZ=2.693
TANG PT=250  DX=-2.693  DY=3.196  DZ=2.693
TANG PT=255  DX=-2.693  DY=3.196  DZ=2.693
BRAD PT=260  RA=1.25
TANG PT=265  DY=3.958
TANG PT=270  DY=3.959
*------------------------------------------------------------------------------
*END REGION IV
*------------------------------------------------------------------------------
*BEGIN REGION IVa
*------------------------------------------------------------------------------
OPER CA=3  TE=283 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=360 PR=1010
OPER CA=11 TE=225 PR=170
OPER CA=12 TE=210 PR=88
OPER CA=13 TE=450 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=247 PR=1135
OPER CA=16 TE=288 PR=1135
OPER CA=17 TE=247 PR=1060
OPER CA=18 TE=283 PR=1135

OPER CA=20 TE=200 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
```

```
OPER CA=27 TE=323 PR=1010
OPER CA=30 TE=180 PR=1010
*
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=283 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=283 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 IS=1 FS=1 IT=265 FT=323 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 IS=1 FS=1 IT=323 FT=360 TT=3924 FL=100 IP=1025 FP=1025 TP=3924
TRAN CA=221 IS=1 FS=1 IT=360 FT=283 TT=4140 FL=100 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=283 FT=225 TT=6264 FL=100 IP=1025 FP=185 TP=6264
TRAN CA=223 IS=1 FS=1 IT=225 FT=210 TT=600 FL=100 IP=185 FP=103 TP=600
TRAN CA=224 IS=1 FS=1 IT=210 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=450 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=450 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=247 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=247 FT=288 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=288 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=247 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=247 FT=283 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=283 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=200 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=200 FT=283 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=180 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=180 FT=283 TT=210 FL=100 IP=1025 FP=1025 TP=210


PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.488 EX=6.4 * Tavg=192
PAIR CA=204 CO=27.6 DI=0.488 EX=6.4 * Tavg=192
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
```

```
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.2 DI=0.455 EX=6.4 * Tavg=294
PAIR CA=220 CO=27.0 DI=0.442 EX=6.4 * Tavg=342
PAIR CA=221 CO=27.1 DI=0.447 EX=6.4 * Tavg=322
PAIR CA=222 CO=27.4 DI=0.466 EX=6.4 * Tavg=254
PAIR CA=223 CO=27.5 DI=0.479 EX=6.4 * Tavg=218
PAIR CA=224 CO=27.6 DI=0.495 EX=6.4 * Tavg=155
PAIR CA=225 CO=26.5 DI=0.422 EX=6.4 * Tavg=421
PAIR CA=226 CO=27.4 DI=0.467 EX=6.4 * Tavg=250
PAIR CA=227 CO=27.6 DI=0.496 EX=6.4 * Tavg=149
PAIR CA=228 CO=27.3 DI=0.462 EX=6.4 * Tavg=268
PAIR CA=229 CO=27.6 DI=0.492 EX=6.4 * Tavg=169
PAIR CA=230 CO=27.6 DI=0.496 EX=6.4 * Tavg=149
PAIR CA=231 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=232 CO=27.6 DI=0.493 EX=6.4 * Tavg=167
PAIR CA=233 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=234 CO=27.4 DI=0.470 EX=6.4 * Tavg=242
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.499 EX=6.4 * Tavg=140
PAIR CA=243 CO=27.5 DI=0.474 EX=6.4 * Tavg=232


TANG PT=275  DY=6.583  EW=0
*
*------------------------------------------------------------------------------
*END REGION IVa
*------------------------------------------------------------------------------
*BEGIN REGION IVb
*------------------------------------------------------------------------------
OPER CA=3  TE=416 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=454 PR=1010
OPER CA=11 TE=300 PR=170
OPER CA=12 TE=270 PR=88
OPER CA=13 TE=507 PR=1190
OPER CA=14 TE=50  PR=1135
```

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OPER CA=15 TE=343 PR=1135
OPER CA=16 TE=427 PR=1135
OPER CA=17 TE=343 PR=1060
OPER CA=18 TE=416 PR=1135

OPER CA=20 TE=250 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=382 PR=1010
OPER CA=30 TE=235 PR=1010
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=416 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=416 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 IS=1 FS=1 IT=265 FT=382 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 IS=1 FS=1 IT=382 FT=454 TT=3924 FL=100 IP=1025 FP=1025 TP=3924
TRAN CA=221 IS=1 FS=1 IT=454 FT=416 TT=4140 FL=100 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=416 FT=300 TT=6264 FL=100 IP=1025 FP=185 TP=6264
TRAN CA=223 IS=1 FS=1 IT=300 FT=270 TT=600 FL=100 IP=185 FP=103 TP=600
TRAN CA=224 IS=1 FS=1 IT=270 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=507 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=507 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=343 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=343 FT=427 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=427 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=343 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=343 FT=416 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=416 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=250 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=250 FT=416 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=235 TT=60 FL=100 IP=1025 FP=1025 TP=60
```

```
TRAN CA=243 IS=1 FS=1 IT=235 FT=416 TT=210 FL=100 IP=1025 FP=1025 TP=210


PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.4 DI=0.465 EX=6.4 * Tavg=258
PAIR CA=204 CO=27.4 DI=0.465 EX=6.4 * Tavg=258
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.1 DI=0.447 EX=6.4 * Tavg=324
PAIR CA=220 CO=26.6 DI=0.423 EX=6.4 * Tavg=418
PAIR CA=221 CO=26.4 DI=0.418 EX=6.4 * Tavg=435
PAIR CA=222 CO=27.0 DI=0.438 EX=6.4 * Tavg=358
PAIR CA=223 CO=27.3 DI=0.457 EX=6.4 * Tavg=285
PAIR CA=224 CO=27.6 DI=0.489 EX=6.4 * Tavg=185
PAIR CA=225 CO=26.3 DI=0.413 EX=6.4 * Tavg=450
PAIR CA=226 CO=27.3 DI=0.459 EX=6.4 * Tavg=279
PAIR CA=227 CO=27.6 DI=0.487 EX=6.4 * Tavg=197
PAIR CA=228 CO=26.8 DI=0.432 EX=6.4 * Tavg=385
PAIR CA=229 CO=27.4 DI=0.471 EX=6.4 * Tavg=239
PAIR CA=230 CO=27.6 DI=0.487 EX=6.4 * Tavg=197
PAIR CA=231 CO=26.8 DI=0.433 EX=6.4 * Tavg=380
PAIR CA=232 CO=27.5 DI=0.473 EX=6.4 * Tavg=233
PAIR CA=233 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=234 CO=27.1 DI=0.444 EX=6.4 * Tavg=333
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.492 EX=6.4 * Tavg=168
PAIR CA=243 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
*
TANG PT=280  DY=6.583
*------------------------------------------------------------------------------
*END REGION IVb
*------------------------------------------------------------------------------
*BEGIN REGION V TO NOZZLE N4A, NODE 290
*------------------------------------------------------------------------------

OPER CA=3  TE=549 PR=1010
OPER CA=4  TE=260 PR=1010
```

```
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=549 PR=1010
OPER CA=11 TE=375 PR=170
OPER CA=12 TE=330 PR=88
OPER CA=13 TE=565 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=440 PR=1135
OPER CA=16 TE=565 PR=1135
OPER CA=17 TE=440 PR=1060
OPER CA=18 TE=549 PR=1135

OPER CA=20 TE=300 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=440 PR=1010
OPER CA=30 TE=290 PR=1010
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=549 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=549 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 IS=1 FS=1 IT=265 FT=440 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 IS=1 FS=1 IT=440 FT=549 TT=3924 FL=100 IP=1025 FP=1025 TP=3924
TRAN CA=221 *IS=1 FS=1 IT=549 FT=549 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=222 IS=1 FS=1 IT=549 FT=375 TT=6264 FL=100 IP=1025 FP=185 TP=6264
TRAN CA=223 IS=1 FS=1 IT=375 FT=330 TT=600 FL=100 IP=185 FP=103 TP=600
TRAN CA=224 IS=1 FS=1 IT=330 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=565 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=565 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=440 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=440 FT=565 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=565 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=440 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=440 FT=549 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=549 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
```

```
TRAN CA=233 IS=1 FS=1 IT=50 FT=300 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=300 FT=549 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=290 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=290 FT=549 TT=210 FL=100 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.1 DI=0.447 EX=6.4 * Tavg=325
PAIR CA=204 CO=27.1 DI=0.447 EX=6.4 * Tavg=325
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.0 DI=0.439 EX=6.4 * Tavg=353
PAIR CA=220 CO=25.9 DI=0.400 EX=6.4 * Tavg=495
PAIR CA=221 CO=25.5 DI=0.387 EX=6.4 * Tavg=549
PAIR CA=222 CO=26.2 DI=0.409 EX=6.4 * Tavg=462
PAIR CA=223 CO=27.0 DI=0.439 EX=6.4 * Tavg=353
PAIR CA=224 CO=27.5 DI=0.480 EX=6.4 * Tavg=215
PAIR CA=225 CO=26.1 DI=0.404 EX=6.4 * Tavg=479
PAIR CA=226 CO=27.2 DI=0.451 EX=6.4 * Tavg=308
PAIR CA=227 CO=27.4 DI=0.469 EX=6.4 * Tavg=245
PAIR CA=228 CO=25.9 DI=0.397 EX=6.4 * Tavg=503
PAIR CA=229 CO=27.2 DI=0.451 EX=6.4 * Tavg=308
PAIR CA=230 CO=27.4 DI=0.469 EX=6.4 * Tavg=245
PAIR CA=231 CO=25.9 DI=0.400 EX=6.4 * Tavg=495
PAIR CA=232 CO=27.2 DI=0.453 EX=6.4 * Tavg=300
PAIR CA=233 CO=27.6 DI=0.491 EX=6.4 * Tavg=175
PAIR CA=234 CO=26.5 DI=0.421 EX=6.4 * Tavg=425
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.487 EX=6.4 * Tavg=195
PAIR CA=243 CO=26.5 DI=0.422 EX=6.4 * Tavg=420
```

```
BRAD PT=285  RA=1.25
TANG PT=290  DX=-4.007  DZ=4.007  EW=1
NOZZ PT=290   *NOZZLE N4A
AMVT  CA=1 PT=290 DX=0.0196 DY=0.1069 DZ=-0.0196
AMVT  CA=2 PT=290 DX=0.0196 DY=0.1069 DZ=-0.0196
AMVT  CA=3 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT  CA=4 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT  CA=5 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT  CA=6 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT  CA=7 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT  CA=8 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT  CA=9 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=10 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=11 PT=290 DX=0.1993 DY=1.0867 DZ=-0.1993
AMVT CA=12 PT=290 DX=0.1699 DY=0.9264 DZ=-0.1699
AMVT CA=13 PT=290 DX=0.3234 DY=1.7637 DZ=-0.3234
AMVT CA=14 PT=290 DX=0.3234 DY=1.7637 DZ=-0.3234
AMVT CA=15 PT=290 DX=0.3234 DY=1.7637 DZ=-0.3234
AMVT CA=16 PT=290 DX=0.3234 DY=1.7637 DZ=-0.3234
AMVT CA=17 PT=290 DX=0.3169 DY=1.7281 DZ=-0.3169
AMVT CA=18 PT=290 DX=0.3234 DY=1.7637 DZ=-0.3234
AMVT CA=19 PT=290 DX=0.2823 DY=1.5392 DZ=-0.2823
AMVT CA=20 PT=290 DX=0.2823 DY=1.5392 DZ=-0.2823
AMVT CA=21 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=22 PT=290 DX=0.0196 DY=0.1069 DZ=-0.0196
AMVT CA=23 PT=290 DX=0.3463 DY=1.8884 DZ=-0.3463
AMVT CA=24 PT=290 DX=0.3064 DY=1.6711 DZ=-0.3064
AMVT CA=25 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=26 PT=290 DX=0.3064 DY=1.6711 DZ=-0.3064
AMVT CA=27 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=28 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=29 PT=290 DX=0.3064 DY=1.6711 DZ=-0.3064
AMVT CA=30 PT=290 DX=0.3130 DY=1.7067 DZ=-0.3130
AMVT CA=31 PT=290 DX=0.3019 DY=1.6461 DZ=-0.3019

AMVT CA=32 PT=290 DX=-.09   DY=.015   DZ=-.093
*-------------------------------------------------------------------------------
*END REGION V
*--------------
*BEGIN REGION IV
*--------------
OPER CA=3  TE=150 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=265 PR=1010
OPER CA=11 TE=150 PR=170
OPER CA=12 TE=150 PR=88
OPER CA=13 TE=392 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=150 PR=1135
OPER CA=16 TE=150 PR=1135
OPER CA=17 TE=150 PR=1060
```

```
OPER CA=18 TE=150 PR=1135

OPER CA=20 TE=150 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=265 PR=1010

OPER CA=30 TE=125 PR=1010
*
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=150 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=221 IS=1 FS=1 IT=265 FT=150 TT=4140 FL=100 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=1025 FP=185 TP=0
TRAN CA=223 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=185 FP=103 TP=0
TRAN CA=224 IS=1 FS=1 IT=150 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=392 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=392 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=150 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=150 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=150 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=150 FT=150 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=150 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=150 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=150 FT=150 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=125 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=125 FT=150 TT=210 FL=100 IP=1025 FP=1025 TP=210
```

```
*
PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=204 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=220 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=221 CO=27.6 DI=0.483 EX=6.4 * Tavg=208
PAIR CA=222 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=223 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=224 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=225 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=226 CO=27.5 DI=0.478 EX=6.4 * Tavg=221
PAIR CA=227 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=228 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=229 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=230 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=231 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=232 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=233 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=234 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=243 CO=27.6 DI=0.500 EX=6.4 * Tavg=138

*
*REGION IV GEOMETRY DOWNSTREAM OF FW brnCH TEE/REDUCER - 10 INCH PIPING
*RUN FROM FW TEE TO ELBOW BEFORE NOZZLE N4A, NODE 155
JUNC PT=115
CROS CD=5
BRAN PT=120  DX=-0.5022  DY=0.596   DZ=-0.5022  TE=1 EW=1
TANG PT=125  DX=-2.594   DY=3.078   DZ=-2.594
TANG PT=130  DX=-2.594   DY=3.078   DZ=-2.594
TANG PT=135  DX=-2.594   DY=3.078   DZ=-2.594  EW=0
```

```
BRAD PT=140  RA=1.25  EW=0
TANG PT=142  DY=4
TANG PT=145  DY=4
TANG PT=150  DY=2.53
*---------------------------------------------------------------------------
*END REGION IV
*---------------------------------------------------------------------------
*BEGIN REGION IVa
*---------------------------------------------------------------------------
OPER CA=3   TE=283 PR=1010
OPER CA=4   TE=260 PR=1010
OPER CA=5   TE=392 PR=1010
OPER CA=6   TE=310 PR=1010
OPER CA=7   TE=280 PR=1010
OPER CA=8   TE=265 PR=1010
OPER CA=9   TE=90  PR=1010
OPER CA=10 TE=360 PR=1010
OPER CA=11 TE=225 PR=170
OPER CA=12 TE=210 PR=88
OPER CA=13 TE=450 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=247 PR=1135
OPER CA=16 TE=288 PR=1135
OPER CA=17 TE=247 PR=1060
OPER CA=18 TE=283 PR=1135

OPER CA=20 TE=200 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=323 PR=1010
OPER CA=30 TE=180 PR=1010
*
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=283 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=283 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 IS=1 FS=1 IT=265 FT=323 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 IS=1 FS=1 IT=323 FT=360 TT=3924 FL=100 IP=1025 FP=1025 TP=3924
```

```
TRAN CA=221 IS=1 FS=1 IT=360 FT=283 TT=4140 FL=100 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=283 FT=225 TT=6264 FL=100 IP=1025 FP=185 TP=6264
TRAN CA=223 IS=1 FS=1 IT=225 FT=210 TT=600 FL=100 IP=185 FP=103 TP=600
TRAN CA=224 IS=1 FS=1 IT=210 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=450 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=450 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=247 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=247 FT=288 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=288 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=247 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=247 FT=283 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=283 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=200 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=200 FT=283 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=180 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=180 FT=283 TT=210 FL=100 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.488 EX=6.4 * Tavg=192
PAIR CA=204 CO=27.6 DI=0.488 EX=6.4 * Tavg=192
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.2 DI=0.455 EX=6.4 * Tavg=294
PAIR CA=220 CO=27.0 DI=0.442 EX=6.4 * Tavg=342
PAIR CA=221 CO=27.1 DI=0.447 EX=6.4 * Tavg=322
PAIR CA=222 CO=27.4 DI=0.466 EX=6.4 * Tavg=254
PAIR CA=223 CO=27.5 DI=0.479 EX=6.4 * Tavg=218
PAIR CA=224 CO=27.6 DI=0.495 EX=6.4 * Tavg=155
PAIR CA=225 CO=26.5 DI=0.422 EX=6.4 * Tavg=421
PAIR CA=226 CO=27.4 DI=0.467 EX=6.4 * Tavg=250
PAIR CA=227 CO=27.6 DI=0.496 EX=6.4 * Tavg=149
PAIR CA=228 CO=27.3 DI=0.462 EX=6.4 * Tavg=268
PAIR CA=229 CO=27.6 DI=0.492 EX=6.4 * Tavg=169
PAIR CA=230 CO=27.6 DI=0.496 EX=6.4 * Tavg=149
PAIR CA=231 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
```

```
PAIR CA=232 CO=27.6 DI=0.493 EX=6.4 * Tavg=167
PAIR CA=233 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=234 CO=27.4 DI=0.470 EX=6.4 * Tavg=242
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.499 EX=6.4 * Tavg=140
PAIR CA=243 CO=27.5 DI=0.474 EX=6.4 * Tavg=232

*
TANG PT=152  DY=6.53  EW=0
*
*--------------------------------------------------------------------------
*END REGION IVa
*--------------------------------------------------------------------------
*BEGIN REGION IVb
*--------------------------------------------------------------------------
OPER CA=3  TE=416 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=454 PR=1010
OPER CA=11 TE=300 PR=170
OPER CA=12 TE=270 PR=88
OPER CA=13 TE=507 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=343 PR=1135
OPER CA=16 TE=427 PR=1135
OPER CA=17 TE=343 PR=1060
OPER CA=18 TE=416 PR=1135

OPER CA=20 TE=250 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=382 PR=1010
OPER CA=30 TE=235 PR=1010
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=416 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=416 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
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TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 IS=1 FS=1 IT=265 FT=382 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 IS=1 FS=1 IT=382 FT=454 TT=3924 FL=100 IP=1025 FP=1025 TP=3924
TRAN CA=221 IS=1 FS=1 IT=454 FT=416 TT=4140 FL=100 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=416 FT=300 TT=6264 FL=100 IP=1025 FP=185 TP=6264
TRAN CA=223 IS=1 FS=1 IT=300 FT=270 TT=600 FL=100 IP=185 FP=103 TP=600
TRAN CA=224 IS=1 FS=1 IT=270 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=507 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=507 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=343 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=343 FT=427 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=427 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=343 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=343 FT=416 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=416 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=250 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=250 FT=416 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=235 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=235 FT=416 TT=210 FL=100 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.4 DI=0.465 EX=6.4 * Tavg=258
PAIR CA=204 CO=27.4 DI=0.465 EX=6.4 * Tavg=258
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.1 DI=0.447 EX=6.4 * Tavg=324
PAIR CA=220 CO=26.6 DI=0.423 EX=6.4 * Tavg=418
PAIR CA=221 CO=26.4 DI=0.418 EX=6.4 * Tavg=435
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PAIR CA=222 CO=27.0 DI=0.438 EX=6.4 * Tavg=358
PAIR CA=223 CO=27.3 DI=0.457 EX=6.4 * Tavg=285
PAIR CA=224 CO=27.6 DI=0.489 EX=6.4 * Tavg=185
PAIR CA=225 CO=26.3 DI=0.413 EX=6.4 * Tavg=450
PAIR CA=226 CO=27.3 DI=0.459 EX=6.4 * Tavg=279
PAIR CA=227 CO=27.6 DI=0.487 EX=6.4 * Tavg=197
PAIR CA=228 CO=26.8 DI=0.432 EX=6.4 * Tavg=385
PAIR CA=229 CO=27.4 DI=0.471 EX=6.4 * Tavg=239
PAIR CA=230 CO=27.6 DI=0.487 EX=6.4 * Tavg=197
PAIR CA=231 CO=26.8 DI=0.433 EX=6.4 * Tavg=380
PAIR CA=232 CO=27.5 DI=0.473 EX=6.4 * Tavg=233
PAIR CA=233 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=234 CO=27.1 DI=0.444 EX=6.4 * Tavg=333
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.492 EX=6.4 * Tavg=168
PAIR CA=243 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
*
TANG PT=155  DY=6.523
*--------------
*END REGION IVb
*-----------------------------------------------
*BEGIN REGION V GEOMETRY TO NOZZLE N4B, NODE 165
*-----------------------------------------------
OPER CA=3  TE=549 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=549 PR=1010
OPER CA=11 TE=375 PR=170
OPER CA=12 TE=330 PR=88
OPER CA=13 TE=565 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=440 PR=1135
OPER CA=16 TE=565 PR=1135
OPER CA=17 TE=440 PR=1060
OPER CA=18 TE=549 PR=1135

OPER CA=20 TE=300 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=440 PR=1010
OPER CA=30 TE=290 PR=1010
```

```
TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=100 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=549 TT=16164 FL=100 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=549 FT=100 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=688.5 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=4590 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=3442.5 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=688.5 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=688.5 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=2295 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=4590 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=4590 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=1025 FP=1025 TP=900
TRAN CA=219 IS=1 FS=1 IT=265 FT=440 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=220 IS=1 FS=1 IT=440 FT=549 TT=3924 FL=100 IP=1025 FP=1025 TP=3924
TRAN CA=221 *IS=1 FS=1 IT=549 FT=549 TT=0 FL=100 IP=1025 FP=1025 TP=0
TRAN CA=222 IS=1 FS=1 IT=549 FT=375 TT=6264 FL=100 IP=1025 FP=185 TP=6264
TRAN CA=223 IS=1 FS=1 IT=375 FT=330 TT=600 FL=100 IP=185 FP=103 TP=600
TRAN CA=224 IS=1 FS=1 IT=330 FT=100 TT=8280 FL=100 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=565 TT=12 FL=100 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=565 FT=50 TT=0 FL=1836 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=440 TT=1380 FL=100 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=440 FT=565 TT=0 FL=100 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=565 FT=50 TT=0 FL=1377 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=440 TT=3060 FL=100 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=440 FT=549 TT=0 FL=100 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=549 FT=50 TT=0 FL=780.3 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=300 TT=300 FL=100 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=300 FT=549 TT=8964 FL=100 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=5049 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=137.7 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=100 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=5049 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=137.7 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=290 TT=60 FL=100 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=290 FT=549 TT=210 FL=100 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.1 DI=0.447 EX=6.4 * Tavg=325
PAIR CA=204 CO=27.1 DI=0.447 EX=6.4 * Tavg=325
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
```

```
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.0 DI=0.439 EX=6.4 * Tavg=353
PAIR CA=220 CO=25.9 DI=0.400 EX=6.4 * Tavg=495
PAIR CA=221 CO=25.5 DI=0.387 EX=6.4 * Tavg=549
PAIR CA=222 CO=26.2 DI=0.409 EX=6.4 * Tavg=462
PAIR CA=223 CO=27.0 DI=0.439 EX=6.4 * Tavg=353
PAIR CA=224 CO=27.5 DI=0.480 EX=6.4 * Tavg=215
PAIR CA=225 CO=26.1 DI=0.404 EX=6.4 * Tavg=479
PAIR CA=226 CO=27.2 DI=0.451 EX=6.4 * Tavg=308
PAIR CA=227 CO=27.4 DI=0.469 EX=6.4 * Tavg=245
PAIR CA=228 CO=25.9 DI=0.397 EX=6.4 * Tavg=503
PAIR CA=229 CO=27.2 DI=0.451 EX=6.4 * Tavg=308
PAIR CA=230 CO=27.4 DI=0.469 EX=6.4 * Tavg=245
PAIR CA=231 CO=25.9 DI=0.400 EX=6.4 * Tavg=495
PAIR CA=232 CO=27.2 DI=0.453 EX=6.4 * Tavg=300
PAIR CA=233 CO=27.6 DI=0.491 EX=6.4 * Tavg=175
PAIR CA=234 CO=26.5 DI=0.421 EX=6.4 * Tavg=425
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.487 EX=6.4 * Tavg=195
PAIR CA=243 CO=26.5 DI=0.422 EX=6.4 * Tavg=420
BRAD PT=160  RA=1.25
TANG PT=165  DX=-4.007  DZ=-4.007  EW=1
NOZZ PT=165   *NOZZLE N4B
AMVT CA=1  PT=165 DX=0.0196 DY=0.1069 DZ=0.0196
AMVT CA=2  PT=165 DX=0.0196 DY=0.1069 DZ=0.0196
AMVT CA=3  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=4  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=5  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=6  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=7  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=8  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=9  PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=10 PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=11 PT=165 DX=0.1993 DY=1.0867 DZ=0.1993
AMVT CA=12 PT=165 DX=0.1699 DY=0.9264 DZ=0.1699
AMVT CA=13 PT=165 DX=0.3234 DY=1.7637 DZ=0.3234
AMVT CA=14 PT=165 DX=0.3234 DY=1.7637 DZ=0.3234
AMVT CA=15 PT=165 DX=0.3234 DY=1.7637 DZ=0.3234
AMVT CA=16 PT=165 DX=0.3234 DY=1.7637 DZ=0.3234
AMVT CA=17 PT=165 DX=0.3169 DY=1.7281 DZ=0.3169
AMVT CA=18 PT=165 DX=0.3234 DY=1.7637 DZ=0.3234
AMVT CA=19 PT=165 DX=0.2823 DY=1.5392 DZ=0.2823
AMVT CA=20 PT=165 DX=0.2823 DY=1.5392 DZ=0.2823
AMVT CA=21 PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=22 PT=165 DX=0.0196 DY=0.1069 DZ=0.0196
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AMVT CA=23 PT=165 DX=0.3463 DY=1.8884 DZ=0.3463
AMVT CA=24 PT=165 DX=0.3064 DY=1.6711 DZ=0.3064
AMVT CA=25 PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=26 PT=165 DX=0.3064 DY=1.6711 DZ=0.3064
AMVT CA=27 PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=28 PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=29 PT=165 DX=0.3064 DY=1.6711 DZ=0.3064
AMVT CA=30 PT=165 DX=0.3130 DY=1.7067 DZ=0.3130
AMVT CA=31 PT=165 DX=0.3019 DY=1.6461 DZ=0.3019
AMVT CA=32 PT=165 DX=-.09   DY=.015   DZ=-.093
*---------------------------------------------------------------------------------
*END REGION V
*---------------------------------------------------------------------------------
*REGION II GEOMETRY - HPCI Line brnch
CROS CD=6
JUNC PT=10
*---------------------------------------------------------------------------------
*BEGIN REGION IIa
*---------------------------------------------------------------------------------
OPER CA=3  TE=150 PR=1010
OPER CA=4  TE=260 PR=1010
OPER CA=5  TE=392 PR=1010
OPER CA=6  TE=310 PR=1010
OPER CA=7  TE=280 PR=1010
OPER CA=8  TE=265 PR=1010
OPER CA=9  TE=90  PR=1010
OPER CA=10 TE=265 PR=1010
OPER CA=11 TE=150 PR=170
OPER CA=12 TE=150 PR=88
OPER CA=13 TE=392 PR=1190
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=150 PR=1135
OPER CA=16 TE=150 PR=1135
OPER CA=17 TE=150 PR=1060
OPER CA=18 TE=150 PR=1135

OPER CA=20 TE=150 PR=675
OPER CA=21 TE=275 PR=885

OPER CA=23 TE=392 PR=1375
OPER CA=24 TE=392 PR=940
OPER CA=25 TE=392 PR=1010
OPER CA=26 TE=275 PR=1010
OPER CA=27 TE=265 PR=1010

OPER CA=30 TE=125 PR=1010

TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=150 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=150 TT=16164 FL=150 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=150 FT=100 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=260 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=260 FT=392 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=392 FT=310 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=310 FT=392 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=392 FT=280 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
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TRAN CA=210 IS=1 FS=1 IT=280 FT=392 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=392 FT=265 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=265 FT=90 TT=360 FL=150 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=90 FT=265 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=265 FT=392 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=392 FT=265 TT=90 FL=150 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=265 FT=392 TT=180 FL=150 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=392 FT=275 TT=60 FL=150 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=275 FT=100 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=219 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=220 *IS=1 FS=1 IT=265 FT=265 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=221 IS=1 FS=1 IT=265 FT=150 TT=4140 FL=150 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=150 FT=150 TT=0 FL=150 IP=1025 FP=185 TP=0
TRAN CA=223 IS=1 FS=1 IT=150 FT=150 TT=0 FL=150 IP=185 FP=103 TP=0
TRAN CA=224 IS=1 FS=1 IT=150 FT=100 TT=8280 FL=150 IP=103 FP=65 TP=8280
TRAN CA=225 IS=1 FS=1 IT=392 FT=392 TT=12 FL=150 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=392 FT=50 TT=0 FL=3672 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=150 TT=1380 FL=150 IP=1150 FP=1150 TP=1380
TRAN CA=228 IS=1 FS=1 IT=150 FT=150 TT=0 FL=150 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=150 FT=50 TT=0 FL=2754 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=150 TT=3060 FL=150 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=150 FT=150 TT=0 FL=150 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=150 FT=50 TT=0 FL=1560.6 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=150 TT=300 FL=150 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=150 FT=150 TT=8964 FL=150 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=392 FT=275 TT=60 FL=150 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=275 FT=100 TT=900 FL=150 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=392 FT=392 TT=60 FL=150 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=392 FT=392 TT=900 FL=150 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=392 FT=392 TT=900 FL=150 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=125 TT=60 FL=150 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=125 FT=150 TT=210 FL=150 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=204 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=205 CO=27.6 DI=0.490 EX=6.4 * Tavg=180
PAIR CA=206 CO=27.1 DI=0.446 EX=6.4 * Tavg=326
PAIR CA=207 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=208 CO=27.0 DI=0.440 EX=6.4 * Tavg=351
PAIR CA=209 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=210 CO=27.1 DI=0.444 EX=6.4 * Tavg=336
PAIR CA=211 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=212 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=213 CO=27.6 DI=0.490 EX=6.4 * Tavg=178
PAIR CA=214 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=215 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=216 CO=27.1 DI=0.445 EX=6.4 * Tavg=329
PAIR CA=217 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=218 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=219 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=220 CO=27.3 DI=0.463 EX=6.4 * Tavg=265
PAIR CA=221 CO=27.6 DI=0.483 EX=6.4 * Tavg=208
```

```
PAIR CA=222 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=223 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=224 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=225 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=226 CO=27.5 DI=0.478 EX=6.4 * Tavg=221
PAIR CA=227 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=228 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=229 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=230 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=231 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=232 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=233 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=234 CO=27.6 DI=0.496 EX=6.4 * Tavg=150
PAIR CA=235 CO=27.1 DI=0.444 EX=6.4 * Tavg=334
PAIR CA=236 CO=27.6 DI=0.488 EX=6.4 * Tavg=188
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=240 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=241 CO=26.7 DI=0.430 EX=6.4 * Tavg=392
PAIR CA=242 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=243 CO=27.6 DI=0.500 EX=6.4 * Tavg=138

*
BRAN PT=301  DY=1  TE=1 EW=1
TANG PT=302  DY=2.333
TANG PT=305  DY=2.333  EW=1
BRAD PT=310  RA=1.75  EW=1
TANG PT=315  DX=-2.333  EW=1
CROS CD=7
VALV PT=317  DX=-1.167 PL=1 MA=2.05
*------------------------------------------------------------------------------
*BEGIN REGION IIb
*------------------------------------------------------------------------------

OPER CA=3  TE=125   PR=1010
OPER CA=4  TE=180   PR=1010
OPER CA=5  TE=246   PR=1010
OPER CA=6  TE=205   PR=1010
OPER CA=7  TE=190   PR=1010
OPER CA=8  TE=182.5 PR=1010
OPER CA=9  TE=95    PR=1010
OPER CA=10 TE=182.5 PR=1010
OPER CA=11 TE=125   PR=170
OPER CA=12 TE=125   PR=88
OPER CA=13 TE=246   PR=1190
OPER CA=14 TE=50    PR=1135
OPER CA=15 TE=125   PR=1135
OPER CA=16 TE=125   PR=1135
OPER CA=17 TE=125   PR=1060
OPER CA=18 TE=125   PR=1135

OPER CA=20 TE=125   PR=675
OPER CA=21 TE=187.5 PR=885

OPER CA=23 TE=246   PR=1375
```

```
OPER CA=24 TE=246   PR=940
OPER CA=25 TE=246   PR=1010
OPER CA=26 TE=187.5 PR=1010
OPER CA=27 TE=182.5 PR=1010

OPER CA=30 TE=112.5 PR=1010

TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=150 IP=15 FP=1115 TP=1800
TRAN CA=202 IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=1115 FP=65 TP=0
TRAN CA=203 IS=1 FS=1 IT=100 FT=125 TT=16164 FL=150 IP=65 FP=1025 TP=16164
TRAN CA=204 IS=1 FS=1 IT=125 FT=100 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=205 IS=1 FS=1 IT=100 FT=180 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=206 IS=1 FS=1 IT=180 FT=246 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=207 IS=1 FS=1 IT=246 FT=205 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=208 IS=1 FS=1 IT=205 FT=246 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=209 IS=1 FS=1 IT=246 FT=190 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=210 IS=1 FS=1 IT=190 FT=246 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=211 IS=1 FS=1 IT=246 FT=182.5 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=212 IS=1 FS=1 IT=182.5 FT=95 TT=360 FL=150 IP=1025 FP=1025 TP=360
TRAN CA=213 IS=1 FS=1 IT=95 FT=182.5 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=214 IS=1 FS=1 IT=182.5 FT=246 TT=1800 FL=150 IP=1025 FP=1025 TP=1800
TRAN CA=215 IS=1 FS=1 IT=246 FT=182.5 TT=90 FL=150 IP=1025 FP=1025 TP=90
TRAN CA=216 IS=1 FS=1 IT=182.5 FT=246 TT=180 FL=150 IP=1025 FP=1025 TP=180
TRAN CA=217 IS=1 FS=1 IT=246 FT=187.5 TT=60 FL=150 IP=1025 FP=1025 TP=60
TRAN CA=218 IS=1 FS=1 IT=187.5 FT=100 TT=900 FL=150 IP=1025 FP=1025 TP=900
TRAN CA=219 *IS=1 FS=1 IT=182.5 FT=182.5 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=220 *IS=1 FS=1 IT=182.5 FT=182.5 TT=0 FL=150 IP=1025 FP=1025 TP=0
TRAN CA=221 IS=1 FS=1 IT=182.5 FT=125 TT=4140 FL=150 IP=1025 FP=1025 TP=4140
TRAN CA=222 IS=1 FS=1 IT=125 FT=125 TT=0 FL=150 IP=1025 FP=185 TP=0
TRAN CA=223 IS=1 FS=1 IT=125 FT=125 TT=0 FL=150 IP=185 FP=103 TP=0
TRAN CA=224 IS=1 FS=1 IT=125 FT=100 TT=8280 FL=150 IP=103 FP=65 TP=8280
TRAN CA=225 *IS=1 FS=1 IT=246 FT=246 TT=12 FL=150 IP=1025 FP=1205 TP=12
TRAN CA=226 IS=1 FS=1 IT=246 FT=50 TT=0 FL=3672 IP=1205 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=125 TT=1380 FL=150 IP=1150 FP=1150 TP=1380
TRAN CA=228 *IS=1 FS=1 IT=125 FT=125 TT=0 FL=150 IP=1150 FP=1150 TP=0
TRAN CA=229 IS=1 FS=1 IT=125 FT=50 TT=0 FL=2754 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=125 TT=3060 FL=150 IP=900 FP=1075 TP=3060
TRAN CA=231 IS=1 FS=1 IT=125 FT=125 TT=0 FL=150 IP=1075 FP=1150 TP=0
TRAN CA=232 IS=1 FS=1 IT=125 FT=50 TT=0 FL=1560.6 IP=1150 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=125 TT=300 FL=150 IP=690 FP=690 TP=300
TRAN CA=234 IS=1 FS=1 IT=125 FT=125 TT=8964 FL=150 IP=255 FP=1025 TP=8964
TRAN CA=235 IS=1 FS=1 IT=246 FT=187.5 TT=60 FL=150 IP=1025 FP=900 TP=60
TRAN CA=236 IS=1 FS=1 IT=187.5 FT=100 TT=900 FL=150 IP=900 FP=65 TP=900
TRAN CA=237 IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=1578 TP=0
TRAN CA=238 IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=1578 FP=65 TP=0
TRAN CA=239 IS=1 FS=1 IT=246 FT=246 TT=60 FL=150 IP=1025 FP=1390 TP=60
TRAN CA=240 IS=1 FS=1 IT=246 FT=246 TT=900 FL=150 IP=1390 FP=955 TP=900
TRAN CA=241 IS=1 FS=1 IT=246 FT=246 TT=900 FL=150 IP=955 FP=1025 TP=900
TRAN CA=242 IS=1 FS=1 IT=100 FT=112.5 TT=60 FL=150 IP=1025 FP=1025 TP=60
TRAN CA=243 IS=1 FS=1 IT=112.5 FT=125 TT=210 FL=150 IP=1025 FP=1025 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=204 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=205 CO=27.6 DI=0.499 EX=6.4 * Tavg=140
```

```
PAIR CA=206 CO=27.5 DI=0.481 EX=6.4 * Tavg=213
PAIR CA=207 CO=27.5 DI=0.476 EX=6.4 * Tavg=226
PAIR CA=208 CO=27.5 DI=0.476 EX=6.4 * Tavg=226
PAIR CA=209 CO=27.5 DI=0.479 EX=6.4 * Tavg=218
PAIR CA=210 CO=27.5 DI=0.479 EX=6.4 * Tavg=218
PAIR CA=211 CO=27.5 DI=0.481 EX=6.4 * Tavg=214
PAIR CA=212 CO=27.6 DI=0.500 EX=6.4 * Tavg=139
PAIR CA=213 CO=27.6 DI=0.500 EX=6.4 * Tavg=139
PAIR CA=214 CO=27.5 DI=0.481 EX=6.4 * Tavg=214
PAIR CA=215 CO=27.5 DI=0.481 EX=6.4 * Tavg=214
PAIR CA=216 CO=27.5 DI=0.481 EX=6.4 * Tavg=214
PAIR CA=217 CO=27.5 DI=0.480 EX=6.4 * Tavg=217
PAIR CA=218 CO=27.6 DI=0.498 EX=6.4 * Tavg=144
PAIR CA=219 CO=27.6 DI=0.489 EX=6.4 * Tavg=183
PAIR CA=220 CO=27.6 DI=0.489 EX=6.4 * Tavg=183
PAIR CA=221 CO=27.6 DI=0.495 EX=6.4 * Tavg=154
PAIR CA=222 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=223 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=224 CO=27.6 DI=0.508 EX=6.4 * Tavg=113
PAIR CA=225 CO=27.4 DI=0.469 EX=6.4 * Tavg=246
PAIR CA=226 CO=27.6 DI=0.497 EX=6.4 * Tavg=148
PAIR CA=227 CO=27.6 DI=0.519 EX=6.4 * Tavg=88
PAIR CA=228 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=229 CO=27.6 DI=0.519 EX=6.4 * Tavg=88
PAIR CA=230 CO=27.6 DI=0.519 EX=6.4 * Tavg=88
PAIR CA=231 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=232 CO=27.6 DI=0.519 EX=6.4 * Tavg=88
PAIR CA=233 CO=27.6 DI=0.519 EX=6.4 * Tavg=88
PAIR CA=234 CO=27.6 DI=0.504 EX=6.4 * Tavg=125
PAIR CA=235 CO=27.5 DI=0.480 EX=6.4 * Tavg=217
PAIR CA=236 CO=27.6 DI=0.498 EX=6.4 * Tavg=144
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=27.4 DI=0.469 EX=6.4 * Tavg=246
PAIR CA=240 CO=27.4 DI=0.469 EX=6.4 * Tavg=246
PAIR CA=241 CO=27.4 DI=0.469 EX=6.4 * Tavg=246
PAIR CA=242 CO=27.6 DI=0.510 EX=6.4 * Tavg=106
PAIR CA=243 CO=27.6 DI=0.506 EX=6.4 * Tavg=119
VALV PT=320  DX=-1.167 PL=2  EW=1
CROS CD=6
TANG PT=325  DX=-0.666
TANG PT=330  DX=-2.667  EW=1
BRAD PT=335  RA=1.75  EW=1
TANP         DZ=-3.5
BRAD PT=340  RA=1.75  EW=1
TANG PT=345  DX=3.333  EW=1
CROS CD=7
VALV PT=346  DX=1.167 PL=1 MA=1.725
*---------------------------------------------------------------------------
*END REGION IIb
*---------------------------------------------------------------------------
*BEGIN REGION II
*-------------------------------------------------------------
OPER CA=1  TE=100 PR=50

OPER CA=3  TE=100 PR=50
```

```
OPER CA=4  TE=100 PR=50
OPER CA=5  TE=100 PR=50
OPER CA=6  TE=100 PR=50
OPER CA=7  TE=100 PR=50
OPER CA=8  TE=100 PR=50
OPER CA=9  TE=100 PR=50
OPER CA=10 TE=100 PR=50
OPER CA=11 TE=100 PR=50
OPER CA=12 TE=100 PR=50
OPER CA=13 TE=100 PR=50
OPER CA=14 TE=50  PR=1135
OPER CA=15 TE=100 PR=50
OPER CA=16 TE=100 PR=50
OPER CA=17 TE=100 PR=50
OPER CA=18 TE=100 PR=50

OPER CA=20 TE=100 PR=50
OPER CA=21 TE=100 PR=50
OPER CA=22 TE=100 PR=50
OPER CA=23 TE=100 PR=50
OPER CA=24 TE=100 PR=50
OPER CA=25 TE=100 PR=50
OPER CA=26 TE=100 PR=50
OPER CA=27 TE=100 PR=50
OPER CA=28 TE=100 PR=50
OPER CA=29 TE=100 PR=50
OPER CA=30 TE=100 PR=50

TRAN CA=201 IS=1 FS=1 IT=70 FT=100 TT=1800 FL=150 IP=15 FP=65 TP=1800
TRAN CA=202 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=203 *IS=1 FS=1 IT=100 FT=100 TT=16164 FL=150 IP=65 FP=65 TP=16164
TRAN CA=204 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=205 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=206 *IS=1 FS=1 IT=100 FT=100 TT=1800 FL=150 IP=65 FP=65 TP=1800
TRAN CA=207 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=208 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=209 *IS=1 FS=1 IT=100 FT=100 TT=1800 FL=150 IP=65 FP=65 TP=1800
TRAN CA=210 *IS=1 FS=1 IT=100 FT=100 TT=1800 FL=150 IP=65 FP=65 TP=1800
TRAN CA=211 *IS=1 FS=1 IT=100 FT=100 TT=1800 FL=150 IP=65 FP=65 TP=1800
TRAN CA=212 *IS=1 FS=1 IT=100 FT=100 TT=360 FL=150 IP=65 FP=65 TP=360
TRAN CA=213 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=214 *IS=1 FS=1 IT=100 FT=100 TT=1800 FL=150 IP=65 FP=65 TP=1800
TRAN CA=215 *IS=1 FS=1 IT=100 FT=100 TT=90 FL=150 IP=65 FP=65 TP=90
TRAN CA=216 *IS=1 FS=1 IT=100 FT=100 TT=180 FL=150 IP=65 FP=65 TP=180
TRAN CA=217 *IS=1 FS=1 IT=100 FT=100 TT=60 FL=150 IP=65 FP=65 TP=60
TRAN CA=218 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=219 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=220 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=221 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=222 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=223 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=224 *IS=1 FS=1 IT=100 FT=100 TT=8280 FL=150 IP=65 FP=65 TP=8280
TRAN CA=225 *IS=1 FS=1 IT=100 FT=100 TT=12 FL=150 IP=65 FP=65 TP=12
TRAN CA=226 IS=1 FS=1 IT=100 FT=50 TT=0 FL=3672 IP=65 FP=1150 TP=0
TRAN CA=227 IS=1 FS=1 IT=50 FT=100 TT=1380 FL=150 IP=1150 FP=65 TP=1380
TRAN CA=228 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
```

```
TRAN CA=229 IS=1 FS=1 IT=100 FT=50 TT=0 FL=2754 IP=1150 FP=900 TP=0
TRAN CA=230 IS=1 FS=1 IT=50 FT=100 TT=3060 FL=150 IP=900 FP=65 TP=3060
TRAN CA=231 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=232 IS=1 FS=1 IT=100 FT=50 TT=0 FL=1560.6 IP=65 FP=690 TP=0
TRAN CA=233 IS=1 FS=1 IT=50 FT=100 TT=300 FL=150 IP=690 FP=65 TP=300
TRAN CA=234 *IS=1 FS=1 IT=100 FT=100 TT=8964 FL=150 IP=65 FP=65 TP=8964
TRAN CA=235 *IS=1 FS=1 IT=100 FT=100 TT=60 FL=150 IP=65 FP=65 TP=60
TRAN CA=236 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=237 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=238 *IS=1 FS=1 IT=100 FT=100 TT=0 FL=150 IP=65 FP=65 TP=0
TRAN CA=239 *IS=1 FS=1 IT=100 FT=100 TT=60 FL=150 IP=65 FP=65 TP=60
TRAN CA=240 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=241 *IS=1 FS=1 IT=100 FT=100 TT=900 FL=150 IP=65 FP=65 TP=900
TRAN CA=242 *IS=1 FS=1 IT=100 FT=100 TT=60 FL=150 IP=65 FP=65 TP=60
TRAN CA=243 *IS=1 FS=1 IT=100 FT=100 TT=210 FL=150 IP=65 FP=65 TP=210

PAIR CA=201 CO=27.6 DI=0.521 EX=6.4 * Tavg=85
PAIR CA=202 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=203 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=204 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=205 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=206 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=207 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=208 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=209 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=210 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=211 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=212 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=213 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=214 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=215 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=216 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=217 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=218 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=219 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=220 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=221 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=222 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=223 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=224 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=225 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=226 CO=27.5 DI=0.526 EX=6.4 * Tavg=75
PAIR CA=227 CO=27.5 DI=0.526 EX=6.4 * Tavg=75
PAIR CA=228 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=229 CO=27.5 DI=0.526 EX=6.4 * Tavg=75
PAIR CA=230 CO=27.5 DI=0.526 EX=6.4 * Tavg=75
PAIR CA=231 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=232 CO=27.5 DI=0.526 EX=6.4 * Tavg=75
PAIR CA=233 CO=27.5 DI=0.526 EX=6.4 * Tavg=75
PAIR CA=234 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=235 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=236 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=237 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=238 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=239 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=240 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
```

```
PAIR CA=241 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=242 CO=27.6 DI=0.512 EX=6.4 * Tavg=100
PAIR CA=243 CO=27.6 DI=0.512 EX=6.4 * Tavg=100

VALV PT=350  DX=1.167 PL=2  EW=1
CROS CD=6
TANG PT=355  DX=0.167
TANG PT=360  DX=2.083  EW=1
BRAD PT=380  RA=1.75  EW=1
TANP         DY=-2.479
BRAD PT=390  RA=1.75  EW=1
TANG PT=392  DX=2.585 DY=-2.585
TANG PT=395  DX=2.585 DY=-2.585  EW=1
BRAD PT=400  RA=1.75  EW=1
TANG PT=405  DZ=-3.417
BRAD PT=410  RA=1.17  EW=1
TANG PT=415  DY=-3
TANG PT=420  DY=-5.25
TANG PT=425  DY=-2.417
BRAD PT=430  RA=1.75  EW=1
TANG PT=435  DZ=2.333
TANG PT=440  DZ=4.757
TANG PT=445  DZ=4.757
TANG PT=450  DZ=4.757
BRAD PT=455  RA=1.75  EW=1
TANG PT=460  DX=-1.989  DZ=1.989
BRAD PT=465  RA=1.75  EW=1
TANG PT=470  DY=-5.722
TANG PT=480  DY=-5.722
TANG PT=485  DY=-5.722
BRAD PT=490  RA=1.17  EW=1
TANG PT=495  DZ=1.667
TANG PT=500  DZ=2.0833
BRAD PT=505  RA=1.75  EW=1
TANG PT=510  DX=3.682
TANG PT=515  DX=3.682
TANG PT=520  DX=3.682
TANG PT=525  DX=3.682
BRAD PT=535  RA=1.75
TANG PT=540  DX=2.556  DZ=-2.556
TANG PT=545  DX=2.555  DZ=-2.555
STRU PT=546  DX=-.7071 DZ=-.7071
STRU PT=547  DX=-.7071 DZ=-.7071
ANCH PT=547
*-----------------------------------------------------------------------------
*END REGION II
*-----------------------------------------------------------------------------
*
*** VALVE OPERATOR ***
CROS CD=7
JUNC PT=346
VALV PT=348 DY=5.567 PL=3 MA=2.52
*** SUPPORTS AND ANCHORS ***
CSUP PT=105 DY=1  KP=5000  PI=0 *FW-9
CSUP PT=190 DY=1  KP=1000  PI=0 *FW-6
CSUP PT=220 DY=-1 KP=1000  PI=0 *FW-4
```

```
CSUP PT=270 DY=1  KP=1000  PI=0 *FW-2
CSUP PT=145 DY=1  KP=1000  PI=0 *FW-7
*
RSTN PT=230 DX=-0.6123  DY=-0.5  DZ=0.6123  SP=370  *FW-3
*
RSTN PT=80   DX=1.0                          SP=200  *FDW-H10

RSTN PT=201  DX=0.198 DZ=0.9802   SP=1000  *FDW-H23
RSTN PT=546  DX=-0.7071  DZ=-0.7071          SP=1000 *BELLOWS
RSTN PT=355   DY=1.0                                 *HPCI-H31
RSTN PT=415   DX=1.0  DZ=1.0                         *HPCI-H32
RSTN PT=30    DX=1.0  DY=1.0                         *FDW-HD37 FLUED HEAD
ROTR PT=30    RZ=1                                   *FDW_HD37 FLUED HEAD
RSTN PT=60  DX=1.0 DY=1.0                    SP=200  *FDW-H24
RSTN PT=5 DX=1 DY=1 DZ=1
ROTR PT=5 RZ=1
ENDP
```

APPENDIX B

PIPESTRESS OUTPUT FILE ("FWHPCI.PRF")

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

DELTA T1 IN DEGREES
PRESSURES IN PSI
STRESSES IN PSI
SUMMARY OF LOAD SETS AT POINT 155 LR ELBOW   155 TO 160   GLOBAL MOMENTS IN FT-LB

| LOAD SET NO. | LOAD SET DESCRIPTION | | CYCLES | DYNAM. CYCLES | PRESSURE | MOMENT X | MOMENT Y | MOMENT Z | TRANSIENT STRESSES EQ. 10 | EQ. 11 | EQ. 13 | DELTA T1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Design Hydrotest + | LS-1 | 120 | | 1100. | 55. | 22. | 54. | 0. | 50. | 0. | 0. |
| 2 | Design Hydrotest - | LS-2 | 120 | | 50. | 56. | 21. | 54. | 0. | 0. | 0. | 0. |
| 3 | Startup + | LS-3 | 300 | | 1010. | 14505. | -695. | -12403. | 25110. | 25114. | 12555. | 0. |
| 4 | TRoll & Inc. PWR1 - | LS-4 | 610 | | 1010. | 24012. | -983. | -21319. | -25109. | -54064. | -12555. | -169. |
| 5 | TRoll & Inc. PWR2 + | LS-5 | 599 | | 1010. | 13760. | -442. | -11409. | 0. | 15049. | 0. | 78. |
| 6 | TRoll & Inc. PWR3 + | LS-6 | 599 | | 1010. | 4661. | 45. | -2630. | 0. | 252. | 0. | 1. |
| 7 | DlyReduction to 75% - | LS-7 | 10000 | | 1010. | 10313. | -259. | -8082. | 0. | -317. | 0. | -1. |
| 8 | DlyReduction to 75% + | LS-8 | 10000 | | 1010. | 4661. | 45. | -2630. | 0. | 317. | 0. | 1. |
| 9 | WklyReduct to 50% - | LS-9 | 2000 | | 1010. | 12381. | -369. | -10078. | 0. | -215. | 0. | -1. |
| 10 | WklyReduct to 50% + | LS-10 | 2000 | | 1010. | 4661. | 45. | -2630. | 0. | 215. | 0. | 1. |
| 11 | LOFWH+TT 1 - | LS-11 | 310 | | 1010. | 13415. | -424. | -11077. | 0. | -243. | 0. | -1. |
| 12 | LOFWH+TT 2 - | LS-12 | 10 | | 1010. | 24520. | -1009. | -21810. | 0. | -1480. | 0. | -7. |
| 13 | LOFWH+TT 3 + | LS-13 | 10 | | 1010. | 13415. | -424. | -11077. | 0. | 619. | 0. | 3. |
| 14 | LOFWH+TT 4 + | LS-14 | 10 | | 1010. | 4661. | 45. | -2630. | 0. | 243. | 0. | 1. |
| 15 | LOFWH+PFWHTR Byp - | LS-15 | 70 | | 1010. | 13415. | -424. | -11077. | 0. | -4784. | 0. | -25. |
| 16 | LOFWH+PFWHTR Byp + | LS-16 | 70 | | 1010. | 4661. | 45. | -2630. | 0. | 2433. | 0. | 13. |
| 17 | SCRAM+TT+AllOtrScm - | LS-17 | 289 | | 1010. | 12192. | -365. | -9935. | 0. | -6434. | 0. | -34. |
| 18 | SCRAM+TT+AllOtrScm - | LS-18 | 289 | | 1010. | 23480. | -960. | -20844. | 0. | -593. | 0. | -3. |
| 19 | HotStandby 1 + | LS-19 | 300 | | 1010. | 10450. | -359. | -8332. | 10951. | 10969. | 5476. | 39. |
| 20 | HotStandby 2 + | LS-20 | 300 | | 1010. | 8500. | -316. | -6524. | 17948. | 17967. | 8974. | 0. |
| 21 | HotStandby 3 - | LS-21 | 300 | | 1010. | 14505. | -695. | -12403. | 0. | 0. | 0. | 0. |
| 22 | Shutdown 1 - | LS-22 | 300 | | 170. | 7904. | -355. | -6594. | -25111. | -25113. | -12555. | -0. |
| 23 | Shutdown 2 - | LS-23 | 300 | | 88. | 6239. | -269. | -5132. | -14160. | -14241. | -7080. | -1. |
| 24 | Shutdown 3 - | LS-24 | 300 | | 50. | 56. | 21. | 54. | -11328. | -11330. | -5664. | -0. |
| 25 | SCRAM+LOFWP1 + | LS-25 | 10 | | 1190. | 2347. | 86. | -451. | 10950. | 10965. | 5475. | 42. |
| 26 | SCRAM+LOFWP2 - | LS-26 | 10 | | 1135. | 26504. | -1110. | -23646. | -10950. | -57147. | -5475. | -251. |
| 27 | SCRAM+LOFWP3 + | LS-27 | 10 | | 1135. | 17301. | -771. | -14962. | 18318. | 18515. | 9159. | 5. |
| 28 | SCRAM+LOFWP4 + | LS-28 | 10 | | 1135. | 15136. | -727. | -12959. | 26076. | 26097. | 13038. | 31. |
| 29 | SCRAM+LOFWP5 - | LS-29 | 10 | | 885. | 24686. | -1036. | -22025. | -26053. | -64906. | -13027. | -223. |
| 30 | SCRAM+LOFWP6 + | LS-30 | 10 | | 1060. | 16738. | -747. | -14459. | 18317. | 18413. | 9159. | 2. |
| 31 | SCRAM+LOFWP7 + | LS-31 | 10 | | 1135. | 15415. | -733. | -13217. | 25130. | 25158. | 12565. | 27. |

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

DELTA T1 IN DEGREES
PRESSURES IN PSI
STRESSES IN PSI
SUMMARY OF LOAD SETS AT POINT 155 LR ELBOW   155 TO 160   GLOBAL MOMENTS IN FT-LB

| LOAD SET NO. | LOAD SET DESCRIPTION | | CYCLES | DYNAM. CYCLES | PRESSURE | MOMENT X | MOMENT Y | MOMENT Z | TRANSIENT STRESSES EQ. 10 | EQ. 11 | EQ. 13 | DELTA T1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 32 | SCRAM+LOFWP8 - | LS-32 | 10 | | 675. | 23044. | -968. | -20560. | -25110. | -53661. | -12555. | -167 |
| 33 | SCRAM+LOFWP9 + | LS-33 | 10 | | 675. | 16095. | -672. | -13953. | 9507. | 10417. | 4754. | 15 |
| 34 | SCRAM+LOFWP10+ | LS-34 | 10 | | 1010. | 14505. | -695. | -12403. | 25119. | 25126. | 12559. | 0. |
| 35 | SCRAM+SRVBLDN1- | LS-35 | 1 | | 885. | 12714. | -388. | -10400. | 0. | -6434. | 0. | -34. |
| 36 | SCRAM+SRVBLDN2- | LS-36 | 1 | | 50. | 56. | 21. | 54. | 0. | -593. | 0. | -3 |
| 37 | Hydro Test + | LS-37 | 1 | | 1563. | 54. | 22. | 54. | 0. | 0. | 0. | 0 |
| 38 | Hydro Test - | LS-38 | 1 | | 50. | 56. | 21. | 54. | 0. | 0. | 0. | 0 |
| 39 | SCRAM+TG+OPres1 - | LS-39 | 289 | | 1375. | 7411. | -66. | -5088. | 0. | 0. | 0. | 0. |
| 40 | SCRAM+TG+OPres2 - | LS-40 | 289 | | 940. | 4126. | 66. | -2152. | 0. | 0. | 0. | 0. |
| 41 | SCRAM+TG+OPres3 - | LS-41 | 289 | | 1010. | 4661. | 45. | -2630. | 0. | 0. | 0. | 0. |
| 42 | HotSbyFWcyc + | LS-42 | 300 | | 1010. | 20056. | -857. | -17600. | 10427. | 10652. | 5214. | 29 |
| 43 | HotSbyFWcyc + | LS-43 | 300 | | 1010. | 14505. | -695. | -12403. | 25130. | 25446. | 12565. | 23 |
| 44 | NORMAL+OBE LS-132 | | 5 | 10(1) | 1010. | 14078. | -2008. | -11434. | 0. | 0. | 0. | 0 |
| 45 | NORMAL-OBE LS-133 | | 5 | 10(1) | 1010. | 10494. | 1458. | -8380. | 0. | 0. | 0. | 0. |
| 101 | WEIGHT | | | | | 10013. | 720. | -7200. | | | | |
| 104 | DYNAMIC FLAG= 1 | | | | | 1792. | 1733. | 1527. | | | | |

| B1 | C1 | K1 | B2 | C2 | K2 | C3 | K3 | C3PRIM | C4 | Z | DIAM/TH | MATERIAL | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.106 | 1.247 | 1.000 | 2.022 | 3.034 | 1.000 | 1.000 | 1.000 | 0.500 | 1.100 | 0.60321E+02 | 12.752 | CARBON STEEL | 0.295 |

THIS ANALYSIS IS FOR THE BODY OF THE FITTING.

CALCULATION NUMBER 2    CODE SECTION III CLASS 1 ASME-1998    KRE    2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW    155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 29 | 62066.b | 7949. | 255.1 | 35508. | 100939. | 1.317 | 66456. | 1808. | 53580. | 759.3 |
| 29 | 31 | 60890.b | 7720. | 251.0 | 35035. | 99771. | 1.273 | 63498. | 2050. | 53580. | 763.1 |
| 29 | 43 | 60634.b | 8457. | 247.4 | 34041. | 99802. | 1.263 | 63040. | 2098. | 53580. | 763.1 |
| 29 | 34 | 60622.b | 8457. | 224.3 | 34035. | 99482. | 1.263 | 62816. | 2122. | 53580. | 763.1 |
| 3 | 29 | 60614.b | 8457. | 224.3 | 34031. | 99470. | 1.263 | 62793. | 2125. | 53580. | 763.1 |
| 28 | 32 | 61463.b | 6621. | 198.3 | 36705. | 90035. | 1.294 | 58265. | 2697. | 53580. | 763.1 |
| 20 | 29 | 58527.b | 13533. | 224.4 | 30450. | 97400. | 1.185 | 57693. | 2783. | 53580. | 763.1 |
| 25 | 29 | 58182.b | 18755. | 266.0 | 28382. | 97049. | 1.172 | 56861. | 2915. | 53580. | 759.3 |
| 31 | 32 | 60288.b | 6392. | 194.2 | 36232. | 88867. | 1.219 | 54146. | 3406. | 54348. | 766.8 |
| 4 | 28 | 59539.b | 7360. | 201.2 | 34042. | 88515. | 1.222 | 54103. | 3415. | 53580. | 763.1 |
| 32 | 43 | 60031.b | 7129. | 190.6 | 35238. | 88898. | 1.209 | 53745. | 3488. | 54348. | 766.8 |
| 32 | 34 | 60020.b | 7129. | 167.6 | 35233. | 88578. | 1.209 | 53533. | 3532. | 54348. | 766.8 |
| 3 | 32 | 60011.b | 7129. | 167.6 | 35228. | 88566. | 1.208 | 53512. | 3536. | 54348. | 766.8 |
| 4 | 31 | 58364.b | 7131. | 197.0 | 33569. | 87347. | 1.148 | 50128. | 4354. | 54348. | 766.8 |
| 4 | 43 | 58108.b | 7868. | 193.5 | 32576. | 87378. | 1.138 | 49733. | 4465. | 54348. | 766.8 |
| 4 | 34 | 58096.b | 7868. | 170.4 | 32570. | 87058. | 1.138 | 49533. | 4523. | 54348. | 766.8 |
| 3 | 4 | 58088.b | 7868. | 170.4 | 32566. | 87046. | 1.138 | 49512. | 4529. | 54348. | 766.8 |
| 25 | 32 | 57580.b | 17427. | 209.2 | 29579. | 86146. | 1.149 | 49505. | 4531. | 53580. | 763.1 |
| 20 | 32 | 57925.b | 12205. | 167.6 | 31647. | 86496. | 1.132 | 48941. | 4700. | 54348. | 766.8 |
| 26 | 43 | 47001.g | 9927. | 274.8 | 26489. | 93513. | 1.000 | 46757. | 5404. | 53580. | 763.1 |
| 26 | 34 | 46989.g | 9927. | 251.8 | 26484. | 93193. | 1.000 | 46597. | 5460. | 53580. | 763.1 |
| 3 | 26 | 46980.g | 9927. | 251.7 | 26479. | 93181. | 1.000 | 46591. | 5462. | 53580. | 763.1 |
| 26 | 28 | 46445.g | 9419. | 282.5 | 25969. | 92663. | 1.000 | 46332. | 5553. | 53580. | 759.3 |
| 27 | 29 | 52528.g | 6169. | 229.1 | 31629. | 91578. | 1.000 | 45789. | 5750. | 53580. | 788.7 |
| 2 | 29 | 52662.g | 19973. | 223.8 | 27119. | 91515. | 1.000 | 45758. | 5762. | 53580. | 849.3 |
| 24 | 29 | 52662.g | 19973. | 223.3 | 27119. | 91515. | 1.000 | 45758. | 5762. | 53580. | 810.3 |

Notes
b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

DELTA T1 IN DEGREES
STRESSES IN PSI

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 36 | 52662.g | 19973. | 220.6 | 27119. | 91515. | 1.000 | 45758. | 5762. | 53580. | 821.0 |
| 29 | 38 | 52662.g | 19973. | 223.8 | 27119. | 91515. | 1.000 | 45758. | 5762. | 53580. | 849.3 |
| 22 | 28 | 64676.b | 5819. | 31.9 | 40719. | 64699. | 1.414 | 45748. | 5766. | 53580. | 763.1 |
| 26 | 31 | 45270.g | 9190. | 278.4 | 25496. | 91495. | 1.000 | 45747. | 5766. | 53580. | 763.1 |
| 29 | 30 | 52386.g | 6625. | 226.2 | 31032. | 91335. | 1.000 | 45668. | 5796. | 53580. | 788.7 |
| 4 | 25 | 55656.b | 18165. | 212.0 | 26916. | 84625. | 1.077 | 45590. | 5825. | 53580. | 763.1 |
| 20 | 26 | 44893.g | 15003. | 251.8 | 22898. | 91110. | 1.000 | 45555. | 5838. | 53580. | 763.1 |
| 29 | 37 | 51415.g | 19974. | 223.8 | 25871. | 90268. | 1.000 | 45134. | 6002. | 53580. | 784.2 |
| 5 | 29 | 36248. | | 302.3 | | 90149. | 1.000 | 45075. | 6025. | 53580. | 823.9 |
| 4 | 20 | 56000.b | 12943. | 170.5 | 28984. | 84975. | 1.061 | 45071. | 6026. | 54348. | 766.8 |
| 19 | 29 | 49926.g | 11928. | 263.5 | 26952. | 88796. | 1.000 | 44398. | 6302. | 53580. | 788.7 |
| 25 | 26 | 42561. | | 293.4 | | 88773. | 1.000 | 44386. | 6307. | 53580. | 759.3 |
| 2 | 26 | 41017. | | 251.2 | | 87213. | 1.000 | 43607. | 6647. | 53580. | 849.3 |
| 24 | 26 | 41395. | | 250.8 | | 87213. | 1.000 | 43607. | 6647. | 53580. | 810.3 |
| 26 | 36 | 41017. | | 248.0 | | 87213. | 1.000 | 43607. | 6647. | 53580. | 821.0 |
| 26 | 38 | 41017. | | 251.2 | | 87213. | 1.000 | 43607. | 6647. | 53580. | 849.3 |
| 1 | 29 | 47735.g | 19973. | 224.1 | 22191. | 86638. | 1.000 | 43319. | 6779. | 53580. | 849.3 |
| 22 | 31 | 63959.b | 6048. | 27.7 | 40246. | 63989. | 1.354 | 43310. | 6783. | 54348. | 766.8 |
| 23 | 29 | 47490.g | 15103. | 222.4 | 26817. | 86343. | 1.000 | 43172. | 6848. | 53580. | 801.6 |
| 16 | 29 | 43884.g | 16837. | 236.9 | 21476. | 85169. | 1.000 | 42585. | 7132. | 53580. | 798.3 |
| 22 | 29 | 45501.g | 13765. | 223.2 | 26165. | 84354. | 1.000 | 42177. | 7338. | 53580. | 763.1 |
| 26 | 30 | 37958. | | 253.6 | | 84251. | 1.000 | 42125. | 7365. | 53580. | 788.7 |
| 29 | 33 | 44347.g | 7118. | 238.8 | 26905. | 84109. | 1.000 | 42055. | 7402. | 53580. | 816.1 |
| 5 | 26 | 22614. | | 329.7 | | 83859. | 1.000 | 41930. | 7467. | 53580. | 823.9 |
| 29 | 39 | 44560.g | 14613. | 223.8 | 24377. | 83413. | 1.000 | 41706. | 7587. | 53580. | 787.5 |
| 26 | 27 | 36908. | | 256.6 | | 83301. | 1.000 | 41651. | 7617. | 53580. | 788.7 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

****************************
INDIVIDUAL STRESS RANGE CHECK
****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 29 | 43884.g | 16837. | 225.5 | 21476. | 83053. | 1.000 | 41527. | 7684. | 53580. | 798.3 |
| 6 | 29 | 43884.g | 16837. | 225.2 | 21476. | 82988. | 1.000 | 41494. | 7702. | 53580. | 798.3 |
| 14 | 29 | 43884.g | 16837. | 225.1 | 21476. | 82979. | 1.000 | 41490. | 7705. | 53580. | 798.3 |
| 10 | 29 | 43884.g | 16837. | 225.0 | 21476. | 82951. | 1.000 | 41475. | 7713. | 53580. | 798.3 |
| 29 | 41 | 43884.g | 16837. | 223.8 | 21476. | 82736. | 1.000 | 41368. | 7772. | 53580. | 798.3 |
| 29 | 40 | 43760.g | 17270. | 223.8 | 20920. | 82613. | 1.000 | 41307. | 7807. | 53580. | 798.3 |
| 19 | 26 | 36292. | | 290.9 | | 82507. | 1.000 | 41253. | 7836. | 53580. | 788.7 |
| 23 | 26 | 39055. | | 249.8 | | 82041. | 1.000 | 41021. | 7969. | 53580. | 801.6 |
| 26 | 37 | 35796. | | 251.2 | | 81993. | 1.000 | 40996. | 7983. | 53580. | 784.2 |
| 2 | 4 | 52124.g | 19385. | 169.9 | 27641. | 81079. | 1.000 | 40539. | 8253. | 54348. | 851.7 |
| 4 | 24 | 52124.g | 19385. | 169.4 | 27641. | 81079. | 1.000 | 40539. | 8253. | 54348. | 813.4 |
| 4 | 36 | 52124.g | 19385. | 166.7 | 27641. | 81079. | 1.000 | 40539. | 8253. | 54348. | 824.1 |
| 4 | 38 | 52124.g | 19385. | 169.9 | 27641. | 81079. | 1.000 | 40539. | 8253. | 54348. | 851.7 |
| 22 | 43 | 62228.b | 5311. | 24.1 | 39253. | 62546. | 1.290 | 40342. | 8374. | 54348. | 766.8 |
| 27 | 32 | 51926.g | 4842. | 172.4 | 32826. | 80674. | 1.000 | 40337. | 8377. | 54348. | 792.1 |
| 30 | 32 | 51784.g | 5297. | 169.4 | 32229. | 80431. | 1.000 | 40216. | 8452. | 54348. | 792.1 |
| 29 | 42 | 41341. | | 253.0 | | 80418. | 1.000 | 40209. | 8456. | 53580. | 818.0 |
| 22 | 34 | 62217.b | 5311. | 1.1 | 39247. | 62226. | 1.290 | 40123. | 8510. | 54348. | 766.8 |
| 3 | 22 | 62208.b | 5311. | 1.1 | 39243. | 62214. | 1.289 | 40105. | 8521. | 54348. | 766.8 |
| 22 | 26 | 48016.g | 15236. | 250.7 | 27681. | 80052. | 1.000 | 40026. | 8571. | 53580. | 763.1 |
| 26 | 33 | 32701. | | 266.2 | | 79807. | 1.000 | 39904. | 8649. | 53580. | 816.1 |
| 32 | 37 | 50812.g | 18645. | 167.0 | 27068. | 79364. | 1.000 | 39682. | 8794. | 54348. | 788.7 |
| 5 | 32 | 35646. | | 245.5 | | 79246. | 1.000 | 39623. | 8832. | 54348. | 827.0 |
| 4 | 27 | 50002.g | 5580. | 175.2 | 30163. | 79153. | 1.000 | 39577. | 8863. | 54348. | 792.1 |
| 1 | 26 | 32672. | | 251.5 | | 78918. | 1.000 | 39459. | 8942. | 53580. | 849.3 |
| 4 | 30 | 49860.g | 6036. | 172.2 | 29566. | 78911. | 1.000 | 39455. | 8944. | 54348. | 792.1 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2  CODE SECTION III CLASS 1 ASME-1998  KRE  2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 26 | 30250. | | 264.3 | | 78880. | 1.000 | 39440. | 8955. | 53580. | 798.3 |
| 7 | 29 | 39141. | | 222.1 | | 77994. | 1.000 | 38997. | 9260. | 53580. | 798.3 |
| 19 | 32 | 49324.g | 10600. | 206.7 | 28149. | 77893. | 1.000 | 38946. | 9296. | 54348. | 792.1 |
| 29 | 45 | 39023. | | 223.8 | | 77876. | 1.000 | 38938. | 9302. | 53580. | 814.2 |
| 4 | 37 | 48890.g | 19386. | 169.9 | 24406. | 77845. | 1.000 | 38922. | 9313. | 54348. | 788.7 |
| 4 | 5 | 33721. | | 248.4 | | 77724. | 1.000 | 38862. | 9356. | 54348. | 827.0 |
| 26 | 40 | 31239. | | 251.2 | | 77436. | 1.000 | 38718. | 9459. | 53580. | 798.3 |
| 2 | 32 | 48721.g | 18644. | 167.0 | 24978. | 77272. | 1.000 | 38636. | 9519. | 54348. | 851.7 |
| 24 | 32 | 48721.g | 18644. | 166.6 | 24978. | 77272. | 1.000 | 38636. | 9519. | 54348. | 813.4 |
| 32 | 36 | 48721.g | 18644. | 163.9 | 24978. | 77272. | 1.000 | 38636. | 9519. | 54348. | 824.1 |
| 32 | 38 | 48721.g | 18644. | 167.0 | 24978. | 77272. | 1.000 | 38636. | 9519. | 54348. | 851.7 |
| 8 | 26 | 30250. | | 252.9 | | 76764. | 1.000 | 38382. | 9707. | 53580. | 798.3 |
| 6 | 26 | 30250. | | 252.6 | | 76698. | 1.000 | 38349. | 9732. | 53580. | 798.3 |
| 14 | 26 | 30250. | | 252.5 | | 76689. | 1.000 | 38345. | 9735. | 53580. | 798.3 |
| 10 | 26 | 30250. | | 252.4 | | 76661. | 1.000 | 38331. | 9746. | 53580. | 798.3 |
| 26 | 41 | 30250. | | 251.2 | | 76447. | 1.000 | 38223. | 9827. | 53580. | 798.3 |
| 17 | 29 | 37547. | | 189.4 | | 76400. | 1.000 | 38200. | 9845. | 53580. | 798.3 |
| 4 | 19 | 47399.g | 11338. | 209.6 | 25486. | 76372. | 1.000 | 38186. | 9856. | 54348. | 792.1 |
| 9 | 29 | 37405. | | 222.7 | | 76258. | 1.000 | 38129. | 9899. | 53580. | 798.3 |
| 13 | 29 | 36537. | | 227.1 | | 76009. | 1.000 | 38004. | 9996. | 53580. | 822.9 |
| 4 | 23 | 46952.g | 14514. | 168.5 | 27338. | 75906. | 1.000 | 37953. | 10042. | 54348. | 804.7 |
| 1 | 32 | 47132.g | 18645. | 167.3 | 23388. | 75733. | 1.000 | 37867. | 10120. | 54348. | 851.7 |
| 11 | 29 | 36537. | | 222.5 | | 75390. | 1.000 | 37695. | 10278. | 53580. | 798.3 |
| 15 | 29 | 36537. | | 198.1 | | 75390. | 1.000 | 37695. | 10278. | 53580. | 798.3 |
| 26 | 39 | 28939. | | 251.2 | | 75136. | 1.000 | 37568. | 10397. | 53580. | 787.5 |
| 29 | 35 | 36132. | | 189.4 | | 74985. | 1.000 | 37492. | 10468. | 53580. | 798.3 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 44 | 36112. | | 223.8 | | 74965. | 1.000 | 37482. | 10477. | 53580. | 814.2 |
| 21 | 29 | 35503. | | 223.8 | | 74356. | 1.000 | 37178. | 10772. | 53580. | 763.1 |
| 16 | 32 | 43282. | | 180.1 | | 74266. | 1.000 | 37133. | 10817. | 54348. | 801.4 |
| 1 | 4 | 45210.g | 19385. | 170.1 | 20726. | 74214. | 1.000 | 37107. | 10843. | 54348. | 851.7 |
| 26 | 42 | 27708. | | 280.4 | | 74129. | 1.000 | 37064. | 10885. | 53580. | 818.0 |
| 4 | 22 | 44964.g | 13177. | 169.3 | 26687. | 73917. | 1.000 | 36959. | 10992. | 54348. | 766.8 |
| 4 | 33 | 43808.g | 6529. | 184.9 | 27427. | 73672. | 1.000 | 36836. | 11117. | 54348. | 819.2 |
| 4 | 16 | 41357. | | 182.9 | | 72745. | 1.000 | 36372. | 11607. | 54348. | 801.4 |
| 32 | 39 | 43959.g | 13286. | 167.0 | 25574. | 72510. | 1.000 | 36255. | 11735. | 54348. | 793.6 |
| 8 | 32 | 43282. | | 168.7 | | 72150. | 1.000 | 36075. | 11936. | 54348. | 801.4 |
| 23 | 32 | 43549.g | 13774. | 165.6 | 24676. | 72100. | 1.000 | 36050. | 11964. | 54348. | 804.7 |
| 6 | 32 | 43282. | | 168.4 | | 72085. | 1.000 | 36042. | 11972. | 54348. | 801.4 |
| 14 | 32 | 43282. | | 168.3 | | 72076. | 1.000 | 36038. | 11978. | 54348. | 801.4 |
| 10 | 32 | 43282. | | 168.2 | | 72048. | 1.000 | 36024. | 11993. | 54348. | 801.4 |
| 32 | 41 | 43282. | | 167.0 | | 71833. | 1.000 | 35917. | 12116. | 54348. | 801.4 |
| 32 | 40 | 43158. | | 167.0 | | 71710. | 1.000 | 35855. | 12187. | 54348. | 801.4 |
| 7 | 26 | 25507. | | 249.5 | | 71704. | 1.000 | 35852. | 12190. | 53580. | 798.3 |
| 26 | 45 | 25383. | | 251.2 | | 71580. | 1.000 | 35790. | 12262. | 53580. | 814.2 |
| 4 | 40 | 42346. | | 169.9 | | 71301. | 1.000 | 35651. | 12426. | 54348. | 801.4 |
| 4 | 39 | 42033. | | 169.9 | | 70988. | 1.000 | 35494. | 12614. | 54348. | 793.6 |
| 26 | 35 | 24485. | | 216.8 | | 70682. | 1.000 | 35341. | 12801. | 53580. | 798.3 |
| 4 | 8 | 41357. | | 171.6 | | 70629. | 1.000 | 35314. | 12834. | 54348. | 801.4 |
| 4 | 6 | 41357. | | 171.2 | | 70563. | 1.000 | 35282. | 12874. | 54348. | 801.4 |
| 4 | 14 | 41357. | | 171.2 | | 70554. | 1.000 | 35277. | 12880. | 54348. | 801.4 |
| 4 | 10 | 41357. | | 171.0 | | 70526. | 1.000 | 35263. | 12897. | 54348. | 801.4 |
| 4 | 41 | 41357. | | 169.9 | | 70312. | 1.000 | 35156. | 13032. | 54348. | 801.4 |

Notes
b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2  CODE SECTION III CLASS 1 ASME-1998  KRE  2007/07/11 11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 32 | 41561. | | 166.5 | | 70111. | 1.000 | 35056. | 13159. | 54348. | 766.8 |
| 17 | 26 | 23913. | | 216.8 | | 70110. | 1.000 | 35055. | 13160. | 53580. | 798.3 |
| 9 | 26 | 23771. | | 250.1 | | 69968. | 1.000 | 34984. | 13251. | 53580. | 798.3 |
| 32 | 33 | 40406. | | 182.1 | | 69867. | 1.000 | 34934. | 13316. | 54348. | 819.2 |
| 13 | 26 | 22903. | | 254.6 | | 69719. | 1.000 | 34860. | 13413. | 53580. | 822.9 |
| 32 | 42 | 40739. | | 196.2 | | 69515. | 1.000 | 34757. | 13548. | 54348. | 821.2 |
| 11 | 26 | 22903. | | 249.9 | | 69100. | 1.000 | 34550. | 13826. | 53580. | 798.3 |
| 15 | 26 | 22903. | | 225.6 | | 69100. | 1.000 | 34550. | 13826. | 53580. | 798.3 |
| 26 | 44 | 22472. | | 251.2 | | 68669. | 1.000 | 34334. | 14124. | 53580. | 814.2 |
| 26 | 29 | 29511. | | 27.4 | | 68364. | 1.000 | 34182. | 14340. | 53580. | 759.3 |
| 22 | 27 | 58697.b | 7598. | 5.9 | 36840. | 58896. | 1.160 | 34161. | 14370. | 54348. | 792.1 |
| 21 | 26 | 21870. | | 251.2 | | 68067. | 1.000 | 34034. | 14554. | 53580. | 763.1 |
| 4 | 42 | 38815. | | 199.0 | | 67994. | 1.000 | 33997. | 14607. | 54348. | 821.2 |
| 29 | 32 | 29051. | | 56.8 | | 67904. | 1.000 | 33952. | 14674. | 53580. | 763.1 |
| 24 | 28 | 58057.b | 12029. | 31.8 | 34782. | 58080. | 1.167 | 33893. | 14760. | 53580. | 810.3 |
| 7 | 32 | 38539. | | 165.3 | | 67091. | 1.000 | 33545. | 15288. | 54348. | 801.4 |
| 32 | 45 | 38428. | | 167.0 | | 66979. | 1.000 | 33489. | 15375. | 54348. | 817.3 |
| 18 | 29 | 28066. | | 220.6 | | 66919. | 1.000 | 33459. | 15422. | 53580. | 821.0 |
| 4 | 29 | 27637. | | 53.9 | | 66490. | 1.000 | 33245. | 15763. | 53580. | 763.1 |
| 12 | 29 | 27212. | | 215.9 | | 66064. | 1.000 | 33032. | 16111. | 53580. | 822.9 |
| 4 | 7 | 36614. | | 168.2 | | 65569. | 1.000 | 32785. | 16530. | 54348. | 801.4 |
| 17 | 32 | 36945. | | 132.6 | | 65496. | 1.000 | 32748. | 16592. | 54348. | 801.4 |
| 4 | 45 | 36498. | | 169.9 | | 65453. | 1.000 | 32726. | 16630. | 54348. | 817.3 |
| 9 | 32 | 36804. | | 165.9 | | 65355. | 1.000 | 32677. | 16715. | 54348. | 801.4 |
| 13 | 32 | 35935. | | 170.4 | | 65106. | 1.000 | 32553. | 16934. | 54348. | 826.0 |
| 22 | 30 | 57644.b | 7142. | 2.9 | 36243. | 57742. | 1.121 | 32373. | 17257. | 54348. | 792.1 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 35 | 35592. | | 135.4 | | 64547. | 1.000 | 32273. | 17438. | 54348. | 801.4 |
| 11 | 32 | 35935. | | 165.7 | | 64487. | 1.000 | 32243. | 17493. | 54348. | 801.4 |
| 15 | 32 | 35935. | | 141.4 | | 64487. | 1.000 | 32243. | 17493. | 54348. | 801.4 |
| 32 | 35 | 35530. | | 132.6 | | 64082. | 1.000 | 32041. | 17873. | 54348. | 801.4 |
| 32 | 44 | 35518. | | 167.0 | | 64070. | 1.000 | 32035. | 17884. | 54348. | 817.3 |
| 4 | 17 | 35020. | | 135.4 | | 63975. | 1.000 | 31987. | 17974. | 54348. | 801.4 |
| 4 | 9 | 34878. | | 168.7 | | 63833. | 1.000 | 31917. | 18111. | 54348. | 801.4 |
| 24 | 31 | 57340.b | 12259. | 27.6 | 34309. | 57370. | 1.110 | 31844. | 18252. | 54348. | 813.4 |
| 26 | 32 | 31565. | | 84.2 | | 63602. | 1.000 | 31801. | 18336. | 53580. | 763.1 |
| 4 | 13 | 34010. | | 173.2 | | 63584. | 1.000 | 31792. | 18353. | 54348. | 826.0 |
| 21 | 32 | 34901. | | 167.0 | | 63452. | 1.000 | 31726. | 18484. | 54348. | 766.8 |
| 4 | 11 | 34010. | | 168.6 | | 62965. | 1.000 | 31483. | 18975. | 54348. | 801.4 |
| 4 | 15 | 34010. | | 144.2 | | 62965. | 1.000 | 31483. | 18975. | 54348. | 801.4 |
| 4 | 44 | 33589. | | 169.9 | | 62544. | 1.000 | 31272. | 19413. | 54348. | 817.3 |
| 4 | 21 | 32977. | | 169.9 | | 61932. | 1.000 | 30966. | 20067. | 54348. | 766.8 |
| 18 | 26 | 14433. | | 248.0 | | 60630. | 1.000 | 30315. | 21420. | 53580. | 821.0 |
| 23 | 28 | 55715.b | 7157. | 32.7 | 35896. | 55816. | 1.080 | 30132. | 21821. | 53580. | 801.6 |
| 4 | 26 | 28162. | | 81.3 | | 60199. | 1.000 | 30100. | 21893. | 53580. | 763.1 |
| 12 | 26 | 13576. | | 243.3 | | 59773. | 1.000 | 29886. | 22376. | 53580. | 822.9 |
| 24 | 43 | 55610.b | 11521. | 24.0 | 33315. | 55927. | 1.046 | 29262. | 23875. | 54348. | 813.4 |
| 24 | 34 | 55598.b | 11521. | 1.0 | 33309. | 55607. | 1.046 | 29083. | 24329. | 54348. | 813.4 |
| 3 | 24 | 55590.b | 11521. | 1.0 | 33305. | 55595. | 1.046 | 29068. | 24367. | 54348. | 813.4 |
| 12 | 32 | 28939. | | 159.1 | | 57491. | 1.000 | 28745. | 25217. | 54348. | 826.0 |
| 4 | 32 | 28514. | | 2.8 | | 57469. | 1.000 | 28735. | 25246. | 54348. | 766.8 |
| 18 | 32 | 28086. | | 163.9 | | 56638. | 1.000 | 28319. | 26401. | 54348. | 824.1 |
| 23 | 31 | 54998.b | 7386. | 28.5 | 35423. | 55107. | 1.024 | 28212. | 26708. | 54348. | 804.7 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 18 | 25540. | | 166.7 | | 54495. | 1.000 | 27247. | 29720. | 54348. | 824.1 |
| 4 | 12 | 25536. | | 161.9 | | 54491. | 1.000 | 27245. | 29726. | 54348. | 826.0 |
| 23 | 43 | 53267.g | 6649. | 25.0 | 34429. | 53664. | 1.000 | 26832. | 31155. | 54348. | 804.7 |
| 23 | 34 | 53256.g | 6649. | 1.9 | 34423. | 53344. | 1.000 | 26672. | 31732. | 54348. | 804.7 |
| 3 | 23 | 53247.g | 6649. | 1.9 | 34419. | 53332. | 1.000 | 26666. | 31754. | 54348. | 804.7 |
| 22 | 42 | 52114.g | 9899. | 29.7 | 31901. | 52341. | 1.000 | 26170. | 33637. | 54348. | 821.2 |
| 24 | 27 | 52078.g | 13808. | 5.8 | 30903. | 52277. | 1.000 | 26138. | 33763. | 58680. | 833.3 |
| 5 | 22 | 36363. | | 79.1 | | 51414. | 1.000 | 25707. | 35533. | 54348. | 827.0 |
| 24 | 30 | 51025.g | 13352. | 2.8 | 30306. | 51123. | 1.000 | 25561. | 36158. | 58680. | 833.3 |
| 20 | 22 | 50097.g | 363. | 1.1 | 35661. | 50120. | 1.000 | 25060. | 38425. | 54348. | 766.8 |
| 23 | 27 | 49736.g | 8936. | 6.7 | 32017. | 50014. | 1.000 | 25007. | 38676. | 58680. | 825.8 |
| 22 | 25 | 49174.g | 5006. | 42.7 | 33593. | 49190. | 1.000 | 24595. | 40698. | 53580. | 763.1 |
| 23 | 30 | 48683.g | 8480. | 3.8 | 31420. | 48860. | 1.000 | 24430. | 41549. | 58680. | 825.8 |
| 28 | 36 | 46729.g | 12029. | 34.5 | 29118. | 47343. | 1.000 | 23672. | 45771. | 53580. | 821.0 |
| 2 | 28 | 46729.g | 12029. | 31.3 | 29118. | 46750. | 1.000 | 23375. | 47577. | 53580. | 849.3 |
| 28 | 38 | 46729.g | 12029. | 31.3 | 29118. | 46750. | 1.000 | 23375. | 47577. | 53580. | 849.3 |
| 31 | 36 | 46012.g | 12259. | 30.3 | 28644. | 46633. | 1.000 | 23317. | 47944. | 54348. | 824.1 |
| 22 | 33 | 45280.g | 6649. | 15.6 | 28778. | 46192. | 1.000 | 23096. | 49364. | 54348. | 819.2 |
| 2 | 31 | 46012.g | 12259. | 27.2 | 28644. | 46040. | 1.000 | 23020. | 49865. | 54348. | 851.7 |
| 31 | 38 | 46012.g | 12259. | 27.2 | 28644. | 46040. | 1.000 | 23020. | 49865. | 54348. | 851.7 |
| 24 | 42 | 45494. | | 29.6 | | 45720. | 1.000 | 22860. | 51538. | 60000. | 856.2 |
| 12 | 22 | 45390.g | 13603. | 7.4 | 26687. | 45392. | 1.000 | 22696. | 53409. | 54348. | 826.0 |
| 36 | 43 | 44282.g | 11521. | 26.8 | 27651. | 45190. | 1.000 | 22595. | 54602. | 54348. | 824.1 |
| 34 | 36 | 44270.g | 11521. | 3.7 | 27645. | 44871. | 1.000 | 22435. | 56559. | 54348. | 824.1 |
| 3 | 36 | 44262.g | 11521. | 3.7 | 27641. | 44859. | 1.000 | 22429. | 56635. | 54348. | 824.1 |
| 5 | 24 | 29744. | | 79.0 | | 44794. | 1.000 | 22397. | 57040. | 60000. | 860.7 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 22 | 44599.g | 1861. | 40.2 | 32163. | 44619. | 1.000 | 22310. | 58159. | 54348. | 792.1 |
| 2 | 43 | 44282.g | 11521. | 23.6 | 27651. | 44597. | 1.000 | 22299. | 58299. | 54348. | 851.7 |
| 38 | 43 | 44282.g | 11521. | 23.6 | 27651. | 44597. | 1.000 | 22299. | 58299. | 54348. | 851.7 |
| 18 | 22 | 44533.g | 12746. | 2.6 | 26687. | 44536. | 1.000 | 22268. | 58701. | 54348. | 824.1 |
| 2 | 34 | 44270.g | 11521. | 0.5 | 27645. | 44278. | 1.000 | 22139. | 60417. | 54348. | 851.7 |
| 34 | 38 | 44270.g | 11521. | 0.5 | 27645. | 44278. | 1.000 | 22139. | 60417. | 54348. | 851.7 |
| 2 | 3 | 44262.g | 11521. | 0.5 | 27641. | 44266. | 1.000 | 22133. | 60499. | 54348. | 851.7 |
| 3 | 38 | 44262.g | 11521. | 0.5 | 27641. | 44266. | 1.000 | 22133. | 60499. | 54348. | 851.7 |
| 23 | 42 | 43153. | | 30.5 | | 43458. | 1.000 | 21729. | 66286. | 60000. | 849.3 |
| 20 | 24 | 43368. | | 1.0 | | 43390. | 1.000 | 21695. | 66803. | 54348. | 813.4 |
| 5 | 23 | 27401. | | 79.9 | | 42530. | 1.000 | 21265. | 73771. | 60000. | 853.9 |
| 22 | 37 | 42394. | | 0.6 | | 42396. | 1.000 | 21198. | 74933. | 54348. | 788.7 |
| 27 | 36 | 40750. | | 8.5 | | 41540. | 1.000 | 20770. | 82915. | 58680. | 841.7 |
| 28 | 37 | 41509. | | 31.3 | | 41529. | 1.000 | 20765. | 83019. | 53580. | 784.2 |
| 37 | 43 | 41048. | | 23.6 | | 41364. | 1.000 | 20682. | 84683. | 54348. | 788.7 |
| 20 | 23 | 41038. | | 2.0 | | 41138. | 1.000 | 20569. | 87007. | 54348. | 804.7 |
| 34 | 37 | 41036. | | 0.5 | | 41044. | 1.000 | 20522. | 88005. | 54348. | 788.7 |
| 3 | 37 | 41028. | | 0.5 | | 41032. | 1.000 | 20516. | 88134. | 54348. | 788.7 |
| 2 | 27 | 40750. | | 5.3 | | 40947. | 1.000 | 20473. | 89044. | 58680. | 868.4 |
| 27 | 38 | 40750. | | 5.3 | | 40947. | 1.000 | 20473. | 89044. | 58680. | 868.4 |
| 31 | 37 | 40792. | | 27.2 | | 40820. | 1.000 | 20410. | 90429. | 54348. | 788.7 |
| 30 | 36 | 39697. | | 5.6 | | 40386. | 1.000 | 20193. | 95348. | 58680. | 841.7 |
| 2 | 30 | 39697. | | 2.4 | | 39793. | 1.000 | 19897. | 101886. | 58680. | 868.4 |
| 30 | 38 | 39697. | | 2.4 | | 39793. | 1.000 | 19897. | 101886. | 58680. | 868.4 |
| 24 | 33 | 38661. | | 15.5 | | 39572. | 1.000 | 19786. | 103950. | 60000. | 854.6 |
| 12 | 24 | 38769. | | 7.5 | | 38770. | 1.000 | 19385. | 111907. | 60000. | 860.0 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 22 | 38714. | | 0.8 | | 38766. | 1.000 | 19383. | 111954. | 54348. | 851.7 |
| 1 28 | 38385. | | 31.1 | | 38406. | 1.000 | 19203. | 115784. | 53580. | 849.3 |
| 19 24 | 37973. | | 40.1 | | 37992. | 1.000 | 18996. | 120392. | 58680. | 833.3 |
| 18 24 | 37912. | | 2.7 | | 37914. | 1.000 | 18957. | 121286. | 60000. | 858.4 |
| 1 31 | 37668. | | 26.9 | | 37696. | 1.000 | 18848. | 123834. | 54348. | 851.7 |
| 1 43 | 37368. | | 23.3 | | 37683. | 1.000 | 18842. | 123981. | 54348. | 851.7 |
| 23 25 | 37549. | | 43.5 | | 37644. | 1.000 | 18822. | 124447. | 53580. | 801.6 |
| 1 34 | 37356. | | 0.3 | | 37364. | 1.000 | 18682. | 127846. | 54348. | 851.7 |
| 1 3 | 37348. | | 0.3 | | 37352. | 1.000 | 18676. | 127996. | 54348. | 851.7 |
| 25 28 | 37321. | | 10.8 | | 37342. | 1.000 | 18671. | 128119. | 53580. | 759.3 |
| 16 22 | 34887. | | 13.6 | | 37322. | 1.000 | 18661. | 128359. | 54348. | 801.4 |
| 23 33 | 36319. | | 16.4 | | 37309. | 1.000 | 18655. | 128517. | 60000. | 847.8 |
| 25 43 | 36861. | | 18.6 | | 37176. | 1.000 | 18588. | 130181. | 53580. | 763.1 |
| 21 22 | 37098. | | 0.6 | | 37100. | 1.000 | 18550. | 131149. | 54348. | 766.8 |
| 28 40 | 36950. | | 31.3 | | 36971. | 1.000 | 18485. | 132812. | 53580. | 798.3 |
| 25 34 | 36849. | | 41.6 | | 36857. | 1.000 | 18428. | 134297. | 53580. | 763.1 |
| 3 25 | 36841. | | 41.6 | | 36845. | 1.000 | 18422. | 134456. | 53580. | 763.1 |
| 13 22 | 36074. | | 3.9 | | 36696. | 1.000 | 18348. | 136430. | 54348. | 826.0 |
| 28 35 | 30200. | | 65.8 | | 36655. | 1.000 | 18328. | 136979. | 53580. | 798.3 |
| 25 31 | 36604. | | 15.0 | | 36632. | 1.000 | 18316. | 137291. | 53580. | 763.1 |
| 22 44 | 36626. | | 0.6 | | 36628. | 1.000 | 18314. | 137342. | 54348. | 817.3 |
| 12 23 | 36429. | | 6.5 | | 36509. | 1.000 | 18255. | 138959. | 60000. | 853.1 |
| 12 28 | 34857. | | 39.3 | | 36357. | 1.000 | 18179. | 141064. | 53580. | 822.9 |
| 31 40 | 36233. | | 27.2 | | 36261. | 1.000 | 18130. | 142421. | 54348. | 801.4 |
| 17 28 | 29626. | | 65.8 | | 36082. | 1.000 | 18041. | 144986. | 53580. | 798.3 |
| 11 22 | 36074. | | 0.7 | | 36077. | 1.000 | 18038. | 145056. | 54348. | 801.4 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 22 | 36074. | | 25.1 | | 36077. | 1.000 | 18038. | 145056. | 54348. | 801.4 |
| 28 41 | 35960. | | 31.3 | | 35981. | 1.000 | 17991. | 146447. | 53580. | 798.3 |
| 6 28 | 35960. | | 30.0 | | 35981. | 1.000 | 17991. | 146449. | 53580. | 798.3 |
| 8 28 | 35960. | | 29.6 | | 35981. | 1.000 | 17991. | 146449. | 53580. | 798.3 |
| 10 28 | 35960. | | 30.2 | | 35981. | 1.000 | 17991. | 146449. | 53580. | 798.3 |
| 14 28 | 35960. | | 30.0 | | 35981. | 1.000 | 17991. | 146449. | 53580. | 798.3 |
| 16 28 | 35960. | | 18.3 | | 35981. | 1.000 | 17991. | 146449. | 53580. | 798.3 |
| 31 35 | 29482. | | 61.6 | | 35944. | 1.000 | 17972. | 146991. | 54348. | 801.4 |
| 30 37 | 35668. | | 2.4 | | 35764. | 1.000 | 17882. | 149673. | 58680. | 819.8 |
| 19 23 | 35632. | | 41.1 | | 35730. | 1.000 | 17865. | 150191. | 58680. | 825.8 |
| 27 37 | 35529. | | 5.3 | | 35726. | 1.000 | 17863. | 150253. | 58680. | 819.8 |
| 22 39 | 35660. | | 0.6 | | 35662. | 1.000 | 17831. | 151224. | 54348. | 793.6 |
| 18 23 | 35572. | | 1.8 | | 35653. | 1.000 | 17826. | 151370. | 60000. | 851.6 |
| 17 31 | 28909. | | 61.6 | | 35371. | 1.000 | 17686. | 155755. | 54348. | 801.4 |
| 31 41 | 35243. | | 27.2 | | 35272. | 1.000 | 17636. | 157347. | 54348. | 801.4 |
| 6 31 | 35243. | | 25.8 | | 35271. | 1.000 | 17636. | 157350. | 54348. | 801.4 |
| 8 31 | 35243. | | 25.5 | | 35271. | 1.000 | 17636. | 157350. | 54348. | 801.4 |
| 10 31 | 35243. | | 26.0 | | 35271. | 1.000 | 17636. | 157350. | 54348. | 801.4 |
| 14 31 | 35243. | | 25.9 | | 35271. | 1.000 | 17636. | 157350. | 54348. | 801.4 |
| 16 31 | 35243. | | 14.1 | | 35271. | 1.000 | 17636. | 157350. | 54348. | 801.4 |
| 12 43 | 33425. | | 31.5 | | 35220. | 1.000 | 17610. | 158176. | 54348. | 826.0 |
| 9 22 | 35211. | | 0.6 | | 35213. | 1.000 | 17606. | 158293. | 54348. | 801.4 |
| 8 22 | 34887. | | 2.3 | | 35206. | 1.000 | 17603. | 158403. | 54348. | 801.4 |
| 12 31 | 33681. | | 35.1 | | 35189. | 1.000 | 17595. | 158680. | 54348. | 826.0 |
| 6 22 | 34887. | | 1.9 | | 35141. | 1.000 | 17570. | 159466. | 54348. | 801.4 |
| 14 22 | 34887. | | 1.9 | | 35132. | 1.000 | 17566. | 159612. | 54348. | 801.4 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

****************************
INDIVIDUAL STRESS RANGE CHECK
****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 22 | 34887. | | 1.7 | | 35104. | 1.000 | 17552. | 160075. | 54348. | 801.4 |
| 17 | 22 | 35068. | | 33.9 | | 35070. | 1.000 | 17535. | 160627. | 54348. | 801.4 |
| 36 | 42 | 34166. | | 32.3 | | 34983. | 1.000 | 17492. | 162071. | 60000. | 864.5 |
| 12 | 34 | 33413. | | 8.5 | | 34900. | 1.000 | 17450. | 163460. | 54348. | 826.0 |
| 22 | 41 | 34887. | | 0.6 | | 34889. | 1.000 | 17445. | 163651. | 54348. | 801.4 |
| 3 | 12 | 33405. | | 8.5 | | 34888. | 1.000 | 17444. | 163664. | 54348. | 826.0 |
| 40 | 43 | 34503. | | 23.6 | | 34819. | 1.000 | 17409. | 164848. | 54348. | 801.4 |
| 22 | 40 | 34759. | | 0.6 | | 34761. | 1.000 | 17381. | 165831. | 54348. | 801.4 |
| 28 | 39 | 34652. | | 31.3 | | 34673. | 1.000 | 17337. | 167354. | 53580. | 787.5 |
| 18 | 28 | 34000. | | 34.5 | | 34614. | 1.000 | 17307. | 168392. | 53580. | 821.0 |
| 39 | 43 | 34193. | | 23.6 | | 34509. | 1.000 | 17254. | 170242. | 54348. | 793.6 |
| 35 | 43 | 27756. | | 58.0 | | 34506. | 1.000 | 17253. | 170292. | 54348. | 801.4 |
| 34 | 40 | 34491. | | 0.5 | | 34499. | 1.000 | 17249. | 170419. | 54348. | 801.4 |
| 22 | 35 | 34495. | | 33.9 | | 34498. | 1.000 | 17249. | 170442. | 54348. | 801.4 |
| 3 | 40 | 34483. | | 0.5 | | 34487. | 1.000 | 17243. | 170635. | 54348. | 801.4 |
| 2 | 42 | 34166. | | 29.2 | | 34390. | 1.000 | 17195. | 172368. | 60000. | 893.7 |
| 38 | 42 | 34166. | | 29.2 | | 34390. | 1.000 | 17195. | 172368. | 60000. | 893.7 |
| 34 | 39 | 34181. | | 0.5 | | 34189. | 1.000 | 17095. | 176049. | 54348. | 793.6 |
| 34 | 35 | 27745. | | 35.0 | | 34186. | 1.000 | 17093. | 176101. | 54348. | 801.4 |
| 3 | 39 | 34173. | | 0.5 | | 34177. | 1.000 | 17089. | 176274. | 54348. | 793.6 |
| 3 | 35 | 27736. | | 35.0 | | 34174. | 1.000 | 17087. | 176326. | 54348. | 801.4 |
| 5 | 36 | 18416. | | 81.7 | | 34057. | 1.000 | 17029. | 178513. | 60000. | 869.1 |
| 22 | 45 | 33979. | | 0.6 | | 33981. | 1.000 | 16990. | 179967. | 54348. | 817.3 |
| 31 | 39 | 33935. | | 27.2 | | 33963. | 1.000 | 16982. | 180307. | 54348. | 793.6 |
| 17 | 43 | 27181. | | 58.0 | | 33931. | 1.000 | 16966. | 180916. | 54348. | 801.4 |
| 41 | 43 | 33514. | | 23.6 | | 33829. | 1.000 | 16915. | 182887. | 54348. | 801.4 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2  CODE SECTION III CLASS 1 ASME-1998  KRE  2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW  155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 43 | 33514. | | 22.2 | | 33829. | 1.000 | 16915. | 182890. | 54348. | 801.4 |
| 8 43 | 33514. | | 21.9 | | 33829. | 1.000 | 16915. | 182890. | 54348. | 801.4 |
| 10 43 | 33514. | | 22.4 | | 33829. | 1.000 | 16915. | 182890. | 54348. | 801.4 |
| 14 43 | 33514. | | 22.3 | | 33829. | 1.000 | 16915. | 182890. | 54348. | 801.4 |
| 16 43 | 33514. | | 10.5 | | 33829. | 1.000 | 16915. | 182890. | 54348. | 801.4 |
| 17 34 | 27170. | | 35.0 | | 33612. | 1.000 | 16806. | 187194. | 54348. | 801.4 |
| 3 17 | 27161. | | 35.0 | | 33599. | 1.000 | 16800. | 187437. | 54348. | 801.4 |
| 34 41 | 33502. | | 0.5 | | 33510. | 1.000 | 16755. | 189252. | 54348. | 801.4 |
| 6 34 | 33502. | | 0.8 | | 33510. | 1.000 | 16755. | 189256. | 54348. | 801.4 |
| 8 34 | 33502. | | 1.2 | | 33510. | 1.000 | 16755. | 189256. | 54348. | 801.4 |
| 10 34 | 33502. | | 0.6 | | 33510. | 1.000 | 16755. | 189256. | 54348. | 801.4 |
| 14 34 | 33502. | | 0.8 | | 33510. | 1.000 | 16755. | 189256. | 54348. | 801.4 |
| 16 34 | 33502. | | 12.5 | | 33510. | 1.000 | 16755. | 189256. | 54348. | 801.4 |
| 7 22 | 33497. | | 1.1 | | 33499. | 1.000 | 16750. | 189470. | 54348. | 801.4 |
| 3 41 | 33494. | | 0.5 | | 33498. | 1.000 | 16749. | 189499. | 54348. | 801.4 |
| 3 6 | 33494. | | 0.8 | | 33497. | 1.000 | 16749. | 189503. | 54348. | 801.4 |
| 3 8 | 33494. | | 1.2 | | 33497. | 1.000 | 16749. | 189503. | 54348. | 801.4 |
| 3 10 | 33494. | | 0.6 | | 33497. | 1.000 | 16749. | 189503. | 54348. | 801.4 |
| 3 14 | 33494. | | 0.8 | | 33497. | 1.000 | 16749. | 189503. | 54348. | 801.4 |
| 3 16 | 33494. | | 12.5 | | 33497. | 1.000 | 16749. | 189503. | 54348. | 801.4 |
| 18 43 | 32568. | | 26.8 | | 33477. | 1.000 | 16738. | 189930. | 54348. | 824.1 |
| 2 5 | 18416. | | 78.5 | | 33465. | 1.000 | 16732. | 190176. | 60000. | 905.8 |
| 5 38 | 18416. | | 78.5 | | 33465. | 1.000 | 16732. | 190176. | 60000. | 905.8 |
| 18 31 | 32824. | | 30.3 | | 33445. | 1.000 | 16723. | 190566. | 54348. | 824.1 |
| 15 28 | 28620. | | 57.0 | | 33425. | 1.000 | 16713. | 190984. | 53580. | 798.3 |
| 18 34 | 32556. | | 3.7 | | 33157. | 1.000 | 16578. | 196612. | 54348. | 824.1 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07 [
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 18 | 32548. | | 3.7 | | 33145. | 1.000 | 16572. | 196871. | 54348. | 824.1 |
| 12 20 | 31318. | | 8.5 | | 32817. | 1.000 | 16409. | 205131. | 54348. | 826.0 |
| 24 25 | 32755. | | 42.6 | | 32771. | 1.000 | 16386. | 206456. | 53580. | 810.3 |
| 15 31 | 27902. | | 52.8 | | 32714. | 1.000 | 16357. | 208114. | 54348. | 801.4 |
| 20 28 | 32655. | | 30.7 | | 32675. | 1.000 | 16338. | 209234. | 53580. | 763.1 |
| 20 36 | 32040. | | 3.8 | | 32653. | 1.000 | 16327. | 209888. | 54348. | 824.1 |
| 1 27 | 32405. | | 5.1 | | 32602. | 1.000 | 16301. | 211385. | 58680. | 868.4 |
| 12 25 | 30973. | | 50.1 | | 32467. | 1.000 | 16233. | 215442. | 53580. | 822.9 |
| 2 22 | 32275. | | 0.6 | | 32278. | 1.000 | 16139. | 221264. | 54348. | 851.7 |
| 22 24 | 32275. | | 0.1 | | 32278. | 1.000 | 16139. | 221264. | 54348. | 813.4 |
| 22 36 | 32275. | | 2.6 | | 32278. | 1.000 | 16139. | 221264. | 54348. | 824.1 |
| 22 38 | 32275. | | 0.6 | | 32278. | 1.000 | 16139. | 221264. | 54348. | 851.7 |
| 1 30 | 31988. | | 2.1 | | 32084. | 1.000 | 16042. | 227424. | 58680. | 868.4 |
| 2 20 | 32040. | | 0.6 | | 32060. | 1.000 | 16030. | 228208. | 54348. | 851.7 |
| 20 38 | 32040. | | 0.6 | | 32060. | 1.000 | 16030. | 228208. | 54348. | 851.7 |
| 20 31 | 31938. | | 26.6 | | 31966. | 1.000 | 15983. | 231302. | 54348. | 766.8 |
| 25 30 | 31481. | | 39.8 | | 31577. | 1.000 | 15789. | 244590. | 53580. | 788.7 |
| 7 28 | 31219. | | 33.0 | | 31557. | 1.000 | 15779. | 245285. | 53580. | 798.3 |
| 25 27 | 31341. | | 36.8 | | 31538. | 1.000 | 15769. | 245964. | 53580. | 788.7 |
| 15 43 | 26180. | | 49.2 | | 31279. | 1.000 | 15640. | 255410. | 54348. | 801.4 |
| 28 45 | 31220. | | 31.3 | | 31241. | 1.000 | 15620. | 256841. | 53580. | 814.2 |
| 28 42 | 31152. | | 2.2 | | 31173. | 1.000 | 15587. | 259394. | 53580. | 818.0 |
| 27 40 | 30970. | | 5.3 | | 31167. | 1.000 | 15583. | 259631. | 58680. | 822.5 |
| 37 42 | 30932. | | 29.2 | | 31156. | 1.000 | 15578. | 260037. | 60000. | 868.4 |
| 18 20 | 30461. | | 3.8 | | 31074. | 1.000 | 15537. | 263206. | 54348. | 824.1 |
| 19 28 | 31051. | | 8.4 | | 31071. | 1.000 | 15536. | 263297. | 53580. | 788.7 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2    CODE SECTION III CLASS 1 ASME-1998    KRE    2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW    155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 34 | 26168. | | 26.2 | | 30959. | 1.000 | 15480. | 267678. | 54348. | 801.4 |
| 3 15 | 26159. | | 26.2 | | 30947. | 1.000 | 15474. | 268157. | 54348. | 801.4 |
| 27 35 | 24217. | | 39.8 | | 30848. | 1.000 | 15424. | 272130. | 58680. | 822.5 |
| 7 31 | 30502. | | 28.9 | | 30847. | 1.000 | 15424. | 272146. | 54348. | 801.4 |
| 23 37 | 30758. | | 1.4 | | 30838. | 1.000 | 15419. | 272503. | 60000. | 838.6 |
| 18 25 | 30116. | | 45.3 | | 30723. | 1.000 | 15362. | 277200. | 53580. | 821.0 |
| 28 33 | 30567. | | 16.3 | | 30588. | 1.000 | 15294. | 282853. | 53580. | 816.1 |
| 20 43 | 30208. | | 23.0 | | 30523. | 1.000 | 15262. | 285593. | 54348. | 766.8 |
| 31 45 | 30493. | | 27.2 | | 30521. | 1.000 | 15260. | 285693. | 54348. | 817.3 |
| 21 24 | 30480. | | 0.5 | | 30481. | 1.000 | 15241. | 287400. | 54348. | 813.4 |
| 19 31 | 30333. | | 12.5 | | 30362. | 1.000 | 15181. | 292600. | 54348. | 792.1 |
| 33 37 | 29424. | | 15.0 | | 30334. | 1.000 | 15167. | 293826. | 60000. | 860.6 |
| 17 27 | 23644. | | 39.8 | | 30276. | 1.000 | 15138. | 296416. | 58680. | 822.5 |
| 5 37 | 15182. | | 78.5 | | 30231. | 1.000 | 15115. | 298432. | 60000. | 892.0 |
| 20 34 | 30196. | | 0.0 | | 30203. | 1.000 | 15102. | 299660. | 54348. | 766.8 |
| 3 20 | 30188. | | 0.1 | | 30191. | 1.000 | 15096. | 300210. | 54348. | 766.8 |
| 27 41 | 29980. | | 5.3 | | 30178. | 1.000 | 15089. | 300835. | 58680. | 822.5 |
| 6 27 | 29980. | | 4.0 | | 30177. | 1.000 | 15089. | 300844. | 58680. | 822.5 |
| 8 27 | 29980. | | 3.6 | | 30177. | 1.000 | 15089. | 300844. | 58680. | 822.5 |
| 10 27 | 29980. | | 4.2 | | 30177. | 1.000 | 15089. | 300844. | 58680. | 822.5 |
| 14 27 | 29980. | | 4.0 | | 30177. | 1.000 | 15089. | 300844. | 58680. | 822.5 |
| 16 27 | 29980. | | 7.7 | | 30177. | 1.000 | 15089. | 300844. | 58680. | 822.5 |
| 13 24 | 29455. | | 3.8 | | 30076. | 1.000 | 15038. | 305510. | 60000. | 860.0 |
| 42 43 | 29721. | | 5.6 | | 30036. | 1.000 | 15018. | 307361. | 54348. | 821.2 |
| 30 40 | 29917. | | 2.4 | | 30014. | 1.000 | 15007. | 308417. | 58680. | 822.5 |
| 31 42 | 29977. | | 2.0 | | 30005. | 1.000 | 15003. | 308818. | 54348. | 821.2 |

Notes
b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 44 | 29966. | | 0.5 | | 29968. | 1.000 | 14984. | 310575. | 60000. | 853.1 |
| 9 | 28 | 29486. | | 32.5 | | 29721. | 1.000 | 14861. | 322516. | 53580. | 798.3 |
| 34 | 42 | 29709. | | 28.6 | | 29716. | 1.000 | 14858. | 322754. | 54348. | 821.2 |
| 3 | 42 | 29701. | | 28.6 | | 29704. | 1.000 | 14852. | 323355. | 54348. | 821.2 |
| 30 | 35 | 23164. | | 36.8 | | 29695. | 1.000 | 14847. | 323829. | 58680. | 822.5 |
| 11 | 24 | 29455. | | 0.8 | | 29457. | 1.000 | 14728. | 335946. | 60000. | 840.6 |
| 15 | 24 | 29455. | | 25.2 | | 29457. | 1.000 | 14728. | 335946. | 60000. | 840.6 |
| 33 | 43 | 29133. | | 8.6 | | 29449. | 1.000 | 14724. | 336356. | 54348. | 819.2 |
| 31 | 33 | 29392. | | 12.1 | | 29420. | 1.000 | 14710. | 337846. | 54348. | 819.2 |
| 7 | 43 | 28774. | | 25.3 | | 29406. | 1.000 | 14703. | 338595. | 54348. | 801.4 |
| 33 | 34 | 29122. | | 14.5 | | 29129. | 1.000 | 14565. | 353547. | 54348. | 819.2 |
| 17 | 30 | 22592. | | 36.8 | | 29122. | 1.000 | 14561. | 353924. | 58680. | 822.5 |
| 3 | 33 | 29113. | | 14.5 | | 29117. | 1.000 | 14559. | 354220. | 54348. | 819.2 |
| 43 | 45 | 28797. | | 23.6 | | 29112. | 1.000 | 14556. | 354495. | 54348. | 817.3 |
| 7 | 34 | 28762. | | 2.2 | | 29086. | 1.000 | 14543. | 355926. | 54348. | 801.4 |
| 3 | 7 | 28753. | | 2.2 | | 29074. | 1.000 | 14537. | 356604. | 54348. | 801.4 |
| 30 | 41 | 28928. | | 2.4 | | 29024. | 1.000 | 14512. | 359424. | 58680. | 822.5 |
| 6 | 30 | 28928. | | 1.0 | | 29024. | 1.000 | 14512. | 359435. | 58680. | 822.5 |
| 8 | 30 | 28928. | | 0.7 | | 29024. | 1.000 | 14512. | 359435. | 58680. | 822.5 |
| 10 | 30 | 28928. | | 1.2 | | 29024. | 1.000 | 14512. | 359435. | 58680. | 822.5 |
| 14 | 30 | 28928. | | 1.1 | | 29024. | 1.000 | 14512. | 359435. | 58680. | 822.5 |
| 16 | 30 | 28928. | | 10.7 | | 29024. | 1.000 | 14512. | 359435. | 58680. | 822.5 |
| 9 | 31 | 28768. | | 28.3 | | 29011. | 1.000 | 14505. | 360192. | 54348. | 801.4 |
| 2 | 12 | 27441. | | 7.9 | | 28921. | 1.000 | 14460. | 365335. | 60000. | 903.8 |
| 12 | 36 | 27441. | | 4.8 | | 28921. | 1.000 | 14460. | 365335. | 60000. | 868.4 |
| 12 | 38 | 27441. | | 7.9 | | 28921. | 1.000 | 14460. | 365335. | 60000. | 903.8 |

Notes
b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 43 | 28604. | | 16.1 | | 28920. | 1.000 | 14460. | 365397. | 54348. | 792.1 |
| 30 | 39 | 28811. | | 2.4 | | 28907. | 1.000 | 14454. | 366116. | 58680. | 822.5 |
| 11 | 28 | 28620. | | 32.6 | | 28884. | 1.000 | 14442. | 367461. | 53580. | 798.3 |
| 27 | 39 | 28671. | | 5.3 | | 28868. | 1.000 | 14434. | 368386. | 58680. | 822.5 |
| 20 | 35 | 22397. | | 35.0 | | 28851. | 1.000 | 14425. | 369387. | 54348. | 801.4 |
| 33 | 36 | 27333. | | 18.2 | | 28836. | 1.000 | 14418. | 370288. | 60000. | 863.0 |
| 20 | 37 | 28806. | | 0.6 | | 28826. | 1.000 | 14413. | 370834. | 54348. | 788.7 |
| 34 | 45 | 28785. | | 0.5 | | 28792. | 1.000 | 14396. | 372829. | 54348. | 817.3 |
| 3 | 45 | 28777. | | 0.5 | | 28780. | 1.000 | 14390. | 373546. | 54348. | 817.3 |
| 27 | 43 | 28412. | | 18.2 | | 28727. | 1.000 | 14364. | 376708. | 54348. | 792.1 |
| 13 | 28 | 28620. | | 28.0 | | 28641. | 1.000 | 14321. | 381903. | 53580. | 822.9 |
| 19 | 34 | 28592. | | 39.1 | | 28600. | 1.000 | 14300. | 384425. | 54348. | 792.1 |
| 9 | 24 | 28590. | | 0.7 | | 28591. | 1.000 | 14296. | 384960. | 60000. | 840.6 |
| 3 | 19 | 28584. | | 39.2 | | 28588. | 1.000 | 14294. | 385169. | 54348. | 792.1 |
| 25 | 35 | 22050. | | 76.6 | | 28499. | 1.000 | 14249. | 390691. | 53580. | 798.3 |
| 28 | 44 | 28431. | | 31.3 | | 28451. | 1.000 | 14226. | 393669. | 53580. | 814.2 |
| 17 | 24 | 28447. | | 34.0 | | 28449. | 1.000 | 14224. | 393854. | 60000. | 840.6 |
| 27 | 34 | 28400. | | 4.8 | | 28407. | 1.000 | 14204. | 396461. | 54348. | 792.1 |
| 3 | 27 | 28392. | | 4.8 | | 28395. | 1.000 | 14198. | 397234. | 54348. | 792.1 |
| 5 | 28 | 28333. | | 47.2 | | 28354. | 1.000 | 14177. | 399912. | 53580. | 823.9 |
| 2 | 33 | 27333. | | 15.0 | | 28243. | 1.000 | 14121. | 407140. | 60000. | 889.7 |
| 33 | 38 | 27333. | | 15.0 | | 28243. | 1.000 | 14121. | 407140. | 60000. | 889.7 |
| 21 | 23 | 28137. | | 1.4 | | 28218. | 1.000 | 14109. | 408793. | 54348. | 804.7 |
| 11 | 31 | 27902. | | 28.5 | | 28173. | 1.000 | 14086. | 411773. | 54348. | 801.4 |
| 28 | 30 | 27997. | | 28.9 | | 28018. | 1.000 | 14009. | 422270. | 53580. | 788.7 |
| 13 | 31 | 27902. | | 23.8 | | 27930. | 1.000 | 13965. | 428376. | 54348. | 826.0 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2    CODE SECTION III CLASS 1 ASME-1998    KRE    2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW    155 TO, 160

****************************
INDIVIDUAL STRESS RANGE CHECK
****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 28 | 27856. | | 26.0 | | 27877. | 1.000 | 13939. | 432081. | 53580. | 788.7 |
| 24 | 35 | 27875. | | 34.0 | | 27877. | 1.000 | 13938. | 432125. | 60000. | 840.6 |
| 13 | 23 | 27112. | | 4.7 | | 27812. | 1.000 | 13906. | 436721. | 60000. | 853.1 |
| 23 | 44 | 27648. | | 1.4 | | 27729. | 1.000 | 13864. | 442732. | 60000. | 846.3 |
| 31 | 44 | 27673. | | 27.2 | | 27701. | 1.000 | 13851. | 444748. | 54348. | 817.3 |
| 30 | 43 | 27360. | | 21.2 | | 27675. | 1.000 | 13838. | 446650. | 54348. | 792.1 |
| 5 | 31 | 27614. | | 51.4 | | 27642. | 1.000 | 13821. | 449150. | 54348. | 827.0 |
| 20 | 42 | 27614. | | 28.6 | | 27634. | 1.000 | 13817. | 449757. | 54348. | 821.2 |
| 15 | 27 | 22635. | | 31.0 | | 27616. | 1.000 | 13808. | 451074. | 58680. | 822.5 |
| 3 | 28 | 27578. | | 30.8 | | 27599. | 1.000 | 13799. | 452344. | 53580. | 763.1 |
| 21 | 28 | 27578. | | 31.3 | | 27599. | 1.000 | 13799. | 452344. | 53580. | 763.1 |
| 28 | 34 | 27578. | | 30.8 | | 27599. | 1.000 | 13799. | 452344. | 53580. | 763.1 |
| 28 | 43 | 27578. | | 7.7 | | 27599. | 1.000 | 13799. | 452344. | 53580. | 763.1 |
| 9 | 43 | 27041. | | 24.7 | | 27572. | 1.000 | 13786. | 454392. | 54348. | 801.4 |
| 1 | 42 | 27252. | | 28.9 | | 27476. | 1.000 | 13738. | 461639. | 60000. | 893.7 |
| 17 | 20 | 20982. | | 35.0 | | 27436. | 1.000 | 13718. | 464734. | 54348. | 801.4 |
| 30 | 34 | 27348. | | 1.8 | | 27356. | 1.000 | 13678. | 470989. | 54348. | 792.1 |
| 3 | 30 | 27340. | | 1.9 | | 27344. | 1.000 | 13672. | 471943. | 54348. | 792.1 |
| 25 | 42 | 27269. | | 13.0 | | 27283. | 1.000 | 13642. | 476732. | 53580. | 818.0 |
| 24 | 39 | 27275. | | 0.5 | | 27276. | 1.000 | 13638. | 477271. | 60000. | 840.6 |
| 19 | 36 | 26645. | | 42.9 | | 27255. | 1.000 | 13628. | 478974. | 58680. | 841.7 |
| 9 | 34 | 27030. | | 1.7 | | 27252. | 1.000 | 13626. | 479249. | 54348. | 801.4 |
| 3 | 9 | 27021. | | 1.7 | | 27240. | 1.000 | 13620. | 480224. | 54348. | 801.4 |
| 1 | 23 | 27078. | | 1.7 | | 27208. | 1.000 | 13604. | 482793. | 60000. | 878.3 |
| 11 | 23 | 27112. | | 0.1 | | 27193. | 1.000 | 13597. | 483997. | 60000. | 833.8 |
| 15 | 23 | 27112. | | 24.3 | | 27193. | 1.000 | 13597. | 483997. | 60000. | 833.8 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 36 | 26584. | | 0.0 | | 27177. | 1.000 | 13589. | 485280. | 60000. | 866.8 |
| 2 | 18 | 26584. | | 3.2 | | 27177. | 1.000 | 13589. | 485286. | 60000. | 899.7 |
| 18 | 38 | 26584. | | 3.2 | | 27177. | 1.000 | 13589. | 485286. | 60000. | 899.7 |
| 31 | 43 | 26861. | | 3.6 | | 27177. | 1.000 | 13588. | 485321. | 54348. | 766.8 |
| 24 | 45 | 27103. | | 0.5 | | 27105. | 1.000 | 13552. | 491227. | 60000. | 853.1 |
| 22 | 23 | 27100. | | 0.8 | | 27103. | 1.000 | 13551. | 491420. | 54348. | 804.7 |
| 17 | 25 | 20635. | | 76.6 | | 27084. | 1.000 | 13542. | 492958. | 53580. | 798.3 |
| 20 | 33 | 27026. | | 14.4 | | 27046. | 1.000 | 13523. | 496131. | 54348. | 819.2 |
| 12 | 27 | 25319. | | 13.3 | | 26996. | 1.000 | 13498. | 500727. | 58680. | 843.2 |
| 3 | 31 | 26861. | | 26.6 | | 26889. | 1.000 | 13445. | 518868. | 54348. | 766.8 |
| 21 | 31 | 26861. | | 27.2 | | 26889. | 1.000 | 13445. | 518868. | 54348. | 766.8 |
| 31 | 34 | 26861. | | 26.6 | | 26889. | 1.000 | 13445. | 518868. | 54348. | 766.8 |
| 20 | 27 | 26676. | | 4.8 | | 26872. | 1.000 | 13436. | 521787. | 54348. | 792.1 |
| 7 | 24 | 26861. | | 1.2 | | 26862. | 1.000 | 13431. | 523582. | 60000. | 840.6 |
| 30 | 31 | 26821. | | 24.8 | | 26850. | 1.000 | 13425. | 525802. | 54348. | 792.1 |
| 15 | 20 | 21992. | | 26.2 | | 26795. | 1.000 | 13398. | 535458. | 54348. | 801.4 |
| 12 | 30 | 25177. | | 10.3 | | 26753. | 1.000 | 13376. | 543158. | 58680. | 843.2 |
| 11 | 43 | 26180. | | 24.9 | | 26738. | 1.000 | 13369. | 545912. | 54348. | 801.4 |
| 27 | 31 | 26681. | | 21.8 | | 26709. | 1.000 | 13355. | 551258. | 54348. | 792.1 |
| 25 | 33 | 26682. | | 27.1 | | 26696. | 1.000 | 13348. | 553668. | 53580. | 816.1 |
| 2 | 19 | 26645. | | 39.7 | | 26662. | 1.000 | 13331. | 560023. | 58680. | 868.4 |
| 19 | 38 | 26645. | | 39.7 | | 26662. | 1.000 | 13331. | 560023. | 58680. | 868.4 |
| 1 | 33 | 25744. | | 14.8 | | 26654. | 1.000 | 13327. | 561655. | 60000. | 889.7 |
| 1 | 5 | 11502. | | 78.2 | | 26550. | 1.000 | 13275. | 581619. | 60000. | 905.8 |
| 13 | 43 | 26180. | | 20.3 | | 26495. | 1.000 | 13248. | 592663. | 54348. | 826.0 |
| 43 | 44 | 26148. | | 23.6 | | 26464. | 1.000 | 13232. | 599029. | 54348. | 817.3 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
*INDIVIDUAL STRESS RANGE CHECK*
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 30 | 21583. | | 28.0 | | 26463. | 1.000 | 13232. | 599165. | 58680. | 822.5 |
| 15 | 25 | 21645. | | 67.8 | | 26444. | 1.000 | 13222. | 603148. | 53580. | 798.3 |
| 11 | 34 | 26168. | | 1.8 | | 26418. | 1.000 | 13209. | 608383. | 54348. | 801.4 |
| 3 | 11 | 26159. | | 1.8 | | 26406. | 1.000 | 13203. | 610902. | 54348. | 801.4 |
| 9 | 23 | 26247. | | 0.2 | | 26328. | 1.000 | 13164. | 627410. | 60000. | 833.8 |
| 28 | 31 | 26306. | | 4.2 | | 26327. | 1.000 | 13163. | 627701. | 53580. | 763.1 |
| 5 | 43 | 25895. | | 54.9 | | 26211. | 1.000 | 13106. | 653074. | 54348. | 827.0 |
| 17 | 23 | 26105. | | 33.1 | | 26185. | 1.000 | 13093. | 658887. | 60000. | 833.8 |
| 13 | 34 | 26168. | | 2.8 | | 26175. | 1.000 | 13088. | 661145. | 54348. | 826.0 |
| 3 | 13 | 26159. | | 2.8 | | 26163. | 1.000 | 13082. | 663907. | 54348. | 826.0 |
| 34 | 44 | 26137. | | 0.5 | | 26144. | 1.000 | 13072. | 668334. | 54348. | 817.3 |
| 3 | 44 | 26128. | | 0.5 | | 26132. | 1.000 | 13066. | 671130. | 54348. | 817.3 |
| 5 | 25 | 21935. | | 36.4 | | 26033. | 1.000 | 13017. | 694402. | 53580. | 823.9 |
| 5 | 34 | 25884. | | 78.0 | | 25891. | 1.000 | 12946. | 729405. | 54348. | 827.0 |
| 3 | 5 | 25875. | | 78.0 | | 25879. | 1.000 | 12940. | 732486. | 54348. | 827.0 |
| 16 | 23 | 23283. | | 14.4 | | 25797. | 1.000 | 12899. | 753773. | 60000. | 833.8 |
| 7 | 27 | 25238. | | 7.0 | | 25752. | 1.000 | 12876. | 765629. | 58680. | 822.5 |
| 20 | 30 | 25623. | | 1.8 | | 25719. | 1.000 | 12859. | 774672. | 54348. | 792.1 |
| 12 | 37 | 24207. | | 7.9 | | 25687. | 1.000 | 12843. | 783405. | 60000. | 888.0 |
| 23 | 35 | 25532. | | 33.1 | | 25613. | 1.000 | 12807. | 803942. | 60000. | 833.8 |
| 5 | 12 | 9038. | | 86.5 | | 25567. | 1.000 | 12783. | 817215. | 60000. | 870.6 |
| 3 | 43 | 25130. | | 23.1 | | 25446. | 1.000 | 12723. | 852773. | 54348. | 766.8 |
| 21 | 43 | 25130. | | 23.6 | | 25446. | 1.000 | 12723. | 852773. | 54348. | 766.8 |
| 34 | 43 | 25130. | | 23.0 | | 25446. | 1.000 | 12723. | 852773. | 54348. | 766.8 |
| 27 | 45 | 25182. | | 5.3 | | 25379. | 1.000 | 12690. | 873244. | 58680. | 836.3 |
| 19 | 27 | 25071. | | 34.3 | | 25268. | 1.000 | 12634. | 908503. | 58680. | 813.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 (1.
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 27 | 24462. | | 8.5 | | 25252. | 1.000 | 12626. | 913613. | 58680. | 841.7 |
| 23 | 39 | 25107. | | 1.4 | | 25188. | 1.000 | 12594. | 934874. | 60000. | 833.8 |
| 1 | 20 | 25126. | | 0.3 | | 25146. | 1.000 | 12573. | 948882. | 54348. | 851.7 |
| 3 | 34 | 25119. | | 0.0 | | 25126. | 1.000 | 12563. | 955635. | 54348. | 766.8 |
| 21 | 34 | 25119. | | 0.5 | | 25126. | 1.000 | 12563. | 955635. | 54348. | 766.8 |
| 3 | 21 | 25110. | | 0.5 | | 25114. | 1.000 | 12557. | 959796. | 54348. | 766.8 |
| 18 | 30 | 24320. | | 5.5 | | 25009. | 1.000 | 12505. | 996650. | 58680. | 841.7 |
| 23 | 45 | 24883. | | 1.4 | | 24963. | 1.000 | 12482. | >1000000. | 60000. | 846.3 |
| 20 | 25 | 24601. | | 41.6 | | 24621. | 1.000 | 12310. | >1000000. | 53580. | 763.1 |
| 40 | 42 | 24388. | | 29.2 | | 24612. | 1.000 | 12306. | >1000000. | 60000. | 846.7 |
| 16 | 24 | 22175. | | 13.5 | | 24609. | 1.000 | 12305. | >1000000. | 60000. | 840.6 |
| 7 | 23 | 24523. | | 0.3 | | 24604. | 1.000 | 12302. | >1000000. | 60000. | 833.8 |
| 7 | 30 | 24186. | | 4.1 | | 24599. | 1.000 | 12300. | >1000000. | 58680. | 822.5 |
| 39 | 42 | 24075. | | 29.2 | | 24300. | 1.000 | 12150. | >1000000. | 60000. | 846.7 |
| 35 | 42 | 17634. | | 63.6 | | 24292. | 1.000 | 12146. | >1000000. | 60000. | 846.7 |
| 30 | 45 | 24139. | | 2.4 | | 24235. | 1.000 | 12118. | >1000000. | 58680. | 836.3 |
| 12 | 19 | 22716. | | 47.6 | | 24214. | 1.000 | 12107. | >1000000. | 58680. | 843.2 |
| 19 | 30 | 24018. | | 37.3 | | 24114. | 1.000 | 12057. | >1000000. | 58680. | 813.2 |
| 18 | 37 | 23350. | | 3.2 | | 23943. | 1.000 | 11972. | >1000000. | 60000. | 880.1 |
| 9 | 27 | 23503. | | 6.5 | | 23914. | 1.000 | 11957. | >1000000. | 58680. | 822.5 |
| 5 | 18 | 8182. | | 81.7 | | 23823. | 1.000 | 11912. | >1000000. | 60000. | 869.1 |
| 17 | 42 | 17061. | | 63.6 | | 23720. | 1.000 | 11860. | >1000000. | 60000. | 846.7 |
| 8 | 23 | 23283. | | 3.1 | | 23681. | 1.000 | 11841. | >1000000. | 60000. | 833.8 |
| 5 | 40 | 8626. | | 78.5 | | 23674. | 1.000 | 11837. | >1000000. | 60000. | 851.3 |
| 41 | 42 | 23398. | | 29.2 | | 23623. | 1.000 | 11811. | >1000000. | 60000. | 846.7 |
| 6 | 42 | 23398. | | 27.8 | | 23622. | 1.000 | 11811. | >1000000. | 60000. | 846.7 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 42 | 23398. | | 27.5 | | 23622. | 1.000 | 11811. | >1000000. | 60000. | 846.7 |
| 10 | 42 | 23398. | | 28.0 | | 23622. | 1.000 | 11811. | >1000000. | 60000. | 846.7 |
| 14 | 42 | 23398. | | 27.8 | | 23622. | 1.000 | 11811. | >1000000. | 60000. | 846.7 |
| 16 | 42 | 23398. | | 16.1 | | 23622. | 1.000 | 11811. | >1000000. | 60000. | 846.7 |
| 6 | 23 | 23283. | | 2.7 | | 23616. | 1.000 | 11808. | >1000000. | 60000. | 833.8 |
| 14 | 23 | 23283. | | 2.7 | | 23607. | 1.000 | 11803. | >1000000. | 60000. | 833.8 |
| 10 | 23 | 23283. | | 2.5 | | 23579. | 1.000 | 11789. | >1000000. | 60000. | 833.8 |
| 2 | 17 | 17119. | | 34.4 | | 23553. | 1.000 | 11777. | >1000000. | 60000. | 875.7 |
| 17 | 36 | 17119. | | 31.3 | | 23553. | 1.000 | 11777. | >1000000. | 60000. | 849.0 |
| 17 | 38 | 17119. | | 34.4 | | 23553. | 1.000 | 11777. | >1000000. | 60000. | 875.7 |
| 33 | 39 | 22569. | | 15.0 | | 23479. | 1.000 | 11740. | >1000000. | 60000. | 845.2 |
| 19 | 37 | 23411. | | 39.7 | | 23428. | 1.000 | 11714. | >1000000. | 58680. | 819.8 |
| 23 | 41 | 23283. | | 1.4 | | 23364. | 1.000 | 11682. | >1000000. | 60000. | 833.8 |
| 5 | 39 | 8313. | | 78.5 | | 23362. | 1.000 | 11681. | >1000000. | 60000. | 851.3 |
| 24 | 37 | 23355. | | 0.5 | | 23356. | 1.000 | 11678. | >1000000. | 60000. | 851.8 |
| 5 | 35 | 1871. | | 113.0 | | 23354. | 1.000 | 11677. | >1000000. | 60000. | 851.3 |
| 23 | 40 | 23146. | | 1.4 | | 23227. | 1.000 | 11613. | >1000000. | 60000. | 833.8 |
| 27 | 33 | 22925. | | 9.7 | | 23122. | 1.000 | 11561. | >1000000. | 58680. | 837.9 |
| 11 | 27 | 22635. | | 6.6 | | 23075. | 1.000 | 11537. | >1000000. | 58680. | 822.5 |
| 20 | 21 | 23025. | | 0.6 | | 23045. | 1.000 | 11522. | >1000000. | 54348. | 766.8 |
| 2 | 35 | 16547. | | 34.4 | | 22981. | 1.000 | 11491. | >1000000. | 60000. | 875.7 |
| 35 | 36 | 16547. | | 31.3 | | 22981. | 1.000 | 11491. | >1000000. | 60000. | 849.0 |
| 35 | 38 | 16547. | | 34.4 | | 22981. | 1.000 | 11491. | >1000000. | 60000. | 875.7 |
| 2 | 15 | 18127. | | 25.7 | | 22911. | 1.000 | 11456. | >1000000. | 60000. | 875.7 |
| 15 | 36 | 18127. | | 22.5 | | 22911. | 1.000 | 11456. | >1000000. | 60000. | 849.0 |
| 15 | 38 | 18127. | | 25.7 | | 22911. | 1.000 | 11456. | >1000000. | 60000. | 875.7 |

Notes
b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 33 | 15555. | | 49.5 | | 22900. | 1.000 | 11450. | >1000000. | 60000. | 845.2 |
| 13 | 27 | 22635. | | 2.0 | | 22832. | 1.000 | 11416. | >1000000. | 58680. | 843.2 |
| 33 | 41 | 21891. | | 15.0 | | 22801. | 1.000 | 11400. | >1000000. | 60000. | 845.2 |
| 6 | 33 | 21891. | | 13.7 | | 22801. | 1.000 | 11400. | >1000000. | 60000. | 845.2 |
| 8 | 33 | 21891. | | 13.3 | | 22801. | 1.000 | 11400. | >1000000. | 60000. | 845.2 |
| 10 | 33 | 21891. | | 13.9 | | 22801. | 1.000 | 11400. | >1000000. | 60000. | 845.2 |
| 14 | 33 | 21891. | | 13.7 | | 22801. | 1.000 | 11400. | >1000000. | 60000. | 845.2 |
| 16 | 33 | 21891. | | 2.0 | | 22801. | 1.000 | 11400. | >1000000. | 60000. | 845.2 |
| 5 | 17 | 1299. | | 113.0 | | 22783. | 1.000 | 11391. | >1000000. | 60000. | 851.3 |
| 9 | 30 | 22450. | | 3.5 | | 22761. | 1.000 | 11381. | >1000000. | 58680. | 822.5 |
| 21 | 25 | 22681. | | 42.2 | | 22695. | 1.000 | 11348. | >1000000. | 53580. | 763.1 |
| 5 | 41 | 7636. | | 78.5 | | 22685. | 1.000 | 11342. | >1000000. | 60000. | 851.3 |
| 5 | 6 | 7636. | | 77.2 | | 22685. | 1.000 | 11342. | >1000000. | 60000. | 851.3 |
| 5 | 8 | 7636. | | 76.8 | | 22685. | 1.000 | 11342. | >1000000. | 60000. | 851.3 |
| 5 | 10 | 7636. | | 77.4 | | 22685. | 1.000 | 11342. | >1000000. | 60000. | 851.3 |
| 5 | 14 | 7636. | | 77.2 | | 22685. | 1.000 | 11342. | >1000000. | 60000. | 851.3 |
| 5 | 16 | 7636. | | 65.5 | | 22685. | 1.000 | 11342. | >1000000. | 60000. | 851.3 |
| 33 | 40 | 21767. | | 15.0 | | 22677. | 1.000 | 11339. | >1000000. | 60000. | 845.2 |
| 20 | 44 | 22548. | | 0.6 | | 22567. | 1.000 | 11284. | >1000000. | 54348. | 817.3 |
| 5 | 27 | 22346. | | 73.2 | | 22543. | 1.000 | 11271. | >1000000. | 58680. | 844.0 |
| 8 | 24 | 22175. | | 2.2 | | 22493. | 1.000 | 11247. | >1000000. | 60000. | 840.6 |
| 27 | 44 | 22291. | | 5.3 | | 22488. | 1.000 | 11244. | >1000000. | 58680. | 836.3 |
| 18 | 19 | 21860. | | 42.9 | | 22470. | 1.000 | 11235. | >1000000. | 58680. | 841.7 |
| 6 | 24 | 22175. | | 1.8 | | 22428. | 1.000 | 11214. | >1000000. | 60000. | 840.6 |
| 14 | 24 | 22175. | | 1.8 | | 22419. | 1.000 | 11210. | >1000000. | 60000. | 840.6 |
| 10 | 24 | 22175. | | 1.6 | | 22391. | 1.000 | 11195. | >1000000. | 60000. | 840.6 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

Structural Integrity Associates, Inc.



++ DST/PIPESTRESS ++   Vermont Yankee   Version 3.5.1+026 PC-EXE   Release: Jun

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 20 | 22281. | | 77.9 | | 22301. | 1.000 | 11150. | >1000000. | 54348. | 827.0 |
| 20 40 | 22243. | | 0.6 | | 22263. | 1.000 | 11132. | >1000000. | 54348. | 801.4 |
| 11 20 | 21992. | | 1.9 | | 22254. | 1.000 | 11127. | >1000000. | 54348. | 801.4 |
| 24 41 | 22175. | | 0.5 | | 22176. | 1.000 | 11088. | >1000000. | 60000. | 840.6 |
| 25 44 | 22161. | | 42.2 | | 22175. | 1.000 | 11088. | >1000000. | 53580. | 814.2 |
| 1 12 | 20527. | | 8.2 | | 22056. | 1.000 | 11028. | >1000000. | 60000. | 903.8 |
| 25 36 | 21427. | | 45.3 | | 22035. | 1.000 | 11017. | >1000000. | 53580. | 821.0 |
| 13 20 | 21992. | | 2.8 | | 22011. | 1.000 | 11006. | >1000000. | 54348. | 826.0 |
| 30 33 | 21873. | | 12.6 | | 21969. | 1.000 | 10984. | >1000000. | 58680. | 837.9 |
| 20 39 | 21947. | | 0.6 | | 21967. | 1.000 | 10983. | >1000000. | 54348. | 793.6 |
| 11 30 | 21583. | | 3.7 | | 21922. | 1.000 | 10961. | >1000000. | 58680. | 822.5 |
| 11 25 | 21645. | | 43.5 | | 21902. | 1.000 | 10951. | >1000000. | 53580. | 798.3 |
| 27 42 | 21615. | | 23.8 | | 21812. | 1.000 | 10906. | >1000000. | 58680. | 839.4 |
| 21 27 | 21600. | | 5.3 | | 21797. | 1.000 | 10898. | >1000000. | 54348. | 792.1 |
| 35 37 | 15300. | | 34.4 | | 21734. | 1.000 | 10867. | >1000000. | 60000. | 833.7 |
| 13 30 | 21583. | | 1.0 | | 21679. | 1.000 | 10840. | >1000000. | 58680. | 843.2 |
| 13 25 | 21645. | | 38.8 | | 21660. | 1.000 | 10830. | >1000000. | 53580. | 822.9 |
| 30 42 | 21473. | | 26.8 | | 21569. | 1.000 | 10784. | >1000000. | 58680. | 839.4 |
| 12 33 | 19125. | | 23.0 | | 21514. | 1.000 | 10757. | >1000000. | 60000. | 864.5 |
| 33 35 | 14141. | | 49.5 | | 21486. | 1.000 | 10743. | >1000000. | 60000. | 845.2 |
| 2 25 | 21427. | | 42.2 | | 21442. | 1.000 | 10721. | >1000000. | 53580. | 849.3 |
| 25 38 | 21427. | | 42.2 | | 21442. | 1.000 | 10721. | >1000000. | 53580. | 849.3 |
| 5 30 | 21294. | | 76.1 | | 21390. | 1.000 | 10695. | >1000000. | 58680. | 844.0 |
| 9 20 | 21124. | | 1.7 | | 21358. | 1.000 | 10679. | >1000000. | 54348. | 801.4 |
| 30 44 | 21261. | | 2.4 | | 21358. | 1.000 | 10679. | >1000000. | 58680. | 836.3 |
| 20 41 | 21254. | | 0.6 | | 21274. | 1.000 | 10637. | >1000000. | 54348. | 801.4 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 20 | 21254. | | 0.8 | | 21274. | 1.000 | 10637. | >1000000. | 54348. | 801.4 |
| 8 20 | 21254. | | 1.1 | | 21274. | 1.000 | 10637. | >1000000. | 54348. | 801.4 |
| 10 20 | 21254. | | 0.6 | | 21274. | 1.000 | 10637. | >1000000. | 54348. | 801.4 |
| 14 20 | 21254. | | 0.7 | | 21274. | 1.000 | 10637. | >1000000. | 54348. | 801.4 |
| 16 20 | 21254. | | 12.5 | | 21274. | 1.000 | 10637. | >1000000. | 54348. | 801.4 |
| 24 40 | 21195. | | 0.5 | | 21197. | 1.000 | 10598. | >1000000. | 60000. | 840.6 |
| 15 42 | 16052. | | 54.8 | | 21060. | 1.000 | 10530. | >1000000. | 60000. | 846.7 |
| 9 25 | 20777. | | 43.3 | | 21006. | 1.000 | 10503. | >1000000. | 53580. | 798.3 |
| 21 30 | 20547. | | 2.4 | | 20643. | 1.000 | 10321. | >1000000. | 54348. | 792.1 |
| 12 16 | 16674. | | 21.0 | | 20587. | 1.000 | 10294. | >1000000. | 60000. | 850.5 |
| 5 42 | 15762. | | 49.4 | | 20384. | 1.000 | 10192. | >1000000. | 60000. | 866.8 |
| 17 37 | 13885. | | 34.4 | | 20319. | 1.000 | 10160. | >1000000. | 60000. | 833.7 |
| 1 18 | 19670. | | 3.4 | | 20313. | 1.000 | 10156. | >1000000. | 60000. | 899.7 |
| 19 35 | 13795. | | 74.1 | | 20247. | 1.000 | 10124. | >1000000. | 58680. | 822.5 |
| 15 33 | 14547. | | 40.7 | | 20241. | 1.000 | 10121. | >1000000. | 60000. | 845.2 |
| 5 15 | 289. | | 104.2 | | 20122. | 1.000 | 10061. | >1000000. | 60000. | 851.3 |
| 20 45 | 19910. | | 0.6 | | 19930. | 1.000 | 9965. | >1000000. | 54348. | 817.3 |
| 5 33 | 14258. | | 63.5 | | 19800. | 1.000 | 9900. | >1000000. | 60000. | 865.3 |
| 18 33 | 18268. | | 18.2 | | 19771. | 1.000 | 9885. | >1000000. | 60000. | 863.0 |
| 1 19 | 19731. | | 39.4 | | 19748. | 1.000 | 9874. | >1000000. | 58680. | 868.4 |
| 21 36 | 19151. | | 3.2 | | 19744. | 1.000 | 9872. | >1000000. | 54348. | 824.1 |
| 7 20 | 19391. | | 2.3 | | 19728. | 1.000 | 9864. | >1000000. | 54348. | 801.4 |
| 1 24 | 19674. | | 0.7 | | 19726. | 1.000 | 9863. | >1000000. | 60000. | 885.1 |
| 15 37 | 14893. | | 25.7 | | 19677. | 1.000 | 9839. | >1000000. | 60000. | 833.7 |
| 19 20 | 19553. | | 39.1 | | 19573. | 1.000 | 9786. | >1000000. | 54348. | 792.1 |
| 27 30 | 19370. | | 3.0 | | 19567. | 1.000 | 9784. | >1000000. | 58680. | 813.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 23 | 19336. | | 1.4 | | 19416. | 1.000 | 9708. | >1000000. | 60000. | 878.3 |
| 23 | 24 | 19336. | | 0.9 | | 19416. | 1.000 | 9708. | >1000000. | 60000. | 843.2 |
| 23 | 36 | 19336. | | 1.8 | | 19416. | 1.000 | 9708. | >1000000. | 60000. | 851.6 |
| 23 | 38 | 19336. | | 1.4 | | 19416. | 1.000 | 9708. | >1000000. | 60000. | 878.3 |
| 7 | 25 | 19041. | | 43.9 | | 19373. | 1.000 | 9686. | >1000000. | 53580. | 798.3 |
| 13 | 36 | 18127. | | 6.5 | | 19339. | 1.000 | 9670. | >1000000. | 60000. | 868.4 |
| 25 | 45 | 19292. | | 42.2 | | 19306. | 1.000 | 9653. | >1000000. | 53580. | 814.2 |
| 36 | 44 | 18638. | | 3.2 | | 19231. | 1.000 | 9616. | >1000000. | 60000. | 861.5 |
| 19 | 25 | 19209. | | 2.5 | | 19227. | 1.000 | 9613. | >1000000. | 53580. | 788.7 |
| 7 | 42 | 18656. | | 30.9 | | 19197. | 1.000 | 9599. | >1000000. | 60000. | 846.7 |
| 2 | 21 | 19151. | | 0.0 | | 19151. | 1.000 | 9576. | >1000000. | 54348. | 851.7 |
| 21 | 38 | 19151. | | 0.0 | | 19151. | 1.000 | 9576. | >1000000. | 54348. | 851.7 |
| 12 | 40 | 17663. | | 7.9 | | 19143. | 1.000 | 9572. | >1000000. | 60000. | 850.5 |
| 19 | 42 | 19013. | | 10.5 | | 19030. | 1.000 | 9515. | >1000000. | 58680. | 839.4 |
| 16 | 18 | 15818. | | 16.2 | | 18843. | 1.000 | 9422. | >1000000. | 60000. | 849.0 |
| 17 | 19 | 12380. | | 74.1 | | 18832. | 1.000 | 9416. | >1000000. | 58680. | 822.5 |
| 12 | 39 | 17350. | | 7.9 | | 18830. | 1.000 | 9415. | >1000000. | 60000. | 850.5 |
| 42 | 45 | 18564. | | 29.2 | | 18789. | 1.000 | 9394. | >1000000. | 60000. | 859.2 |
| 2 | 13 | 18127. | | 3.3 | | 18746. | 1.000 | 9373. | >1000000. | 60000. | 903.8 |
| 13 | 38 | 18127. | | 3.3 | | 18746. | 1.000 | 9373. | >1000000. | 60000. | 903.8 |
| 11 | 36 | 18127. | | 1.9 | | 18720. | 1.000 | 9360. | >1000000. | 60000. | 849.0 |
| 2 | 44 | 18638. | | 0.0 | | 18638. | 1.000 | 9319. | >1000000. | 60000. | 888.2 |
| 38 | 44 | 18638. | | 0.0 | | 18638. | 1.000 | 9319. | >1000000. | 60000. | 888.2 |
| 8 | 12 | 16674. | | 9.6 | | 18471. | 1.000 | 9235. | >1000000. | 60000. | 850.5 |
| 19 | 33 | 18426. | | 24.7 | | 18443. | 1.000 | 9222. | >1000000. | 58680. | 837.9 |
| 6 | 12 | 16674. | | 9.3 | | 18406. | 1.000 | 9203. | >1000000. | 60000. | 850.5 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 14 | 16674. | | 9.2 | | 18397. | 1.000 | 9198. | >1000000. | 60000. | 850.5 |
| 7 | 33 | 17149. | | 16.7 | | 18376. | 1.000 | 9188. | >1000000. | 60000. | 845.2 |
| 2 | 11 | 18127. | | 1.3 | | 18370. | 1.000 | 9185. | >1000000. | 60000. | 875.7 |
| 11 | 38 | 18127. | | 1.3 | | 18370. | 1.000 | 9185. | >1000000. | 60000. | 875.7 |
| 10 | 12 | 16674. | | 9.1 | | 18368. | 1.000 | 9184. | >1000000. | 60000. | 850.5 |
| 5 | 7 | 2894. | | 80.2 | | 18259. | 1.000 | 9130. | >1000000. | 60000. | 851.3 |
| 15 | 19 | 13390. | | 65.3 | | 18192. | 1.000 | 9096. | >1000000. | 58680. | 822.5 |
| 12 | 41 | 16674. | | 7.9 | | 18154. | 1.000 | 9077. | >1000000. | 60000. | 850.5 |
| 1 | 35 | 11620. | | 34.7 | | 18104. | 1.000 | 9052. | >1000000. | 60000. | 875.7 |
| 33 | 45 | 17108. | | 15.0 | | 18018. | 1.000 | 9009. | >1000000. | 60000. | 857.7 |
| 5 | 45 | 2922. | | 78.5 | | 17971. | 1.000 | 8985. | >1000000. | 60000. | 863.8 |
| 9 | 36 | 17262. | | 2.0 | | 17855. | 1.000 | 8927. | >1000000. | 60000. | 849.0 |
| 5 | 19 | 13679. | | 38.8 | | 17777. | 1.000 | 8888. | >1000000. | 58680. | 844.0 |
| 2 | 9 | 17262. | | 1.2 | | 17476. | 1.000 | 8738. | >1000000. | 60000. | 875.7 |
| 9 | 38 | 17262. | | 1.2 | | 17476. | 1.000 | 8738. | >1000000. | 60000. | 875.7 |
| 18 | 40 | 16807. | | 3.2 | | 17400. | 1.000 | 8700. | >1000000. | 60000. | 849.0 |
| 9 | 42 | 16920. | | 30.3 | | 17359. | 1.000 | 8679. | >1000000. | 60000. | 846.7 |
| 12 | 35 | 10909. | | 26.5 | | 17343. | 1.000 | 8672. | >1000000. | 60000. | 850.5 |
| 18 | 39 | 16494. | | 3.2 | | 17087. | 1.000 | 8543. | >1000000. | 60000. | 849.0 |
| 19 | 40 | 16851. | | 39.7 | | 16868. | 1.000 | 8434. | >1000000. | 58680. | 822.5 |
| 12 | 17 | 10337. | | 26.5 | | 16772. | 1.000 | 8386. | >1000000. | 60000. | 850.5 |
| 8 | 18 | 15818. | | 4.9 | | 16727. | 1.000 | 8364. | >1000000. | 60000. | 849.0 |
| 1 | 17 | 10205. | | 34.7 | | 16689. | 1.000 | 8344. | >1000000. | 60000. | 875.7 |
| 6 | 18 | 15818. | | 4.5 | | 16662. | 1.000 | 8331. | >1000000. | 60000. | 849.0 |
| 14 | 18 | 15818. | | 4.5 | | 16653. | 1.000 | 8327. | >1000000. | 60000. | 849.0 |
| 10 | 18 | 15818. | | 4.3 | | 16625. | 1.000 | 8312. | >1000000. | 60000. | 849.0 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

**Structural Integrity** Associates, Inc.





CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 35 | 7752. | | 47.5 | | 16619. | 1.000 | 8309. | >1000000. | 60000. | 831.2 |
| 25 | 39 | 16565. | | 42.2 | | 16580. | 1.000 | 8290. | >1000000. | 53580. | 787.5 |
| 33 | 42 | 16341. | | 14.1 | | 16565. | 1.000 | 8283. | >1000000. | 60000. | 860.7 |
| 19 | 39 | 16541. | | 39.7 | | 16559. | 1.000 | 8280. | >1000000. | 58680. | 822.5 |
| 36 | 39 | 15947. | | 3.2 | | 16540. | 1.000 | 8270. | >1000000. | 60000. | 849.0 |
| 9 | 33 | 15414. | | 16.2 | | 16539. | 1.000 | 8269. | >1000000. | 60000. | 845.2 |
| 11 | 42 | 16052. | | 30.5 | | 16519. | 1.000 | 8259. | >1000000. | 60000. | 846.7 |
| 18 | 35 | 10053. | | 31.3 | | 16487. | 1.000 | 8244. | >1000000. | 60000. | 849.0 |
| 5 | 9 | 1158. | | 79.7 | | 16421. | 1.000 | 8210. | >1000000. | 60000. | 851.3 |
| 18 | 41 | 15818. | | 3.2 | | 16410. | 1.000 | 8205. | >1000000. | 60000. | 849.0 |
| 36 | 45 | 15775. | | 3.2 | | 16368. | 1.000 | 8184. | >1000000. | 60000. | 861.5 |
| 13 | 42 | 16052. | | 25.8 | | 16276. | 1.000 | 8138. | >1000000. | 60000. | 866.1 |
| 7 | 36 | 15533. | | 1.5 | | 16126. | 1.000 | 8063. | >1000000. | 60000. | 849.0 |
| 1 | 15 | 11213. | | 25.9 | | 16047. | 1.000 | 8023. | >1000000. | 60000. | 875.7 |
| 5 | 44 | 964. | | 78.5 | | 16013. | 1.000 | 8007. | >1000000. | 60000. | 863.8 |
| 2 | 39 | 15947. | | 0.0 | | 15947. | 1.000 | 7974. | >1000000. | 60000. | 875.7 |
| 38 | 39 | 15947. | | 0.0 | | 15947. | 1.000 | 7974. | >1000000. | 60000. | 875.7 |
| 21 | 37 | 15918. | | 0.0 | | 15918. | 1.000 | 7959. | >1000000. | 54348. | 788.7 |
| 17 | 18 | 9481. | | 31.3 | | 15915. | 1.000 | 7958. | >1000000. | 60000. | 849.0 |
| 42 | 44 | 15657. | | 29.2 | | 15881. | 1.000 | 7940. | >1000000. | 60000. | 859.2 |
| 19 | 41 | 15861. | | 39.7 | | 15879. | 1.000 | 7940. | >1000000. | 58680. | 822.5 |
| 6 | 19 | 15861. | | 38.3 | | 15879. | 1.000 | 7939. | >1000000. | 58680. | 822.5 |
| 8 | 19 | 15861. | | 38.0 | | 15879. | 1.000 | 7939. | >1000000. | 58680. | 822.5 |
| 10 | 19 | 15861. | | 38.5 | | 15879. | 1.000 | 7939. | >1000000. | 58680. | 822.5 |
| 14 | 19 | 15861. | | 38.4 | | 15879. | 1.000 | 7939. | >1000000. | 58680. | 822.5 |
| 16 | 19 | 15861. | | 26.6 | | 15879. | 1.000 | 7939. | >1000000. | 58680. | 822.5 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW.   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 7 | 15533. | | 1.7 | | 15850. | 1.000 | 7925. | >1000000. | 60000. | 875.7 |
| 7 38 | 15533. | | 1.7 | | 15850. | 1.000 | 7925. | >1000000. | 60000. | 875.7 |
| 12 42 | 14132. | | 37.1 | | 15836. | 1.000 | 7918. | >1000000. | 60000. | 866.1 |
| 5 21 | 765. | | 78.5 | | 15814. | 1.000 | 7907. | >1000000. | 54348. | 827.0 |
| 2 45 | 15775. | | 0.0 | | 15775. | 1.000 | 7888. | >1000000. | 60000. | 888.2 |
| 38 45 | 15775. | | 0.0 | | 15775. | 1.000 | 7888. | >1000000. | 60000. | 888.2 |
| 11 33 | 14547. | | 16.3 | | 15700. | 1.000 | 7850. | >1000000. | 60000. | 845.2 |
| 5 11 | 289. | | 79.8 | | 15581. | 1.000 | 7790. | >1000000. | 60000. | 851.3 |
| 13 37 | 14893. | | 3.3 | | 15512. | 1.000 | 7756. | >1000000. | 60000. | 888.0 |
| 13 33 | 14547. | | 11.7 | | 15457. | 1.000 | 7729. | >1000000. | 60000. | 864.5 |
| 37 44 | 15404. | | 0.0 | | 15404. | 1.000 | 7702. | >1000000. | 60000. | 857.6 |
| 25 37 | 15333. | | 42.2 | | 15347. | 1.000 | 7673. | >1000000. | 53580. | 784.2 |
| 5 13 | 289. | | 75.2 | | 15338. | 1.000 | 7669. | >1000000. | 60000. | 870.6 |
| 21 42 | 15018. | | 29.2 | | 15242. | 1.000 | 7621. | >1000000. | 54348. | 821.2 |
| 16 17 | 6337. | | 47.5 | | 15204. | 1.000 | 7602. | >1000000. | 60000. | 831.2 |
| 33 44 | 14277. | | 15.0 | | 15187. | 1.000 | 7594. | >1000000. | 60000. | 857.7 |
| 11 37 | 14893. | | 1.3 | | 15136. | 1.000 | 7568. | >1000000. | 60000. | 833.7 |
| 35 39 | 8429. | | 34.4 | | 14863. | 1.000 | 7431. | >1000000. | 60000. | 831.2 |
| 15 16 | 7347. | | 38.7 | | 14564. | 1.000 | 7282. | >1000000. | 60000. | 831.2 |
| 8 35 | 7752. | | 36.1 | | 14503. | 1.000 | 7251. | >1000000. | 60000. | 831.2 |
| 19 21 | 14425. | | 39.7 | | 14443. | 1.000 | 7221. | >1000000. | 54348. | 792.1 |
| 6 35 | 7752. | | 35.8 | | 14438. | 1.000 | 7219. | >1000000. | 60000. | 831.2 |
| 25 40 | 14423. | | 42.2 | | 14437. | 1.000 | 7218. | >1000000. | 53580. | 798.3 |
| 14 35 | 7752. | | 35.8 | | 14429. | 1.000 | 7214. | >1000000. | 60000. | 831.2 |
| 21 33 | 13510. | | 15.0 | | 14420. | 1.000 | 7210. | >1000000. | 54348. | 819.2 |
| 10 35 | 7752. | | 35.6 | | 14400. | 1.000 | 7200. | >1000000. | 60000. | 831.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 41 | 14299. | | 42.2 | | 14314. | 1.000 | 7157. | >1000000. | 53580. | 798.3 |
| 6 | 25 | 14299. | | 40.8 | | 14314. | 1.000 | 7157. | >1000000. | 53580. | 798.3 |
| 8 | 25 | 14299. | | 40.5 | | 14314. | 1.000 | 7157. | >1000000. | 53580. | 798.3 |
| 10 | 25 | 14299. | | 41.0 | | 14314. | 1.000 | 7157. | >1000000. | 53580. | 798.3 |
| 14 | 25 | 14299. | | 40.8 | | 14314. | 1.000 | 7157. | >1000000. | 53580. | 798.3 |
| 16 | 25 | 14299. | | 29.1 | | 14314. | 1.000 | 7157. | >1000000. | 53580. | 798.3 |
| 9 | 37 | 14028. | | 1.2 | | 14242. | 1.000 | 7121. | >1000000. | 60000. | 833.7 |
| 35 | 41 | 7752. | | 34.4 | | 14186. | 1.000 | 7093. | >1000000. | 60000. | 831.2 |
| 12 | 15 | 9327. | | 17.7 | | 14111. | 1.000 | 7056. | >1000000. | 60000. | 850.5 |
| 18 | 42 | 13275. | | 32.3 | | 14092. | 1.000 | 7046. | >1000000. | 60000. | 864.5 |
| 35 | 40 | 7628. | | 34.4 | | 14063. | 1.000 | 7031. | >1000000. | 60000. | 831.2 |
| 19 | 44 | 13999. | | 39.7 | | 14017. | 1.000 | 7008. | >1000000. | 58680. | 836.3 |
| 16 | 36 | 10847. | | 16.2 | | 13873. | 1.000 | 6936. | >1000000. | 60000. | 849.0 |
| 17 | 40 | 7326. | | 34.4 | | 13761. | 1.000 | 6880. | >1000000. | 60000. | 831.2 |
| 11 | 19 | 13390. | | 41.0 | | 13651. | 1.000 | 6825. | >1000000. | 58680. | 822.5 |
| 17 | 39 | 7014. | | 34.4 | | 13448. | 1.000 | 6724. | >1000000. | 60000. | 831.2 |
| 7 | 12 | 11932. | | 6.2 | | 13411. | 1.000 | 6706. | >1000000. | 60000. | 850.5 |
| 13 | 19 | 13390. | | 36.3 | | 13408. | 1.000 | 6704. | >1000000. | 58680. | 843.2 |
| 12 | 45 | 11813. | | 7.9 | | 13293. | 1.000 | 6647. | >1000000. | 60000. | 863.0 |
| 2 | 16 | 10847. | | 13.1 | | 13280. | 1.000 | 6640. | >1000000. | 60000. | 875.7 |
| 16 | 38 | 10847. | | 13.1 | | 13280. | 1.000 | 6640. | >1000000. | 60000. | 875.7 |
| 15 | 18 | 8471. | | 22.5 | | 13255. | 1.000 | 6627. | >1000000. | 60000. | 849.0 |
| 15 | 40 | 8336. | | 25.7 | | 13120. | 1.000 | 6560. | >1000000. | 60000. | 831.2 |
| 1 | 25 | 13083. | | 41.9 | | 13097. | 1.000 | 6549. | >1000000. | 53580. | 849.3 |
| 8 | 17 | 6337. | | 36.2 | | 13088. | 1.000 | 6544. | >1000000. | 60000. | 831.2 |
| 6 | 17 | 6337. | | 35.8 | | 13023. | 1.000 | 6511. | >1000000. | 60000. | 831.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

Structural Integrity Associates, Inc.



CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 (1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 17 | 6337. | | 35.8 | | 13014. | 1.000 | 6507. | >1000000. | 60000. | 831.2 |
| 10 17 | 6337. | | 35.6 | | 12986. | 1.000 | 6493. | >1000000. | 60000. | 831.2 |
| 15 39 | 8023. | | 25.7 | | 12807. | 1.000 | 6404. | >1000000. | 60000. | 831.2 |
| 17 41 | 6337. | | 34.4 | | 12771. | 1.000 | 6386. | >1000000. | 60000. | 831.2 |
| 9 19 | 12522. | | 40.8 | | 12755. | 1.000 | 6377. | >1000000. | 58680. | 822.5 |
| 36 37 | 12027. | | 3.2 | | 12620. | 1.000 | 6310. | >1000000. | 60000. | 880.1 |
| 7 37 | 12299. | | 1.7 | | 12616. | 1.000 | 6308. | >1000000. | 60000. | 833.7 |
| 37 45 | 12541. | | 0.0 | | 12541. | 1.000 | 6271. | >1000000. | 60000. | 857.6 |
| 8 15 | 7347. | | 27.4 | | 12448. | 1.000 | 6224. | >1000000. | 60000. | 831.2 |
| 6 15 | 7347. | | 27.0 | | 12382. | 1.000 | 6191. | >1000000. | 60000. | 831.2 |
| 14 15 | 7347. | | 27.0 | | 12373. | 1.000 | 6187. | >1000000. | 60000. | 831.2 |
| 10 15 | 7347. | | 26.8 | | 12345. | 1.000 | 6173. | >1000000. | 60000. | 831.2 |
| 1 21 | 12237. | | 0.3 | | 12287. | 1.000 | 6144. | >1000000. | 54348. | 851.7 |
| 15 41 | 7347. | | 25.7 | | 12131. | 1.000 | 6065. | >1000000. | 60000. | 831.2 |
| 19 45 | 12049. | | 39.7 | | 12066. | 1.000 | 6033. | >1000000. | 58680. | 836.3 |
| 2 37 | 12027. | | 0.0 | | 12027. | 1.000 | 6013. | >1000000. | 60000. | 970.1 |
| 37 38 | 12027. | | 0.0 | | 12027. | 1.000 | 6013. | >1000000. | 60000. | 970.1 |
| 1 13 | 11213. | | 3.1 | | 11832. | 1.000 | 5916. | >1000000. | 60000. | 903.8 |
| 1 44 | 11724. | | 0.3 | | 11774. | 1.000 | 5887. | >1000000. | 60000. | 888.2 |
| 8 36 | 10847. | | 4.9 | | 11757. | 1.000 | 5878. | >1000000. | 60000. | 849.0 |
| 6 36 | 10847. | | 4.5 | | 11691. | 1.000 | 5846. | >1000000. | 60000. | 849.0 |
| 14 36 | 10847. | | 4.5 | | 11682. | 1.000 | 5841. | >1000000. | 60000. | 849.0 |
| 9 12 | 10196. | | 6.8 | | 11676. | 1.000 | 5838. | >1000000. | 60000. | 850.5 |
| 7 18 | 11075. | | 1.5 | | 11668. | 1.000 | 5834. | >1000000. | 60000. | 849.0 |
| 10 36 | 10847. | | 4.3 | | 11654. | 1.000 | 5827. | >1000000. | 60000. | 849.0 |
| 18 45 | 10961. | | 3.2 | | 11553. | 1.000 | 5777. | >1000000. | 60000. | 861.5 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

**Structural Integrity Associates, Inc.**



CALCULATION NUMBER 2        CODE SECTION III CLASS 1  ASME-1998        KRE        2007/07/11  11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW        155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 11 | 11213. | | 1.6 | | 11506. | 1.000 | 5753. | >1000000. | 60000. | 875.7 |
| 7 | 19 | 11134. | | 41.4 | | 11469. | 1.000 | 5734. | >1000000. | 58680. | 822.5 |
| 36 | 41 | 10847. | | 3.2 | | 11440. | 1.000 | 5720. | >1000000. | 60000. | 849.0 |
| 12 | 13 | 9327. | | 11.3 | | 11426. | 1.000 | 5713. | >1000000. | 60000. | 869.9 |
| 2 | 24 | 11328. | | 0.5 | | 11330. | 1.000 | 5665. | >1000000. | 60000. | 885.1 |
| 24 | 36 | 11328. | | 2.7 | | 11330. | 1.000 | 5665. | >1000000. | 60000. | 858.4 |
| 24 | 38 | 11328. | | 0.5 | | 11330. | 1.000 | 5665. | >1000000. | 60000. | 885.1 |
| 2 | 8 | 10847. | | 1.7 | | 11164. | 1.000 | 5582. | >1000000. | 60000. | 875.7 |
| 8 | 38 | 10847. | | 1.7 | | 11164. | 1.000 | 5582. | >1000000. | 60000. | 875.7 |
| 2 | 6 | 10847. | | 1.4 | | 11098. | 1.000 | 5549. | >1000000. | 60000. | 875.7 |
| 6 | 38 | 10847. | | 1.4 | | 11098. | 1.000 | 5549. | >1000000. | 60000. | 875.7 |
| 2 | 14 | 10847. | | 1.3 | | 11090. | 1.000 | 5545. | >1000000. | 60000. | 875.7 |
| 14 | 38 | 10847. | | 1.3 | | 11090. | 1.000 | 5545. | >1000000. | 60000. | 875.7 |
| 2 | 10 | 10847. | | 1.2 | | 11061. | 1.000 | 5531. | >1000000. | 60000. | 875.7 |
| 10 | 38 | 10847. | | 1.2 | | 11061. | 1.000 | 5531. | >1000000. | 60000. | 875.7 |
| 2 | 41 | 10847. | | 0.0 | | 10847. | 1.000 | 5423. | >1000000. | 60000. | 875.7 |
| 38 | 41 | 10847. | | 0.0 | | 10847. | 1.000 | 5423. | >1000000. | 60000. | 875.7 |
| 16 | 21 | 8383. | | 13.1 | | 10816. | 1.000 | 5408. | >1000000. | 54348. | 801.4 |
| 11 | 12 | 9327. | | 6.6 | | 10807. | 1.000 | 5404. | >1000000. | 60000. | 850.5 |
| 1 | 9 | 10348. | | 1.4 | | 10612. | 1.000 | 5306. | >1000000. | 60000. | 875.7 |
| 36 | 40 | 9867. | | 3.2 | | 10460. | 1.000 | 5230. | >1000000. | 60000. | 849.0 |
| 12 | 44 | 8904. | | 7.9 | | 10384. | 1.000 | 5192. | >1000000. | 60000. | 863.0 |
| 16 | 44 | 7878. | | 13.1 | | 10311. | 1.000 | 5156. | >1000000. | 60000. | 843.7 |
| 16 | 37 | 7613. | | 13.1 | | 10046. | 1.000 | 5023. | >1000000. | 60000. | 833.7 |
| 11 | 16 | 7347. | | 14.4 | | 10023. | 1.000 | 5011. | >1000000. | 60000. | 831.2 |
| 9 | 18 | 9339. | | 2.0 | | 9932. | 1.000 | 4966. | >1000000. | 60000. | 849.0 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 40 | 9867. | | 0.0 | | 9867. | 1.000 | 4934. | >1000000. | 60000. | 875.7 |
| 38 40 | 9867. | | 0.0 | | 9867. | 1.000 | 4934. | >1000000. | 60000. | 875.7 |
| 13 16 | 7347. | | 9.7 | | 9780. | 1.000 | 4890. | >1000000. | 60000. | 850.5 |
| 12 21 | 8294. | | 7.9 | | 9774. | 1.000 | 4887. | >1000000. | 54348. | 826.0 |
| 13 18 | 8471. | | 6.5 | | 9683. | 1.000 | 4841. | >1000000. | 60000. | 868.4 |
| 35 45 | 3119. | | 34.4 | | 9554. | 1.000 | 4777. | >1000000. | 60000. | 843.7 |
| 7 35 | 3009. | | 32.7 | | 9443. | 1.000 | 4722. | >1000000. | 60000. | 831.2 |
| 21 40 | 9372. | | 0.0 | | 9373. | 1.000 | 4686. | >1000000. | 54348. | 801.4 |
| 9 16 | 6478. | | 14.2 | | 9126. | 1.000 | 4563. | >1000000. | 60000. | 831.2 |
| 11 18 | 8471. | | 1.9 | | 9064. | 1.000 | 4532. | >1000000. | 60000. | 849.0 |
| 21 39 | 9063. | | 0.0 | | 9063. | 1.000 | 4531. | >1000000. | 54348. | 793.6 |
| 21 35 | 2626. | | 34.4 | | 9060. | 1.000 | 4530. | >1000000. | 54348. | 801.4 |
| 1 36 | 8346. | | 3.4 | | 8989. | 1.000 | 4494. | >1000000. | 60000. | 899.7 |
| 1 7 | 8619. | | 2.0 | | 8985. | 1.000 | 4493. | >1000000. | 60000. | 875.7 |
| 13 40 | 8336. | | 3.3 | | 8955. | 1.000 | 4478. | >1000000. | 60000. | 850.5 |
| 1 45 | 8861. | | 0.3 | | 8911. | 1.000 | 4455. | >1000000. | 60000. | 888.2 |
| 40 44 | 8864. | | 0.0 | | 8865. | 1.000 | 4432. | >1000000. | 60000. | 843.7 |
| 35 44 | 2416. | | 34.4 | | 8850. | 1.000 | 4425. | >1000000. | 60000. | 843.7 |
| 8 21 | 8383. | | 1.7 | | 8700. | 1.000 | 4350. | >1000000. | 54348. | 801.4 |
| 18 44 | 8053. | | 3.2 | | 8646. | 1.000 | 4323. | >1000000. | 60000. | 861.5 |
| 13 39 | 8023. | | 3.3 | | 8643. | 1.000 | 4321. | >1000000. | 60000. | 850.5 |
| 13 35 | 1582. | | 37.8 | | 8635. | 1.000 | 4318. | >1000000. | 60000. | 850.5 |
| 6 21 | 8383. | | 1.4 | | 8635. | 1.000 | 4317. | >1000000. | 54348. | 801.4 |
| 14 21 | 8383. | | 1.3 | | 8626. | 1.000 | 4313. | >1000000. | 54348. | 801.4 |
| 10 21 | 8383. | | 1.2 | | 8598. | 1.000 | 4299. | >1000000. | 54348. | 801.4 |
| 11 40 | 8336. | | 1.3 | | 8579. | 1.000 | 4289. | >1000000. | 60000. | 831.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 39 44 | 8578. | | 0.0 | | 8579. | 1.000 | 4289. | >1000000. | 60000. | 843.7 |
| 17 21 | 2051. | | 34.4 | | 8485. | 1.000 | 4243. | >1000000. | 54348. | 801.4 |
| 1 2 | 8346. | | 0.3 | | 8396. | 1.000 | 4198. | >1000000. | 60000. | 970.1 |
| 1 38 | 8346. | | 0.3 | | 8396. | 1.000 | 4198. | >1000000. | 60000. | 970.1 |
| 21 41 | 8383. | | 0.0 | | 8383. | 1.000 | 4192. | >1000000. | 54348. | 801.4 |
| 11 39 | 8023. | | 1.3 | | 8266. | 1.000 | 4133. | >1000000. | 60000. | 831.2 |
| 17 45 | 1772. | | 34.4 | | 8206. | 1.000 | 4103. | >1000000. | 60000. | 843.7 |
| 8 44 | 7878. | | 1.7 | | 8195. | 1.000 | 4098. | >1000000. | 60000. | 843.7 |
| 17 44 | 1760. | | 34.4 | | 8194. | 1.000 | 4097. | >1000000. | 60000. | 843.7 |
| 6 44 | 7878. | | 1.4 | | 8130. | 1.000 | 4065. | >1000000. | 60000. | 843.7 |
| 14 44 | 7878. | | 1.3 | | 8121. | 1.000 | 4060. | >1000000. | 60000. | 843.7 |
| 10 44 | 7878. | | 1.2 | | 8093. | 1.000 | 4046. | >1000000. | 60000. | 843.7 |
| 13 17 | 1010. | | 37.8 | | 8064. | 1.000 | 4032. | >1000000. | 60000. | 850.5 |
| 18 21 | 7438. | | 3.2 | | 8031. | 1.000 | 4015. | >1000000. | 54348. | 824.1 |
| 7 17 | 1594. | | 32.7 | | 8029. | 1.000 | 4014. | >1000000. | 60000. | 831.2 |
| 11 35 | 1582. | | 33.1 | | 8016. | 1.000 | 4008. | >1000000. | 60000. | 831.2 |
| 15 35 | 1582. | | 8.8 | | 8016. | 1.000 | 4008. | >1000000. | 60000. | 831.2 |
| 13 41 | 7347. | | 3.3 | | 7966. | 1.000 | 3983. | >1000000. | 60000. | 850.5 |
| 6 13 | 7347. | | 2.0 | | 7966. | 1.000 | 3983. | >1000000. | 60000. | 850.5 |
| 8 13 | 7347. | | 1.6 | | 7966. | 1.000 | 3983. | >1000000. | 60000. | 850.5 |
| 10 13 | 7347. | | 2.2 | | 7966. | 1.000 | 3983. | >1000000. | 60000. | 850.5 |
| 13 14 | 7347. | | 2.0 | | 7966. | 1.000 | 3983. | >1000000. | 60000. | 850.5 |
| 8 37 | 7613. | | 1.7 | | 7930. | 1.000 | 3965. | >1000000. | 60000. | 833.7 |
| 8 11 | 7347. | | 3.0 | | 7906. | 1.000 | 3953. | >1000000. | 60000. | 831.2 |
| 41 44 | 7878. | | 0.0 | | 7878. | 1.000 | 3939. | >1000000. | 60000. | 843.7 |
| 6 37 | 7613. | | 1.4 | | 7865. | 1.000 | 3932. | >1000000. | 60000. | 833.7 |

Notes
b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 37 | 7613. | | 1.3 | | 7856. | 1.000 | 3928. | >1000000. | 60000. | 833.7 |
| 17 | 35 | 1415. | | 0.0 | | 7850. | 1.000 | 3925. | >1000000. | 60000. | 831.2 |
| 6 | 11 | 7347. | | 2.7 | | 7841. | 1.000 | 3921. | >1000000. | 60000. | 831.2 |
| 11 | 14 | 7347. | | 2.6 | | 7832. | 1.000 | 3916. | >1000000. | 60000. | 831.2 |
| 10 | 37 | 7613. | | 1.2 | | 7828. | 1.000 | 3914. | >1000000. | 60000. | 833.7 |
| 10 | 11 | 7347. | | 2.5 | | 7804. | 1.000 | 3902. | >1000000. | 60000. | 831.2 |
| 37 | 40 | 7746. | | 0.0 | | 7746. | 1.000 | 3873. | >1000000. | 60000. | 833.7 |
| 9 | 35 | 1273. | | 33.3 | | 7707. | 1.000 | 3854. | >1000000. | 60000. | 831.2 |
| 9 | 40 | 7468. | | 1.2 | | 7683. | 1.000 | 3841. | >1000000. | 60000. | 831.2 |
| 1 | 39 | 7602. | | 0.3 | | 7652. | 1.000 | 3826. | >1000000. | 60000. | 875.7 |
| 37 | 41 | 7613. | | 0.0 | | 7613. | 1.000 | 3807. | >1000000. | 60000. | 833.7 |
| 11 | 41 | 7347. | | 1.3 | | 7589. | 1.000 | 3795. | >1000000. | 60000. | 831.2 |
| 16 | 39 | 5128. | | 13.1 | | 7561. | 1.000 | 3780. | >1000000. | 60000. | 831.2 |
| 7 | 16 | 4742. | | 14.8 | | 7493. | 1.000 | 3746. | >1000000. | 60000. | 831.2 |
| 16 | 45 | 5016. | | 13.1 | | 7449. | 1.000 | 3725. | >1000000. | 60000. | 843.7 |
| 11 | 17 | 1010. | | 33.1 | | 7444. | 1.000 | 3722. | >1000000. | 60000. | 831.2 |
| 15 | 17 | 1010. | | 8.8 | | 7444. | 1.000 | 3722. | >1000000. | 60000. | 831.2 |
| 15 | 45 | 2654. | | 25.7 | | 7438. | 1.000 | 3719. | >1000000. | 60000. | 843.7 |
| 7 | 15 | 2604. | | 24.0 | | 7388. | 1.000 | 3694. | >1000000. | 60000. | 831.2 |
| 9 | 39 | 7155. | | 1.2 | | 7370. | 1.000 | 3685. | >1000000. | 60000. | 831.2 |
| 8 | 9 | 6478. | | 2.9 | | 7010. | 1.000 | 3505. | >1000000. | 60000. | 831.2 |
| 6 | 9 | 6478. | | 2.5 | | 6945. | 1.000 | 3472. | >1000000. | 60000. | 831.2 |
| 9 | 14 | 6478. | | 2.5 | | 6936. | 1.000 | 3468. | >1000000. | 60000. | 831.2 |
| 37 | 39 | 6911. | | 0.0 | | 6911. | 1.000 | 3456. | >1000000. | 60000. | 833.7 |
| 9 | 10 | 6478. | | 2.3 | | 6908. | 1.000 | 3454. | >1000000. | 60000. | 831.2 |
| 9 | 41 | 6478. | | 1.2 | | 6693. | 1.000 | 3347. | >1000000. | 60000. | 831.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

Structural Integrity Associates, Inc.



CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 17 | 143. | | 33.3 | | 6577. | 1.000 | 3289. | >1000000. | 60000. | 831.2 |
| 1 16 | 3933. | | 12.8 | | 6366. | 1.000 | 3183. | >1000000. | 60000. | 875.7 |
| 39 40 | 6117. | | 0.0 | | 6118. | 1.000 | 3059. | >1000000. | 60000. | 831.2 |
| 7 40 | 5732. | | 1.7 | | 6049. | 1.000 | 3025. | >1000000. | 60000. | 831.2 |
| 40 45 | 5998. | | 0.0 | | 5998. | 1.000 | 2999. | >1000000. | 60000. | 843.7 |
| 15 44 | 1059. | | 25.7 | | 5843. | 1.000 | 2921. | >1000000. | 60000. | 843.7 |
| 15 21 | 1049. | | 25.7 | | 5833. | 1.000 | 2917. | >1000000. | 54348. | 801.4 |
| 39 45 | 5775. | | 0.0 | | 5775. | 1.000 | 2887. | >1000000. | 60000. | 843.7 |
| 7 39 | 5420. | | 1.7 | | 5737. | 1.000 | 2869. | >1000000. | 60000. | 831.2 |
| 9 15 | 868. | | 24.5 | | 5652. | 1.000 | 2826. | >1000000. | 60000. | 831.2 |
| 8 39 | 5128. | | 1.7 | | 5445. | 1.000 | 2722. | >1000000. | 60000. | 831.2 |
| 13 15 | 0. | | 29.0 | | 5403. | 1.000 | 2702. | >1000000. | 60000. | 850.5 |
| 6 39 | 5128. | | 1.4 | | 5380. | 1.000 | 2690. | >1000000. | 60000. | 831.2 |
| 7 8 | 4742. | | 3.4 | | 5377. | 1.000 | 2688. | >1000000. | 60000. | 831.2 |
| 14 39 | 5128. | | 1.3 | | 5371. | 1.000 | 2685. | >1000000. | 60000. | 831.2 |
| 10 39 | 5128. | | 1.2 | | 5342. | 1.000 | 2671. | >1000000. | 60000. | 831.2 |
| 8 45 | 5016. | | 1.7 | | 5333. | 1.000 | 2667. | >1000000. | 60000. | 843.7 |
| 6 7 | 4742. | | 3.1 | | 5311. | 1.000 | 2656. | >1000000. | 60000. | 831.2 |
| 7 14 | 4742. | | 3.0 | | 5302. | 1.000 | 2651. | >1000000. | 60000. | 831.2 |
| 7 10 | 4742. | | 2.9 | | 5274. | 1.000 | 2637. | >1000000. | 60000. | 831.2 |
| 6 45 | 5016. | | 1.4 | | 5268. | 1.000 | 2634. | >1000000. | 60000. | 843.7 |
| 14 45 | 5016. | | 1.3 | | 5259. | 1.000 | 2630. | >1000000. | 60000. | 843.7 |
| 10 45 | 5016. | | 1.2 | | 5231. | 1.000 | 2615. | >1000000. | 60000. | 843.7 |
| 39 41 | 5128. | | 0.0 | | 5128. | 1.000 | 2564. | >1000000. | 60000. | 831.2 |
| 7 41 | 4742. | | 1.7 | | 5060. | 1.000 | 2530. | >1000000. | 60000. | 831.2 |
| 41 45 | 5016. | | 0.0 | | 5016. | 1.000 | 2508. | >1000000. | 60000. | 843.7 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 15 | 0. | | 24.4 | | 4784. | 1.000 | 2392. | >1000000. | 60000. | 831.2 |
| 1 | 8 | 3933. | | 1.4 | | 4250. | 1.000 | 2125. | >1000000. | 60000. | 875.7 |
| 1 | 6 | 3933. | | 1.1 | | 4184. | 1.000 | 2092. | >1000000. | 60000. | 875.7 |
| 1 | 14 | 3933. | | 1.0 | | 4176. | 1.000 | 2088. | >1000000. | 60000. | 875.7 |
| 1 | 10 | 3933. | | 0.9 | | 4147. | 1.000 | 2074. | >1000000. | 60000. | 875.7 |
| 1 | 40 | 4066. | | 0.3 | | 4116. | 1.000 | 2058. | >1000000. | 60000. | 875.7 |
| 1 | 41 | 3933. | | 0.3 | | 3983. | 1.000 | 1991. | >1000000. | 60000. | 875.7 |
| 7 | 21 | 3643. | | 1.7 | | 3960. | 1.000 | 1980. | >1000000. | 54348. | 801.4 |
| 1 | 37 | 3680. | | 0.3 | | 3730. | 1.000 | 1865. | >1000000. | 60000. | 970.1 |
| 21 | 45 | 3666. | | 0.0 | | 3666. | 1.000 | 1833. | >1000000. | 54348. | 0.0 |
| 7 | 13 | 2604. | | 5.0 | | 3540. | 1.000 | 1770. | >1000000. | 60000. | 850.5 |
| 7 | 44 | 3221. | | 1.7 | | 3538. | 1.000 | 1769. | >1000000. | 60000. | 843.7 |
| 44 | 45 | 3528. | | 0.0 | | 3528. | 1.000 | 1764. | >1000000. | 60000. | 0.0 |
| 16 | 40 | 990. | | 13.1 | | 3423. | 1.000 | 1712. | >1000000. | 60000. | 831.2 |
| 13 | 45 | 2654. | | 3.3 | | 3273. | 1.000 | 1636. | >1000000. | 60000. | 863.0 |
| 7 | 11 | 2604. | | 0.4 | | 2921. | 1.000 | 1461. | >1000000. | 60000. | 831.2 |
| 11 | 45 | 2654. | | 1.3 | | 2897. | 1.000 | 1448. | >1000000. | 60000. | 843.7 |
| 16 | 41 | 0. | | 13.1 | | 2433. | 1.000 | 1217. | >1000000. | 60000. | 831.2 |
| 6 | 16 | 0. | | 11.7 | | 2433. | 1.000 | 1217. | >1000000. | 60000. | 831.2 |
| 8 | 16 | 0. | | 11.4 | | 2433. | 1.000 | 1217. | >1000000. | 60000. | 831.2 |
| 10 | 16 | 0. | | 11.9 | | 2433. | 1.000 | 1217. | >1000000. | 60000. | 831.2 |
| 14 | 16 | 0. | | 11.8 | | 2433. | 1.000 | 1217. | >1000000. | 60000. | 831.2 |
| 12 | 18 | 857. | | 4.8 | | 2337. | 1.000 | 1168. | >1000000. | 60000. | 868.4 |
| 9 | 21 | 1911. | | 1.2 | | 2126. | 1.000 | 1063. | >1000000. | 54348. | 801.4 |
| 9 | 45 | 1887. | | 1.2 | | 2102. | 1.000 | 1051. | >1000000. | 60000. | 843.7 |
| 7 | 9 | 1736. | | 0.5 | | 2053. | 1.000 | 1027. | >1000000. | 60000. | 831.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2 CODE SECTION III CLASS 1 ASME-1998 KRE 2007/07/11 11:35:07 [
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 44 | 1642. | | 1.2 | | 1857. | 1.000 | 929. | >1000000. | 60000. | 843.7 |
| 9 | 13 | 868. | | 4.5 | | 1702. | 1.000 | 851. | >1000000. | 60000. | 850.5 |
| 13 | 44 | 1059. | | 3.3 | | 1678. | 1.000 | 839. | >1000000. | 60000. | 863.0 |
| 13 | 21 | 1049. | | 3.3 | | 1668. | 1.000 | 834. | >1000000. | 54348. | 826.0 |
| 7 | 45 | 1057. | | 1.7 | | 1374. | 1.000 | 687. | >1000000. | 60000. | 843.7 |
| 8 | 40 | 990. | | 1.7 | | 1307. | 1.000 | 654. | >1000000. | 60000. | 831.2 |
| 11 | 44 | 1059. | | 1.3 | | 1301. | 1.000 | 651. | >1000000. | 60000. | 843.7 |
| 11 | 21 | 1049. | | 1.3 | | 1292. | 1.000 | 646. | >1000000. | 54348. | 801.4 |
| 6 | 40 | 990. | | 1.4 | | 1242. | 1.000 | 621. | >1000000. | 60000. | 831.2 |
| 14 | 40 | 990. | | 1.3 | | 1233. | 1.000 | 616. | >1000000. | 60000. | 831.2 |
| 10 | 40 | 990. | | 1.2 | | 1205. | 1.000 | 602. | >1000000. | 60000. | 831.2 |
| 9 | 11 | 868. | | 0.2 | | 1111. | 1.000 | 556. | >1000000. | 60000. | 831.2 |
| 21 | 44 | 1018. | | 0.0 | | 1018. | 1.000 | 509. | >1000000. | 54348. | 0.0 |
| 40 | 41 | 990. | | 0.0 | | 990. | 1.000 | 495. | >1000000. | 60000. | 831.2 |
| 11 | 13 | 0. | | 4.6 | | 862. | 1.000 | 431. | >1000000. | 60000. | 850.5 |
| 2 | 36 | 0. | | 3.2 | | 593. | 1.000 | 296. | >1000000. | 60000. | 899.7 |
| 36 | 38 | 0. | | 3.2 | | 593. | 1.000 | 296. | >1000000. | 60000. | 899.7 |
| 8 | 41 | 0. | | 1.7 | | 317. | 1.000 | 159. | >1000000. | 60000. | 831.2 |
| 6 | 8 | 0. | | 0.4 | | 317. | 1.000 | 159. | >1000000. | 60000. | 831.2 |
| 8 | 10 | 0. | | 0.5 | | 317. | 1.000 | 159. | >1000000. | 60000. | 831.2 |
| 8 | 14 | 0. | | 0.4 | | 317. | 1.000 | 159. | >1000000. | 60000. | 831.2 |
| 6 | 41 | 0. | | 1.4 | | 252. | 1.000 | 126. | >1000000. | 60000. | 831.2 |
| 6 | 10 | 0. | | 0.2 | | 252. | 1.000 | 126. | >1000000. | 60000. | 831.2 |
| 6 | 14 | 0. | | 0.0 | | 252. | 1.000 | 126. | >1000000. | 60000. | 831.2 |
| 14 | 41 | 0. | | 1.3 | | 243. | 1.000 | 121. | >1000000. | 60000. | 831.2 |
| 10 | 14 | 0. | | 0.2 | | 243. | 1.000 | 121. | >1000000. | 60000. | 831.2 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW 155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR | SN EQN.10 | SE EQN.12 | DELTA T1 RANGE | EQN.13 | SP EQN.11 | KE | SALT EQN.14 | ALLOW CYCLES | 3*SM | ALLOWABLE FOR DELTA T1 RANGE |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 41 | 0. | | 1.2 | | 215. | 1.000 | 107. | >1000000. | 60000. | 831.2 |
| 2 38 | 0. | | 0.0 | | 0. | 1.000 | 0. | >1000000. | 60000. | 0.0 |

Notes b,d,e,k: Fails
g: Weld ISI
h,i: Rupture Location
L: Information

Structural Integrity Associates, Inc.



++ DST/PIPESTRESS ++   Vermont Yankee   Version 3.5.1+026 PC-EXE   Release: Ju

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR I | J | SALT EQN.14 | OCCURENCES NI | OCCURENCES NJ | NUMBER USED | SETS ELIMINATED DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 28 | 29 | 66456. | 10 | 10 | 10 | 28,29 | 1808. | 0.0055 | |
| | | | 0 | 0 | | | | | |
| 31 | 32 | 54146. | 10 | 10 | 10 | 31,32 | 3406. | 0.0029 | |
| | | | 0 | 0 | | | | | |
| 4 | 43 | 49733. | 610 | 300 | 300 | 43 | 4465. | 0.0672 | |
| | | | 310 | 0 | | | | | |
| 4 | 34 | 49533. | 310 | 10 | 10 | 34 | 4523. | 0.0022 | |
| | | | 300 | 0 | | | | | |
| 3 | 4 | 49512. | 300 | 300 | 300 | 3, 4 | 4529. | 0.0662 | |
| | | | 0 | 0 | | | | | |
| 20 | 26 | 45555. | 300 | 10 | 10 | 26 | 5838. | 0.0017 | |
| | | | 290 | 0 | | | | | |
| 22 | 27 | 34161. | 300 | 10 | 10 | 27 | 14370. | 0.0007 | |
| | | | 290 | 0 | | | | | |
| 22 | 30 | 32373. | 290 | 10 | 10 | 30 | 17257. | 0.0006 | |
| | | | 280 | 0 | | | | | |
| 22 | 42 | 26170. | 280 | 300 | 280 | 22 | 33637. | 0.0083 | |
| | | | 0 | 20 | | | | | |
| 24 | 42 | 22860. | 300 | 20 | 20 | 42 | 51538. | 0.0004 | |
| | | | 280 | 0 | | | | | |
| 5 | 24 | 22397. | 599 | 280 | 280 | 24 | 57040. | 0.0049 | |
| | | | 319 | 0 | | | | | |
| 5 | 23 | 21265. | 319 | 300 | 300 | 23 | 73771. | 0.0041 | |
| | | | 19 | 0 | | | | | |
| 5 | 36 | 17029. | 19 | 1 | 1 | 36 | 178513. | 0.0000 | |
| | | | 18 | 0 | | | | | |
| 2 | 5 | 16732. | 120 | 18 | 18 | 5 | 190176. | 0.0001 | |
| | | | 102 | 0 | | | | | |
| 12 | 20 | 16409. | 10 | 290 | 10 | 12 | 205131. | 0.0000 | |
| | | | 0 | 280 | | | | | |

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [1
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET I | PAIR J | SALT EQN.14 | OCCURENCES NI | OCCURENCES NJ | NUMBER USED | SETS ELIMINATED DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 20 | 16030. | 102<br>0 | 280<br>178 | 102 | 2 | 228208. | 0.0004 | |
| 20 | 38 | 16030. | 178<br>177 | 1<br>0 | 1 | 38 | 228208. | 0.0000 | |
| 18 | 20 | 15537. | 289<br>112 | 177<br>0 | 177 | 20 | 263206. | 0.0007 | |
| 18 | 25 | 15362. | 112<br>102 | 10<br>0 | 10 | 25 | 277200. | 0.0000 | |
| 33 | 37 | 15167. | 10<br>9 | 1<br>0 | 1 | 37 | 293826. | 0.0000 | |
| 1 | 33 | 13327. | 120<br>111 | 9<br>0 | 9 | 33 | 561655. | 0.0000 | |
| 18 | 19 | 11235. | 102<br>0 | 300<br>198 | 102 | 18 | >1000000. | 0.0000 | |
| 19 | 35 | 10124. | 198<br>197 | 1<br>0 | 1 | 35 | >1000000. | 0.0000 | |
| 1 | 19 | 9874. | 111<br>0 | 197<br>86 | 111 | 1 | >1000000. | 0.0000 | |
| 17 | 19 | 9416. | 289<br>203 | 86<br>0 | 86 | 19 | >1000000. | 0.0000 | |
| 16 | 17 | 7602. | 70<br>0 | 203<br>133 | 70 | 16 | >1000000. | 0.0000 | |
| 17 | 40 | 6880. | 133<br>0 | 289<br>156 | 133 | 17 | >1000000. | 0.0000 | |
| 15 | 40 | 6560. | 70<br>0 | 156<br>86 | 70 | 15 | >1000000. | 0.0000 | |
| 21 | 40 | 4686. | 300<br>214 | 86<br>0 | 86 | 40 | >1000000. | 0.0000 | |
| 21 | 39 | 4531. | 214<br>0 | 289<br>75 | 214 | 21 | >1000000. | 0.0000 | |

CALCULATION NUMBER 2   CODE SECTION III CLASS 1 ASME-1998   KRE   2007/07/11 11:35:07 [
Vermont Yankee Feedwater PipingSI Fatigue Analysis

FATIGUE ANALYSIS AT POINT 155, LR ELBOW   155 TO 160

*****************************
INDIVIDUAL STRESS RANGE CHECK
*****************************

DELTA T1 IN DEGREES
STRESSES IN PSI

| LOAD SET PAIR I | J | SALT EQN.14 | OCCURENCES NI | OCCURENCES NJ | | NUMBER USED | SETS ELIMINATED | DYNAM. | NO. CYCLES TO FAILURE | USAGE FACTOR | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 39 | 4321. | 10 | 75 | | 10 | 13 | | >1000000. | 0.0000 | |
| | | | 0 | 65 | | | | | | | |
| 39 | 44 | 4289. | 65 | 5 | | 5 | 44 | | >1000000. | 0.0000 | |
| | | | 60 | 0 | 45 | | | | | | |
| 11 | 39 | 4133. | 310 | 60 | | 60 | 39 | | >1000000. | 0.0000 | |
| | | | 250 | 0 | | | | | | | |
| 8 | 11 | 3953. | 10000 | 250 | | 250 | 11 | | >1000000. | 0.0000 | |
| | | | 9750 | 0 | | | | | | | |
| 8 | 9 | 3505. | 9750 | 2000 | | 2000 | 9 | | >1000000. | 0.0000 | |
| | | | 7750 | 0 | | | | | | | |
| 7 | 8 | 2688. | 10000 | 7750 | | 7750 | 8 | | >1000000. | 0.0000 | |
| | | | 2250 | 0 | | | | | | | |
| 6 | 7 | 2656. | 599 | 2250 | | 599 | 6 | | >1000000. | 0.0000 | |
| | | | 0 | 1651 | | | | | | | |
| 7 | 14 | 2651. | 1651 | 10 | | 10 | 14 | | >1000000. | 0.0000 | |
| | | | 1641 | 0 | | | | | | | |
| 7 | 10 | 2637. | 1641 | 2000 | | 1641 | 7 | | >1000000. | 0.0000 | |
| | | | 0 | 359 | | | | | | | |
| 10 | 45 | 2615. | 359 | 5 | | 5 | 45 | | >1000000. | 0.0000 | |
| | | | 354 | 0 | 45 | | | | | | |
| 44 | 45 | 1764. | 45 | 45 | | 45 | ,45 | 44 | >1000000. | 0.0000 | DYN. RANGE OF EVENT NO. |
| | | | 0 | 0 | | | | | | | |
| 10 | 41 | 107. | 354 | 289 | | 289 | 41 | | >1000000. | 0.0000 | |
| | | | 65 | 0 | | | | | | | |

TOTAL USAGE FACTOR = 0.1661j

NEC-JH_15

REDACTED VERSION

Report No.: SIR-07-130-NPS
Revision No.: 0
Project No.: VY-16Q
File No.: VY-16Q-401
July 2007

# Environmental Fatigue Analysis for the Vermont Yankee Reactor Pressure Vessel Feedwater Nozzles

*NOTE*

~~*This document references vendor proprietary information. Such information is identified with -2xxP SI Project File numbers in the list of references. Any such references and the associated information in this document where those references are used are identified so that this information can be treated in accordance with applicable vendor proprietary agreements.*~~

*Prepared for:*
Entergy Nuclear Operations, Inc.
(Contract No. 10150394)

*Prepared by:*
Structural Integrity Associates, Inc.
Centennial, CO

| | | |
|---|---|---|
| *Prepared by:* | M. Qin | Date: 7/26/2007 |
| *Reviewed by:* | J. F. Staples | Date: 7/26/2007 |
| *Approved by:* | T. J. Herrmann, P.E. | Date: 7/26/2007 |

*Structural Integrity* Associates, Inc.

**REVISION CONTROL SHEET**

Document Number: SIR-07-130-NPS

Title: Environmental Fatigue Analysis for the Vermont Yankee Reactor Pressure Vessel Feedwater Nozzles

Client: Entergy Nuclear Vermont Yankee, LLC

SI Project Number: VY-16Q

| Section | Pages | Revision | Date | Comments |
|---|---|---|---|---|
| 1.0 | 1-1 – 1-8 | 0 | 07/26/07 | Initial Issue |
| 2.0 | 2-1 – 2-4 | | | |
| 3.0 | 3-1 – 3-34 | | | |
| 4.0 | 4-1 – 4-11 | | | |
| 5.0 | 5-1 – 5-2 | | | |
| 6.0 | 6-1 | | | |
| 7.0 | 7-1 – 7-3 | | | |
| | | | | |
| | | | | |

## Table of Contents

## List of Tables

## List of Figures

## 1.0 INTRODUCTION

In Table 4.3-3 of the Vermont Yankee (VY) License Renewal Application (LRA), the 60-year cumulative usage factor (CUF) value for the reactor pressure vessel (RPV) feedwater nozzle (FW) is reported as 0.750. Application of an environmentally assisted fatigue (EAF) multiplier, as required for the license renewal period, resulted in an unacceptable EAF CUF value of 2.86. Therefore, further refined analysis was necessitated to show acceptable EAF CUF results for this component.

REDACTED

The VY FW nozzles were re-evaluated in detail by SI in 2004 for EPU and 60 years of operation. However, that analysis used conservative transient definitions and cyclic projections for 60 years of operation that have since been updated as a part of LRA development.

This report documents a refined fatigue evaluation for the VY FW nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the FW nozzle and safe end are included in the evaluation, to be consistent with NUREG/CR-6260 [16] needs for EAF evaluation for license renewal. The resulting fatigue results will be used as a replacement to the values previously reported in the VY LRA.

The refined evaluation summarized in this report included development of a detailed finite element model of the FW nozzle, including relevant portions of the safe end, thermal sleeve, and the RPV wall. Thermal and pressure stress histories were developed for relevant transients affecting the FW nozzle, including any effects of EPU, as specified by the VY RPV Design Specification [3], the VY EPU Design Specification [17] and other boiling water reactor (BWR) operating experience. The thermal and pressure stress histories were used to determine total stress and primary plus secondary stress for use in a subsequent fatigue evaluation. Stresses were also included due to loads from the attached piping for application in the stress/fatigue analysis based on the bounding reaction loads obtained from the relevant design documents. The revised fatigue calculation was performed using Section III methodology from the 1998 Edition, 2000 Addenda of the ASME Code [15], and was performed using actual cycles from past plant operation projected out to 60 years of operation.

## 1.1 Green's Function Methodology

In order to provide an overall approach and strategy for evaluating the feedwater nozzle, the Green's Function methodology and associated ASME Code stress and fatigue analyses are described in this section.

Revised stress and fatigue analyses are being performed for the feedwater nozzle using ASME Code, Section III methodology. These analyses are being performed to address license renewal requirements to evaluate environmental fatigue for this component in response to Generic Aging Lessons Learned (GALL) Report [22] requirements. The revised analysis is being performed to refine the fatigue usage so that an environmental fatigue factor can be determined for subsequent license renewal efforts.

Two sets of rules are available under ASME Code, Section III, Class 1 [15]. Subparagraph NB-3600 of Section III provides simplified rules for analysis of piping components, and NB-3200 allows for more detailed analysis of vessel components. The NB-3600 piping equations combine by absolute sum the stresses due to pressure, moments and through wall thermal gradient effects, regardless of where within the pipe cross-section the maximum value of the components of stress are located. By considering stress signs, affected surface (inside or outside) and azimuthal position, the stress ranges can be significantly reduced. In addition, NB-3600 assigns stress indices by which the stresses are multiplied to conservatively incorporate the effects of geometric discontinuities. In NB-3200, these are not required, as the stresses are calculated by finite element analysis and any applicable stress concentration factors. This generally results in a net reduction of the stress ranges and consequently, in the fatigue usage. Article 4 [27] methodology was originally used to evaluate the feedwater nozzle. NB-3200 methodology, which is the modern day equivalent to Article 4, is used in this analysis to be consistent with the Section III design bases for this component, as well as to allow a more detailed analysis of this component. In addition, several of the conservatisms originally used in the original feedwater nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve as accurate a CUF as reasonably achievable.

For the feedwater nozzle evaluated as a part of this work, stress histories will be computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's Function integration scheme is similar in concept to the well-known Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [4]. A general outline is provided in this section.

The steps involved in the evaluation are as follows:

- Develop finite element model
- Develop heat transfer coefficients and boundary conditions for the finite element model
- Develop Green's Functions
- Develop thermal transient definitions
- Perform stress analysis to determine stresses for all thermal transients
- Perform fatigue analysis

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 1-1 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 1-2. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 1-2. These five step changes produce the five successive stress responses in the second plot shown in Figure 1-2. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY reactor feedwater nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.

Fatigue calculations are performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology. Fatigue analysis is performed for the three limiting locations (two in the safe end and one in the nozzle forging, representing the three materials of the nozzle assembly) using the Green's Functions developed for the three feedwater flow conditions and 60-year projected cycle counts.

Three Structural Integrity utility computer programs are used to facilitate the fatigue analysis process: STRESS.EXE, P V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys, as required by ASME Code fatigue evaluation methods. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III range-pair methodology. All three programs are explained in detail and have been independently verified for generic use in the Reference [14] calculation.

In order to perform the fatigue analysis, Green's Functions are developed using the finite element model. Then, input files with the necessary data are prepared and the three utility computer programs are run. The first program (STRESS.EXE) requires the following three input files:

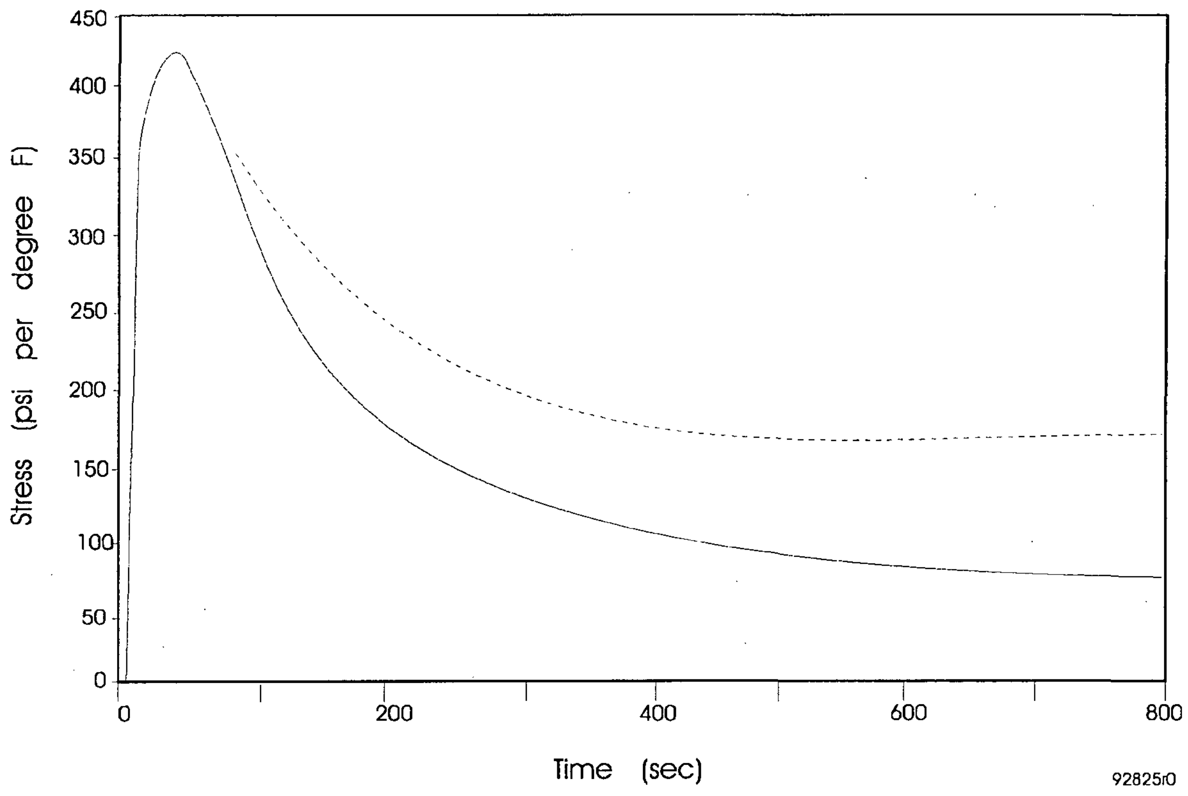
- Input file "GREEN.DAT": This file contains the Green's Function for the location being evaluated. For each flow condition, two Green's Functions are determined: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function. This allows computation of total stress, as well as membrane plus bending stress, which is necessary to compute $K_e$ per ASME Code, Section III requirements.

- Input file "GREEN.CFG": This file is a configuration file containing parameters that define the Green's Function (i.e., number of points, temperature drop analyzed, etc.).
- Input file "TRANSNT.INP": This file contains the input transient history for all thermal transients to be analyzed for the location being evaluated.

Pressure and piping stress intensities are also included for each transient case, based on pressure stress results from finite element analysis and attached piping load calculations.
The second program (P-V.EXE) simply extracts only the maxima and minima stress (i.e., the peaks and valleys) from the stress histories generated by program STRESS.EXE.

The third program (FATIGUE.EXE) performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data consists of the output peak and valley history from program P-V.EXE and a configuration input file that provides ASME Code configuration data relevant to the fatigue analysis (i.e., $K_e$ parameters, $S_m$, Young's modulus, etc.). The output is the final fatigue calculation for the location being evaluated.

The Green's Function methodology described above uses standard industry stress and fatigue analysis practices, and is the same as the methodology used in typical stress reports. Special approval for the use of this methodology is therefore not required.




Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

**Figure 1-1. Typical Green's Functions for Thermal Transient Stress**

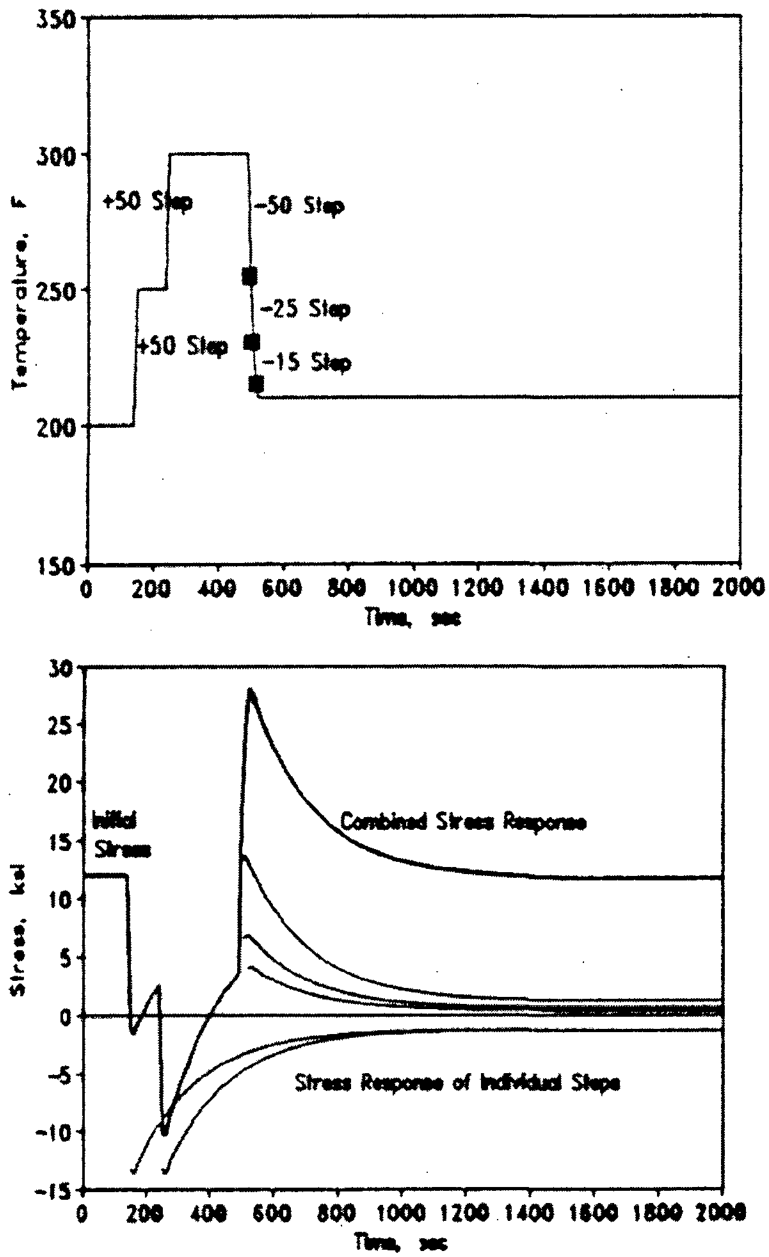



**Figure 1-2. Typical Stress Response Using Green's Functions**

## 2.0 FINITE ELEMENT MODEL

A previously generated ANSYS [5] finite element model (FEM) of the VY feedwater nozzle and safe end was used to perform the updated stress and fatigue analyses. The details of the model development are documented in the Reference [6] calculation.

A few key points with respect to model development are as follows:

- The model is identical to the geometry and mesh of the model previously developed for feedwater nozzle fracture mechanics work performed for VY [7].
- The boundary condition corresponding to the location of the start of the thermal sleeve in the FEM are consistent with Reference [8].

The materials of the various components of the model are listed below:

- Reactor Pressure Vessel – SA533 Grade B
- Reactor Pressure Vessel Cladding – Stainless Steel
- Nozzle Forging – ASTM A508 Class II
- Safe End Forging – ASTM A508 Class I
- Feedwater Piping – ASTM A106 Grade B

The FEM model the radius of RPV was increased by a factor of two to account for the fact that the vessel portion of the finite element model is a sphere and the actual geometry is a cylinder.

Material properties were based upon the 1998 ASME Code, Section II, Part D, with 2000 Addenda [9], and are shown in Table 2-1. The properties were evaluated at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which was applied to the FEM model for Green's Function development.

The finite element model is shown in Figures 2-1 and 2-2.

**Table 2-1. Material Properties @ 300°F [(1)]**

| Material Ident. | Young's Modulus, E x $10^6$ (psi) | Instantaneous Coefficient of Thermal Expansion, $\alpha$ x $10^{-6}$ (in/in-°F) | Density, $\rho$ (lb/in$^3$) (assumed) | Conductivity, k (BTU/hr-ft-°F) | Diffusivity, d (ft$^2$/hr) | Specific Heat, $c_p$ (BTU/lbm-°F) (see Note 5) | Poisson's Ratio (assumed) |
|---|---|---|---|---|---|---|---|
| SA533 Grade B, A508 Class II (see Note 2) | 26.7 | 7.3 | 0.283 | 23.4 | 0.401 | 0.119 | 0.3 |
| SS Clad (see Note 3) | 27.0 | 9.8 | 0.283 | 9.8 | 0.160 | 0.125 | 0.3 |
| A508 Class I (see Note 4) | 28.1 | 7.3 | 0.283 | 32.3 | 0.561 | 0.118 | 0.3 |
| A106 Grade B (see Note 4) | 28.3 | 7.3 | 0.283 | 32.3 | 0.561 | 0.118 | 0.3 |

Notes
1. The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, 2000 Addenda, Section II, Part D [9], except for density and Poisson's ratio, which are assumed typical values.
2. Properties of A508 Class II are used (3/4Ni-1/2Mo-1/3Cr-V).
3. Properties of 18Cr - 8Ni austenitic stainless steel are used.
4. Composition = C-Si.
5. Calculated as $k/(\rho d)/12^3$.

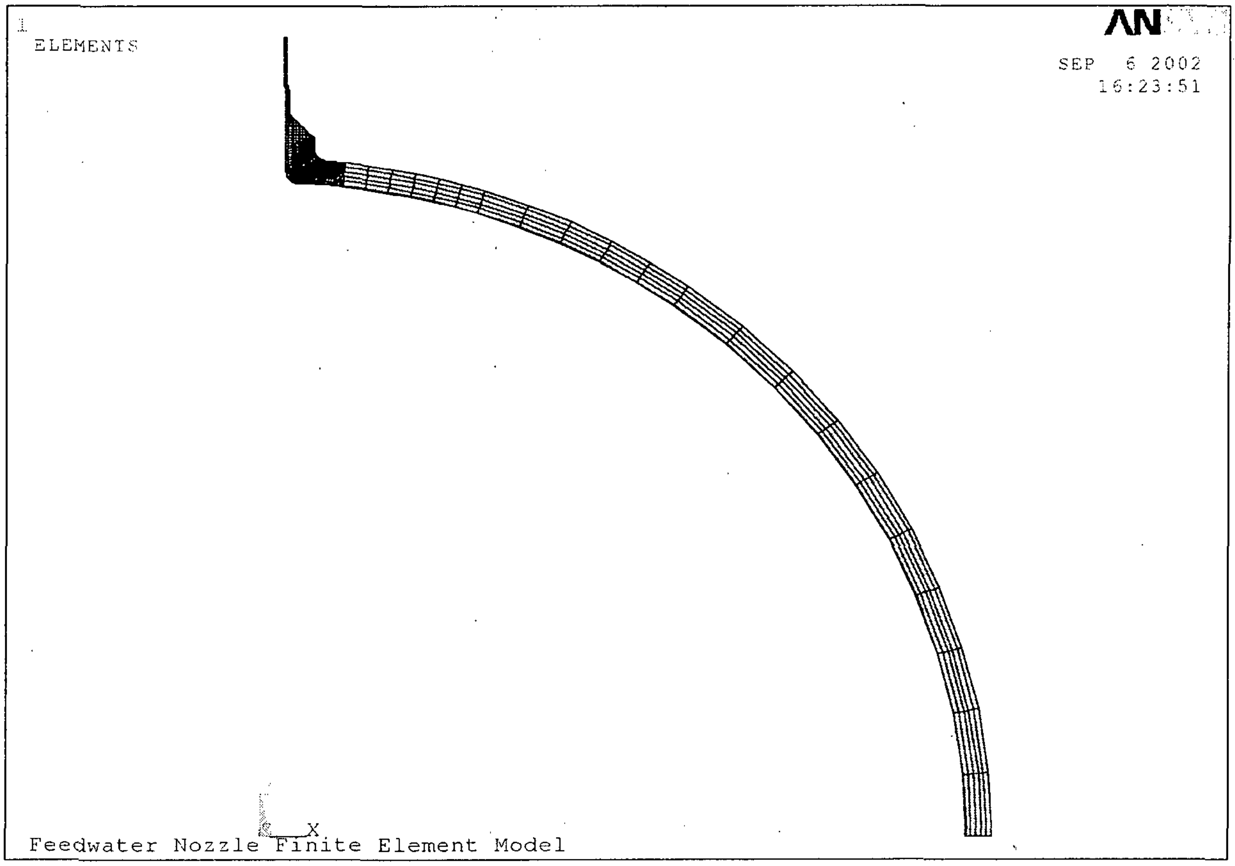



**Figure 2-1: VY Feedwater Nozzle FEM**

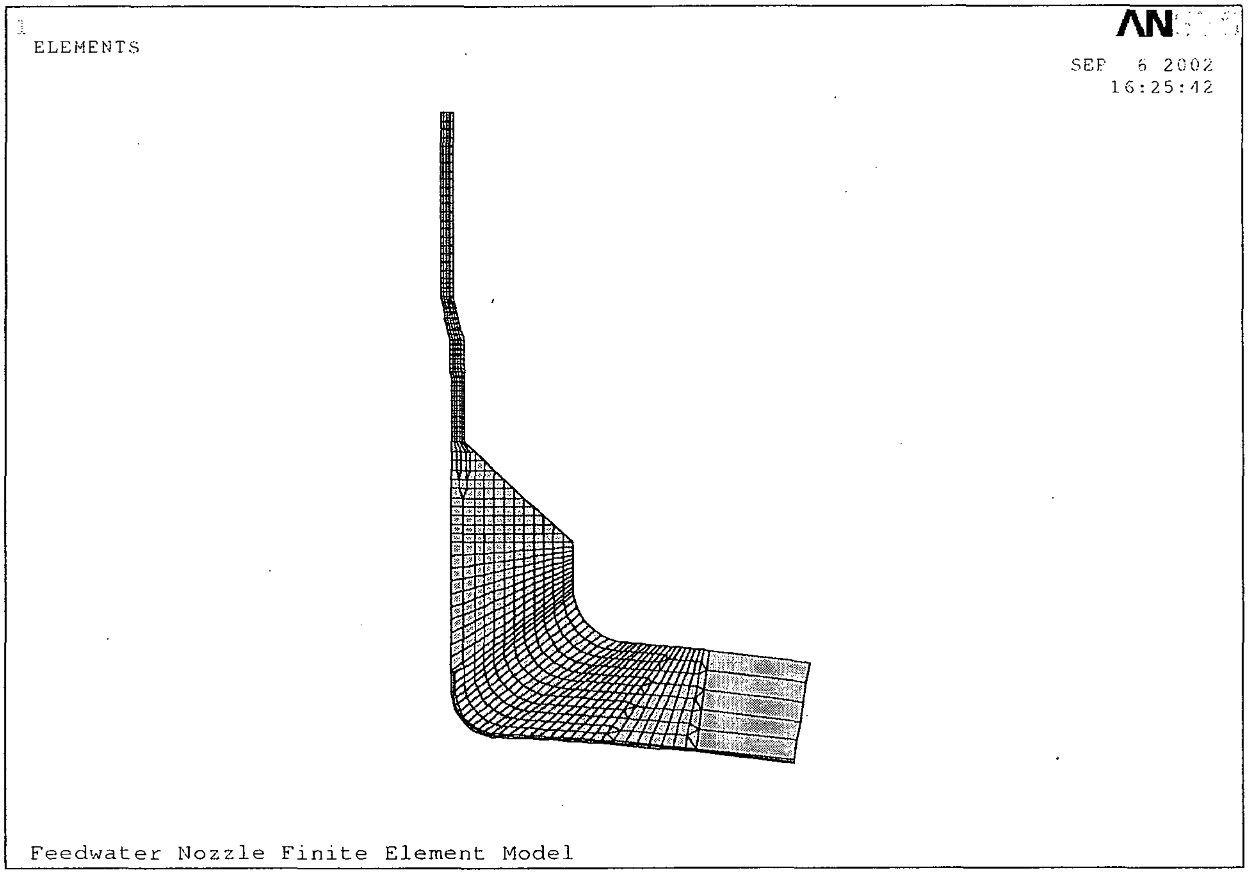



**Figure 2-2: VY Feedwater Nozzle FEM – Safe End/Nozzle Region**

## 3.0 LOAD DEFINITIONS

The pressure and thermal stresses for the feedwater nozzle for the revised fatigue evaluation were developed using the axisymmetric FEM model described in Section 2.0 of this report. The details of the Green's function development and associated stress evaluation are documented in the Reference [10] calculation.

### 3.1 Thermal Loading

Thermal loads are applied to the feedwater nozzle model. The heat transfer coefficients after power uprate were determined in Reference [10]. These values were determined for various regions of the finite element model and for 100% (4,590 GPM), 40% (1836 GPM) and 25% (1,148 GPM) [10]. The annulus leakage flow rate is assumed to be 25 GPM for non-EPU conditions and 31 GPM for EPU conditions. The 25 GPM value is calculated by scaling the 23 GPM [Page 6, 13] value up by approximately 9%. The 23 GPM value is scaled up to provide some conservatism and allow for inaccuracies in the determination of leakage flow. The 31 GPM value is calculated by multiplying the 25 GPM value by 1.25 [Page 6, 13]. Based on this, the annulus leakage flow rate is assumed to be 8 GPM for EPU conditions with 25% flow rate and 13 GPM for EPU condition with 40% flow rate. The temperatures used are based upon a thermal shock from 500°F to 100°F.

#### *3.1.1 Heat Transfer Coefficients and Boundary Fluid Temperatures*

Referring to Figure 3-4, heat transfer coefficients were applied as follows:

- The heat transfer coefficient for the outside surfaces of the FEM (Region 8) was a constant value of 0.2 BTU/hr-ft$^2$-°F ($3.858 \times 10^{-7}$ BTU/sec-in$^2$-°F).
- Table 3-3 shows a sampling of the heat transfer coefficient calculations for Region 1 for the 40% flow case.

For all Green's Functions, a 500°F to 100°F thermal shock was run to determine the stress response.

The applied heat transfer coefficients and the initial temperatures for all regions are contained in Reference [10].

### *3.1.2 Green's Function's*

Three flow dependent thermal load cases were run on the FEM model with the heat transfer coefficients and the fluid temperature conditions listed above. Two locations were selected for analysis (see Figures 3-5 and 3-6):

1. The critical safe end location was chosen as the node with the highest stress intensity due to thermal loading under high flow conditions. The highest stress intensity due to thermal loading occurred at Node 192 (see Figure 3-5), on the inside diameter of the nozzle safe end, and therefore, this node was selected for analysis. Because the safe end stress response is affected by flow, three flow conditions were analyzed (100%, 40% and 25%).
2. The critical blend radius location was chosen, based upon the highest pressure stress. Conservatively assuming the cladding has cracked, the critical location is selected as node 657 at base metal of the nozzle, as shown in Figure 3-6. Because the blend radius stress response is affected by flow, three flow conditions were analyzed (100%, 40% and 25%).

Two stress intensity time history were developed for each location and each flow case: (1) total stress intensity, and (2) membrane plus bending stress intensity. The stress time histories for the safe end location, where the maximum stress was obtained for each of the flow conditions, are shown in Figures 3-7 through 3-12. The stress time histories for the blend radius location, where the maximum stress was obtained for each of the flow conditions, are shown in Figures 3-13 through 3-18.

### *3.1.3 Thermal Transients (for program STRESS.EXE)*

The program STRESS.EXE requires the following three input files for analyzing an individual transient:

- Green.dat. There are 12 stress history functions obtained from Reference [10]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. Both of the blend radius and the safe end have two stress history functions for each of the following flow conditions; 100%, 40%, and 25% flow.
- Green.cfg is configured as described in Reference [14].
- Transnt.inp. These files are created to represent the transients shown on the thermal cycle diagrams and redefined by power uprate. Note that transients 12, 13, and 15 are nearly identical on the thermal cycle diagram [19] and the results from running transient 12 will be used for all three transients. Transient 16, 17 and 18 will not be considered since there is no temperature change. Tables 3-4 and 3-5 show the thermal history used to represent each transient. Based upon the thermal cycle diagram for the feedwater nozzle [19], the transients are split into the following groups based upon flow rate:
    - Transients 3, 20, 20A, and 21-23 are run at 25% flow. Although Reference [19] shows 15% flow rate, it is conservative to use 25% flow rate for these transients. Transient 20, Hot Standby, is split up into two parts. The first portion is "Heatup portion" and the second portion is "Feedwater Injection portion" that are defined from Reference [19].
    - Transient 11 is run at 40% flow. Transient 11 starts off and ends at 100% flow.
    - Transients 5, 6, 9, 10, and 19 are run at 100% flow.
    - Transient 4 is run at 100% flow only to obtain the last stress point. The remainder of the stress points for transient 4 is obtained from the 25% flow stress results. The results are pulled from the two flow case results based upon the flow rates defined in the thermal cycle diagram [19].
    - Transients 12, 13, 14 and 15 were run at 100% flow. Heat transfer coefficients were not re-calculated for the 1 minute intervals each of these transients is at 110% flow. The effect of this small flow rate increase for such a relatively short duration should be minor.

- Transients 1, 2, 24, and 25 are set as no thermal stress due to very small temperature changes (70°F to 100°F) at these transients.

### 3.2 Pressure Loading

A uniform pressure of 1,000 psi was applied along the inside surface of the feedwater nozzle and the vessel wall. A pressure load of 1,000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the nozzle. The nodal forces shown in Table 3-1 [10] are defined by the following equation:

$$F_{element} = \pi (IR)^2 P \cdot \frac{\pi\left(R_o^{\,2} - R_i^{\,2}\right)}{\pi\left(OR^2 - IR^2\right)}$$

| | | | |
|---|---|---|---|
| where: | P | = | unit pressure load = 1,000 psi |
| | IR | = | inner pipe radius = 4.8345 in |
| | OR | = | outer pipe radius = 5.42 in |
| | $R_i$ | = | inside radius of element that node is attached to |
| | $R_o$ | = | outside radius of element that node is attached to |
| | $F_{node}$ | = | average of the element forces on either side of the node. |

*Note: The force on the innermost and outermost nodes is calculated as one half of the force on the element that they are attached to.*

The calculated nodal forces were applied as positive values so they would exert tension on the end of the model. Figures 3-1, 3-2, and 3-3 show the internal pressure distribution, cap load, and symmetry condition applied to the vessel end of the model, respectively.

The pressure stress associated with a 1000 psi internal pressure was determined in Reference [10]. These values are as follows:

Pressure stress for the safe end:

- 8693 psi membrane plus bending stress intensity.
- 8891 psi total linearized stress intensity.

Pressure stress for the blend radius:

- 36653 psi membrane plus bending stress intensity.
- 37733 psi total linearized stress intensity.

These pressure stress values for each location were linearly scaled with pressure. The actual pressure for column 6 of Tables 4-1 and 4-2 is obtained from Tables 3-4 and 3-5. The scaled pressure stress values are shown in columns 7 and 8 of Tables 4-1 and 4-2.

The pressure stress is combined with the thermal and piping loads to calculate the final stress values used for fatigue analysis. The piping load sign is set as the same as the thermal stress sign.

### 3.3 Piping Loading

Additionally, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 3-36.

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first and second cut locations using the following equations:

For Cut I:
$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:
$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:

$$M_{xy} = \sqrt{(M_x)_1^2 + (M_y)_1^2}$$
$$F_{xy} = \sqrt{(F_x)_1^2 + (F_y)_1^2}$$

For Cut II:

$$M_{xy} = \sqrt{(M_x)_2^2 + (M_y)_2^2}$$
$$F_{xy} = \sqrt{(F_x)_2^2 + (F_y)_2^2}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, $P_M$, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$

$$(P_M)_\theta = \frac{Pa_N}{t_N}$$

$$(P_M)_R = -P$$

$$\tau_M = \frac{q_N}{t_N}$$

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

where:

$L_1$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.

$L_2$ = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.

$M_{xy}$ = The maximum bending moment in the xy plane.

$F_{yx}$ = The maximum shear force in the xy plane.

$N_z$ = The normal force per inch of circumference applied to the end of the nozzle in the z direction.

$q_N$ = The shear force per inch of circumference applied to the nozzle.

$R_N$ = The mid-wall nozzle radius.

Because pressure was not considered in this analysis, the equations used for Cut I are valid for Cut II. Furthermore, since the pressure was not considered in this analysis, the equations can be simplified as follows:

$$(P_M)_z = \frac{Nz}{t_N}$$

$$(P_M)_\theta = 0$$

$$(P_M)_R = 0$$

$$\tau_M = \frac{q_N}{t_N}$$

$$SI_{MAX} = 2(\tau_M)_{z\theta}$$

*or*

$$SI_{MAX} = 2\sqrt{\left(\frac{Nz}{2t_N}\right)^2 + (\tau_M)_{z\theta}^{\ 2}}$$

Per Reference [11], the feedwater nozzle piping loads are as follows:

| | |
|---|---|
| $F_x$ = 3,000 lbs | $M_x$ = 28,000 ft-lb = 336,000 in-lb |
| $F_y$ = 15,000 lbs | $M_y$ = 13,000 ft-lb = 156,000 in-lb |
| $F_z$ = 3,200 lbs | $M_z$ = 40,000 ft-lb = 480,000 in-lb |

The loads are applied at the connection of the piping and safe end. Therefore, the $L_1$ is equal to 12.0871 inches and the $L_2$ is equal to 27.572 inches. The calculations for the safe end and blend radius are shown in Table 3-2. The first cut location is the same as the Green's Function cross section per [10] at the safe end, and the second cut is from Node 645 (outside) to Node 501 (inside). The maximum stress intensities due to piping loads are 5707.97 psi at the safe end and 265.47 psi at the blend radius, respectively.

These piping stress values are scaled assuming no stress occurs at an ambient temperature of 70°F and the full values are reached at reactor design temperature, 575°F. The scaled piping stress values are shown in columns 9 and 10 of Tables 4-1 and 4-2. Columns 11 and 12 of Tables 4-1 and 4-1 show the summation of all stresses for each thermal peak and valley stress point.

**Table 3-1: Nodal Force Calculation for End Cap Load**

| Node Number | Element Number | Radius (in) | Δ Radius (in) | $R_o^2$-$Ri^2$ ($in^2$) | $F_{element}$ (lb) | $F_{node}$ (lb) |
|---|---|---|---|---|---|---|
| 1 | | 5.42 | | | | 7678.0 |
| | 1022 | | 0.1171 | 1.25565 | 15356.1 | |
| 2 | | 5.3029 | | | | 15188.4 |
| | 1021 | | 0.1171 | 1.22823 | 15020.7 | |
| 3 | | 5.1858 | | | | 14853.0 |
| | 1020 | | 0.1171 | 1.20080 | 14685.3 | |
| 4 | | 5.0687 | | | | 14517.6 |
| | 1019 | | 0.1171 | 1.17338 | 14349.9 | |
| 5 | | 4.9516 | | | | 14182.2 |
| | 1018 | | 0.1171 | 1.14595 | 14014.5 | |
| 6 | | 4.8345 | | | | 7007.3 |

**Table 3-2: Maximum Piping Stress Intensity Calculations**

| Safe End External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 3.00 | kips |
| $F_y$ = | 15.00 | kips |
| $F_Z$ = | 3.20 | kips |
| $M_x$ = | 336.00 | in-kips |
| $M_y$ = | 156.00 | in-kips |
| $M_Z$ = | 480.00 | in-kips |
| OD= | 11.86 | in |
| ID= | 10.409 | in |
| $R_N$ = | 5.57 | in |
| L = | 12.09 | in |
| $t_N$ = | 0.72 | in |
| $(M_x)_1$ = | 154.69 | in-kips |
| $(M_y)_1$ = | 192.26 | in-kips |
| $M_{xy}$ = | 246.77 | in-kips |
| $F_{xy}$ = | 15.30 | kips |
| $N_Z$ = | 2.63 | kips/in |
| $q_N$ = | -1.59 | kips/in |
| Primary Membrane Stress Intensity | | |
| $PM_Z$ = | 3.63 | ksi |
| $\tau$ = | -2.20 | ksi |
| $SI_{max}$ = | 5.71 | ksi |
| $SI_{max}$ = | 5707.97 | psi |

| Blend Radius External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 3.00 | kips |
| $F_y$ = | 15.00 | kips |
| $F_Z$ = | 3.20 | kips |
| $M_x$ = | 336.00 | in-kips |
| $M_y$ = | 156.00 | in-kips |
| $M_Z$ = | 480.00 | in-kips |
| OD= | 22.67 | in |
| ID= | 10.750 | in |
| $R_N$ = | 8.35 | in |
| L = | 27.57 | in |
| $t_N$ = | 5.96 | in |
| $(M_x)_2$ = | -77.58 | in-kips |
| $(M_y)_2$ = | 238.72 | in-kips |
| $M_{xy}$ = | 251.01 | in-kips |
| $F_{xy}$ = | 15.30 | kips |
| $N_Z$ = | 1.21 | kips/in |
| $q_N$ = | -0.51 | kips/in |
| Primary Membrane Stress Intensity | | |
| $PM_Z$ = | 0.20 | ksi |
| $\tau$ = | -0.09 | ksi |
| $SI_{max}$ = | 0.27 | ksi |
| $SI_{max}$ = | 265.47 | psi |

Note: The locations for Cut I and Cut II were defined in Reference [10] for safe end and blend radius paths, respectively.

# Table 3-3: Heat Transfer Coefficients for Region 1 (40% Flow)

*Calculation of Heat Transfer Coefficients for Feedwater Nozzle Flow Path*

Pipe Inside Diameter, D = 9.669 inches = 0.806 ft
= 0.246 m

Flow, % of rated = 40%

*Fluid Velocity, V =* 8.022 *ft/sec =* 1,836.0 *gpm =* 0.793742524 *Mlb/hr*

Characteristic Length, L = D = 0.806 ft = 0.246 m

| 100% rated flow = | 4,590 | gpm |
|---|---|---|
| @ T = | 391.9 | °F |
| Density, ρ = | 53.8997 | $lbm/ft^3$ |

$T_{fluid} - T_{surface}$, ΔT = assumed to be 12% of fluid temperature = 8.40, 12.00, 24.00, 36.00, 48.00, 60.00, 72.00 °F
= 4.67, 6.67, 13.33, 20.00, 26.67, 33.33, 40.00 °C

*Note: The above assumption is based on experience with past RPV heat transfer analyses.*

| Water Property | Conversion Factor [24] | Value at Fluid Temperature, T [26] | | | | | | | Units |
|---|---|---|---|---|---|---|---|---|---|
| | | 70 | 100 | 200 | 300 | 400 | 500 | 600 | °F |
| | | 21.11 | 37.78 | 93.33 | 148.89 | 204.44 | 260.00 | 315.56 | °C |
| k | 1.7307 | 0.5997 | 0.6300 | 0.6784 | 0.6836 | 0.6611 | 0.6040 | 0.5071 | W/m-°C |
| (Thermal Conductivity) | | 0.3465 | 0.3640 | 0.3920 | 0.3950 | 0.3820 | 0.3490 | 0.2930 | Btu/hr-ft-°F |
| $c_p$ | 4.1869 | 4.185 | 4.179 | 4.229 | 4.313 | 4.522 | 4.982 | 6.322 | kJ/kg-°C |
| (Specific Heat) | | 1.000 | 0.998 | 1.010 | 1.030 | 1.080 | 1.190 | 1.510 | Btu/lbm-°F |
| ρ | 16.018 | 997.1 | 994.7 | 962.7 | 917.8 | 858.6 | 784.9 | 679.2 | $kg/m^3$ |
| (Density) | | 62.3 | 62.1 | 60.1 | 57.3 | 53.6 | 49.0 | 42.4 | $lbm/ft^3$ |
| β | 1.8 | 1.89E-04 | 3.24E-04 | 6.66E-04 | 1.01E-03 | 1.40E-03 | 1.98E-03 | 3.15E-03 | $m^3/m^3$-°C |
| (Volumetric Rate of Expansion) | | 1.05E-04 | 1.80E-04 | 3.70E-04 | 5.60E-04 | 7.80E-04 | 1.10E-03 | 1.75E-03 | $ft^3/ft^3$-°F |
| g | 0.3048 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | 9.806 | $m/s^2$ |
| (Gravitational Constant) | | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | 32.17 | $ft/s^2$ |
| μ | 1.4881 | 9.96E-04 | 6.82E-04 | 3.07E-04 | 1.93E-04 | 1.38E-04 | 1.04E-04 | 8.62E-05 | kg/m-s |
| (Dynamic Viscosity) | | 6.69E-04 | 4.58E-04 | 2.06E-04 | 1.30E-04 | 9.30E-05 | 7.00E-05 | 5.79E-05 | lbm/ft-s |
| Pr (Prandtl Number) | | 6.980 | 4.510 | 1.910 | 1.220 | 0.950 | 0.859 | 1.070 | --- |
| **Calculated Parameter** | **Formula** | 70 | 100 | 200 | 300 | 400 | 500 | 600 | °F |
| Reynold's Number, Re | $\rho VD/\mu$ | 6.0147E+05 | 8.7645E+05 | 1.8859E+06 | 2.8491E+06 | 3.7255E+06 | 4.5248E+06 | 4.7336E+06 | --- |
| Grashof Number, Gr | $g\beta\Delta TL^3/(\mu/\rho)^2$ | 1.2852E+08 | 6.6834E+08 | 1.2721E+10 | 6.5918E+10 | 2.0931E+11 | 5.4429E+11 | 1.1372E+12 | --- |
| Rayleigh Number, Ra | GrPr | 8.9710E+08 | 3.0142E+09 | 2.4297E+10 | 8.0420E+10 | 1.9885E+11 | 4.6755E+11 | 1.2168E+12 | --- |
| *From [24]:* *Inside Surface Forced Convection Heat Transfer Coefficient:* | | | | | | | | | |
| $H_{forced}$ = | $0.023Re^{0.8}Pr^{0.4}k/D$ | 5,132.76 | 6,119.10 | 8,626.61 | 10,107.53 | 10,960.57 | 11,236.63 | 10,678.39 | $W/m^2$-°C |
| | | 903.95 | 1,077.66 | 1,519.26 | 1,780.07 | 1,930.31 | 1,978.92 | 1,880.61 | $Btu/hr-ft^2$-°F |
| | | 1.744E-03 | 2.079E-03 | 2.931E-03 | 3.434E-03 | 3.724E-03 | 3.817E-03 | 3.628E-03 | $Btu/sec-in^2$-°F |
| *From [24]:* *Inside Surface Natural Convection Heat Transfer Coefficient:* | | | | | | | | | |
| Case: | Enclosed cylinder | | C = | 0.55 | n = | 0.25 | (see page 289 of [25]) | | |
| $H_{free}$ = | $C(GrPr)^n k/L$ | 232.43 | 330.57 | 599.85 | 815.28 | 988.69 | 1,118.54 | 1,192.73 | $W/m^2$-°C |
| | | 40.93 | 58.22 | 105.64 | 143.58 | 174.12 | 196.99 | 210.06 | $Btu/hr-ft^2$-°F |
| | | 7.896E-05 | 1.123E-04 | 2.038E-04 | 2.770E-04 | 3.359E-04 | 3.800E-04 | 4.052E-04 | $Btu/sec-in^2$-°F |

## Table 3-4: Blend Radius Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 1. Bolt-up | 0 | 70 | | 0 |
| 123 Cycles | 10 | 70 | 10 | 0 |
| 2. Design | 0 | 70 | | 0 |
| HYD Test | 1080 | 100 | 1080 | 0 |
| 120 Cycles | 1680 | 100 | 600 | 1100 |
| | 5280 | 100 | 3600 | 1100 |
| | 5880 | 100 | 600 | 50 |
| | 10880 | 100 | 5000 | 50 |
| 3. Startup | 0 | 100 | | 50 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 |
| LF_25 | 21164 | 549 | 5000 | 1010 |
| 4. Turbine Roll | 0 | 549 | | 1010 |
| and Increased to | 1 | 100 | 1 | 1010 |
| Rated | 1801 | 100 | 1800 | 1010 |
| Power | 1802 | 260 | 1 | 1010 |
| 300 cycles | 3602 | 392 | 1800 | 1010 |
| LF_25, HF_100 | 8602 | 392 | 5000 | 1010 |
| 5. Daily | 0 | 392 | | 1010 |
| Reduction | 900 | 310 | 900 | 1010 |
| 75% Power | 2700 | 310 | 1800 | 1010 |
| 10,000 Cycles | 3600 | 392 | 900 | 1010 |
| HF_100 | 8600 | 392 | 5000 | 1010 |
| 6. Weekly Reduct | 0 | 392 | | 1010 |
| 50% Power | 1800 | 280 | 1800 | 1010 |
| 2,000 Cycles | 3600 | 280 | 1800 | 1010 |
| HF_100 | 5400 | 392 | 1800 | 1010 |
| | 10400 | 392 | 5000 | 1010 |
| 9. Turbine | 0 | 392 | | 1010 |
| Trip at 25% | 1800 | 265 | 1800 | 1010 |
| Power | 1980 | 265 | 180 | 1010 |
| 10 Cycles | 2340 | 90 | 360 | 1010 |
| HF_100 | 2520 | 90 | 180 | 1010 |
| | 3420 | 265 | 900 | 1010 |
| | 3600 | 265 | 180 | 1010 |
| | 5400 | 392 | 1800 | 1010 |
| | 10400 | 392 | 5000 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 10. FW Heater | 0 | 392 | | 1010 |
| Bypass | 90 | 265 | 90 | 1010 |
| 70 Cycles | 1890 | 265 | 1800 | 1010 |
| HF_100 | 2070 | 392 | 180 | 1010 |
| | 7070 | 392 | 5000 | 1010 |
| 11. Loss of | 0 | 392 | | 1010 |
| FW Pumps | 1 | 565 | 1 | 1010 |
| 10 Cycles | 3.5 | 565 | 2.5 | 1190 |
| MF_40, HF_100 | 4.5 | 50 | 1 | 1185 |
| | 13.5 | 50 | 9 | 1135 |
| | 184.5 | 50 | 171 | 1135 |
| | 1564.5 | 440 | 1380 | 1135 |
| | 1565.5 | 565 | 1 | 1135 |
| | 2165.5 | 565 | 600 | 1135 |
| | 2166.5 | 50 | 1 | 1135 |
| | 2346.5 | 50 | 180 | 885 |
| | 5406.5 | 440 | 3060 | 1055 |
| | 5407.5 | 565 | 1 | 1055 |
| | 6727.5 | 565 | 1320 | 1135 |
| | 6728.5 | 50 | 1 | 1135 |
| | 7148.5 | 50 | 420 | 675 |
| | 7448.5 | 300 | 300 | 675 |
| | 11048.5 | 400 | 3600 | 232 |
| | 16411.5 | 549 | 5363 | 885 |
| | 16412.5 | 549 | 1 | 1010 |
| | 18212.5 | 549 | 1800 | 1010 |
| | 18213.5 | 100 | 1 | 1010 |
| | 20013.5 | 100 | 1800 | 1010 |
| | 20014.5 | 260 | 1 | 1010 |
| | 21814.5 | 392 | 1800 | 1010 |
| | 26814.5 | 392 | 5000 | 1010 |
| 12. Turbine | 0 | 392 | | 1010 |
| Generator Trip | 10 | 392 | *10* | 1135/1375[2] |
| 60 Cycles | 15 | 392 | *5* | 1135/1375[2] |
| 13. Reactor | 30 | 392 | 15 | 940 |
| Overpressure | 90 | 275 | 60 | 940 |
| 1 Cycles | 990 | 100 | 900 | 940 |
| 15. Other | 2790 | 100 | 1800 | 940 |
| SCRAMs | 2791 | 260 | 1 | 940 |
| 228 cycles | 3210 | 291 | 419 | 1010 |
| HF_100 | 4591 | 392 | 1381 | 1010 |
| | 9591 | 392 | 5000 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 14. SRV | 0 | 392 | | 1010 |
| Blowdown | 60 | 275 | 60 | 885 |
| 1 Cycles | 960 | 100 | 900 | 50 |
| HF_100 | 5960 | 100 | 5000 | 50 |
| 19. Reduction to 0% | 0 | 392 | | 1010 |
| Power 300 Cycles | 1800 | 265 | 1800 | 1010 |
| HF_100 | 6800 | 265 | 5000 | 1010 |
| 20. Hot Standby | 0 | 265 | | 1010 |
| (Heatup Portion) | 1 | 440 | 1 | 1010 |
| 300 Cycles | 3925 | 549 | 3924 | 1010 |
| LF_25 | 8925 | 549 | 5000 | 1010 |
| 20A. Hot Standby | 0 | 549 | | 1010 |
| (FW Injection Portion) | 1 | 100 | 1 | 1010 |
| 300 Cycles | 181 | 100 | 180 | 1010 |
| LF_25 | 241 | 290 | 60 | 1010 |
| | 451 | 549 | 210 | 1010 |
| | 5451 | 549 | 5000 | 1010 |
| 21-23. Shutdown | 0 | 549 | | 1010 |
| 300 Cycles | 6264 | 375 | 6264 | 50 |
| LF_25 | 6864 | 330 | 600 | 50 |
| | 15144 | 100 | 8280 | 50 |
| | 20144 | 100 | 5000 | 50 |
| 24. Hydrostatic | 0 | 100 | | 50 |
| Test | 600 | 100 | 600 | 1563 |
| 1 Cycles | 1200 | 100 | 600 | 1563 |
| | 1800 | 100 | 600 | 50 |
| | 2400 | 100 | 600 | 50 |
| 25. Unbolt | 0 | 100 | | 0 |
| 123 Cycles | 1080 | 70 | 1080 | 0 |
| | 6080 | 70 | 5000 | 0 |

*Note: 1. The indicated time or pressure was assumed.*
*2. 1375 psi is for Transient 13 only.*

## Table 3-5: Safe End Transient

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 1. Bolt-up | 0 | 70 | | 0 |
| 123 Cycles | 10 | 70 | 10 | 0 |
| 2. Design | 0 | 70 | | 0 |
| HYD Test | 1080 | 100 | 1080 | 0 |
| 123 Cycles | 1580 | 100 | 600 | 1100 |
| | 5280 | 100 | 3600 | 1100 |
| | 5880 | 100 | 600 | 50 |
| | 6380 | 100 | 500 | 50 |
| 3. Startup | 0 | 100 | | 50 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 |
| LF_25 | 16664 | 549 | 500 | 1010 |
| 4. Turbine Roll | 0 | 549 | | 1010 |
| and Increased to | 1 | 100 | 1 | 1010 |
| Rated | 1801 | 100 | 1800 | 1010 |
| Power | 1802 | 260 | 1 | 1010 |
| 300 cycles | 3602 | 392 | 1800 | 1010 |
| LF_25, HF_100 | 4102 | 392 | 500 | 1010 |
| 5. Daily | 0 | 392 | | 1010 |
| Reduction | 900 | 310 | 900 | 1010 |
| 75% Power | 2700 | 310 | 1800 | 1010 |
| 10,000 Cycles | 3600 | 392 | 900 | 1010 |
| HF_100 | 4100 | 392 | 500 | 1010 |
| 6. Weekly Reduc: | 0 | 392 | | 1010 |
| 50% Power | 1800 | 280 | 1800 | 1010 |
| 2,000 Cycles | 3600 | 280 | 1800 | 1010 |
| HF_100 | 5400 | 392 | 1800 | 1010 |
| | 5900 | 392 | 500 | 1010 |
| 9. Turbine | 0 | 392 | | 1010 |
| Trip at 25% | 1800 | 265 | 1800 | 1010 |
| Power | 1980 | 265 | 180 | 1010 |
| 10 Cycles | 2340 | 90 | 360 | 1010 |
| HF_100 | 2520 | 90 | 180 | 1010 |
| | 3420 | 265 | 900 | 1010 |
| | 3600 | 265 | 180 | 1010 |
| | 5400 | 392 | 1800 | 1010 |
| | 5900 | 392 | 500 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 10. FW Heater | 0 | 392 | | 1010 |
| Bypass | 90 | 265 | 90 | 1010 |
| 70 Cycles | 1890 | 265 | 1800 | 1010 |
| HF_100 | 2070 | 392 | 180 | 1010 |
| | 2570 | 392 | 500 | 1010 |
| 11. Loss of | 0 | 392 | | 1010 |
| FW Pumps | 1 | 565 | 1 | 1010 |
| 10 Cycles | 3.5 | 565 | 2.5 | 1190 |
| MF_40, HF_100 | 4.5 | 50 | 1 | 1185 |
| | 13.5 | 50 | 9 | 1135 |
| | 184.5 | 50 | 171 | 1135 |
| | 1564.5 | 440 | 1380 | 1135 |
| | 1565.5 | 565 | 1 | 1135 |
| | 2165.5 | 565 | 600 | 1135 |
| | 2166.5 | 50 | 1 | 1135 |
| | 2346.5 | 50 | 180 | 865 |
| | 5406.5 | 440 | 3060 | 1055 |
| | 5407.5 | 565 | 1 | 1055 |
| | 6727.5 | 565 | 1320 | 1135 |
| | 6728.5 | 50 | 1 | 1135 |
| | 7148.5 | 50 | 420 | 675 |
| | 7448.5 | 300 | 300 | 675 |
| | 11048.5 | 400 | 3600 | 232 |
| | 16411.5 | 549 | 5363 | 885 |
| | 16412.5 | 549 | 1 | 1010 |
| | 18212.5 | 549 | 1800 | 1010 |
| | 18213.5 | 100 | 1 | 1010 |
| | 20013.5 | 100 | 1800 | 1010 |
| | 20014.5 | 260 | 1 | 1010 |
| | 21814.5 | 392 | 1800 | 1010 |
| | 22314.5 | 392 | 500 | 1010 |
| 12. Turbine | 0 | 392 | | 1010 |
| Generator Trip | 10 | 392 | 10 | 1135/1375[3] |
| 60 Cycles | 15 | 392 | 5 | 1135/1375[3] |
| 13. Reactor | 30 | 392 | 15 | 940 |
| Overpressure | 90 | 275 | 60 | 940 |
| 1 Cycles | 990 | 100 | 900 | 940 |
| 15. Other | 2790 | 100 | 1800 | 940 |
| SCRAMs | 2791 | 260 | 1 | 940 |
| 228 cycles | 3210 | 291 | 419 | 1010 |
| HF_100 | 4591 | 392 | 1381 | 1010 |
| | 5091 | 392 | 500 | 1010 |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) |
|---|---|---|---|---|
| 14. SRV | 0 | 392 | | 1010 |
| Blowdown | 60 | 275 | 60 | 885 |
| 1 Cycles | 960 | 100 | 900 | 50 |
| HF_100 | 1460 | 100 | 500 | 50 |
| 19. Reduction to 0% | 0 | 392 | | 1010 |
| Power 300 Cycles | 1800 | 265 | 1800 | 1010 |
| HF_100 | 2300 | 265 | 500 | 1010 |
| 20. Hot Standby | 0 | 265 | | 1010 |
| (Heatup Portion) | 1 | 440 | 1 | 1010 |
| 300 Cycles | 3925 | 549 | 3924 | 1010 |
| LF_25 | 4425 | 549 | 500 | 1010 |
| 20A. Hot Standby | 0 | 549 | | 1010 |
| (FW Injection Portion) | 1 | 100 | 1 | 1010 |
| 300 Cycles | 181 | 100 | 180 | 1010 |
| LF_25 | 241 | 290 | 60 | 1010 |
| | 451 | 549 | 210 | 1010 |
| | 951 | 549 | 500 | 1010 |
| 21-23. Shutdown | 0 | 549 | | 1010 |
| 300 Cycles | 6264 | 375 | 6264 | 50 |
| LF_25 | 6864 | 330 | 600 | 50 |
| | 15144 | 100 | 8280 | 50 |
| | 15644 | 100 | 500 | 50 |
| 24. Hydrostatic | 0 | 100 | | 50 |
| Test | 600 | 100 | 600 | 1563 |
| 1 Cycles | 1200 | 100 | 600 | 1563 |
| | 1800 | 100 | 600 | 50 |
| | 2400 | 100 | 600 | 50 |
| 25. Unbolt | 0 | 100 | | 0 |
| 123 Cycles | 1080 | 70 | 1080 | 0 |
| | 1580 | 70 | 500 | 0 |

*Note:* 1. *These transients are the same as in Table 3-4 with the exception of the 500 second steady state time increment that is used. The transients in Table 3-4 are plotted using a 5000 second steady state increment. The difference is due to the length of the Green's Function for the safe end which is shorter compared to the blend Radius.*

2. *The indicated time or pressure was assumed.*

3. *1375 psi is for Transient 13 only.*

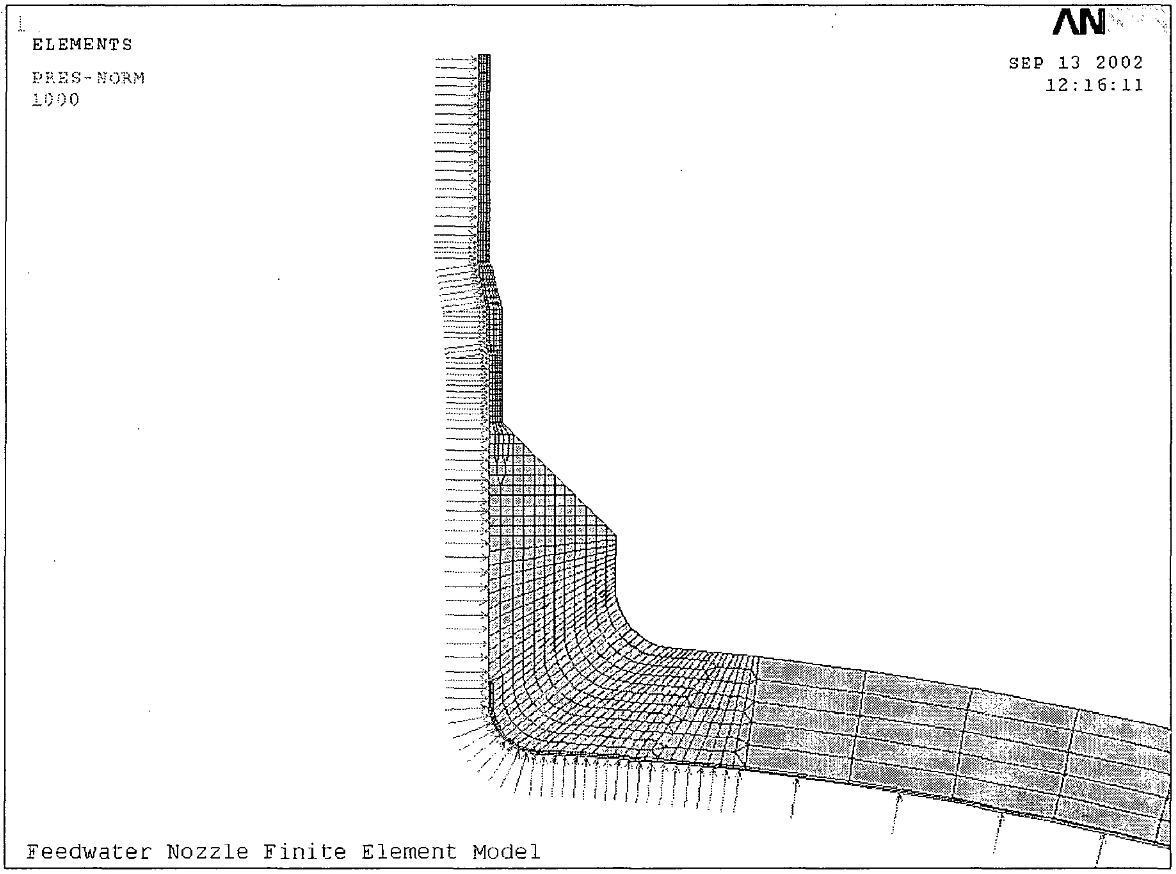



**Figure 3-1: Feedwater Nozzle Internal Pressure Distribution**

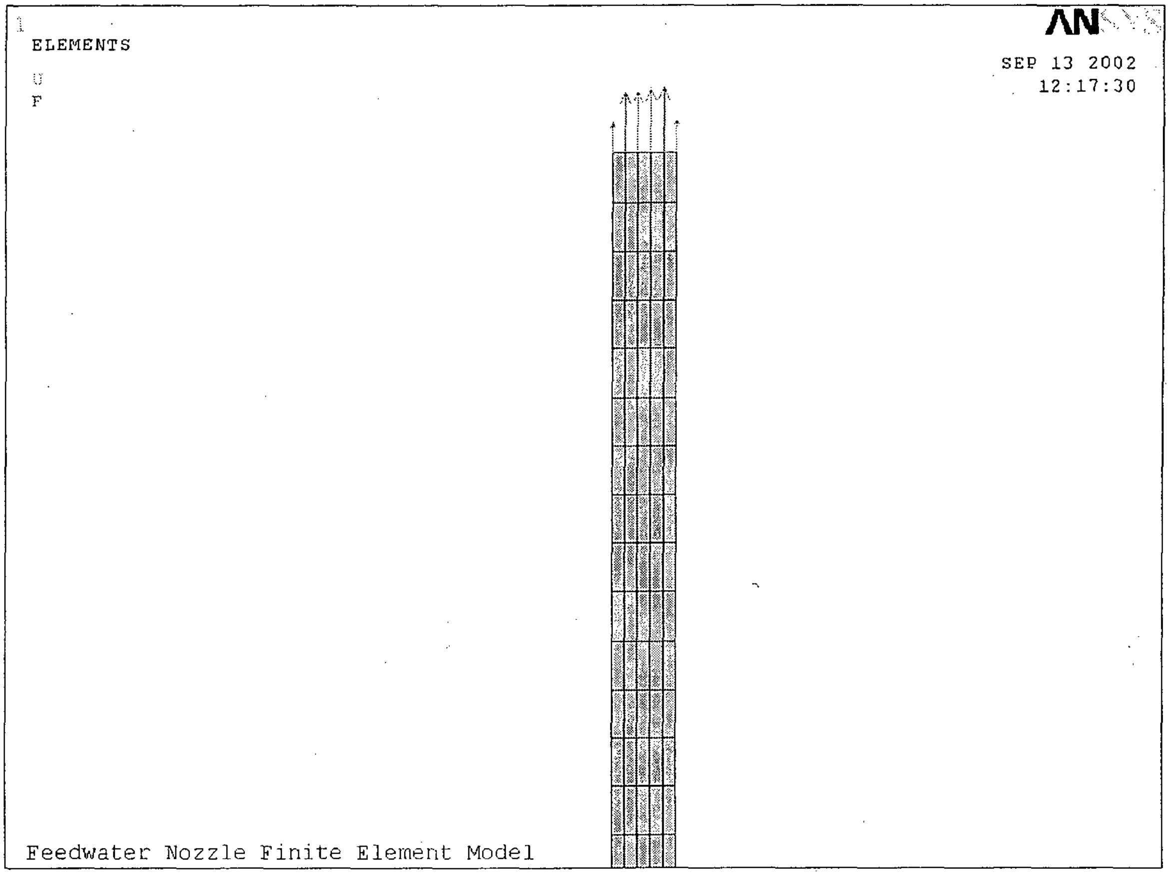



**Figure 3-2: Feedwater Nozzle Pressure Cap Load**

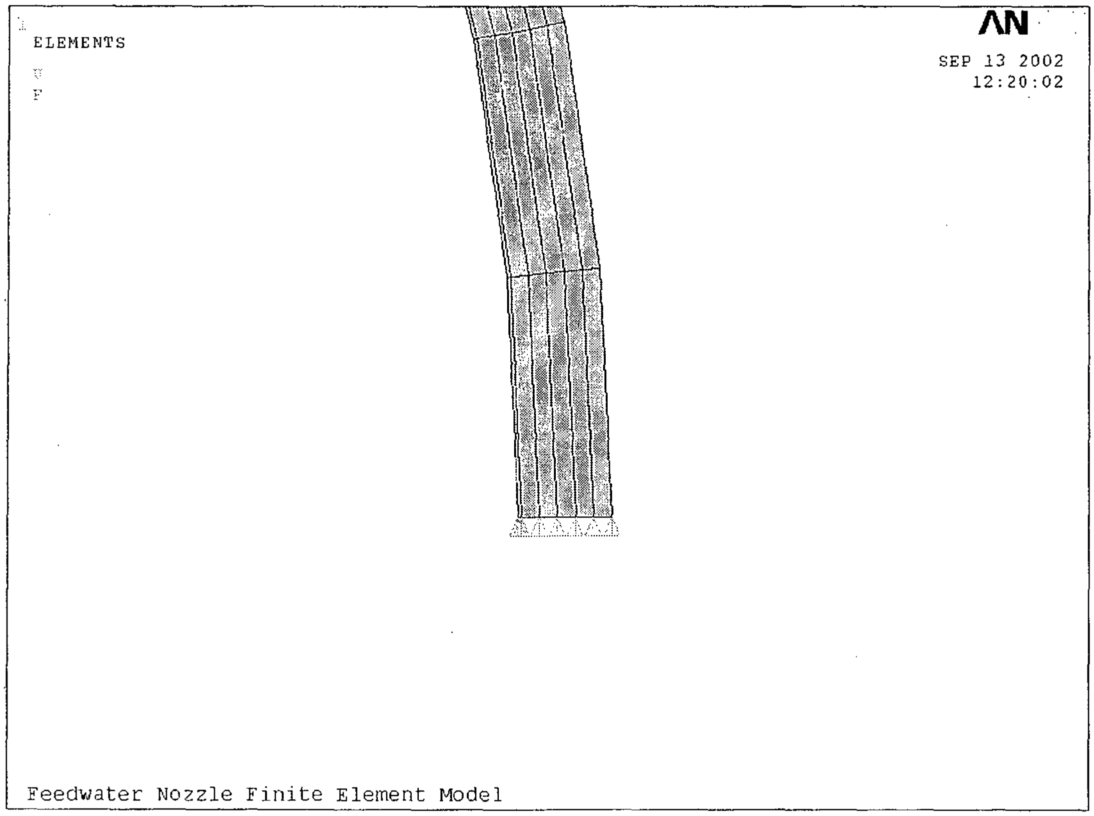
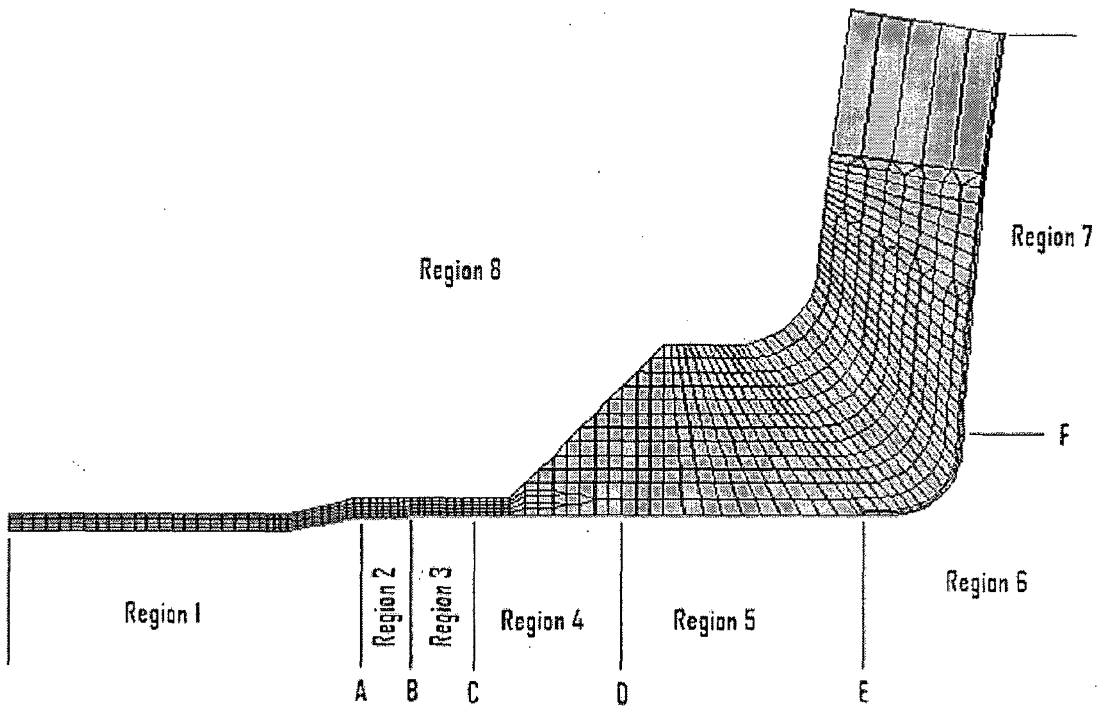



**Figure 3-3: Feedwater Nozzle Vessel Boundary Condition**




Notes: Point A: End of thermal sleeve = Node 204 = 0.25" from feedwater inlet side of thermal sleeve flat per Reference [8].
Point B: Beginning of annulus = Node 252.
Point C: Beginning of thermal sleeve transition = approximately 4.0" from Point A per Reference [8] = Node 294.
Point D: End of thermal sleeve transition = approximately 9.5" from Point A per Reference [8] = Node 387.
Point E: End of inner blend radius (nozzle side) = Node 553.
Point F: End of inner blend radius (vessel wall side) = Node 779.

**Figure 3-4: Thermal Regions**

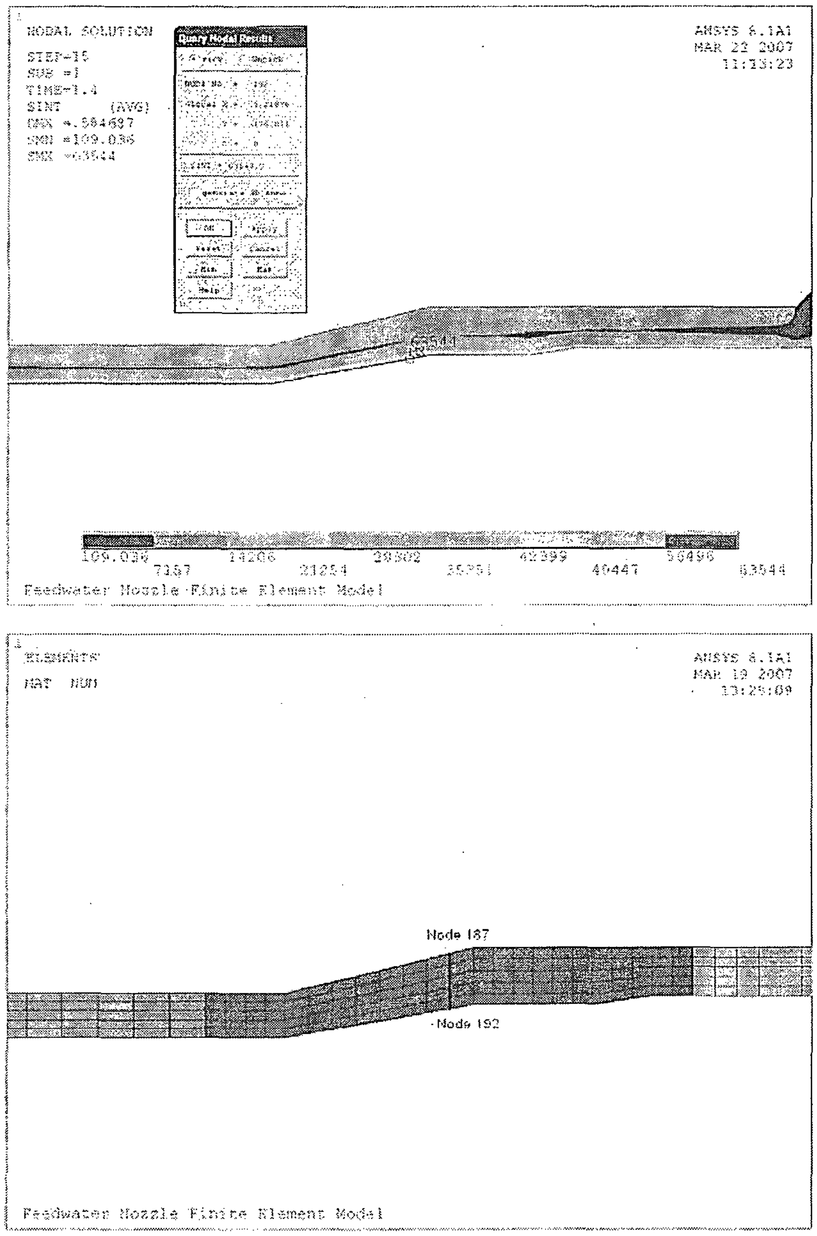
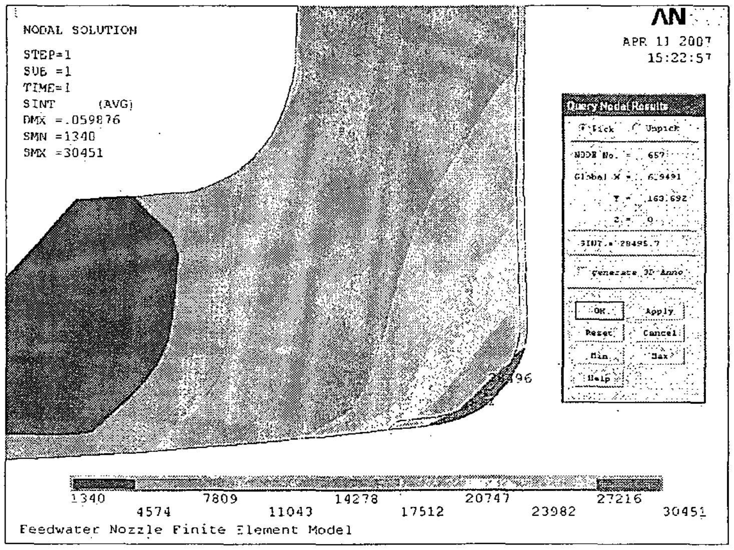



**Figure 3-5: Safe End Critical Thermal Stress Location and Linearized Stress Paths**



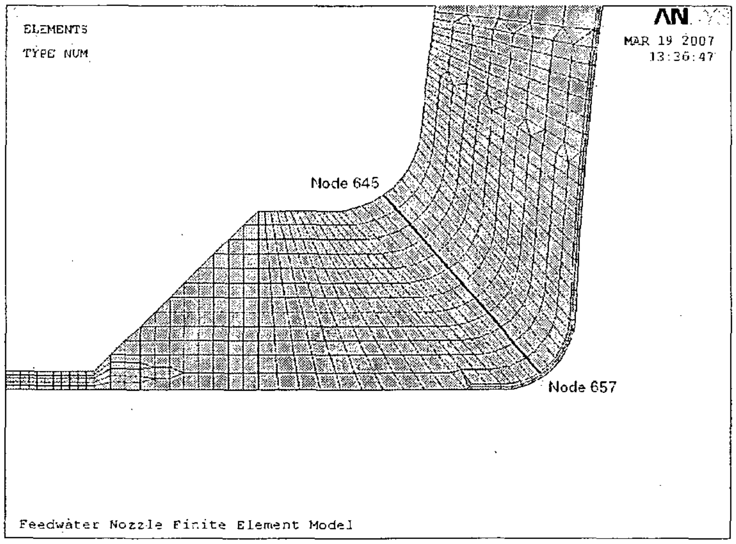




**Figure 3-6: Brand Radius Critical Thermal Stress Location and Linearized Stress Paths**

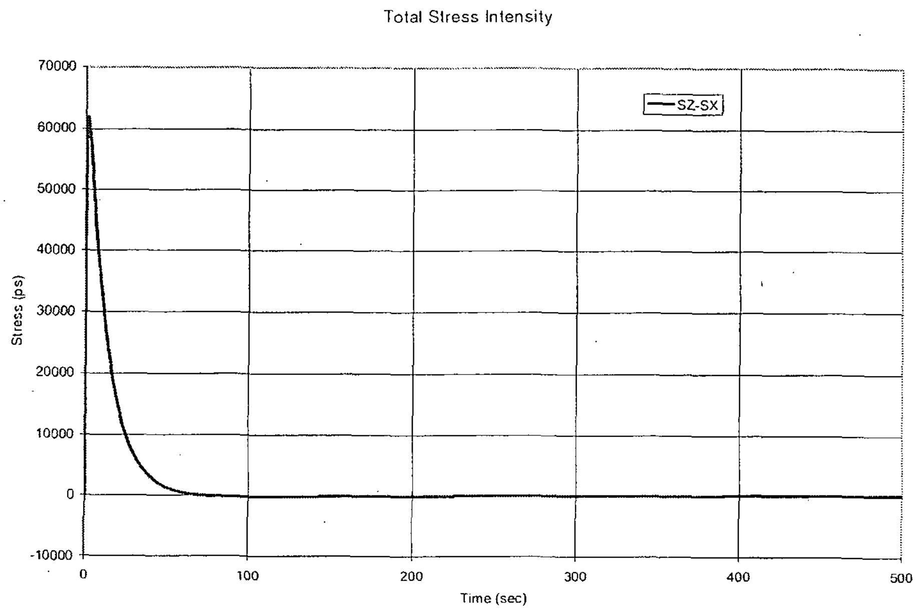



**Figure 3-7: Safe End Total Stress History for 100% Flow**

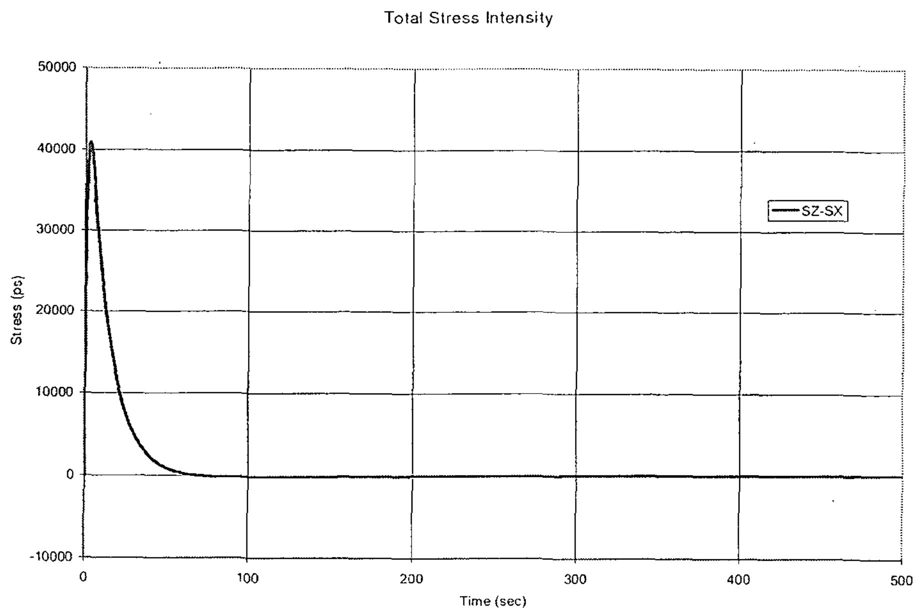



**Figure 3-8: Safe End Membrane Plus Bending Stress History for 100% Flow**

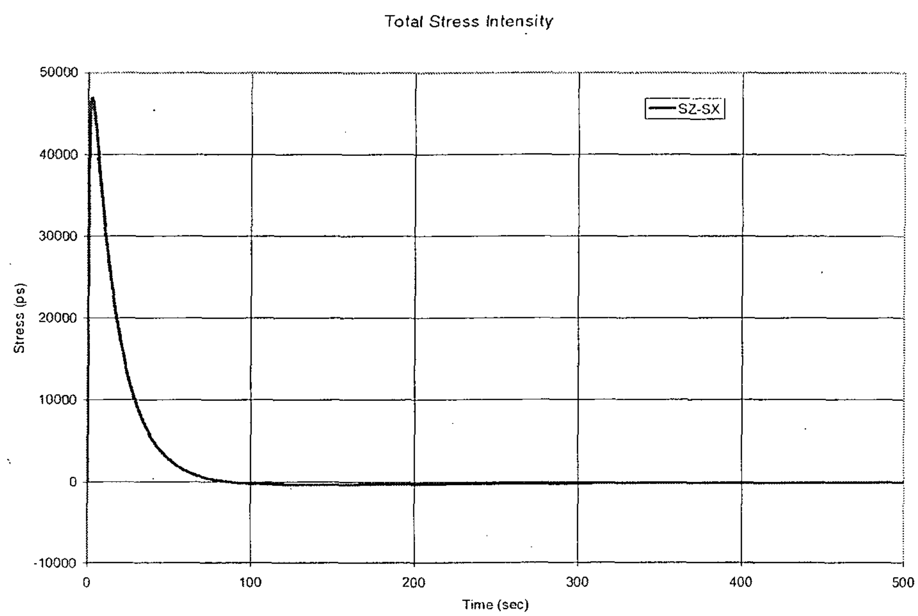



**Figure 3-9: Safe End Total Stress History for 40% Flow**

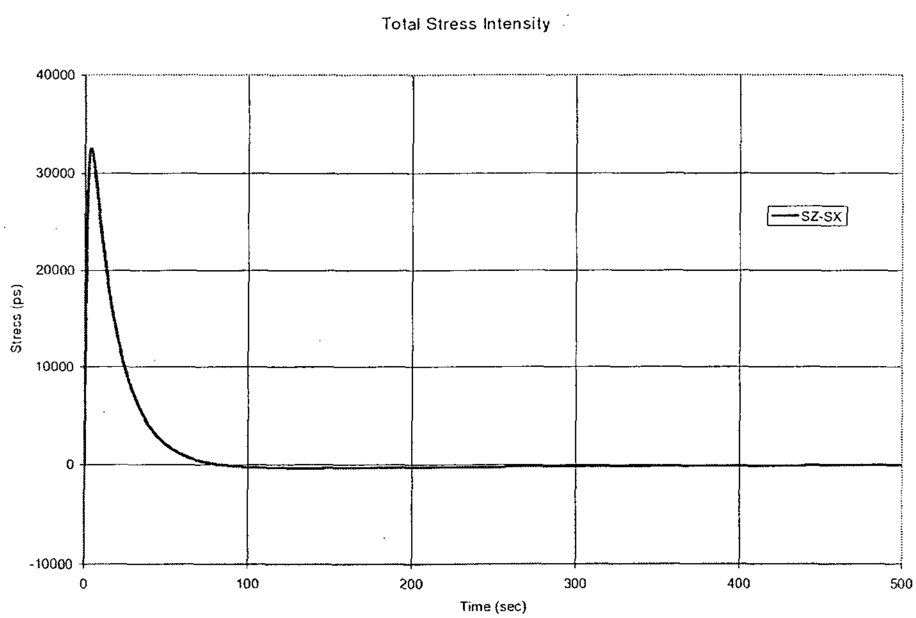



**Figure 3-10: Safe End Membrane Plus Bending Stress History for 40% Flow**

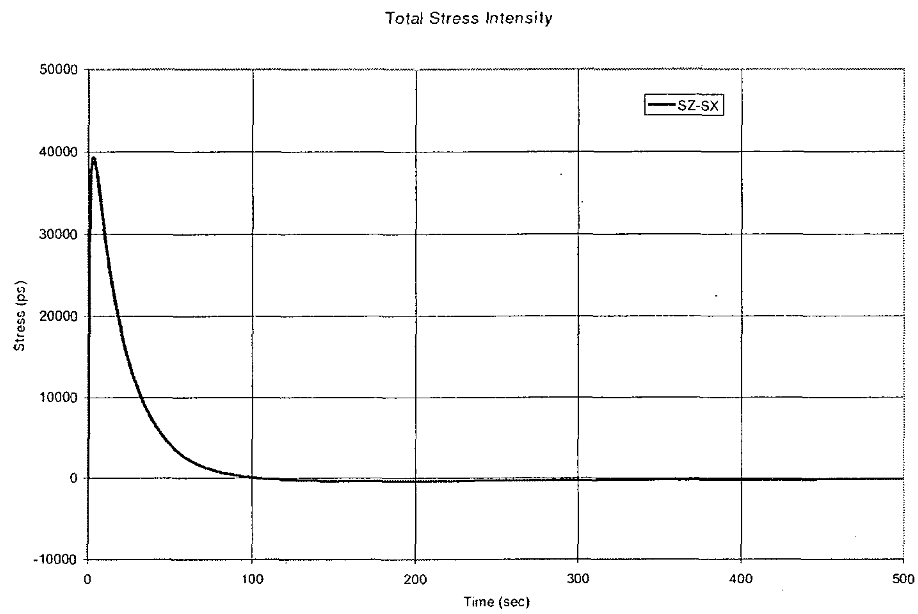



**Figure 3-11: Safe End Total Stress History for 25% Flow**

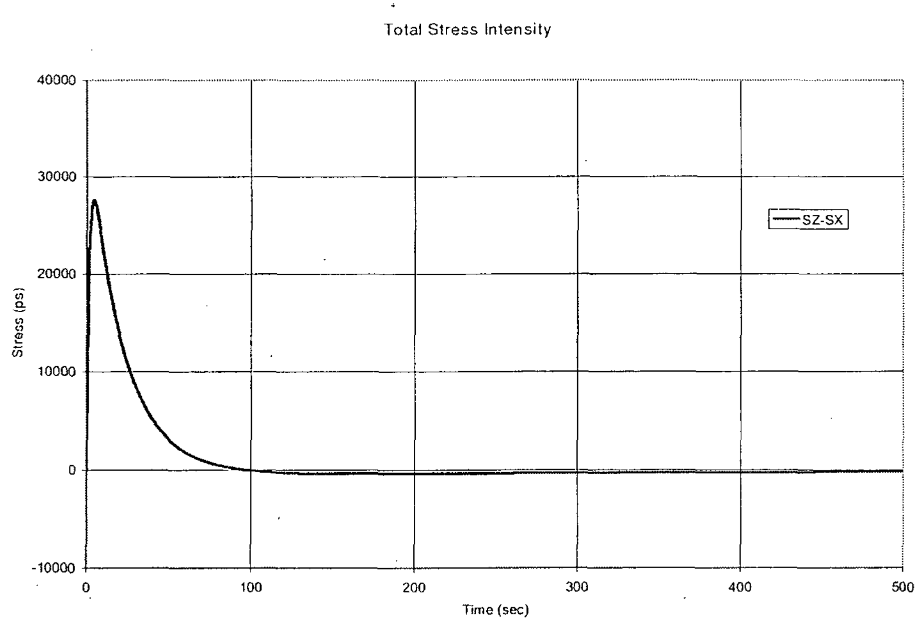



**Figure 3-12: Safe End Membrane Plus Bending Stress History for 25% Flow**

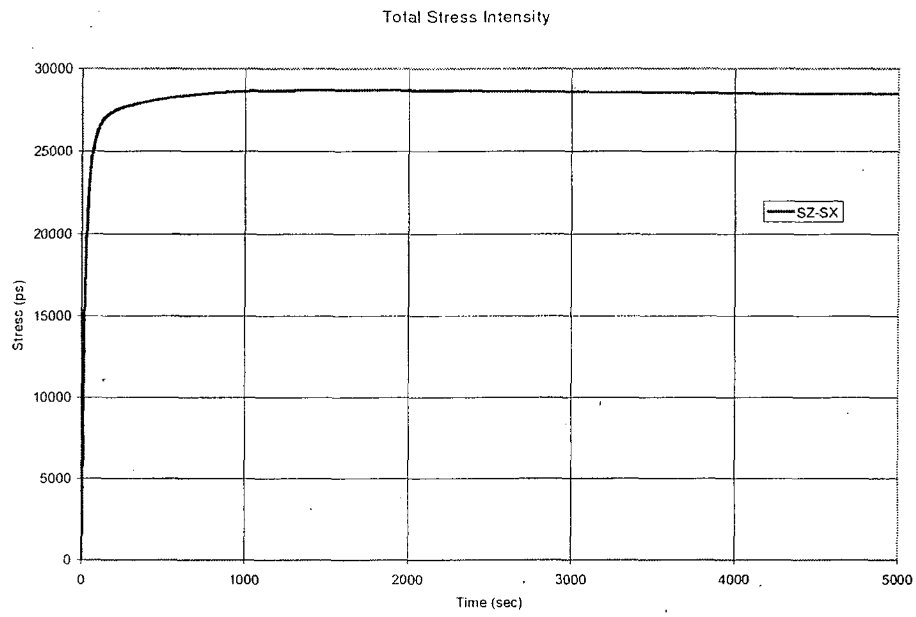



**Figure 3-13: Blend Radius Total Stress History for 100% Flow**

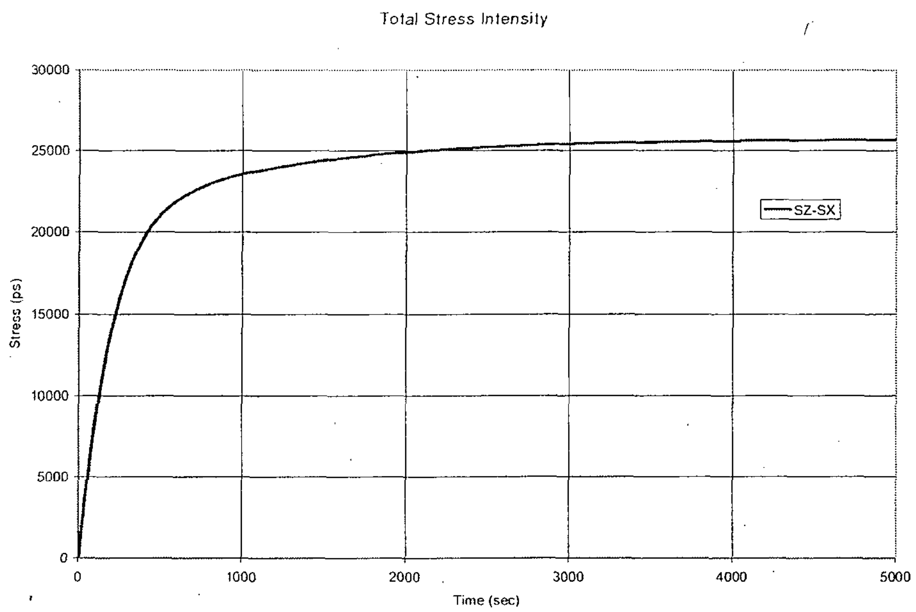



**Figure 3-14: Blend Radius Membrane Plus Bending Stress History for 100% Flow**

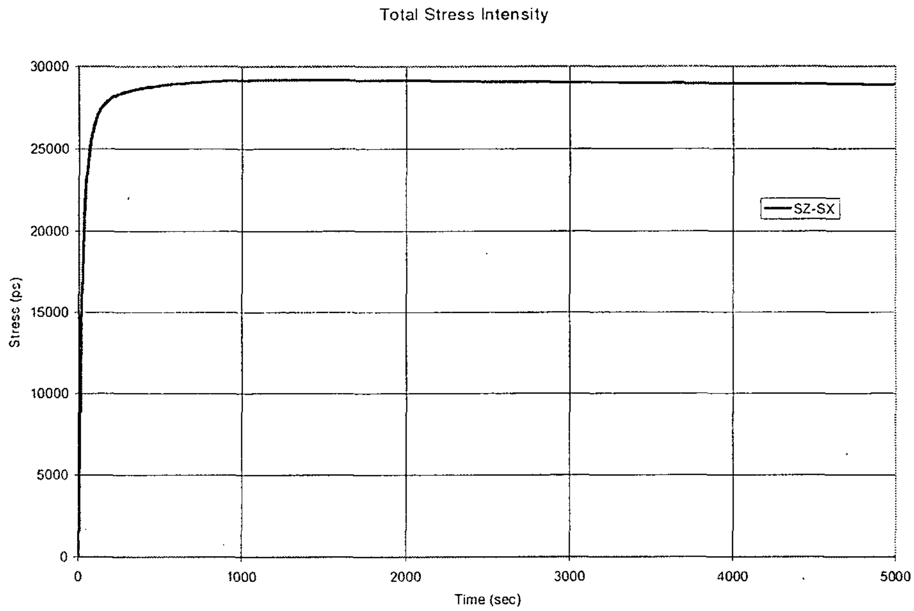



**Figure 3-15: Blend Radius Total Stress History for 40% Flow**

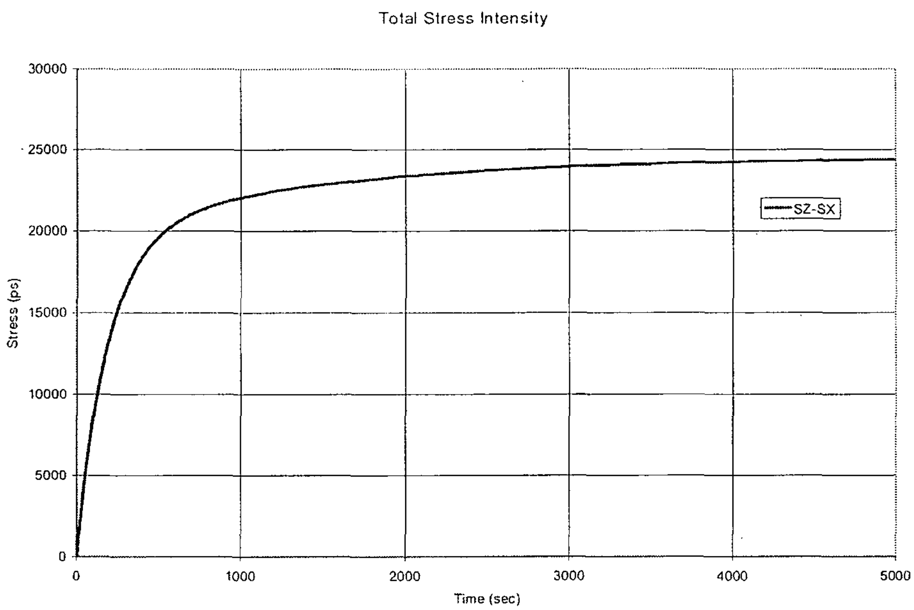



**Figure 3-16: Blend Radius Membrane Plus Bending Stress History for 40% Flow**

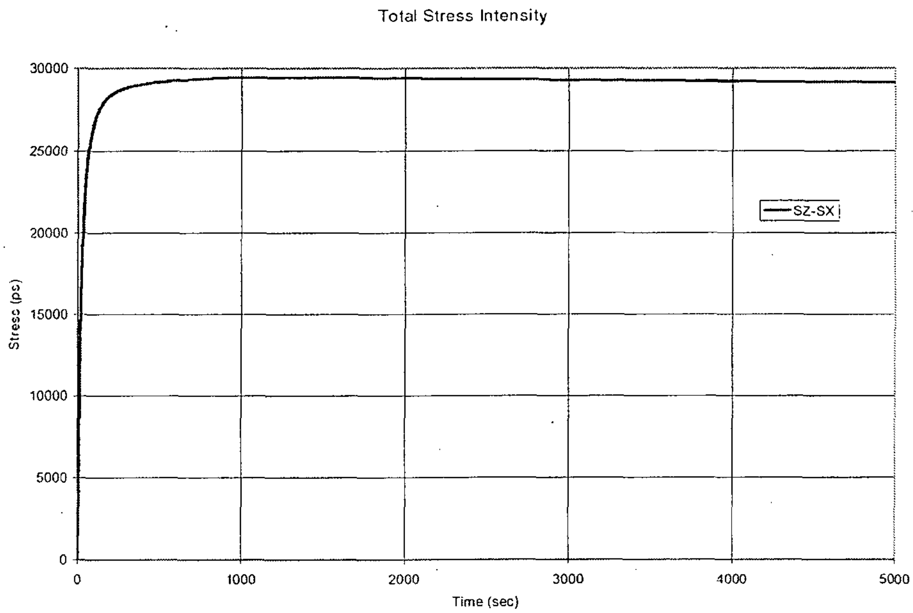



**Figure 3-17: Blend Radius Total Stress History for 25% Flow**

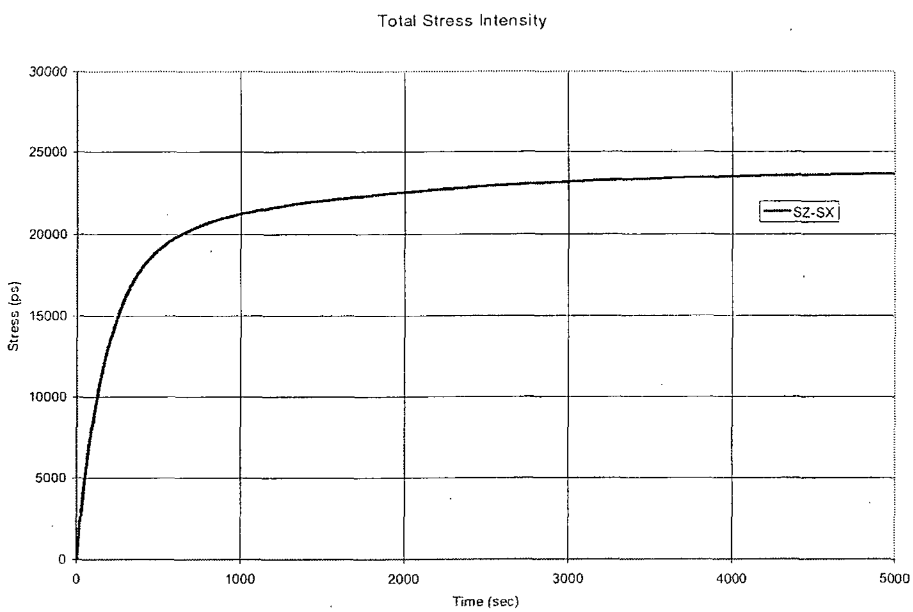



**Figure 3-18: Blend Radius Membrane Plus Bending Stress History for 25% Flow**

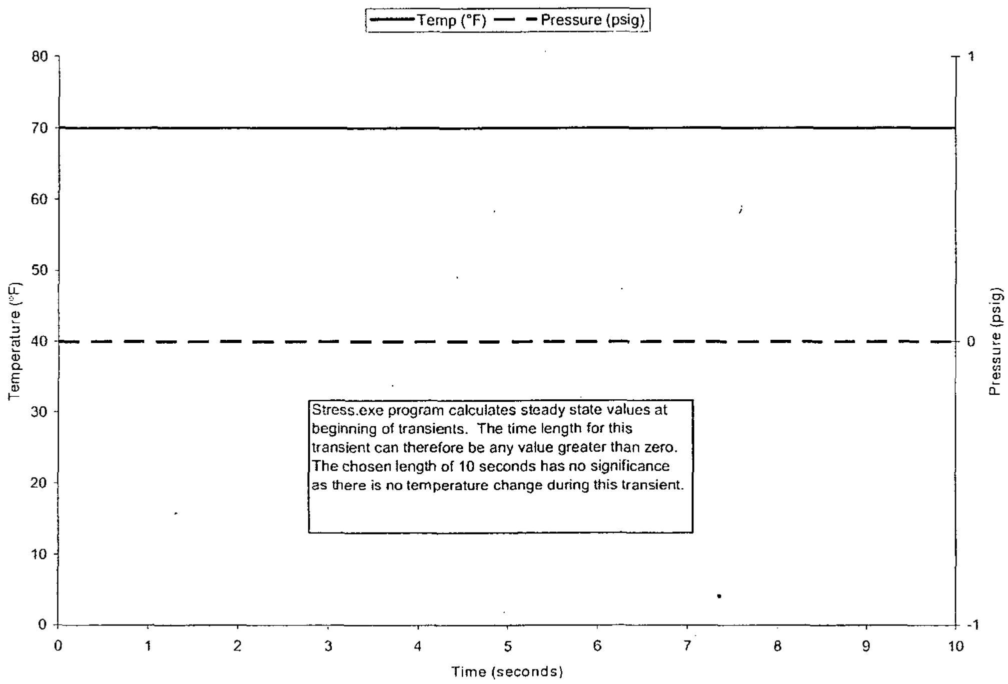



**Figure 3-19: Transient 1, Bolt-up**

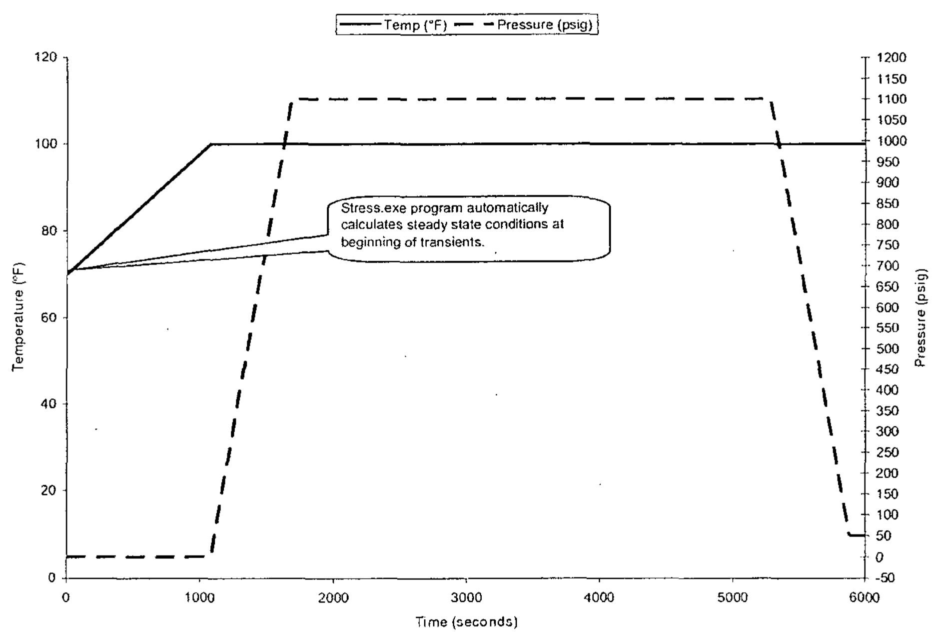



**Figure 3-20: Transient 2, Design HYD Test**

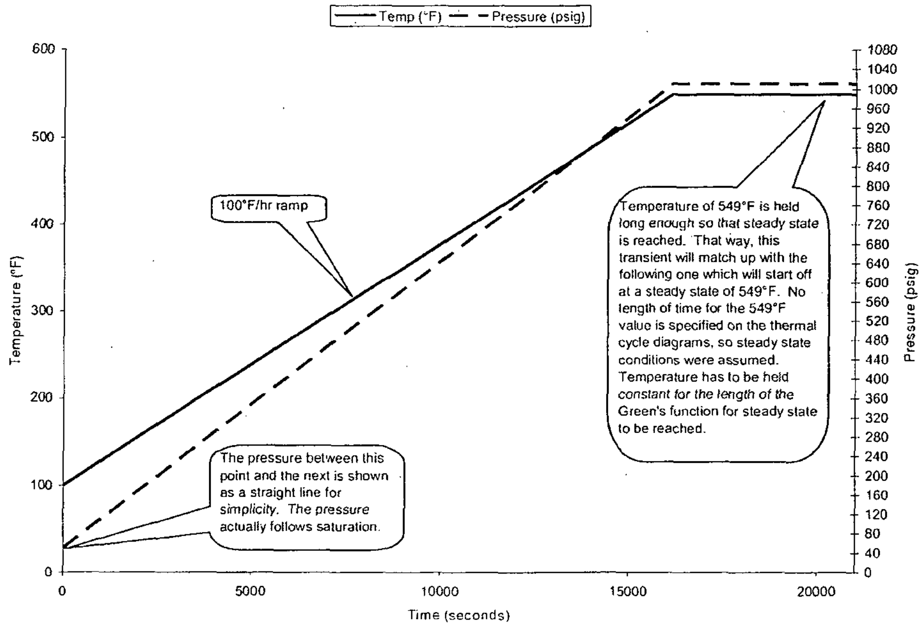



Figure 3-21: Transient 3, Startup

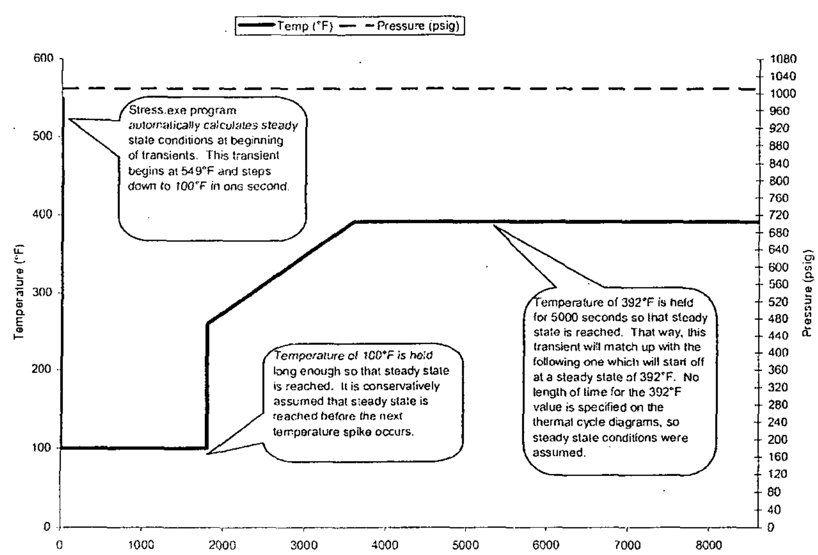



Figure 3-22: Transient 4, Turbine Roll and Increased to Rated Power

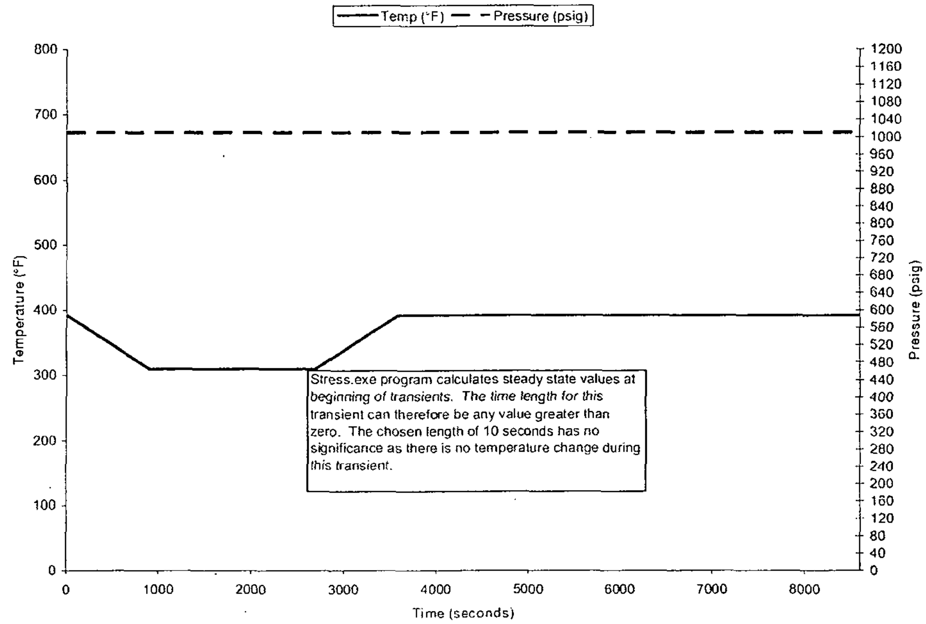



**Figure 3-23: Transient 5, Daily Reduction 75% Power**

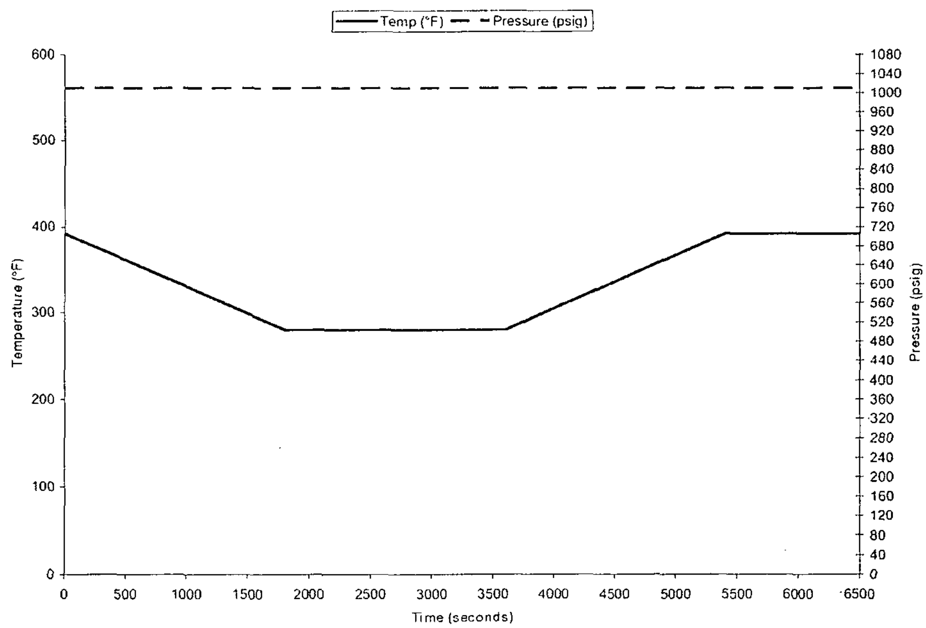



**Figure 3-24: Transient 6, Weekly Reduction 50% Power**

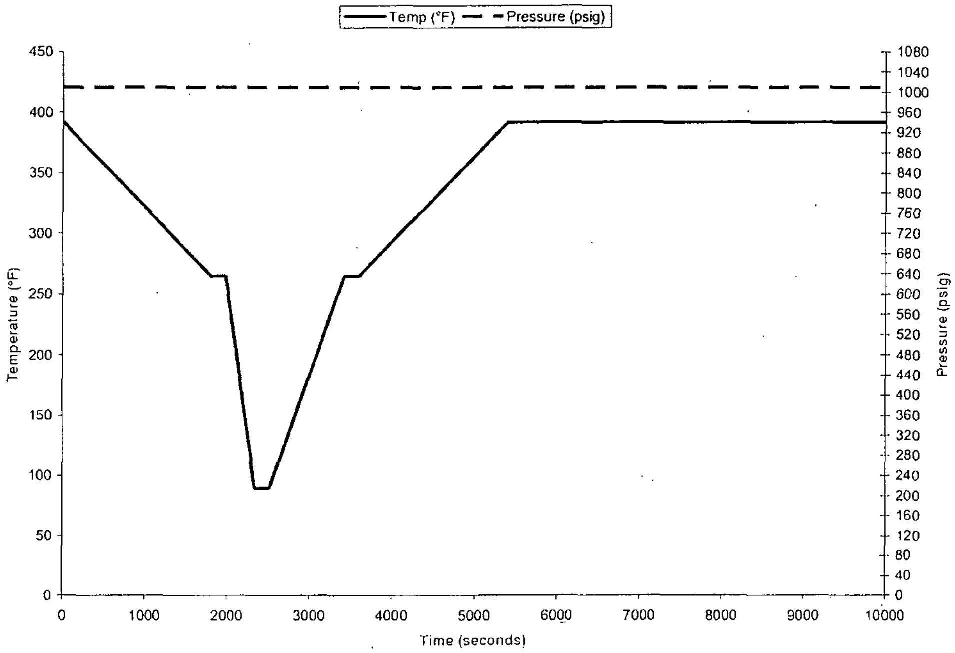



**Figure 3-25: Transient 9, Turbine Trip at 25% Power**

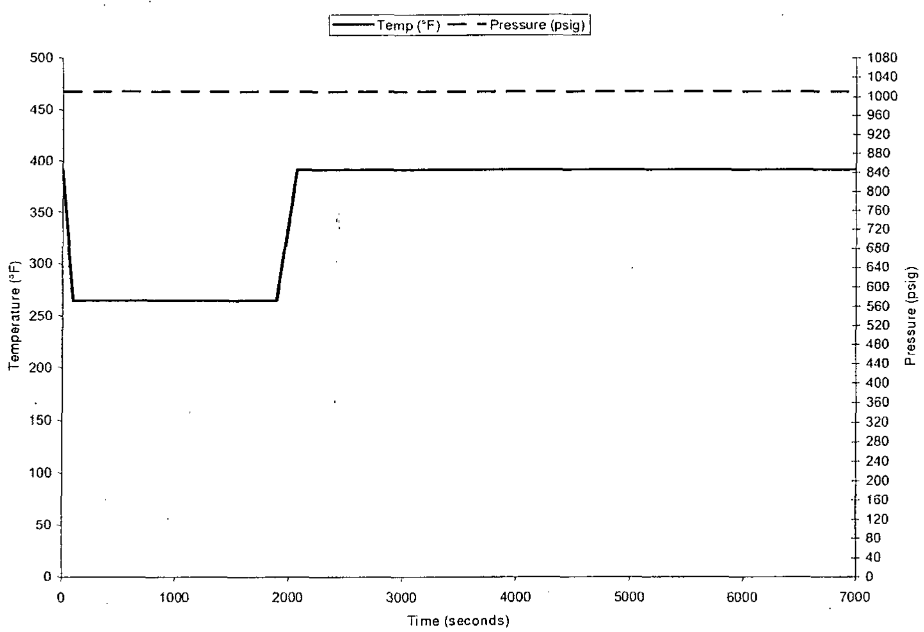



**Figure 3-26: Transient 10, Feedwater Bypass**

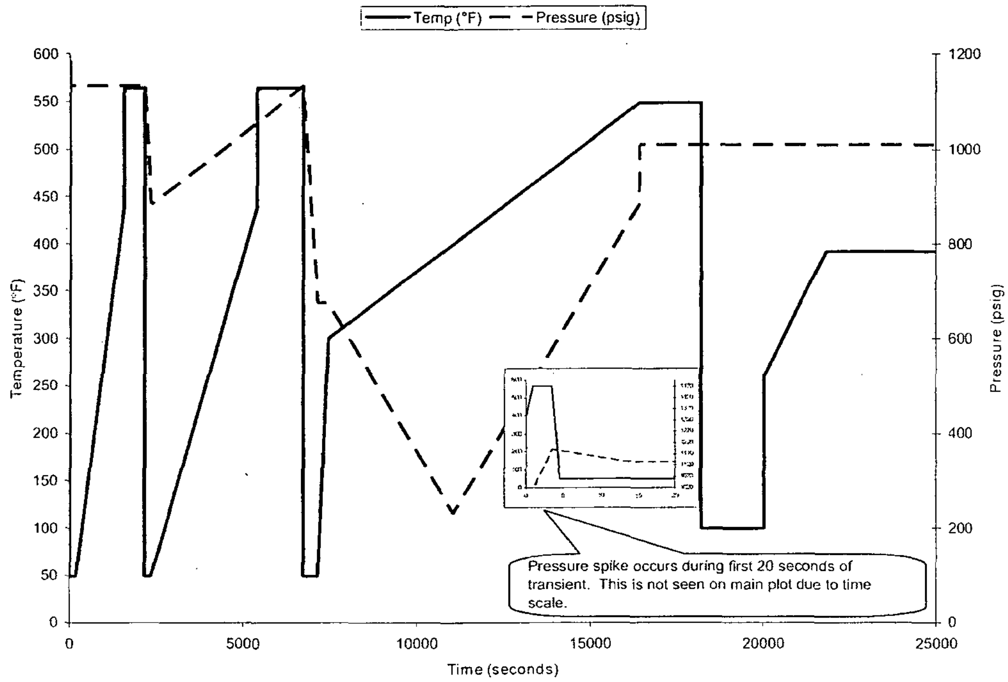



**Figure 3-27: Transient 11, Loss of Feedwater Pumps**

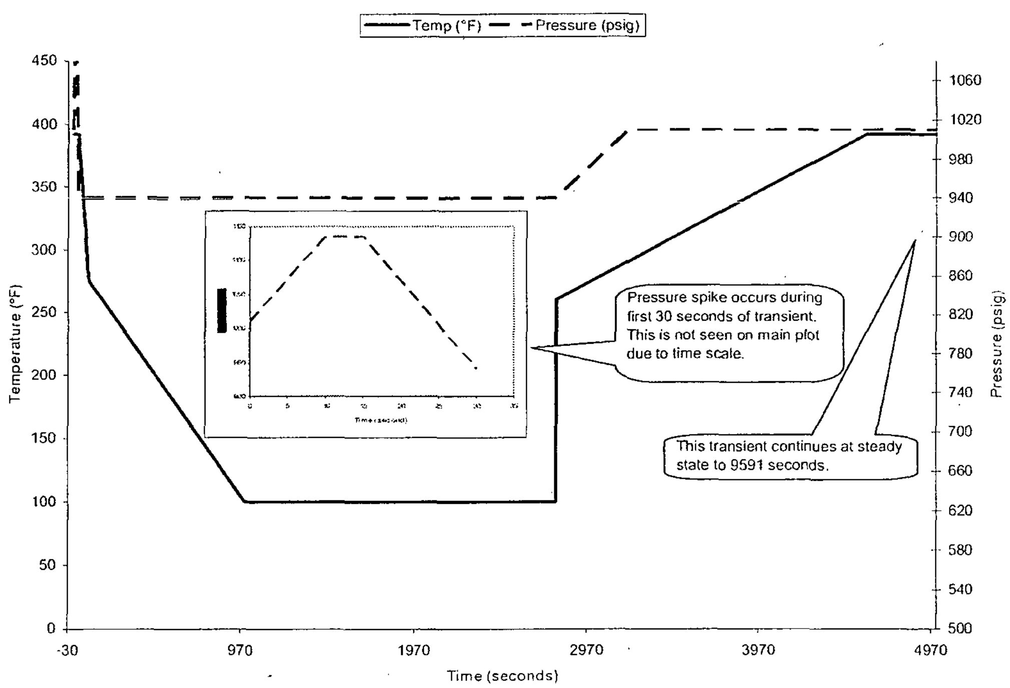



**Figure 3-28: Transient 12, Turbine Generator Trip**

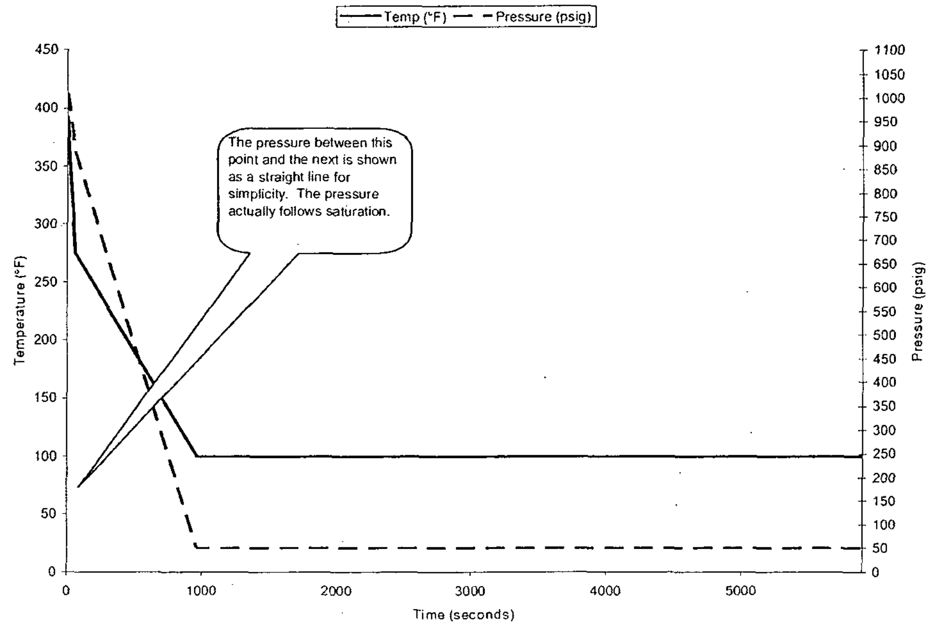



**Figure 3-29: Transient 14, SRV Blowdown**

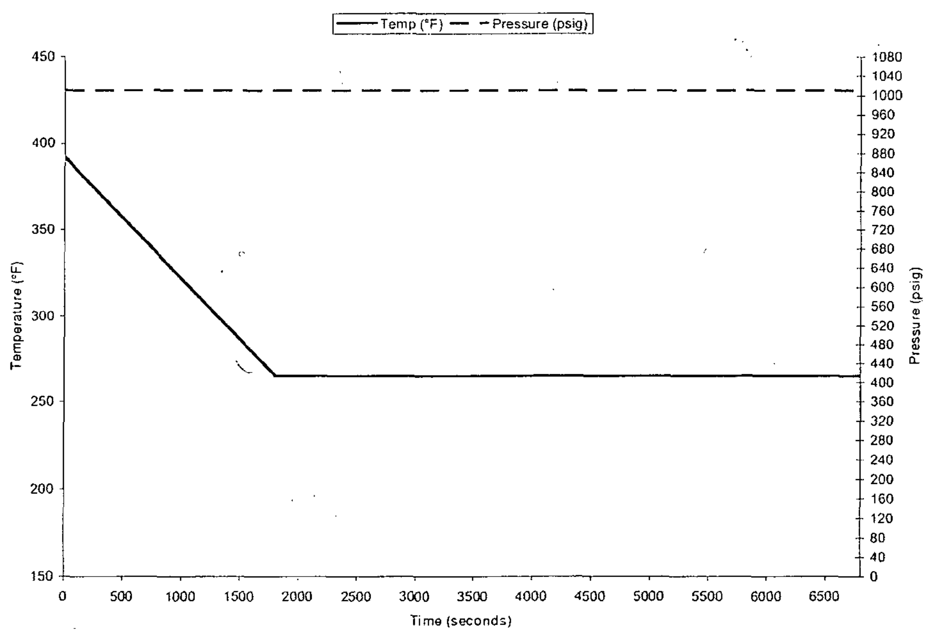



**Figure 3-30: Transient 19, Reduction to 0% Power**

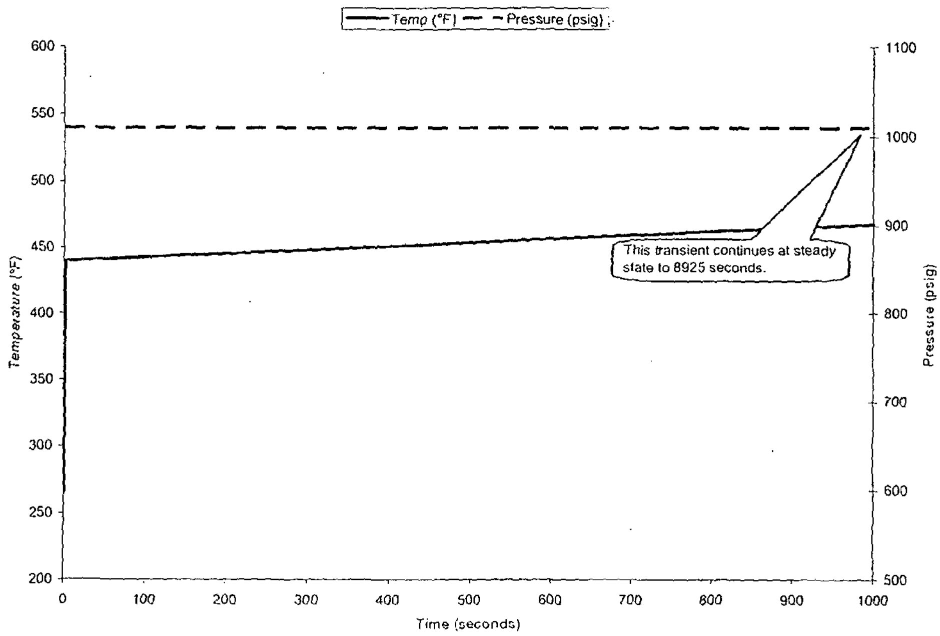



**Figure 3-31: Transient 20, Hot Standby (Heatup Portion)**

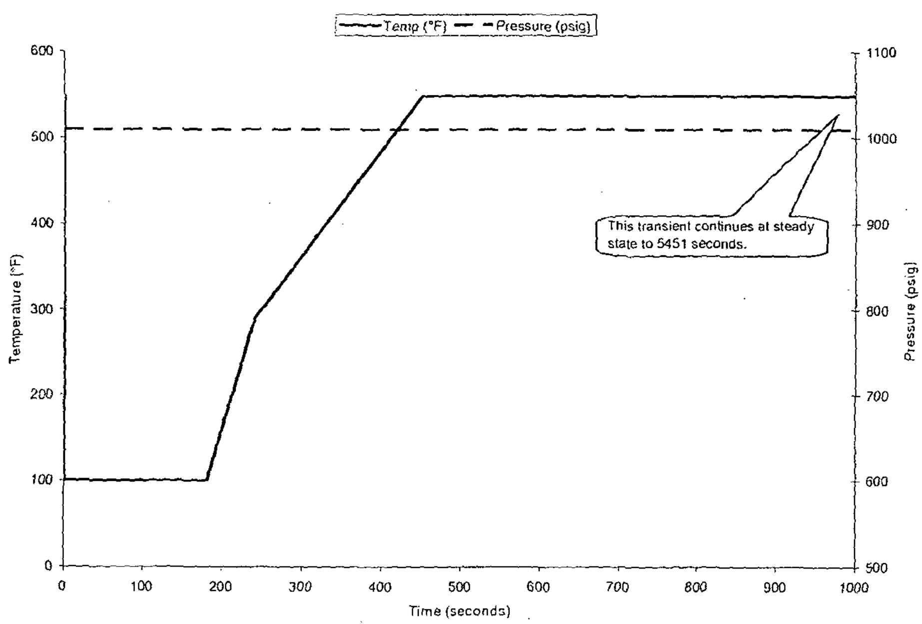



**Figure 3-32: Transient 20A, Hot Standby (Feedwater Injection Portion)**

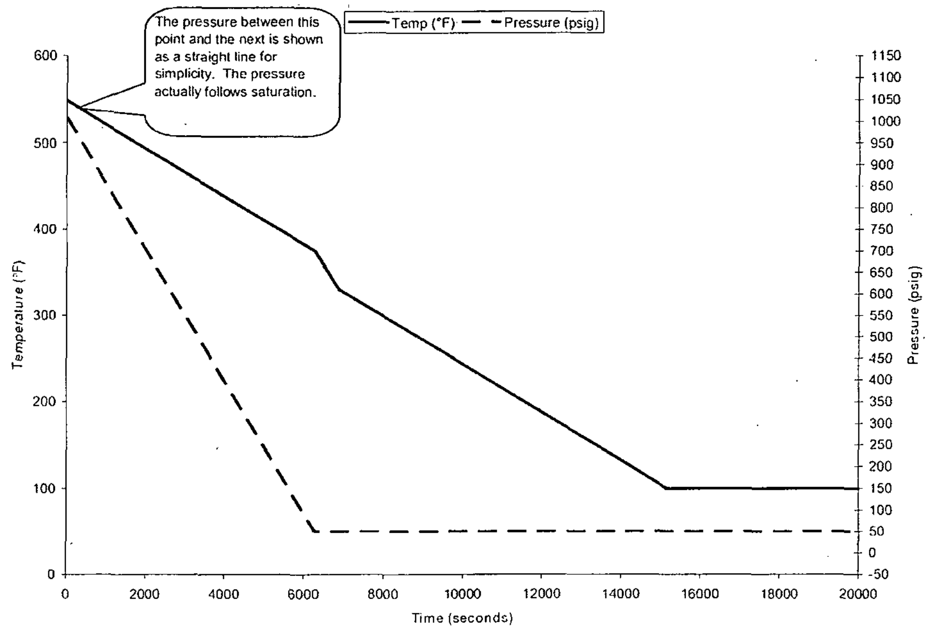



**Figure 3-33: Transient 21-23, Shutdown**

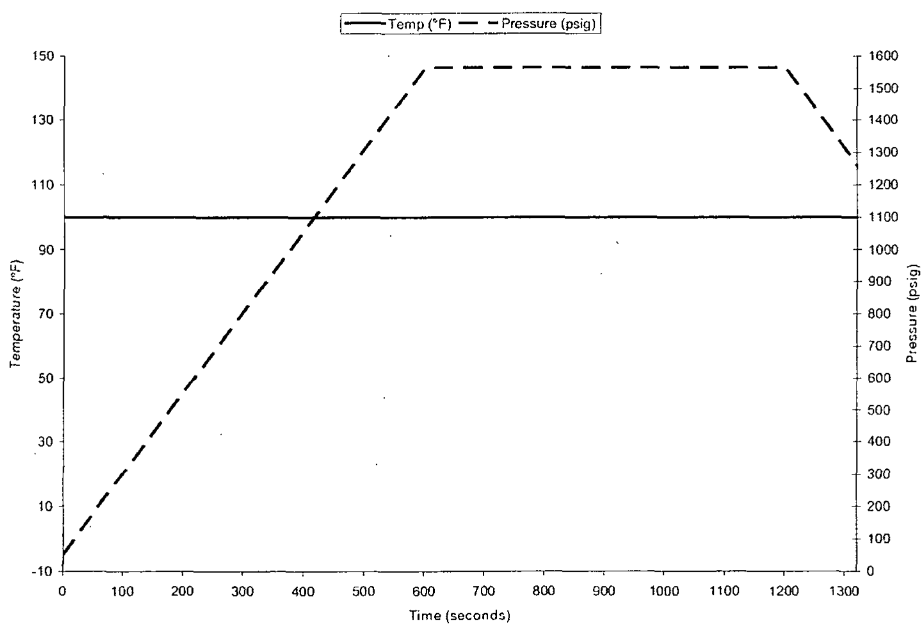



**Figure 3-34: Transient 24, Hydrostatic Test**

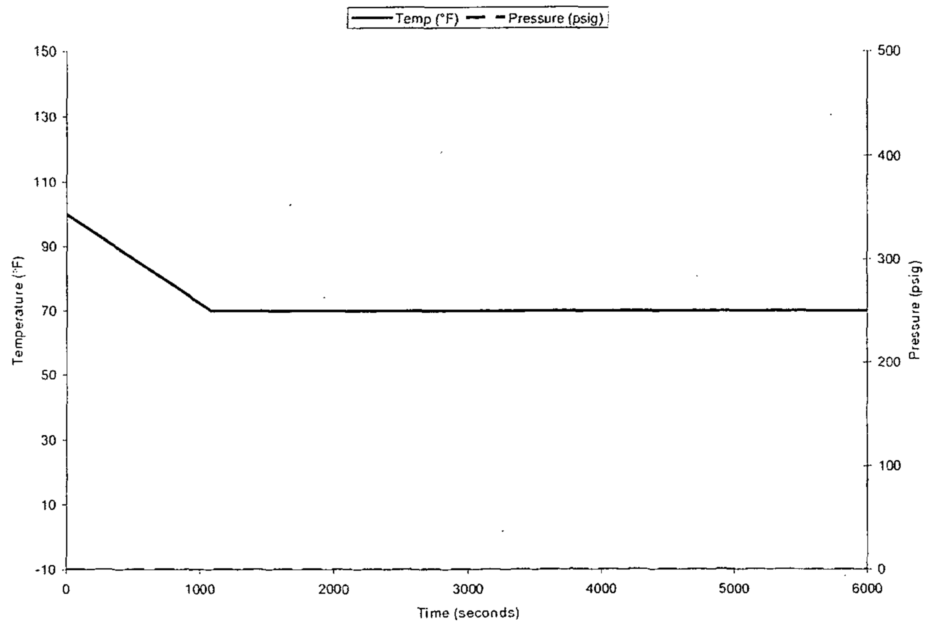



Figure 3-35: Transient 25, Unbolt

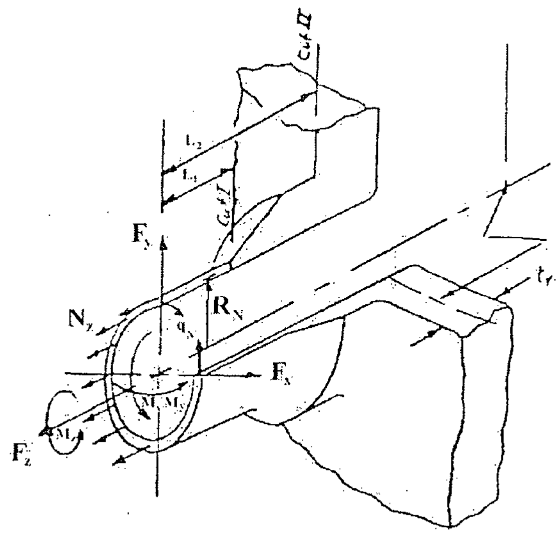



Figure 3-36: External Forces and Moments on the Feedwater Nozzle

## 4.0 STRESS AND FATIGUE ANALYSIS RESULTS

Fatigue calculations for the VY FW nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [15]. Fatigue analysis was performed in the Reference [23] calculation for the two locations identified in Section 3.1.2 using the Green's Functions developed for these two locations and the 60-year projected cycle counts from Reference [19].

Tables 4-1 and 4-2 show the stresses for each location that were used in the fatigue analysis. Columns 2 through 5 of Table 4-1 (for the blend radius) and Table 4-2 (for the safe end) show the final thermal peak and valley output. The pressure values for Column 6 in each table were determined from the transient pressures specified in Tables 3-4 and 3-5. The pressure stress intensities from Section 3.2 were scaled appropriately for each transient case. The scaled piping stress values are shown in Columns 9 and 10 of Tables 4-1 and 4-2. The piping stress intensities from Section 3.3 were scaled based on the transient case RPV fluid temperature and assuming no stress occurs at an ambient temperature of 70°F. Both of these stress intensities were then added to the thermal stress intensity peak and valley points to calculate the final stress values used for the fatigue analysis. In the case of the piping load stress intensities, the sign of the stress intensity was conservatively set to the same sign as the thermal stress intensity to ensure bounding fatigue usage results. Columns 11 and 12 of Tables 4-1 and 4-2 show the summation of all stresses for each thermal peak and valley stress point. The last column shows the number of cycles associated with each peak or valley based on the cycle counts shown in Tables 3-4 and 3-5.

The program FATIGUE.EXE performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data for the configuration input file for FATIGUE.EXE, which is named FATIGUE.CFG, is shown in Table 4-3.

The results of the fatigue analysis are presented in Tables 4-4 and 4-5 for the safe end and blend radius for 60 years, respectively. The blend radius cumulative usage factor (CUF) from system cycling is 0.0636 for 60 years. The safe end CUF is 0.1471 for 60 years.

# Table 4-1: Feedwater Nozzle Blend Radius Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |
| 2 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 120 |
| | 1680 | 0 | 0 | 100 | 1100 | 41506.3 | 40318.3 | 15.77042 | 15.77042 | 41522.07 | 40334.07 | 120 |
| | 10880 | 0 | 0 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 1902.42 | 1848.42 | 120 |
| 3 | 0 | 29166 | 23676 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 31068.42 | 25524.42 | 300 |
| | 16782.8 | -3577 | -3138 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34281.53 | 33629.73 | 300 |
| | 21164 | -3532 | -3138 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34326.53 | 33629.73 | 300 |
| 4 | 0 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| | 1801.9 | 29465 | 22266 | 244.004 | 1010 | 38110.33 | 37019.53 | 91.47053 | 91.47053 | 67666.80 | 59377.00 | 300 |
| | 8602 | 7720 | 6749 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43937.80 | 300 |
| 5 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10000 |
| | 2229.8 | 13598 | 11941 | 311.002 | 1010 | 38110.33 | 37019.53 | 126.6901 | 126.6901 | 51835.02 | 49087.22 | 10000 |
| | 8600 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10000 |
| 6 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 2000 |
| | 2820.3 | 15742 | 13892 | 280.691 | 1010 | 38110.33 | 37019.53 | 110.7562 | 110.7562 | 53963.09 | 51022.29 | 2000 |
| | 10400 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 2000 |
| 9 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10 |
| | 2524 | 29006 | 23417 | 118.311 | 1010 | 38110.33 | 37019.53 | 25.39616 | 25.39616 | 67141.73 | 60461.93 | 10 |
| | 10400 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10 |
| 10 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 70 |
| | 1632.4 | 16828 | 14701 | 267.399 | 1010 | 38110.33 | 37019.53 | 103.7688 | 103.7688 | 55042.10 | 51824.30 | 70 |
| | 7070 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 70 |
| 11 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 10 |
| | 3.5 | 6620 | 6632 | 565 | 1190 | 44902.27 | 43617.07 | 260.2119 | 260.2119 | 51782.48 | 50509.28 | 10 |
| | 4.5 | 6190 | 6608 | 50 | 1185 | 44713.61 | 43433.81 | 10.51361 | 10.51361 | 50914.12 | 50052.32 | 10 |
| | 194.5 | 31720 | 21067 | 109.348 | 1135 | 42826.96 | 41601.16 | 20.68448 | 20.68448 | 74567.64 | 62688.84 | 10 |
| | 2166.3 | -4761 | -1859 | 513.483 | 972 | 36676.48 | 35626.72 | -233.1304 | -233.1304 | 31682.35 | 33534.59 | 10 |
| | 2362.5 | 31268 | 22070 | 102.255 | 1010 | 38110.33 | 37019.53 | 16.95583 | 16.95583 | 69395.29 | 59106.49 | 10 |
| | 6728.3 | -4913 | -3149 | 513.448 | 1010 | 38110.33 | 37019.53 | -233.112 | -233.112 | 32964.22 | 33637.42 | 10 |
| | 7149.9 | 32114 | 21472 | 83.333 | 1010 | 38110.33 | 37019.53 | 7.0089 | 7.0089 | 70231.34 | 58498.54 | 10 |
| | 18213.3 | -3565 | -3162 | 503.978 | 1010 | 38110.33 | 37019.53 | -228.1338 | -228.1338 | 34317.20 | 33629.40 | 10 |
| | 19122.6 | 29156 | 23083 | 100.048 | 1010 | 38110.33 | 37019.53 | 15.79565 | 15.79565 | 67282.13 | 60118.33 | 10 |
| | 26814.5 | 7720 | 6410 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43598.80 | 10 |
| 12 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 60 |
| | 10 | 7720 | 6752 | 392 | 1135 | 42826.96 | 41601.16 | 169.2692 | 169.2692 | 50716.22 | 48522.42 | 60 |
| | 30 | 7720 | 6752 | 392 | 940 | 35469.02 | 34453.82 | 169.2692 | 169.2692 | 43358.29 | 41375.09 | 60 |
| | 2033.7 | 28648 | 25301 | 132.007 | 940 | 35469.02 | 34453.82 | 32.59588 | 32.59588 | 64149.62 | 59787.42 | 60 |
| | 9591 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 60 |
| 13 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 1 |
| | 10 | 7720 | 6752 | 392 | 1375 | 51882.88 | 50397.88 | 169.2692 | 169.2692 | 59772.14 | 57319.14 | 1 |
| | 30 | 7720 | 6752 | 392 | 940 | 35469.02 | 34453.82 | 169.2692 | 169.2692 | 43358.29 | 41375.09 | 1 |
| | 2033.7 | 28648 | 25301 | 132.007 | 1010 | 38110.33 | 37019.53 | 32.59588 | 32.59588 | 66790.93 | 62353.13 | 1 |
| | 9591 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 1 |
| 14 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 1 |
| | 5960 | 28487 | 25650 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 30389.42 | 27498.42 | 1 |
| 15 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 228 |
| | 10 | 7720 | 6752 | 392 | 1135 | 42826.96 | 41601.16 | 169.2692 | 169.2692 | 50716.22 | 48522.42 | 228 |
| | 30 | 7720 | 6752 | 392 | 940 | 35469.02 | 34453.82 | 169.2692 | 169.2692 | 43358.29 | 41375.09 | 228 |
| | 2033.7 | 28648 | 25301 | 132.007 | 1010 | 38110.33 | 37019.53 | 32.59588 | 32.59588 | 66790.93 | 62353.13 | 228 |
| | 9591 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 228 |
| 19 | 0 | 7720 | 6752 | 392 | 1010 | 38110.33 | 37019.53 | 169.2692 | 169.2692 | 45999.60 | 43940.80 | 300 |
| | 6800 | 16752 | 14971 | 265 | 1010 | 38110.33 | 37019.53 | 102.5077 | 102.5077 | 54964.84 | 52093.04 | 300 |
| 20 | 0 | 17151 | 13815 | 265 | 1010 | 38110.33 | 37019.53 | 102.5077 | 102.5077 | 55363.84 | 50937.04 | 300 |
| | 8925 | -3531 | -3146 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34327.53 | 33621.73 | 300 |
| 20A | 0 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| | 183 | 28102 | 12153 | 233 | 1010 | 38110.33 | 37019.53 | 85.68595 | 85.68595 | 66298.02 | 49258.22 | 300 |
| | 5451 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| 21-23 | 0 | -3530 | -3158 | 549 | 1010 | 38110.33 | 37019.53 | -251.801 | -251.801 | 34328.53 | 33609.73 | 300 |
| | 20144 | 29168 | 23656 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 31070.42 | 25504.42 | 300 |
| 24 | 0 | 0 | 0 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 1902.42 | 1848.42 | 1 |
| | 600 | 0 | 0 | 100 | 1563 | 58976.68 | 57288.64 | 15.77042 | 15.77042 | 58992.45 | 57304.41 | 1 |
| | 2400 | 0 | 0 | 100 | 50 | 1886.65 | 1832.65 | 15.77042 | 15.77042 | 1902.42 | 1848.42 | 1 |
| 25 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 15.77042 | 15.77042 | 15.77 | 15.77 | 123 |
| | 1580 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |

For notes, see last page of table…

### Table 4-1: Feedwater Nozzle Blend Radius Stress Summary (continued)

NOTES:
Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 3-4.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 37733)/1000 [Table3, 10].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 36653)/1000 [Table 3, 10].
Column 9: Total external stress from calculation in Table 3-2, 265.47 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

## Table 4-2: Feedwater Nozzle Safe End Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |
| 2 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 120 |
| | 1680 | 0 | 0 | 100 | 1100 | 9780.1 | 9562.3 | 339.0875 | 339.0875 | 10119.19 | 9901.39 | 120 |
| | 6960 | 0 | 0 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 783.64 | 773.74 | 120 |
| 3 | 0 | -170 | -165 | 100 | 50 | 444.55 | 434.65 | -339.0875 | -339.0875 | -64.54 | -69.44 | 300 |
| | 153.2 | -235 | -212 | 104.256 | 50 | 444.55 | 434.65 | -387.1927 | -387.1927 | -177.64 | -164.54 | 300 |
| | 16328.2 | 2 | 3 | 549 | 1010 | 8979.91 | 8779.93 | 5414.097 | 5414.097 | 14396.01 | 14197.03 | 300 |
| | 16664 | -1 | 0 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | 5414.097 | 3564.81 | 14194.03 | 300 |
| 4 | 0 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| | 3.6 | 44060 | 30988 | 100 | 1010 | 8979.91 | 8779.93 | 339.0875 | 339.0875 | 53379.00 | 40107.02 | 300 |
| | 1804.6 | -15889 | -11224 | 260.286 | 1010 | 8979.91 | 8779.93 | -2150.787 | -2150.787 | -9059.88 | -4594.86 | 300 |
| | 4102 | 21 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12640.45 | 12442.47 | 300 |
| 5 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10000 |
| | 900.1 | 244 | 189 | 310 | 1010 | 8979.91 | 8779.93 | 2712.7 | 2712.7 | 11936.61 | 11681.63 | 10000 |
| | 3600 | -169 | -110 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5171.37 | 5030.39 | 10000 |
| | 3684.4 | 33 | 35 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12652.45 | 12454.47 | 10000 |
| | 4100 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10000 |
| 6 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 2000 |
| | 1800.1 | 196 | 159 | 280 | 1010 | 8979.91 | 8779.93 | 2373.612 | 2373.612 | 11549.52 | 11312.54 | 2000 |
| | 5400.2 | -108 | -68 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5232.37 | 5072.39 | 2000 |
| | 5496.6 | 29 | 31 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12648.45 | 12450.47 | 2000 |
| | 5900 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 2000 |
| 9 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10 |
| | 97.3 | 180 | 137 | 385.135 | 1010 | 8979.91 | 8779.93 | 3561.945 | 3561.945 | 12721.85 | 12478.87 | 10 |
| | 1884.1 | 63 | 65 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11246.98 | 11049.00 | 10 |
| | 2059.2 | 1161 | 859 | 226.597 | 1010 | 8979.91 | 8779.93 | 1770.003 | 1770.003 | 11910.91 | 11408.93 | 10 |
| | 3420.1 | -334 | -211 | 265 | 1010 | 8979.91 | 8779.93 | -2204.069 | -2204.069 | 6441.84 | 6364.86 | 10 |
| | 3490.2 | 97 | 98 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11280.98 | 11082.00 | 10 |
| | 5400.1 | -126 | -80 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5214.37 | 5060.39 | 10 |
| | 5470.6 | 31 | 32 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12650.45 | 12451.47 | 10 |
| | 5900 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 10 |
| 10 | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 70 |
| | 77.1 | 2308 | 3188 | 285.461 | 1010 | 8979.91 | 8779.93 | 2435.338 | 2435.338 | 13723.25 | 14403.27 | 70 |
| | 169.4 | -12 | -13 | 265 | 1010 | 8979.91 | 8779.93 | -2204.069 | -2204.069 | 6763.84 | 6562.86 | 70 |
| | 1890 | 74 | 72 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11257.98 | 11056.00 | 70 |
| | 1968.2 | -1069 | -1511 | 322.362 | 1010 | 8979.91 | 8779.93 | -2852.427 | -2852.427 | 5058.48 | 4416.50 | 70 |
| | 2147.2 | 91 | 90 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12710.45 | 12509.47 | 70 |
| | 2570 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 70 |
| 11 | 0 | -29 | -27 | 392 | 1010 | 8979.91 | 8779.93 | -3639.539 | -3639.539 | 5311.37 | 5113.39 | 10 |
| | 2.9 | -20317 | -13859 | 565 | 1147 | 10197.98 | 9970.871 | -5594.944 | -5594.944 | -15713.97 | -9483.07 | 10 |
| | 6.8 | 42852 | 29563 | 565 | 1172 | 10420.25 | 10188.2 | 5594.944 | 5594.944 | 58867.20 | 45346.14 | 10 |
| | 1567.4 | -15216 | -10526 | 565 | 1135 | 10091.29 | 9866.555 | -5594.944 | -5594.944 | -10719.66 | -6254.39 | 10 |
| | 2168.4 | 60377 | 41773 | 50 | 1134 | 10082.39 | 9857.862 | -226.0583 | -226.0583 | 70233.34 | 51404.80 | 10 |
| | 5409.4 | -14924 | -10329 | 565 | 1054 | 9371.114 | 9162.422 | -5594.944 | -5594.944 | -11147.83 | -6761.52 | 10 |
| | 6730.4 | 60377 | 41773 | 50 | 1133 | 10073.5 | 9849.169 | -226.0583 | -226.0583 | 70224.44 | 51396.11 | 10 |
| | 7243.2 | -1965 | -1434 | 128.917 | 675 | 6001.425 | 5867.775 | -665.9339 | -665.9339 | 3370.49 | 3767.84 | 10 |
| | 18215.4 | 52636 | 36417 | 100 | 1010 | 8979.91 | 8779.93 | 339.0875 | 339.0875 | 61955.00 | 45536.02 | 10 |
| | 20015.5 | -24511 | -16189 | 260.183 | 1010 | 8979.91 | 8779.93 | -2149.623 | -2149.623 | -17680.71 | -9558.69 | 10 |
| | 22314.5 | 22 | 23 | 392 | 937 | 8330.867 | 8145.341 | 3639.539 | 3639.539 | 11992.41 | 11807.88 | 10 |
| 12 | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 60 |
| | 10 | 23 | 22 | 392 | 1135 | 10091.29 | 9866.555 | 3639.539 | 3639.539 | 13753.82 | 13528.09 | 60 |
| | 30 | 23 | 22 | 392 | 940 | 8357.54 | 8171.42 | 3639.539 | 3639.539 | 12020.08 | 11832.96 | 60 |
| | 90 | 3174 | 4383 | 275 | 940 | 8357.54 | 8171.42 | 2317.098 | 2317.098 | 13848.64 | 14871.52 | 60 |
| | 2793.5 | -16189 | -24511 | 260.183 | 941 | 8366.431 | 8180.113 | -2149.623 | -2149.623 | -9972.19 | -18480.51 | 60 |
| | 5091 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 60 |
| 13 | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 1 |
| | 10 | 23 | 22 | 392 | 1375 | 12225.13 | 11952.88 | 3639.539 | 3639.539 | 15887.66 | 15614.41 | 1 |
| | 30 | 23 | 22 | 392 | 940 | 8357.54 | 8171.42 | 3639.539 | 3639.539 | 12020.08 | 11832.96 | 1 |
| | 90 | 3174 | 4383 | 275 | 940 | 8357.54 | 8171.42 | 2317.098 | 2317.098 | 13848.64 | 14871.52 | 1 |
| | 2793.5 | -16189 | -24511 | 260.183 | 941 | 8366.431 | 8180.113 | -2149.623 | -2149.623 | -9972.19 | -18480.51 | 1 |
| | 5091 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 1 |

For notes, see last page of table...

## Table 4-2: Feedwater Nozzle Safe End Stress Summary (continued)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 14 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 1 |
| | 60 | 4383 | 3174 | 275 | 885 | 7868.535 | 7693.305 | 2317.098 | 2317.098 | 14568.63 | 13184.40 | 1 |
| | 148 | 420 | 300 | 258.492 | 803 | 7139.473 | 6980.479 | 2130.509 | 2130.509 | 9689.98 | 9410.99 | 1 |
| | 960 | 544 | 424 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 1327.64 | 1197.74 | 1 |
| | 1460 | 137 | 139 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 920.64 | 912.74 | 1 |
| 15 | 0 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 228 |
| | 10 | 23 | 22 | 392 | 1135 | 10091.29 | 9866.555 | 3639.539 | 3639.539 | 13753.82 | 13528.09 | 228 |
| | 30 | 23 | 22 | 392 | 940 | 8357.54 | 8171.42 | 3639.539 | 3639.539 | 12020.08 | 11832.96 | 228 |
| | 90 | 3174 | 4383 | 275 | 940 | 8357.54 | 8171.42 | 2317.098 | 2317.098 | 13848.64 | 14871.52 | 228 |
| | 2793.5 | -16189 | -24511 | 260.183 | 941 | 8366.431 | 8180.113 | -2149.623 | -2149.623 | -9972.19 | -18480.51 | 228 |
| | 5091 | 23 | 22 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12642.45 | 12441.47 | 228 |
| 19 | 0 | 22 | 23 | 392 | 1010 | 8979.91 | 8779.93 | 3639.539 | 3639.539 | 12641.45 | 12442.47 | 300 |
| | 1800 | 219 | 177 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11402.98 | 11161.00 | 300 |
| | 2300 | 72 | 74 | 265 | 1010 | 8979.91 | 8779.93 | 2204.069 | 2204.069 | 11255.98 | 11058.00 | 300 |
| 20 | 0 | -109 | -105 | 265 | 1010 | 8979.91 | 8779.93 | -2204.069 | -2204.069 | 6666.84 | 6470.86 | 300 |
| | 4 | -17288 | -12189 | 440.106 | 1010 | 8979.91 | 8779.93 | -4183.277 | -4183.277 | -12491.37 | -7592.35 | 300 |
| | 4425 | -2 | -1 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3563.81 | 3364.83 | 300 |
| 20A | 0 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| | 4 | 44060 | 30988 | 100 | 1010 | 8979.91 | 8779.93 | 339.0875 | 339.0875 | 53379.00 | 40107.02 | 300 |
| | 241 | -7461 | -5525 | 290.247 | 1010 | 8979.91 | 8779.93 | -2489.433 | -2489.433 | -970.52 | 765.50 | 300 |
| | 572 | 128 | 132 | 549 | 1010 | 8979.91 | 8779.93 | 5414.097 | 5414.097 | 14522.01 | 14326.03 | 300 |
| | 951 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| 21-23 | 0 | -3 | -2 | 549 | 1010 | 8979.91 | 8779.93 | -5414.097 | -5414.097 | 3562.81 | 3363.83 | 300 |
| | 138 | 62 | 45 | 545.167 | 989 | 8793.199 | 8597.377 | 5370.773 | 5370.773 | 14225.97 | 14013.15 | 300 |
| | 6264 | -5 | -20 | 374.97 | 50 | 444.55 | 434.65 | -3447.05 | -3447.05 | -3007.50 | -3032.40 | 300 |
| | 6390 | 104 | 59 | 366.172 | 50 | 444.55 | 434.65 | 3347.607 | 3347.607 | 3896.16 | 3841.26 | 300 |
| | 15644 | -173 | -167 | 100 | 50 | 444.55 | 434.65 | -339.0875 | -339.0875 | -67.54 | -71.44 | 300 |
| 24 | 0 | 0 | 0 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 783.64 | 773.74 | 1 |
| | 600 | 0 | 0 | 100 | 1563 | 13896.63 | 13587.16 | 339.0875 | 339.0875 | 14235.72 | 13926.25 | 1 |
| | 2400 | 0 | 0 | 100 | 50 | 444.55 | 434.65 | 339.0875 | 339.0875 | 783.64 | 773.74 | 1 |
| 25 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 339.0875 | 339.0875 | 339.09 | 339.09 | 123 |
| | 1580 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 123 |

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 3-5.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 8891)/1000 [Table 3, 10].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 8693)/1000 [Table3, 10].
Column 9: Total external stress from calculation in Table 3-2, 5707.97 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

**Table 4-3: Fatigue Parameters Used in the Feedwater Nozzle Fatigue Analysis**

| | Blend Radius | Safe End |
|---|---|---|
| Parameters *m* and *n* for Computing $K_e$ | 2.0 & 0.2 (low alloy steel) [15] | 3.0 & 0.2 (carbon steel) [15] |
| Design Stress Intensity Values, $S_m$ | 26700 psi [9] @ 600°F | 17800 psi [9] @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi [15] | $30.0 \times 10^6$ psi [15] |
| Elastic Modulus Used in Finite Element Model | $26.7 \times 10^6$ psi [10] | $28.1 \times 10^6$ psi [10] |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 1.34 [2, page 35 of S4] |

## Table 4-4: Fatigue Results for Feedwater Nozzle Blend Radius

```
LOCATION = LOCATION NO. 2 -- BLEND RADIUS
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
m = 2.0
n =  .2
Sm = 26700. psi
Ecurve = 3.000E+07 psi
Eanalysis = 2.670E+07 psi
Kt = 1.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 74568. | 0. | 74568. | 62689. | 1.000 | 41892. | 1.000E+01 | 7.488E+03 | .0013 |
| 70231. | 0. | 70231. | 58499. | 1.000 | 39456. | 1.000E+01 | 8.944E+03 | .0011 |
| 69395. | 0. | 69395. | 59106. | 1.000 | 38986. | 1.000E+01 | 9.268E+03 | .0011 |
| 67667. | 0. | 67667. | 59377. | 1.000 | 38015. | 9.300E+01 | 9.988E+03 | .0093 |
| 67667. | 0. | 67667. | 59377. | 1.000 | 38015. | 1.200E+02 | 9.988E+03 | .0120 |
| 67667. | 0. | 67667. | 59377. | 1.000 | 38015. | 8.700E+01 | 9.988E+03 | .0087 |
| 67282. | 0. | 67282. | 60118. | 1.000 | 37799. | 1.000E+01 | 1.018E+04 | .0010 |
| 67142. | 0. | 67142. | 60462. | 1.000 | 37720. | 1.000E+01 | 1.025E+04 | .0010 |
| 66791. | 0. | 66791. | 62353. | 1.000 | 37523. | 1.000E+00 | 1.044E+04 | .0001 |
| 66791. | 0. | 66791. | 62353. | 1.000 | 37523. | 1.500E+01 | 1.044E+04 | .0014 |
| 66791. | 16. | 66775. | 62337. | 1.000 | 37514. | 1.230E+02 | 1.045E+04 | .0118 |
| 66791. | 1902. | 64889. | 60505. | 1.000 | 36454. | 9.000E+01 | 1.152E+04 | .0078 |
| 66298. | 1902. | 64396. | 47410. | 1.000 | 36177. | 3.000E+01 | 1.182E+04 | .0025 |
| 66298. | 1902. | 64396. | 47410. | 1.000 | 36177. | 1.000E+00 | 1.182E+04 | .0001 |
| 66298. | 1902. | 64396. | 47410. | 1.000 | 36177. | 1.000E+00 | 1.182E+04 | .0001 |
| 66298. | 30389. | 35909. | 21760. | 1.000 | 20173. | 1.000E+00 | 9.581E+04 | .0000 |
| 66298. | 31068. | 35230. | 23734. | 1.000 | 19792. | 2.670E+02 | 1.038E+05 | .0026 |
| 64150. | 31068. | 33081. | 34263. | 1.000 | 18585. | 3.300E+01 | 1.303E+05 | .0003 |
| 64150. | 31070. | 33079. | 34283. | 1.000 | 18584. | 2.700E+01 | 1.303E+05 | .0002 |
| 59772. | 31070. | 28702. | 31815. | 1.000 | 16125. | 1.000E+00 | 2.222E+05 | .0000 |
| 58992. | 31070. | 27922. | 31800. | 1.000 | 15687. | 1.000E+00 | 2.519E+05 | .0000 |
| 55364. | 31070. | 24293. | 25433. | 1.000 | 13648. | 2.710E+02 | 4.757E+05 | .0006 |
| 55364. | 31682. | 23681. | 17402. | 1.000 | 13304. | 1.000E+01 | 5.703E+05 | .0000 |
| 55364. | 32964. | 22400. | 17300. | 1.000 | 12584. | 1.000E+01 | 9.414E+05 | .0000 |
| 55364. | 34282. | 21082. | 17307. | 1.000 | 11844. | 9.000E+00 | 1.912E+06 | .0000 |
| 55042. | 34282. | 20761. | 18195. | 1.000 | 11663. | 7.000E+01 | 2.231E+06 | .0000 |
| 54965. | 34282. | 20683. | 18463. | 1.000 | 11620. | 2.210E+02 | 2.310E+06 | .0001 |
| 54965. | 34317. | 20648. | 18464. | 1.000 | 11600. | 1.000E+01 | 2.348E+06 | .0000 |
| 54965. | 34327. | 20638. | 18463. | 1.000 | 11595. | 6.900E+01 | 2.358E+06 | .0000 |
| 53963. | 34327. | 19637. | 17393. | 1.000 | 11032. | 2.310E+02 | 3.757E+06 | .0001 |
| 53963. | 34328. | 19636. | 17401. | 1.000 | 11031. | 3.000E+02 | 3.758E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 34329. | 19635. | 17413. | 1.000 | 11031. | 3.000E+02 | 3.760E+06 | .0001 |
| 53963. | 41522. | 12441. | 10688. | 1.000 | 6989. | 1.200E+02 | 1.000E+20 | .0000 |
| 53963. | 43358. | 10605. | 9647. | 1.000 | 5958. | 6.000E+01 | 1.000E+20 | .0000 |
| 53963. | 43358. | 10605. | 9647. | 1.000 | 5958. | 1.000E+00 | 1.000E+20 | .0000 |
| 53963. | 43358. | 10605. | 9647. | 1.000 | 5958. | 8.800E+01 | 1.000E+20 | .0000 |
| 51835. | 43358. | 8477. | 7712. | 1.000 | 4762. | 1.400E+02 | 1.000E+20 | .0000 |
| 51835. | 46000. | 5835. | 5149. | 1.000 | 3278. | 3.000E+02 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 51835. | 46000. | 5835. | 5146. | 1.000 | 3278. | 9.560E+03 | 1.000E+20 | .0000 |
| 51782. | 46000. | 5783. | 6568. | 1.000 | 3249. | 1.000E+01 | 1.000E+20 | .0000 |
| 50914. | 46000. | 4915. | 6112. | 1.000 | 2761. | 1.000E+01 | 1.000E+20 | .0000 |
| 50716. | 46000. | 4717. | 4582. | 1.000 | 2650. | 6.000E+01 | 1.000E+20 | .0000 |
| 50716. | 46000. | 4717. | 4582. | 1.000 | 2650. | 2.280E+02 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.320E+02 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+04 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 7.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 7.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 6.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 6.000E+01 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.280E+02 | 1.000E+20 | .0000 |
| 46000. | 46000. | 0. | 0. | 1.000 | 0. | 2.280E+02 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | TOTAL USAGE FACTOR = | | .0636 |

## Table 4-5: Fatigue Results for the Feedwater Nozzle Safe End

LOCATION = LOCATION NO. 1 -- SAFE END
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
m = 3.0
n = .2
Sm = 17800. psi
Ecurve = 3.000E+07 psi
Eanalysis = 2.810E+07 psi
Kt = 1.34

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 70233. | -17681. | 87914. | 60963. | 1.283 | 74422. | 1.000E+01 | 1.338E+03 | .0075 |
| 70224. | -15714. | 85938. | 60879. | 1.280 | 72869. | 1.000E+01 | 1.415E+03 | .0071 |
| 61955. | -12491. | 74446. | 53128. | 1.000 | 49383. | 1.000E+01 | 4.568E+03 | .0022 |
| 58867. | -12491. | 71359. | 52938. | 1.000 | 47700. | 1.000E+01 | 5.094E+03 | .0020 |
| 53379. | -12491. | 65870. | 47699. | 1.000 | 43819. | 2.800E+02 | 6.552E+03 | .0427 |
| 53379. | -11148. | 64527. | 46869. | 1.000 | 42951. | 1.000E+01 | 6.953E+03 | .0014 |
| 53379. | -10720. | 64099. | 46361. | 1.000 | 42631. | 1.000E+01 | 7.109E+03 | .0014 |
| 53379. | -9972. | 63351. | 58588. | 1.194 | 53087. | 6.000E+01 | 3.628E+03 | .0165 |
| 53379. | -9972. | 63351. | 58588. | 1.194 | 53087. | 1.000E+00 | 3.628E+03 | .0003 |
| 53379. | -9972. | 63351. | 58588. | 1.194 | 53087. | 2.280E+02 | 3.628E+03 | .0628 |
| 53379. | -9060. | 62439. | 44702. | 1.000 | 41444. | 1.100E+01 | 7.731E+03 | .0014 |
| 15888. | -9060. | 24948. | 20209. | 1.000 | 16985. | 1.000E+00 | 1.802E+05 | .0000 |
| 14569. | -9060. | 23629. | 17779. | 1.000 | 15840. | 1.000E+00 | 2.410E+05 | .0000 |
| 14522. | -9060. | 23582. | 18921. | 1.000 | 16022. | 2.870E+02 | 2.287E+05 | .0013 |
| 14522. | -3008. | 17530. | 17358. | 1.000 | 12508. | 1.300E+01 | 9.944E+05 | .0000 |
| 14396. | -3008. | 17404. | 17229. | 1.000 | 12417. | 2.870E+02 | 1.083E+06 | .0003 |
| 14396. | -971. | 15367. | 13432. | 1.000 | 10641. | 1.300E+01 | 5.165E+06 | .0000 |
| 14236. | -971. | 15206. | 13161. | 1.000 | 10506. | 1.000E+00 | 5.563E+06 | .0000 |
| 14226. | -971. | 15196. | 13248. | 1.000 | 10516. | 2.860E+02 | 5.531E+06 | .0001 |
| 14226. | -178. | 14404. | 14178. | 1.000 | 10262. | 1.400E+01 | 6.379E+06 | .0000 |
| 13849. | -178. | 14026. | 15036. | 1.000 | 10216. | 6.000E+01 | 6.547E+06 | .0000 |
| 13849. | -178. | 14026. | 15036. | 1.000 | 10216. | 1.000E+00 | 6.547E+06 | .0000 |
| 13849. | -178. | 14026. | 15036. | 1.000 | 10216. | 2.250E+02 | 6.547E+06 | .0000 |
| 13849. | -68. | 13916. | 14943. | 1.000 | 10141. | 3.000E+00 | 6.837E+06 | .0000 |
| 13754. | -68. | 13821. | 13600. | 1.000 | 9846. | 6.000E+01 | 8.117E+06 | .0000 |
| 13754. | -68. | 13821. | 13600. | 1.000 | 9846. | 2.280E+02 | 8.117E+06 | .0000 |
| 13723. | -68. | 13791. | 14475. | 1.000 | 9989. | 9.000E+00 | 7.465E+06 | .0000 |
| 13723. | -65. | 13788. | 14473. | 1.000 | 9987. | 6.100E+01 | 7.474E+06 | .0000 |
| 12722. | -65. | 12786. | 12548. | 1.000 | 9103. | 1.000E+01 | 1.729E+07 | .0000 |
| 12710. | -65. | 12775. | 12579. | 1.000 | 9102. | 7.000E+01 | 1.730E+07 | .0000 |
| 12652. | -65. | 12717. | 12524. | 1.000 | 9061. | 1.590E+02 | 1.833E+07 | .0000 |
| 12652. | 0. | 12652. | 12454. | 1.000 | 9014. | 1.230E+02 | 1.959E+07 | .0000 |
| 12652. | 0. | 12652. | 12454. | 1.000 | 9014. | 1.200E+02 | 1.959E+07 | .0000 |
| 12652. | 0. | 12652. | 12454. | 1.000 | 9014. | 1.230E+02 | 1.959E+07 | .0000 |
| 12652. | 339. | 12313. | 12115. | 1.000 | 8772. | 1.230E+02 | 2.905E+07 | .0000 |
| 12652. | 784. | 11869. | 11681. | 1.000 | 8456. | 1.200E+02 | 4.952E+07 | .0000 |
| 12652. | 784. | 11869. | 11681. | 1.000 | 8456. | 1.000E+00 | 4.952E+07 | .0000 |
| 12652. | 784. | 11869. | 11681. | 1.000 | 8456. | 1.000E+00 | 4.952E+07 | .0000 |
| 12652. | 921. | 11732. | 11542. | 1.000 | 8357. | 1.000E+00 | 5.462E+07 | .0000 |
| 12652. | 1328. | 11325. | 11257. | 1.000 | 8088. | 1.000E+00 | 7.100E+07 | .0000 |
| 12652. | 3370. | 9282. | 8687. | 1.000 | 6531. | 1.000E+01 | 1.000E+20 | .0000 |
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3563. | 9090. | 9091. | 1.000 | 6502. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3564. | 9089. | 9090. | 1.000 | 6501. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3565. | 9088. | -1740. | 1.000 | 4535. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 3896. | 8756. | 8613. | 1.000 | 6237. | 3.000E+02 | 1.000E+20 | .0000 |
| 12652. | 5058. | 7594. | 8038. | 1.000 | 5513. | 7.000E+01 | 1.000E+20 | .0000 |
| 12652. | 5171. | 7481. | 7424. | 1.000 | 5341. | 7.048E+03 | 1.000E+20 | .0000 |
| 12650. | 5171. | 7479. | 7421. | 1.000 | 5339. | 1.000E+01 | 1.000E+20 | .0000 |
| 12648. | 5171. | 7477. | 7420. | 1.000 | 5338. | 2.000E+03 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 7.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 7.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 6.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 6.000E+01 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 1.000E+00 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 1.000E+00 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 2.280E+02 | 1.000E+20 | .0000 |
| 12642. | 5171. | 7471. | 7411. | 1.000 | 5333. | 2.280E+02 | 1.000E+20 | .0000 |
| 12641. | 5171. | 7470. | 7412. | 1.000 | 5333. | 2.240E+02 | 1.000E+20 | .0000 |
| 12641. | 5214. | 7427. | 7382. | 1.000 | 5304. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 5232. | 7409. | 7370. | 1.000 | 5293. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 5311. | 7330. | 7329. | 1.000 | 5243. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 6442. | 6200. | 6078. | 1.000 | 4412. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 6667. | 5975. | 5972. | 1.000 | 4273. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 6764. | 5878. | 5880. | 1.000 | 4205. | 7.000E+01 | 1.000E+20 | .0000 |
| 12641. | 9690. | 2951. | 3031. | 1.000 | 2126. | 1.000E+00 | 1.000E+20 | .0000 |
| 12641. | 10119. | 2522. | 2541. | 1.000 | 1808. | 1.200E+02 | 1.000E+20 | .0000 |
| 12641. | 11247. | 1394. | 1393. | 1.000 | 997. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11256. | 1385. | 1384. | 1.000 | 991. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 11258. | 1383. | 1386. | 1.000 | 990. | 7.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11281. | 1360. | 1360. | 1.000 | 973. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11403. | 1238. | 1281. | 1.000 | 894. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 11550. | 1092. | 1130. | 1.000 | 788. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 11911. | 731. | 1034. | 1.000 | 578. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 11937. | 705. | 761. | 1.000 | 514. | 4.555E+03 | 1.000E+20 | .0000 |
| 12641. | 11937. | 705. | 761. | 1.000 | 514. | 5.445E+03 | 1.000E+20 | .0000 |
| 12641. | 11992. | 649. | 635. | 1.000 | 462. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12020. | 621. | 610. | 1.000 | 442. | 6.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12020. | 621. | 610. | 1.000 | 442. | 1.000E+00 | 1.000E+20 | .0000 |
| 12641. | 12020. | 621. | 610. | 1.000 | 442. | 2.280E+02 | 1.000E+20 | .0000 |
| 12641. | 12640. | 1. | 0. | 1.000 | 1. | 3.000E+02 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 3.956E+03 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 2.000E+03 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 1.000E+01 | 1.000E+20 | .0000 |
| 12641. | 12641. | 0. | 0. | 1.000 | 0. | 1.000E+00 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | TOTAL USAGE FACTOR = | | .1471 |

## 5.0 ENVIRONMENTAL FATIGUE ANALYSIS

In the response to NRC request for additional information (RAI) 4.3-H-02 [19], VYNPS states that they have conservatively assumed that fatigue cracks may be present in the clad. VYNPS manages this cracking by performing periodic inspections that were implemented in response to Generic Letters 80-095 and 81-11, and NUREG-0619. The inspection frequency is based on the calculated fatigue crack growth of a postulated flaw in the nozzle inner blend radius. The VYNPS fatigue crack growth calculation uses methods in compliance with GE BWR Owners Group Topical Report "Alternate BWR Feedwater Nozzle Inspection Requirements", GE-NE-523-A71-0594, Revision 1, August 1999 and the associated NRC Final Safety Evaluation (TAC No. MA6787) dated March 10, 2000. The NRC has reviewed and approved this approach to handling FW nozzle inner blend radius cracking (Letter D.H. Dorman (USNRC) to D.A. Reid (VYNPC), Subject: Evaluation of Request for Relief from NUREG-0619 for VYNPS dated 2/6/95, (TAC No. M88803)).

The analysis performed for the feedwater nozzle calculated fatigue in the blend radius base metal, not the clad. This is consistent with the VYNPS position stated in the response to RAI 4.3-H-02, and is also consistent with ASME Code methodology since cladding is structurally neglected in fatigue analyses, per ASME Code, Section III, NB-3122.3 [15].

Environmental fatigue multipliers were computed for both normal water chemistry (NWC) and hydrogen water chemistry (HWC) conditions in Reference [21] for various regions of the VY RPV and attached piping. Based on VY-specific dates for plant startup and HWC implementation, as well as past and future predicted HWC system availability, it was determined that overall HWC availability is 47% over the sixty year operating period for VY. Therefore, for the purposes of the EAF assessment of the FW nozzle, it was assumed that HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time over the 60-year operating life of the plant. RPV upper region chemistry was assumed for the FW nozzle blend radius location, since this location experiences reactor conditions for all times. FW line chemistry was assumed for the FW nozzle safe end location, since this location experiences feedwater conditions for all times.

For the safe end location, the environmental fatigue factors for pre-HWC and post-HWC are both 1.74 from Table 3 of Reference [21] for the RPV FW line. This results in an EAF adjusted CUF as follows:

> 60-Year CUF, $U_{60}$ = 0.1470 (from Table 4-5)
> Overall EAF multiplier, $F_{en}$ = 1.74
> 60-Year EAF CUF, $U_{60\text{-}env}$ = 0.14709 x 1.74 = 0.2560

The EAF CUF value of 0.2560 for 60 years for the safe end is acceptable (i.e., less than the allowable value of 1.0).

The fatigue calculation documented in Section 4.0 for the blend radius location was performed for the nozzle base material since cladding is structurally neglected in modern-day fatigue analyses, per ASME Code, Section III, NB-3122.3 [15]. This is also consistent with Sections 5.7.1 and 5.7.4 of NUREG/CR-6260 [16]. Therefore, the cladding was neglected and EAF assessment of the nozzle base material was performed for the blend radius location.

For the blend radius location, the environmental fatigue factors for pre-HWC and post-HWC are 11.14 and 8.82, respectively, from Table 4 of Reference [21] for the RPV upper region. This results in an EAF adjusted CUF as follows:

> 60-Year CUF, $U_{60}$ = 0.0636 (from Table 4-4)
> Overall EAF multiplier, $F_{en}$ = (11.14 x 53% + 8.82 x 47%) = 10.05
> 60-Year EAF CUF, $U_{60\text{-}env}$ = 0.0636 x 10.05 = 0.6392

The EAF CUF value of 0.6392 for 60 years for the blend radius is acceptable (i.e., less than the allowable value of 1.0).

## 6.0 CONCLUSIONS

This report documents a refined fatigue evaluation for the VY FW nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the FW nozzle and safe end are included in the evaluation, to be consistent with NUREG/CR-6260 [16] needs for EAF evaluation for license renewal. The final fatigue results are considered to be a replacement to the values previously reported in the VY LRA.

The fatigue calculations for the VY FW nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [15]. The stress evaluation is summarized in Section 3.0, and the fatigue analysis is summarized in Section 4.0. The results in Section 4.0 reveal that the CUF for the limiting safe end location is 0.1470, and the CUF for the limiting blend radius location is 0.0636. Both of these values represent 60 years of plant operation, including all relevant EPU effects.

EAF calculations for the VY FW nozzle were also performed, as summarized in Section 5.0. The results in Section 5.0 reveal that the EAF CUF for the limiting safe end location is 0.2560, and the EAF CUF for the limiting blend radius location is 0.6392. Both of these values represent 60 years of plant operation, including all relevant EPU effects.

All fatigue allowables, both with and without EAF effects, are met, thus demonstrating acceptability for 60 years of operation.

## 7.0 REFERENCES


1. **REDACTED**

2. CB&I RPV Stress Report, Sections T4 and S4, "Feedwater Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," SI File No. VY-05Q-238.

3. GE Design Specification No. 21A1115, Revision 4, "Vermont Yankee Reactor Pressure Vessel," October 21, 1969, SI File No. VY-05Q-210.

4. Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green's Functions," ASME PVP Conference, Chicago, 1986.

5. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.

6. Structural Integrity Associates Calculation No. VY-10Q-301, Revision 0, "Feedwater Nozzle Finite Element Model and Heat Transfer Coefficients."

7. Structural Integrity Associates Calculation No. YAEC-13Q-303, Revision 0, "Thermal Transient Analysis."

8. VY Drawing No. 5920-9057, Sheet 1, Revision 1, SI File No. VY-05Q-215.

9. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.

10. Structural Integrity Associates Calculation No. VY-16Q-301, Revision 0, "Feedwater Stress History Development for Nozzle Green's Function."

11. Vermont Yankee Drawing 5920-00024, Rev. 11, GE Drawing No. 919D294, Revision 11, Sheet No. 7, "Reactor Vessel," SI File No. VY-05Q-241.

12. CB&I Addenda to RPV Stress Report, "Certification of Addenda to the Stress Report for Vermont Yankee Reactor Vessel," July 9, 1971, SI File No. VY-05Q-238.

13. VY Calculation Change Notice (CCN), CCN Number 1 for Calculation VYC1005 Revision 2, "This CCN Provides a Basis for the Power Uprate Safety Analysis Report being submitted as part of the power uprate project. The 50.59 assessment will be handled by the EPU design change and NRC SER for this submittal." SI File Number VY-05Q-208.

14. Structural Integrity Associates Calculation No. SW-SPVF-01Q-301, Revision 0, "STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification."

15. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III Subsection NB, 1998 Edition, 2000 Addenda.

16. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

17. GE Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," August 29, 2003, SI File No. VY-05Q-236.

18. General Electric Stress Report No. DC22A5583, Revision 0, Section T, "Thermal Analysis FitzPatrick Feedwater Nozzle Modification," SI File No. NYPA-53Q-212.

19. Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Revision 0 "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/2007, SI File No. VY-16Q-209.

20. Chicago Bridge & Iron Company Contractor 9-6201, Revision 2, "Section S4, Stress Analysis Feedwater Nozzle Vermont Yankee Reactor Vessel," SI File No. VY-05Q-238.

21. Structural Integrity Associates Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell Bottom Head."

22. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.

23. Structural Integrity Associates Calculation No. VY-16Q-302, Revision 0, "Fatigue Analysis of Feedwater Nozzle."

24. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.

25. J. P. Holman, "Heat Transfer," 5th Edition, McGraw-Hill, 1981.

26. N. P. Cheremisinoff, "Heat Transfer Pocket Handbook," Gulf Publishing Co, 1984.

27. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection A, Article 4, 1965 Edition with Winter 1966 Addenda.

NEC-JH_16

Report No.: SIR-07-141-NPS
Revision No.: 0
Project No.: VY-16Q
File No.: VY-16Q-402
July 2007

# Environmental Fatigue Analysis for the Vermont Yankee Reactor Pressure Vessel Reactor Recirculation Outlet Nozzle

*Prepared for:*
Entergy Nuclear Operations, Inc.
Contract Number: 10150394

*Prepared by:*
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Centennial, CO

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*Approved by*: Terry J. Herrmann, P.E. Date: 7/26/2007

Structural Integrity Associates, Inc.

# REVISION CONTROL SHEET

Document Number: SIR-07-141-NPS

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Client: Entergy Nuclear Operations, Inc.

SI Project Number: VY-16Q

| Section | Pages | Revision | Date | Comments |
|---|---|---|---|---|
| 1.0 | 1-1 – 1-5 | 0 | 7/26/07 | Initial Issue |
| 2.0 | 2-1 – 2-3 | | | |
| 3.0 | 3-1 – 3-34 | | | |
| 4.0 | 4-1 – 4-11 | | | |
| 5.0 | 5-1 – 5-2 | | | |
| 6.0 | 6-1 | | | |
| 7.0 | 7-1 – 7-2 | | | |

## Table of Contents

## List of Tables

**Table** **Page**

## List of Figures

## 1.0 INTRODUCTION

In Table 4.3-3 of the Vermont Yankee License Renewal Application (LRA), the 60-year cumulative usage factor (CUF) value for the reactor pressure vessel (RPV) reactor recirculation outlet nozzle is reported as 0.810. Application of environmentally assisted fatigue (EAF) multipliers, as required for the license renewal period, resulted in an unacceptable EAF CUF value of 1.98. Therefore, further refined analysis is necessary to show acceptable EAF CUF results for this component.

This report documents a refined fatigue evaluation for the VY reactor recirculation outlet nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the reactor recirculation outlet nozzle are included in the evaluation, to be consistent with NUREG/CR-6260 [1] needs for EAF evaluation for license renewal. The resulting fatigue results will be used as a replacement to the value previously reported in the VY LRA.

The refined evaluation summarized in this report included development of a detailed finite element model of the reactor recirculation outlet nozzle, including relevant portions of the safe end, the nozzle forging, a portion of the vessel shell, and cladding as shown in the applicable drawings [2, 3]. Thermal and pressure stress histories were developed for relevant transients affecting the reactor recirculation outlet nozzle, including any effects of Extended Power Uprate (EPU), as specified by the VY RPV Design Specification [4], the VY EPU Design Specification [5] and other boiling water reactor (BWR) operating experience. The thermal and pressure stress histories were used to determine total stress intensities and primary plus secondary stress intensities for use in a subsequent fatigue evaluation [11]. Stress intensities were also included due to loads from the attached piping for application in the stress/fatigue analysis based on the bounding reaction loads obtained from the relevant design document. The revised fatigue calculation was performed using Section III methodology from the 1998 Edition, 2000 Addenda of the ASME Code [17], and was performed using actual cycles from past plant operation projected out to 60 years of operation.

## 1.1 Green's Function Methodology

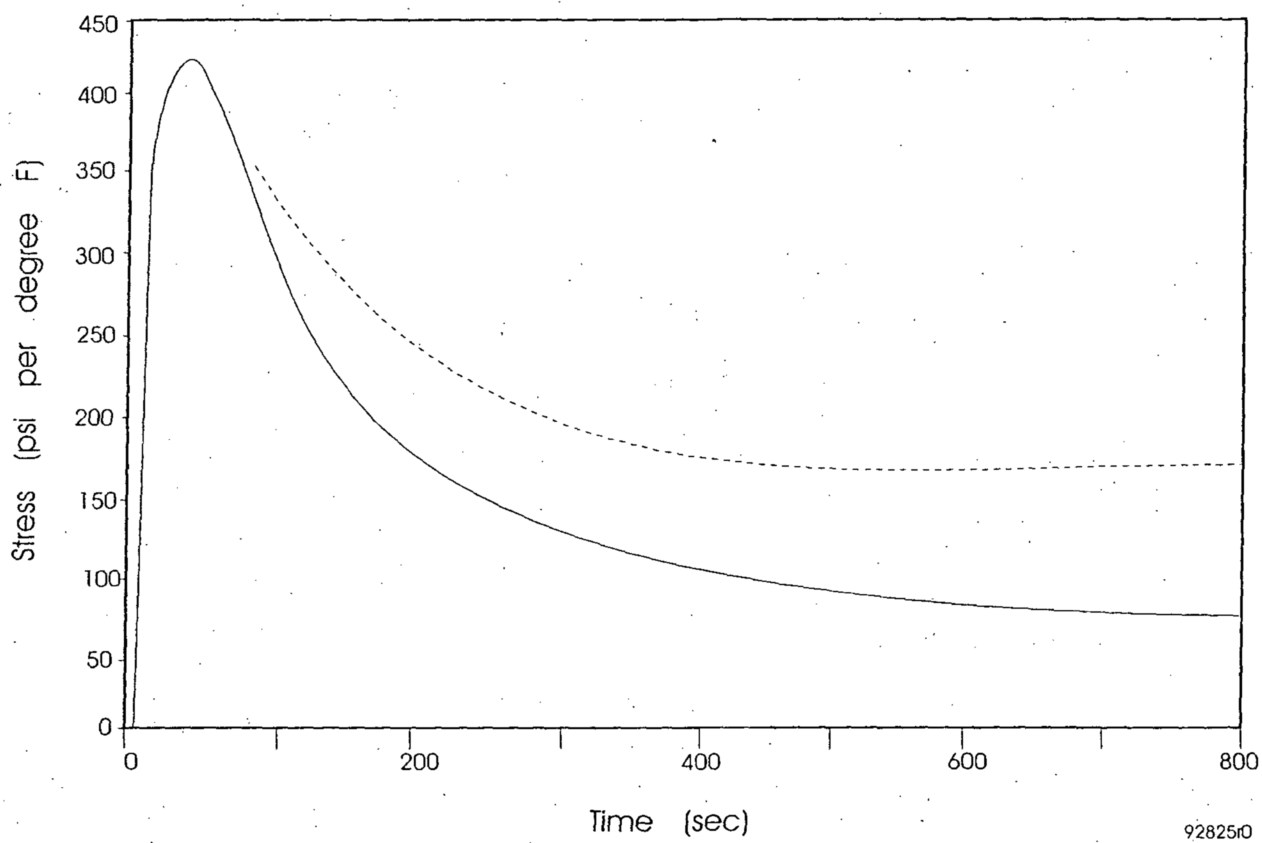
For the reactor recirculation outlet nozzle evaluated as a part of this work, stress intensity histories were computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's Function integration scheme is similar in concept to the Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [6]. A general outline is provided in this section.

A Green's Function is derived by using finite element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress intensity, and the thermal stress intensity response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 1-1 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 1-2. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 1-2. These five step changes produce the five successive stress responses in the second plot shown in Figure 1-2. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY reactor recirculation outlet nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements [17].




Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

**Figure 1-1. Typical Green's Functions for Thermal Transient Stress**

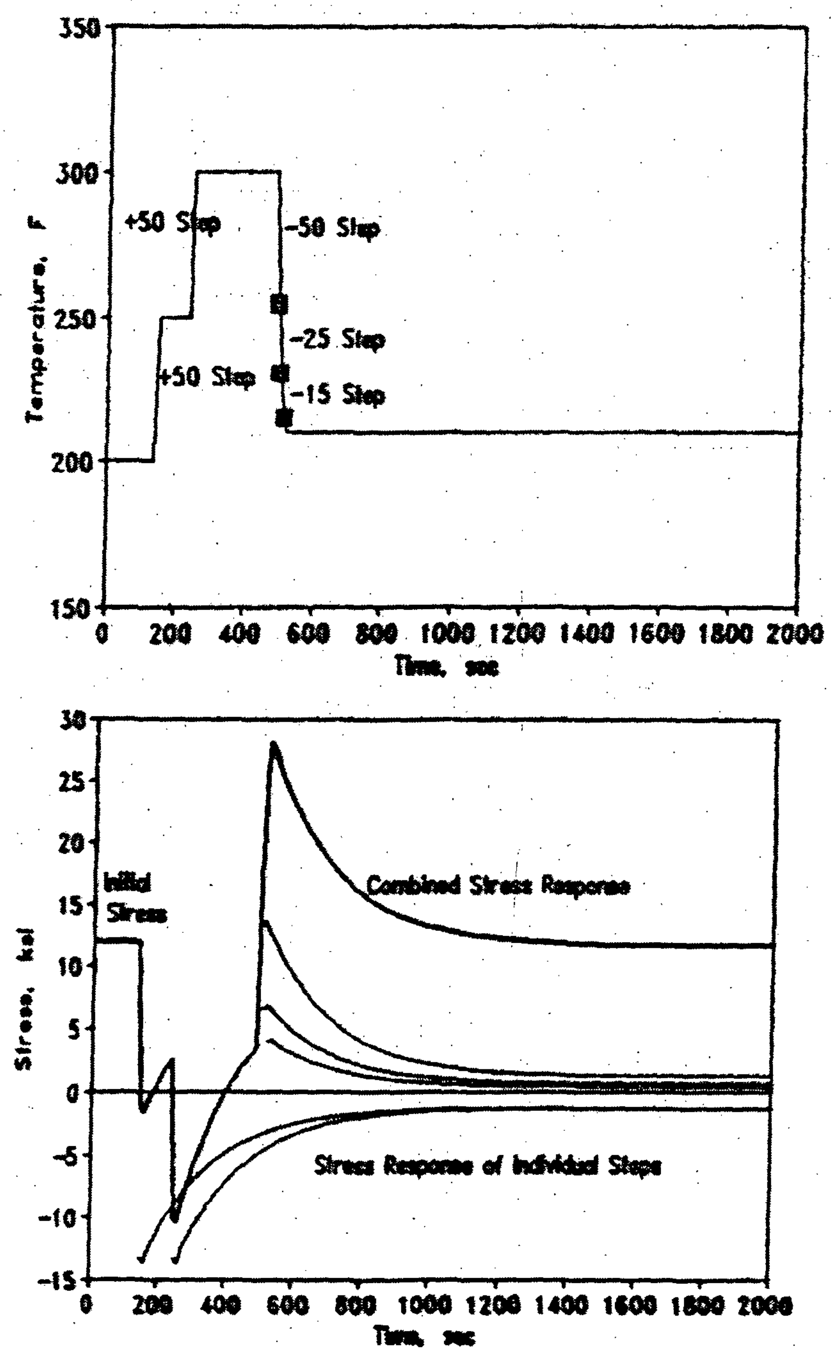



Figure 1-2. Typical Stress Response Using Green's Functions

## 2.0 FINITE ELEMENT MODEL

An ANSYS [7] finite element model (FEM) of the VY reactor recirculation outlet nozzle configuration was developed and used to perform the updated stress and fatigue analyses. The details of the model development are documented in the Reference [8] calculation.

The materials of the various components of the model are listed below:

- Safe End – SA182 F316 (16Cr-12Ni-2Mo)
- Piping – SA376 TP316 (16Cr-12Ni-2Mo)
- Nozzle Forging – SA508 Class 2 (3/4Ni-1/2Mo-1/3Cr-V)
- Vessel – SA533 Grade B (Mn-1/2Mo-1/2Ni)
- Cladding – SA240 Type 304 (18Cr-8Ni)

The radius of the RPV was increased by a factor of two to account for the fact that the vessel portion of the two dimensional axisymmetric finite element model is a sphere and the actual geometry is a cylinder.

Material properties were based upon the 1998 ASME Code, Section II, Part D, with 2000 Addenda [9], and are shown in Table 2-1. The properties for the Green's Functions were evaluated at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which was applied to the FEM model for Green's Function development. Due to the thermal shocks having a different temperature range at the nozzle blend radius and safe end for the Improper Start transient (Transient 9), this transient was run separately. Material properties were evaluated at 400°F for all locations except for the safe end and piping, which were evaluated using material properties at 300°F since the temperature is lower at this location and the properties at 300°F are closest to the average temperature of 330°F.

The finite element model is shown in Figure 2-1.

## Table 2-1. Material Properties

For the Green's Functions (evaluated at 300°F):

| Material | SA533 Gr. B Mn-1/2Mo-1/2Ni | SA508 Cl. 2 3/4Ni-1/2Mo-1/3Cr-V | SA240 TP 304 18Cr-8Ni | SA18 SA37( 16Cr-1 |
|---|---|---|---|---|
| Modulus of Elasticity, e+6 psi | 28.0 | 26.7 | 27.0 | 2 |
| Coefficient of Thermal Expansion, e-6, in/in/°F | 7.7 | 7.3 | 9.8 | 9 |
| Thermal Conductivity, Btu/hr-ft-°F | 23.4 | 23.4 | 9.8 | 9 |
| Thermal Diffusivity, ft²/hr | 0.401 | 0.401 | 0.160 | 0. |
| Specific Heat, Btu/lb-°F | 0.119 | 0.119 | 0.125 | 0. |
| Density, lb/in³ | 0.283 | 0.283 | 0.283 | 0. |
| Poisson's Ratio | 0.3 | 0.3 | 0.3 | ( |

For Transient 9 (evaluated at 400°F – except for the safe end and piping, which are evaluated at 300°F):

| Property | SA533 Gr. B Mn-1/2Mo-1/2Ni | SA508 Cl. 2 3/4Ni-1/2Mo-1/3Cr-V | SA240 TP 304 18Cr-8Ni | SA18 SA37 16Cr- @ |
|---|---|---|---|---|
| Modulus of Elasticity, e+6 psi | 27.4 | 26.1 | 26.5 | 2 |
| Coefficient of Thermal Expansion, e-6, in/in/°F | 8.0 | 7.7 | 10.2 | |
| Thermal Conductivity, Btu/hr-ft-°F | 23.1 | 23.1 | 10.4 | |
| Thermal Diffusivity, ft²/hr | 0.378 | 0.378 | 0.165 | 0 |
| Specific Heat, Btu/lb-°F | 0.125 | 0.125 | 0.129 | 0 |
| Density, lb/in³ | 0.283 | 0.283 | 0.283 | 0. |
| Poisson's Ratio | 0.3 | 0.3 | 0.3 | |

Note: 1. Material properties are taken from the 1998 ASME Code, Section II, Part D, with 2000 Addenda [9], except for den: which are assumed typical values and specific heat calculated as [k/ρd] /12³.

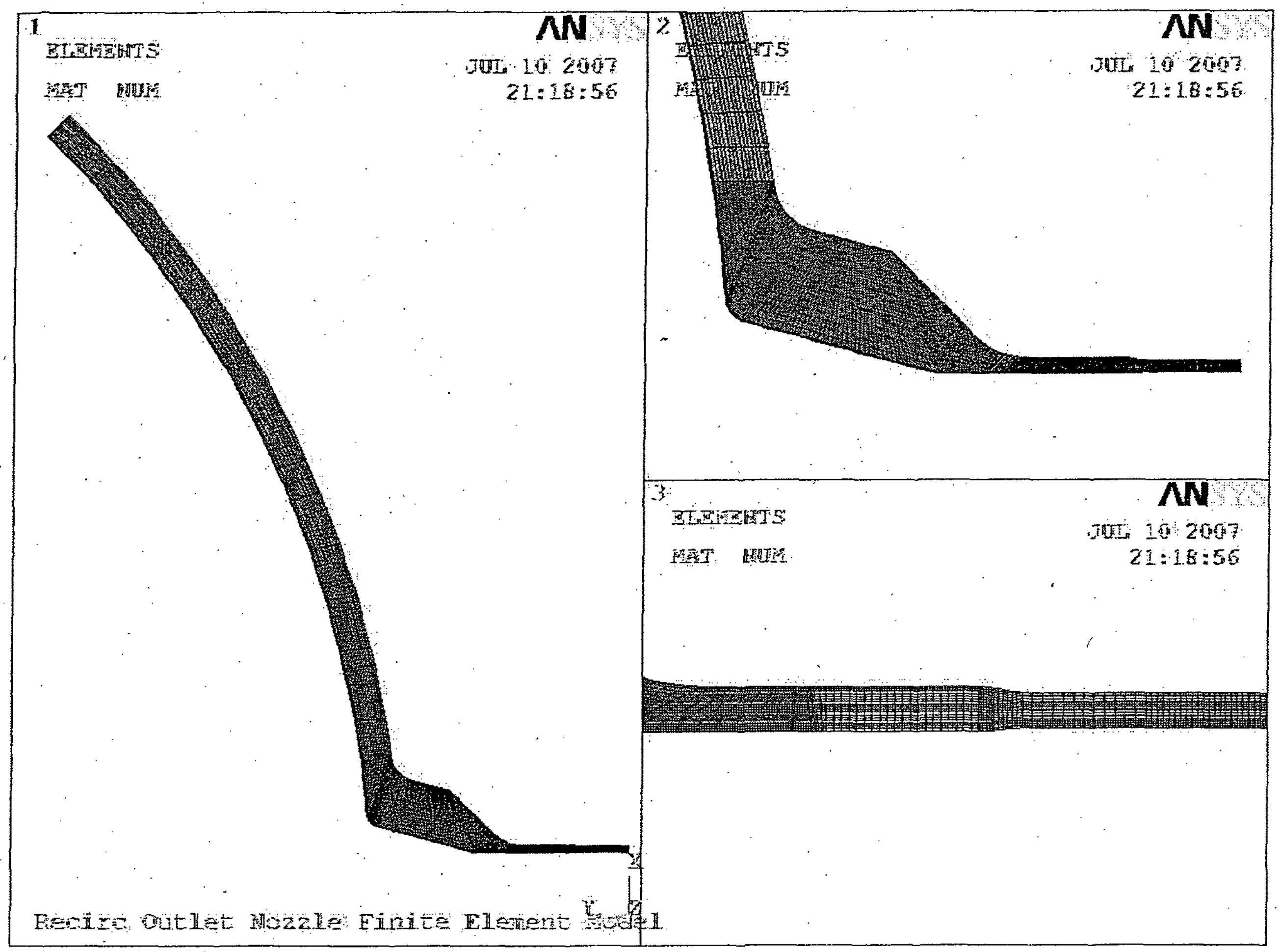



**Figure 2-1. VY Reactor Recirculation Outlet Nozzle FEM**

## 3.0 LOAD DEFINITIONS

The pressure and thermal stresses for the reactor recirculation outlet nozzle for the revised fatigue evaluation were developed using the axisymmetric FEM model described in Section 2.0 of this report. The details of the Green's Function development and associated stress and fatigue evaluations are documented in the Reference [10] and [11] calculations.

### 3.1 Thermal Loading

Thermal loads were applied to the recirculation outlet nozzle model to generate the Green's Functions. As a first step in the Green's Function process, heat transfer coefficients were determined for various regions of the reactor recirculation outlet nozzle FEM for three different flow cases: (1) 100% reactor recirculation outlet nozzle flow, (2) 50% reactor recirculation outlet nozzle flow and (3) 0% reactor recirculation outlet nozzle flow.

The 100% flow case simulates the operational condition of the reactor recirculation outlet nozzle (i.e., normal recirculation system flow). The heat transfer coefficients for the high flow case are for forced convection. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the reactor recirculation outlet nozzle due to normal operating conditions.

The 50% flow case simulates a reduced flow condition of the reactor recirculation outlet nozzle (i.e., during power ascension). The heat transfer coefficients for the reduced flow case are also for forced convection. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the reactor recirculation outlet nozzle under reduced flow conditions.

The 0% flow case simulates a stagnant condition of the reactor recirculation outlet nozzle when recirculation flow is stopped and the entire reactor recirculation outlet nozzle is at the same temperature as the RPV fluid. The heat transfer coefficients for the 0% flow case are for free convection (stagnant) conditions. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the reactor recirculation outlet nozzle in the stagnant condition.

The temperature on the exterior of the reactor, nozzle, safe end and pipe was assumed to be 120°F (ambient). Figure 3-1 shows the heat transfer coefficient regions assumed for the reactor recirculation outlet nozzle FEM. The applied heat transfer coefficients and the fluid temperatures are summarized in the sections that follow.

### *3.1.1 Heat Transfer Coefficients and Boundary Fluid Temperatures*

Referring to Figure 3-1, heat transfer coefficients for the Green's Functions were applied as follows:

*For Green's Functions:*

Region 1

The heat transfer coefficient, h, for 100% flow is 3,577.8 BTU/hr-ft$^2$-°F at 300°F.

The heat transfer coefficient, h, for 50% flow is 2,054.9 BTU/hr-ft$^2$-°F at 300°F.

The heat transfer coefficient, h, for 0% flow is 112.34 BTU/hr-ft$^2$-°F at 300°F.

Region 2

The heat transfer coefficient for Region 2 was linearly transitioned from the value of the heat transfer coefficient used in Region 1 to the value used in Region 3.

Region 3

The heat transfer coefficient, h, for 100% flow is 3,361 BTU/hr-ft$^2$-°F at 300°F.

The heat transfer coefficient, h, for 50% flow is 1,930.9 BTU/hr-ft$^2$-°F at 300°F.

The heat transfer coefficient, h, for 0% flow is 112.34 BTU/hr-ft$^2$-°F at 300°F.

Region 4

The heat transfer coefficient for Region 4 (nozzle blend radius) was linearly transitioned from the value of the heat transfer coefficient used in Region 3 to the value used in Region 5.

Region 5

The heat transfer coefficient, h, for 100% flow is 1,788.9 BTU/hr-ft$^2$-°F at 300°F.

The heat transfer coefficient, h, for 50% flow is 1,027.4 BTU/hr-ft$^2$-°F at 300°F.

The heat transfer coefficient, h, for 0% flow is 101 BTU/hr-ft$^2$-°F at 300°F.

Region 6

The heat transfer coefficient, h, is 0.4 BTU/hr-ft$^2$-°F.

For all three Green's functions, a 500°F to 100°F thermal shock was evaluated in Regions 1 through 5 to determine the stress response. For Region 6, a constant temperature of 120°F was used.

Referring to Figure 3-2, heat transfer coefficients for Transient 9 were applied as follows:

*For Transient 9:*

Region 1

The heat transfer coefficient, h, for 12% flow is 672.8 BTU/hr-ft$^2$-°F at 500°F.

The heat transfer coefficient, h, for 12% flow is 308.2 BTU/hr-ft$^2$-°F at 100°F.

The fluid temperature shock is: T = 526°F - 130°F - 526°F.

Region 2

The heat transfer coefficient, h, for 12% flow is 632.2 BTU/hr-ft$^2$-°F at 500°F.

The heat transfer coefficient, h, for 12% flow is 616.6 BTU/hr-ft$^2$-°F at 300°F.

The fluid temperature shock is: T = 526°F - 268°F - 526°F.

Region 3

The heat transfer coefficient, h, for 12% flow is 336.4 BTU/hr-ft$^2$-°F at 500°F.

The heat transfer coefficient, h, for 12% flow is 328.0 BTU/hr-ft$^2$-°F at 300°F.

The fluid temperature shock is:

Case 1: T = 526°F - 268°F - 526°F

Case 2: T = 526°F

Region 4

The heat transfer coefficient, h, is 0.4 BTU/hr-ft$^2$-°F.

The temperature, T, is 120°F.

Transition Regions

The heat transfer coefficient was linearly transitioned from the value of the heat transfer coefficient used in adjacent regions.

### *3.1.2 Green's Functions*

The three flow-dependent thermal load cases outlined in the previous section were run on the reactor recirculation outlet nozzle FEM with the heat transfer coefficients and the fluid temperature conditions listed in Section 3.1.1. Two locations were selected for analysis (see Figures 3-3 and 3-4):

1. The critical safe end location was chosen as the node with the highest stress intensity due to thermal loading under high flow conditions. The highest stress intensity due to thermal loading occurred at Node 6395 (see Figure 3-3), on the inside diameter of the nozzle safe end. Therefore, this node was selected for analysis.
2. The critical blend radius location was chosen based upon the highest pressure stress intensity, neglecting the cladding. The critical location is selected as Node 3829, as shown in Figure 3-4.

Twelve stress intensity Green's Functions were developed (i.e., total stress intensity and membrane plus bending stress intensity for each location and each flow case). The total stress intensity Green's Functions for the safe end location at 100%, 50% and 0% flow are shown in Figures 3-5, 3-6 and 3-7, respectively. The total stress intensity Green's Function for the blend radius location at 100%, 50% and 0% flow are shown in Figures 3-8, 3-9 and 3-10, respectively.

### *3.1.3 Thermal Transients*

The transients analyzed for the reactor recirculation outlet nozzle were developed based on the definitions in the original RPV Design Specification [4], as modified for EPU [5], as well as more recent definitions based on BWR operating experience. For BWR operating experience, the transients described in the thermal cycle diagrams for a BWR-4 plant similar in design and vintage to VY were obtained, and plant-specific data from VY was applied to each transient. The resulting thermal cycle diagrams are shown in References [12 and 13]. The final transients evaluated in the stress and fatigue analyses are shown in Figures 3-11 through 3-20.

The number of cycles projected for the 60-year operating life was used for each transient [14]. Tables 3-1 and 3-2 summarize the thermal transients for the safe end and blend radius locations, respectively.

## 3.2 Pressure Loading

A uniform pressure of 1,000 psi was applied along the inside surface of the reactor recirculation outlet nozzle and the RPV wall. A pressure load of 1,000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the FEM. This cap load was calculated as follows:

$$P_{cap} = P \cdot \frac{\left(R_i^2\right)}{\left(R_o^2 - R_i^2\right)}$$

where:

| | | | |
|---|---|---|---|
| | $P_{cap}$ | = | end cap pressure load (psi) |
| | $P$ | = | unit pressure load = 1,000 psi |
| | $R_i$ | = | Inner Radius = 12.969 in |
| | $R_o$ | = | Outer Radius = 14.188 in |

The calculated pressure cap load of 5,081.7 psi was applied as a negative value so that it would exert tension on the end of the model. The nodes on the end of the FEM were coupled in the axial direction to ensure mutual displacement of the end of the FEM due to the attached piping. Figures 3-21, 3-22, and 3-23 show the internal pressure distribution, cap load, and symmetry condition applied to the RPV end of the model, respectively.

The internal pressure load case for the blend radius resulted in a total stress intensity of 31,300 psi, and for the safe-end resulted in a total stress intensity of 11,490 psi. The membrane plus bending stress intensity at the blend radius is 33,640 psi and at the safe end is 11,350 psi, respectively.

## 3.3 Piping Loading

The piping stress intensities (stress caused by the attached piping) were determined for the two evaluated reactor recirculation outlet nozzle locations. The design piping reactions that were used in the stress and fatigue evaluation are defined on the Reference [15] drawing. These loads represent shear and moment loadings on the nozzle resulting from thermal expansion of the attached piping and seismic loads. The loads are as shown in Figure 3-24. The stresses resulting from these loads were calculated by hand using classical structural mechanics formulas, as documented in Reference [11], and are shown in Tables 3-3 and 3-4 for the safe end and blend radius locations, respectively.

# Table 3-1: Safe End Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| **1. Normal Startup with Heatup at 100°F/hr 300 Cycles** | 0 | 100 | | 0 | 14147.0 |
| | 16164 | 549 | 16164 | 1010 | (50%)[1] |
| | 16864 | 549 | 700 | 1010 | |
| **2. Turbine Roll and Increase to Rated Power 300 Cycles** | 0 | 549 | | 1010 | 28294 |
| | 1 | 542 | 1 | 1010 | (100%)[1] |
| | 601 | 542 | 600 | 1010 | |
| | 602 | 526 | 1 | 1010 | |
| | 1302 | 526 | 700 | 1010 | |
| **3. Loss of Feedwater Heaters Turbine Trip 25% Power 10 Cycles** | 0 | 526 | | 1010 | 28294 |
| | 1800 | 542 | 1800 | 1010 | (100%)[1] |
| | 2100 | 542 | 300 | 1010 | |
| | 2460 | 526 | 360 | 1010 | |
| | 3060 | 526 | 600 | 1010 | |
| | 3960 | 542 | 900 | 1010 | |
| | 4260 | 542 | 300 | 1010 | |
| | 6060 | 526 | 1800 | 1010 | |
| | 6760 | 526 | 700 | 1010 | |
| **4. Loss of Feedwater Pumps 10 Cycles** | 0 | 526 | | 1010 | 0 |
| | 3 | 526 | 3 | 1190 | (0%)[1] |
| | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6773 | 500 | 4380 | 1135 | |
| | 7193 | 300 | 420 | 675 | 14147 |
| | 7493 | 300 | 300 | 675 | (50%)[1] |
| | 11093 | 400 | 3600 | 240 | |
| | 16457 | 549 | 5364 | 1010 | |
| | 16517 | 549 | 60 | 1010 | |
| | 16518 | 542 | 1 | 1010 | 28294 |
| | 17118 | 542 | 600 | 1010 | (100%)[1] |
| | 17119 | 526 | 1 | 1010 | |
| | 17819 | 526 | 700 | 1010 | |
| **5. Turbine Generator Trip 60 Cycles** | 0 | 526 | | 1010 | 28294 |
| | 10 | 526 | 10 | 1135 | (100%)[1] |
| | 15 | 526 | 5 | 1135 | |
| | 30 | 526 | 15 | 940 | |
| | 1830 | 526 | 1800 | 940 | |
| | 2250 | 549 | 420 | 1010 | |
| | 2310 | 549 | 60 | 1010 | |
| | 2311 | 542 | 1 | 1010 | |
| | 2911 | 542 | 600 | 1010 | |
| | 2912 | 526 | 1 | 1010 | |
| | 3612 | 526 | 700 | 1010 | |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| **6. Reactor Overpressure 1 Cycle** | 0 | 526 | | 1010 | 28294 |
| | 2 | 526 | 2 | 1375 | (100%)[1] |
| | 32 | 526 | 30 | 940 | |
| | 1832 | 526 | 1800 | 940 | |
| | 2252 | 549 | 420 | 1010 | |
| | 2312 | 549 | 60 | 1010 | |
| | 2313 | 542 | 1 | 1010 | |
| | 2913 | 542 | 600 | 1010 | |
| | 2914 | 526 | 1 | 1010 | |
| | 3614 | 526 | 700 | 1010 | |
| **7. SRV Blowdown 1 Cycle** | 0 | 526 | | 1010 | 28294 |
| | 600 | 375 | 600 | 170 | (100%)[1] |
| | 11580 | 70 | 10980 | 50 | |
| | 12280 | 70 | 700 | 50 | |
| **8. SCRAM Other 228 Cycles** | 0 | 526 | | 1010 | 28294 |
| | 15 | 526 | 15 | 940 | (100%)[1] |
| | 1815 | 526 | 1800 | 940 | |
| | 2235 | 549 | 420 | 1010 | |
| | 2295 | 549 | 60 | 1010 | |
| | 2296 | 542 | 1 | 1010 | |
| | 2356 | 542 | 60 | 1010 | |
| | 2357 | 526 | 1 | 1010 | |
| | 3057 | 526 | 700 | 1010 | |
| **9. Improper Startup 1 Cycle** | 0 | 526 | | 1010 | 3395 |
| | 1 | 130 [3] | 1 | 1010 | (12%)[1] |
| | 27 | 130 [3] | 26 | 1010 | |
| | 28 | 526 | 1 | 1010 | |
| | 728 | 526 | 700 | 1010 | |
| **10. Shutdown 300 Cycles** | 0 | 549 | | 1010 | 14147 |
| | 6264 | 375 | 6264 | 170 | (50%)[1] |
| | 6864 | 330 | 600 | 88 | |
| | 16224 | 70 | 9360 | 50 | |
| | 16924 | 70 | 700 | 50 | |
| **11. Design Hydrostatic Test 120 Cycles** | — | 100 | — | 0 | 1981 |
| | | | | 1100 | (7%)[1] |
| | | | | 50 | |
| **12. Hydrostatic Test 1 Cycle** | — | 100 | — | 50 | 1981 |
| | | | | 1563 | (7%)[1] |
| | | | | 50 | |

Notes:
1. The instant temperature change is assumed as 1 second time step.
2. The number of cycles is for 60 years [14].
3. 130°F is the safe end temperature for this transient. The blend radius has a different temperature for Transient 9. [13]

Note: *These transients are the same as in Table 3-2 with the exception of the 700 second steady state time increment that is used. The transients in Table 2 are plotted using a 6000 second steady state increment. The difference is due to the length of the Green's Function for the safe end which is shorter compared to the blend radius.*

## Table 3-2: Blend Radius Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 1. Normal Startup with Heatup at 100°F/hr 300 Cycles | 0 | 100 | | 0 | 14147.0 |
| | 16164 | 549 | 16164 | 1010 | (50%)' |
| | 22164 | 549 | 6000 | 1010 | |
| 2. Turbine Roll and Increase to Rated Power 300 Cycles | 0 | 549 | | 1010 | 28294 |
| | 1 | 542 | 1 | 1010 | (100%)' |
| | 601 | 542 | 600 | 1010 | |
| | 602 | 526 | 1 | 1010 | |
| | 6602 | 526 | 6000 | 1010 | |
| 3. Loss of Feedwater Heaters Turbine Trip 25% Power 10 Cycles | 0 | 526 | | 1010 | 28294 |
| | 1800 | 542 | 1800 | 1010 | (100%)' |
| | 2100 | 542 | 300 | 1010 | |
| | 2460 | 526 | 360 | 1010 | |
| | 3060 | 526 | 600 | 1010 | |
| | 3960 | 542 | 900 | 1010 | |
| | 4260 | 542 | 300 | 1010 | |
| | 6060 | 526 | 1800 | 1010 | |
| | 12060 | 526 | 6000 | 1010 | |
| 4. Loss of Feedwater Pumps 10 Cycles | 0 | 526 | | 1010 | 0 |
| | 3 | 526 | 3 | 1190 | (0%)' |
| | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1136 | |
| | 2393 | 300 | 180 | 885 | |
| | 6773 | 500 | 4380 | 1135 | |
| | 7193 | 300 | 420 | 675 | |
| | 7493 | 300 | 300 | 675 | |
| | 10793 | 400 | 3600 | 240 | |
| | 12862 | 549 | 5369 | 1010 | |
| | 12922 | 549 | 60 | 1010 | |
| | 12923 | 542 | 1 | 1010 | |
| | 13523 | 542 | 600 | 1010 | |
| | 13524 | 526 | 1 | 1010 | |
| | 19524 | 526 | 6000 | 1010 | |
| 5. Turbine Generator Trip 60 Cycles | 0 | 526 | | 1010 | 28294 |
| | 10 | 526 | 10 | 1135 | (100%)' |
| | 15 | 526 | 5 | 1135 | |
| | 30 | 526 | 15 | 940 | |
| | 1830 | 526 | 1800 | 940 | |
| | 2250 | 549 | 420 | 1010 | |
| | 2310 | 549 | 60 | 1010 | |
| | 2311 | 542 | 1 | 1010 | |
| | 2911 | 542 | 600 | 1010 | |
| | 2912 | 526 | 1 | 1010 | |
| | 8912 | 526 | 6000 | 1010 | |

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 6. Reactor Overpressure 1 Cycle | 0 | 526 | | 1010 | 28294 |
| | 2 | 526 | 2 | 1375 | (100%)' |
| | 32 | 526 | 30 | 940 | |
| | 1832 | 526 | 1800 | 940 | |
| | 2252 | 549 | 420 | 1010 | |
| | 2312 | 549 | 60 | 1010 | |
| | 2313 | 542 | 1 | 1010 | |
| | 2913 | 542 | 600 | 1010 | |
| | 2914 | 526 | 1 | 1010 | |
| | 8914 | 526 | 6000 | 1010 | |
| 7. SRV Blowdown 1 Cycle | 0 | 526 | | 1010 | 28294 |
| | 600 | 375 | 600 | 170 | (100%)' |
| | 11580 | 70 | 10980 | 50 | |
| | 17580 | 70 | 6000 | 50 | |
| 8. SCRAM Other 228 Cycles | 0 | 526 | | 1010 | 28294 |
| | 15 | 526 | 15 | 940 | (100%)' |
| | 1815 | 526 | 1800 | 940 | |
| | 2235 | 549 | 420 | 1010 | |
| | 2295 | 549 | 60 | 1010 | |
| | 2296 | 542 | 1 | 1010 | |
| | 2356 | 542 | 60 | 1010 | |
| | 2357 | 526 | 1 | 1010 | |
| | 8357 | 526 | 6000 | 1010 | |
| 9. Improper Startup 1 Cycle | 0 | 526 | | 1010 | 3395 |
| | 1 | 268 (3) | 1 | 1010 | (12%)' |
| | 27 | 268 (3) | 26 | 1010 | |
| | 28 | 526 | 1 | 1010 | |
| | 6028 | 526 | 6000 | 1010 | |
| 10. Shutdown 300 Cycles | 0 | 549 | | 1010 | 14147 |
| | 6264 | 375 | 6264 | 170 | (50%)' |
| | 6864 | 330 | 600 | 88 | |
| | 16224 | 70 | 9360 | 50 | |
| | 22224 | 70 | 6000 | 50 | |
| 11. Design Hydrostatic Test 120 cycles | — | 100 | — | 50 | 1981 |
| | | | | 1563 | (7%) |
| | | | | 50 | |
| 12. Hydrostatic Test 1 Cycle | — | 100 | — | 0 | 1981 |
| | | | | 1100 | (7%) |
| | | | | 50 | |

Notes:
1. The instant temperature change is assumed as 1 second time step.
2. The number of cycles is for 60 years [14].
3. 268°F is the blend radius temperature for this transient. The safe end has a different temperature for Transient 9. [13]

Table 3-3: Stresses Due to Piping Loads for Safe End Location

| Safe End External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 20.00 | kips |
| $F_y$ = | 20.00 | kips |
| $F_Z$ = | 30.00 | kips |
| $M_x$ = | 2004.00 | in-kips |
| $M_y$ = | 3000.00 | in-kips |
| $M_Z$ = | 2004.00 | in-kips |
| OD= | 28.38 | in |
| ID= | 25.938 | in |
| $R_N$ = | 13.58 | in |
| L = | 4.25 | in |
| $t_N$ = | 1.22 | in |
| $(M_x)_2$ = | 1919.00 | in-kips |
| $(M_y)_2$ = | 3085.00 | in-kips |
| $M_{xy}$ = | 3633.15 | in-kips |
| $F_{xy}$ = | 28.28 | kips |
| $N_Z$ = | 6.62 | kips/in |
| $q_N$ = | -1.07 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 5.43 | ksi |
| $\tau$ = | -0.88 | ksi |
| $SI_{max}$ = | 5.71 | ksi |
| $SI_{max}$ = | 5708.89 | psi |

Table 3-4: Stresses Due to Piping Loads for Blend Radius Location

| Blend Radius External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 20.00 | kips |
| $F_y$ = | 20.00 | kips |
| $F_Z$ = | 30.00 | kips |
| $M_x$ = | 2004.00 | in-kips |
| $M_y$ = | 3000.00 | in-kips |
| $M_Z$ = | 2004.00 | in-kips |
| OD= | 55.88 | in |
| ID= | 37.368 | in |
| $R_N$ = | 23.31 | in |
| L = | 42.77 | in |
| $t_N$ = | 9.25 | in |
| $(M_x)_2$ = | 1148.54 | in-kips |
| $(M_y)_2$ = | 3855.46 | in-kips |
| $M_{xy}$ = | 4022.90 | in-kips |
| $F_{xy}$ = | 28.28 | kips |
| $N_Z$ = | 2.56 | kips/in |
| $q_N$ = | -0.20 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 0.28 | ksi |
| $\tau$ = | -0.02 | ksi |
| $SI_{max}$ = | 0.28 | ksi |
| $SI_{max}$ = | 280.16 | psi |

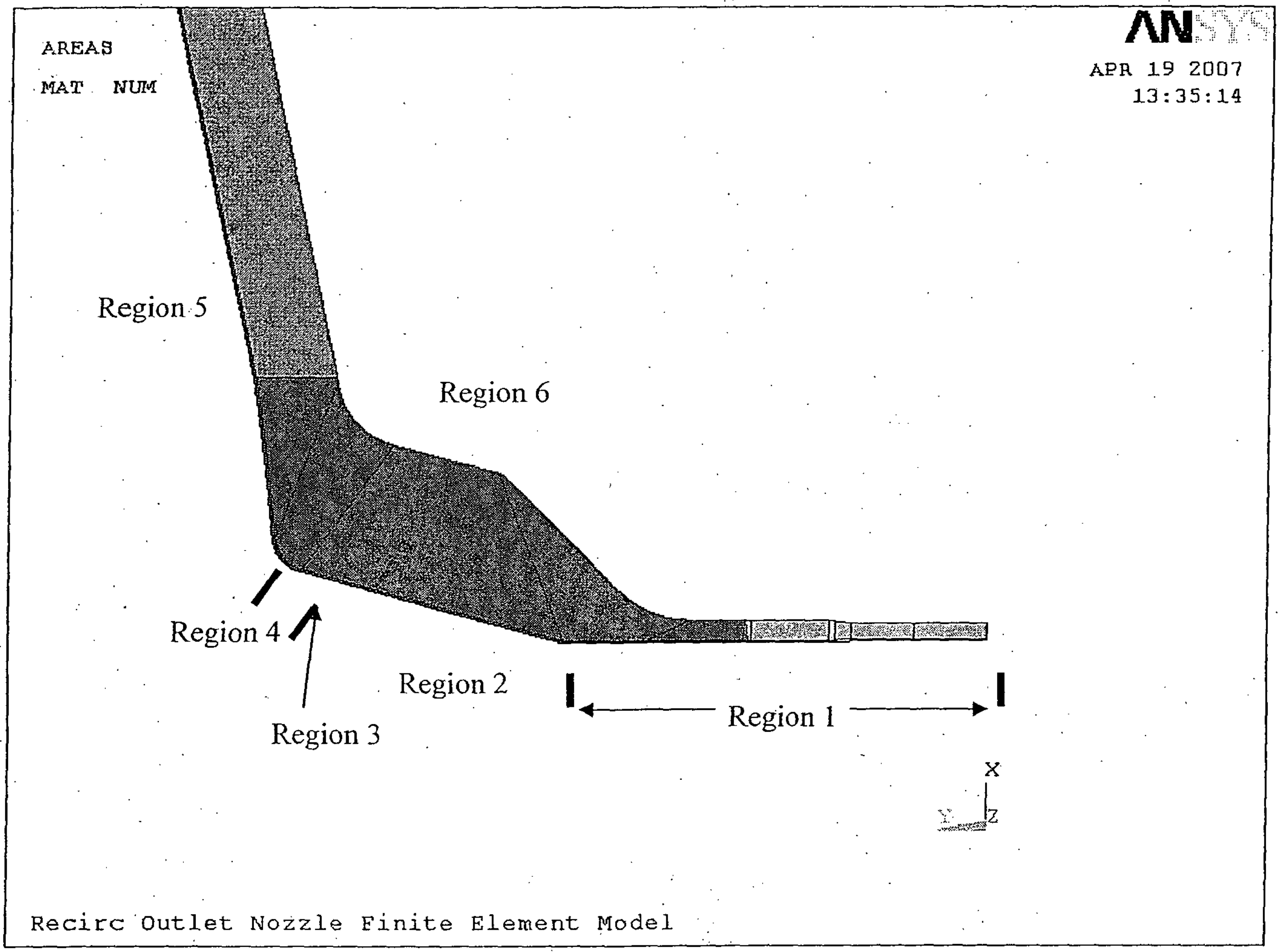



**Figure 3-1: Thermal Regions for Green's Functions**

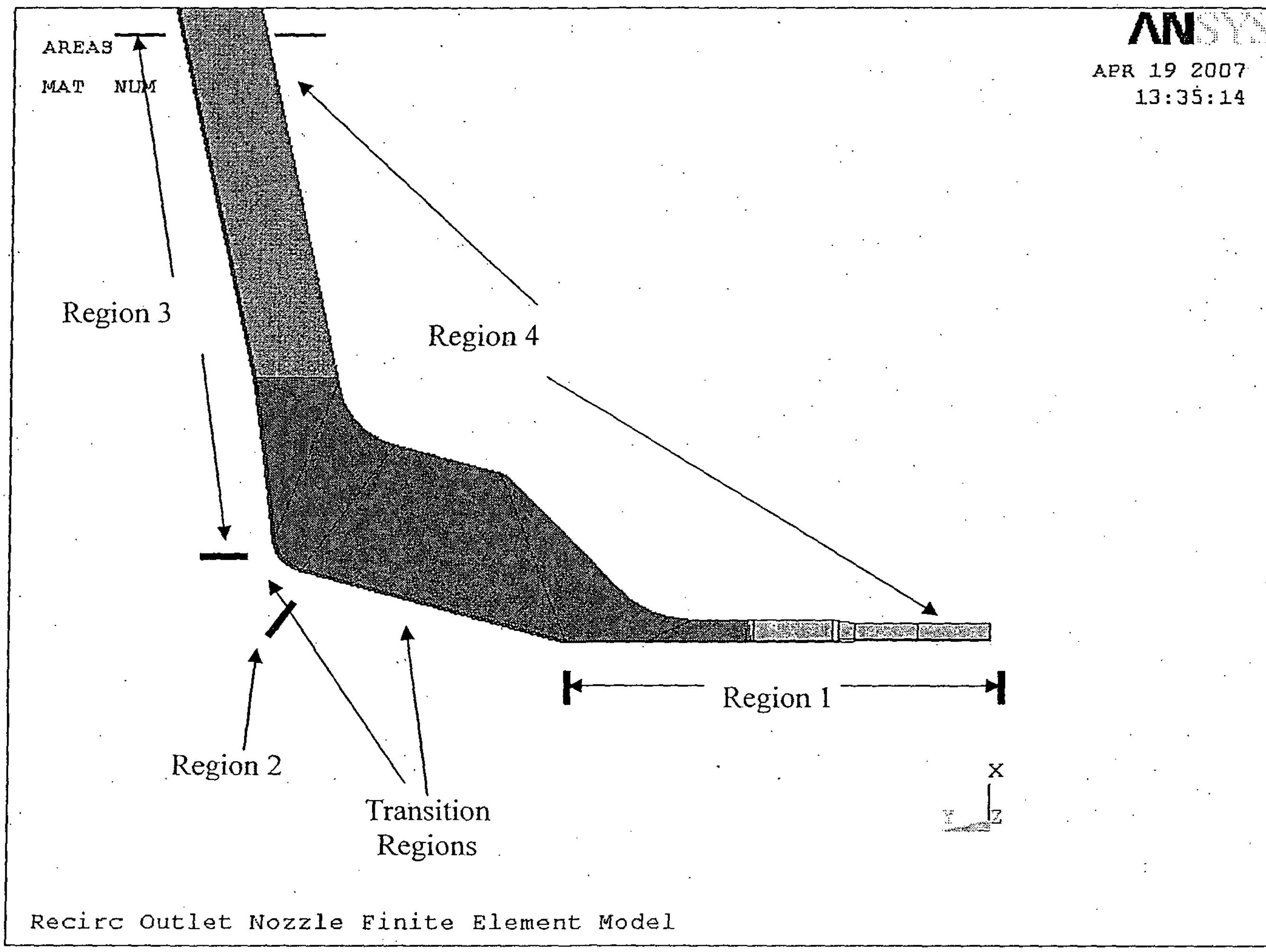



**Figure 3-2: Thermal Regions for Transient 9**

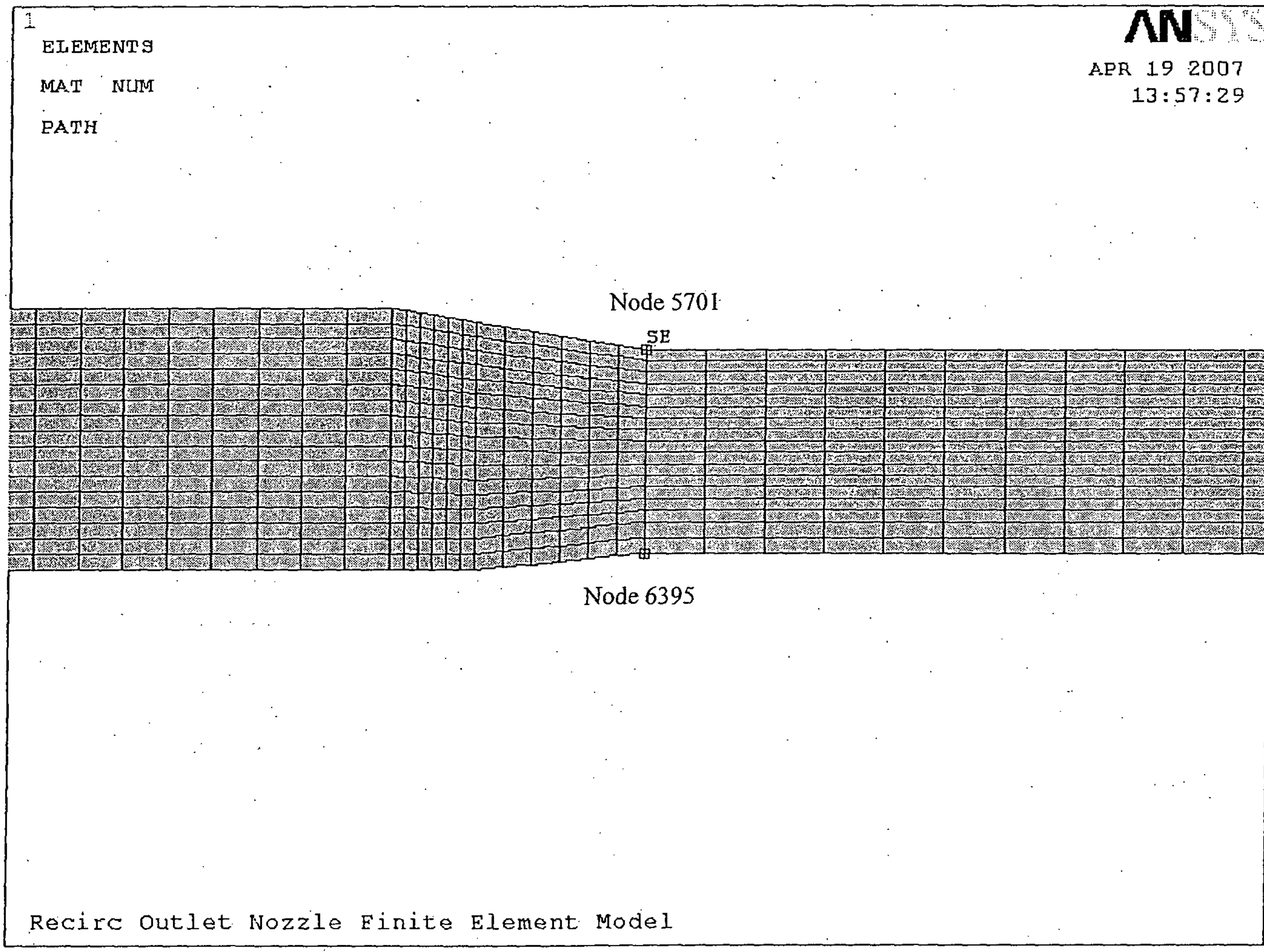



**Figure 3-3: Safe End Critical Thermal Stress Location**

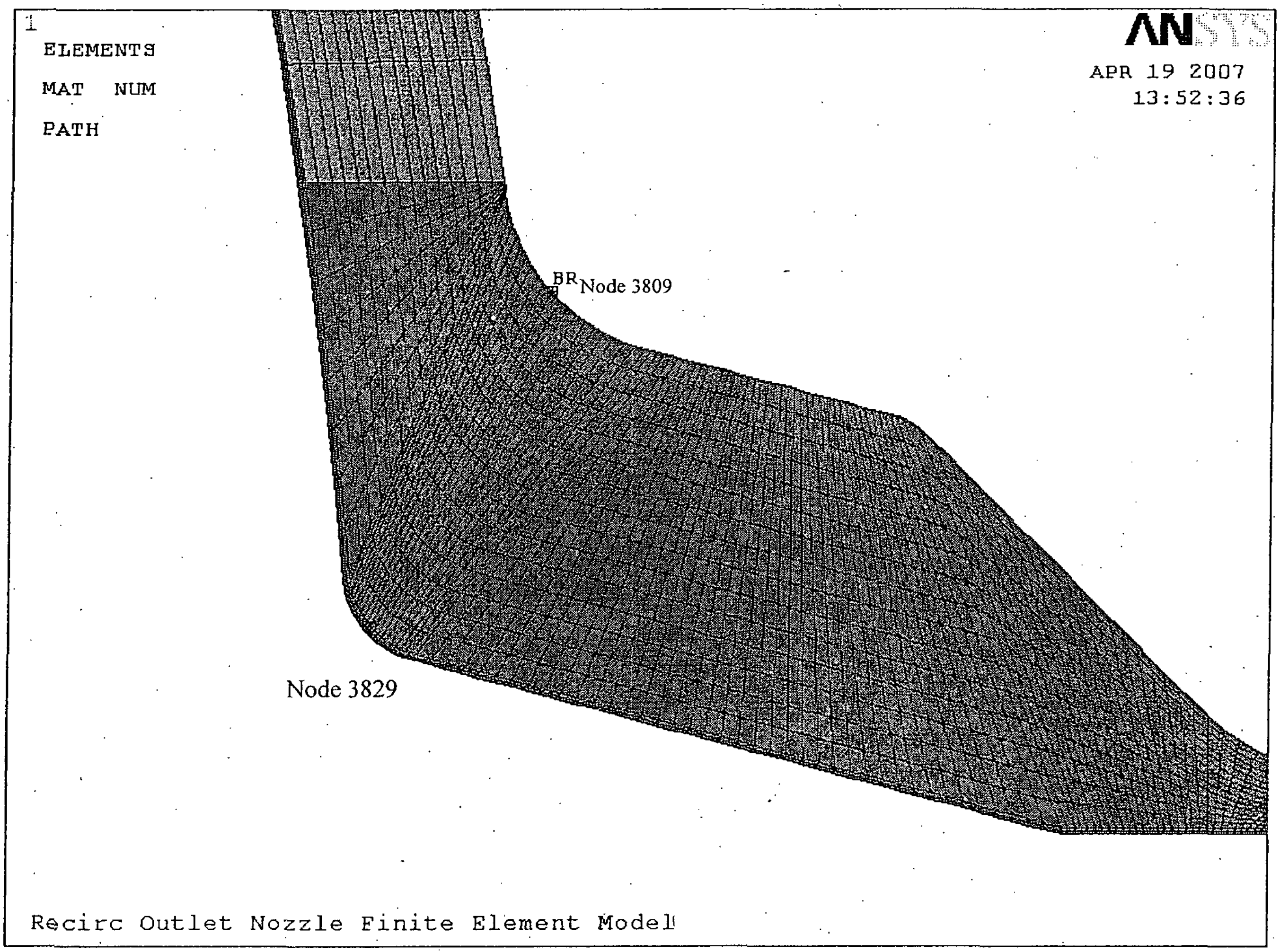



**Figure 3-4: Blend Radius Critical Thermal Stress Location**

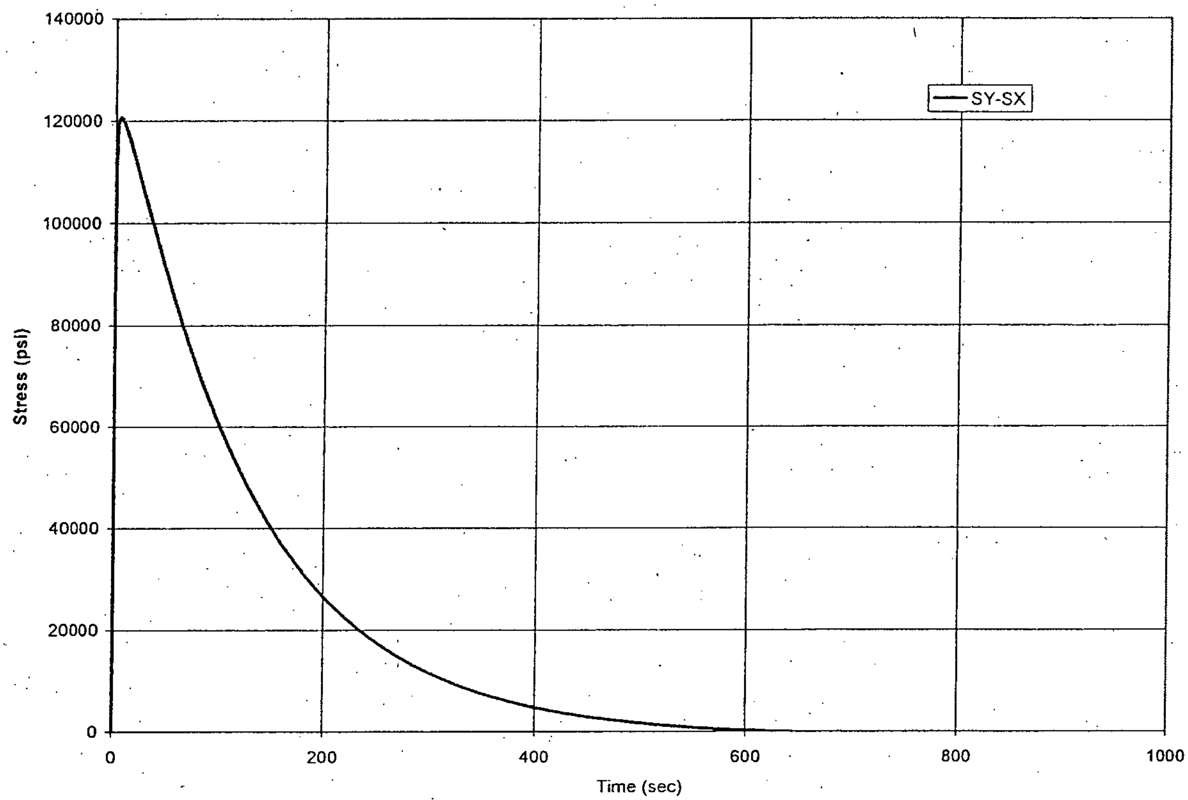



**Figure 3-5: Safe End Total Stress Intensity Green's Function for 100% Flow**

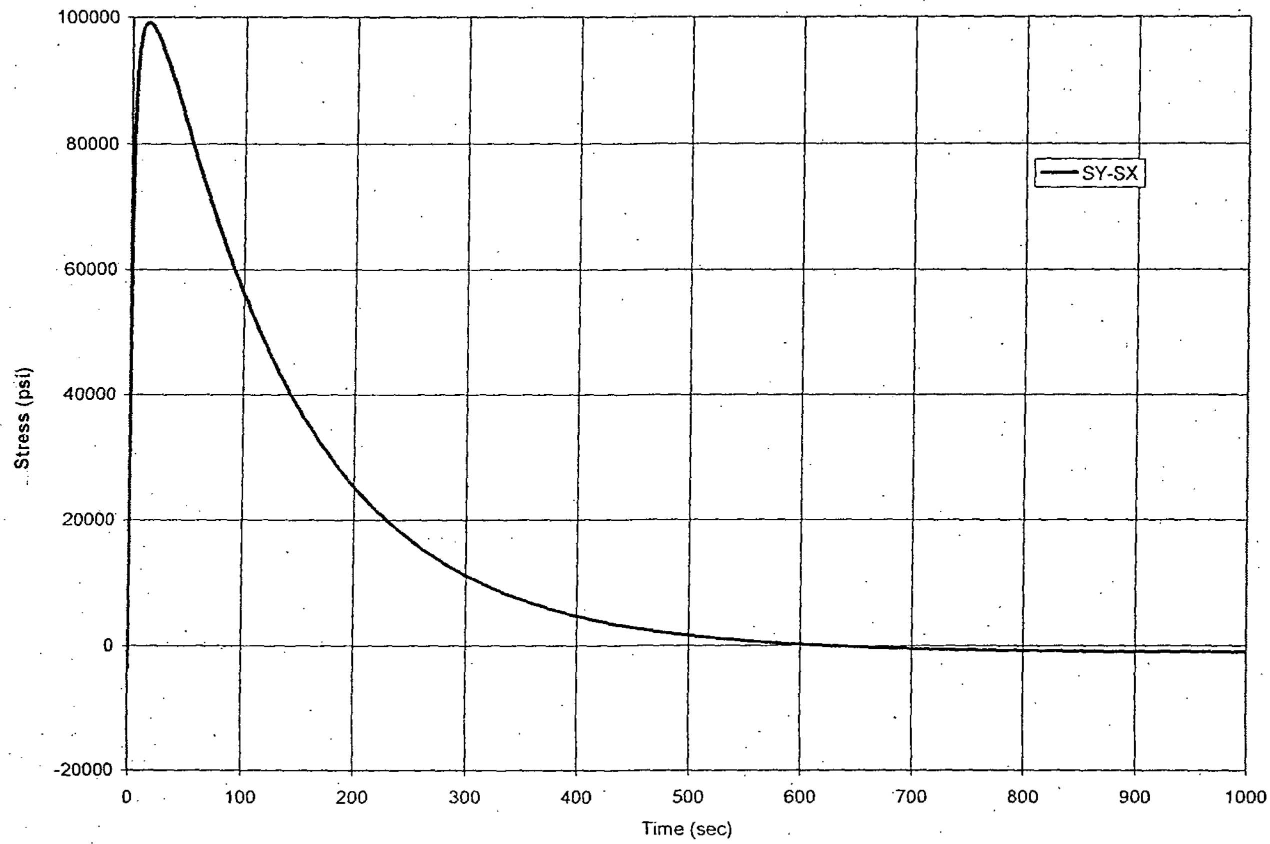



**Figure 3-6: Safe End Total Stress Intensity Green's Function for 50% Flow**

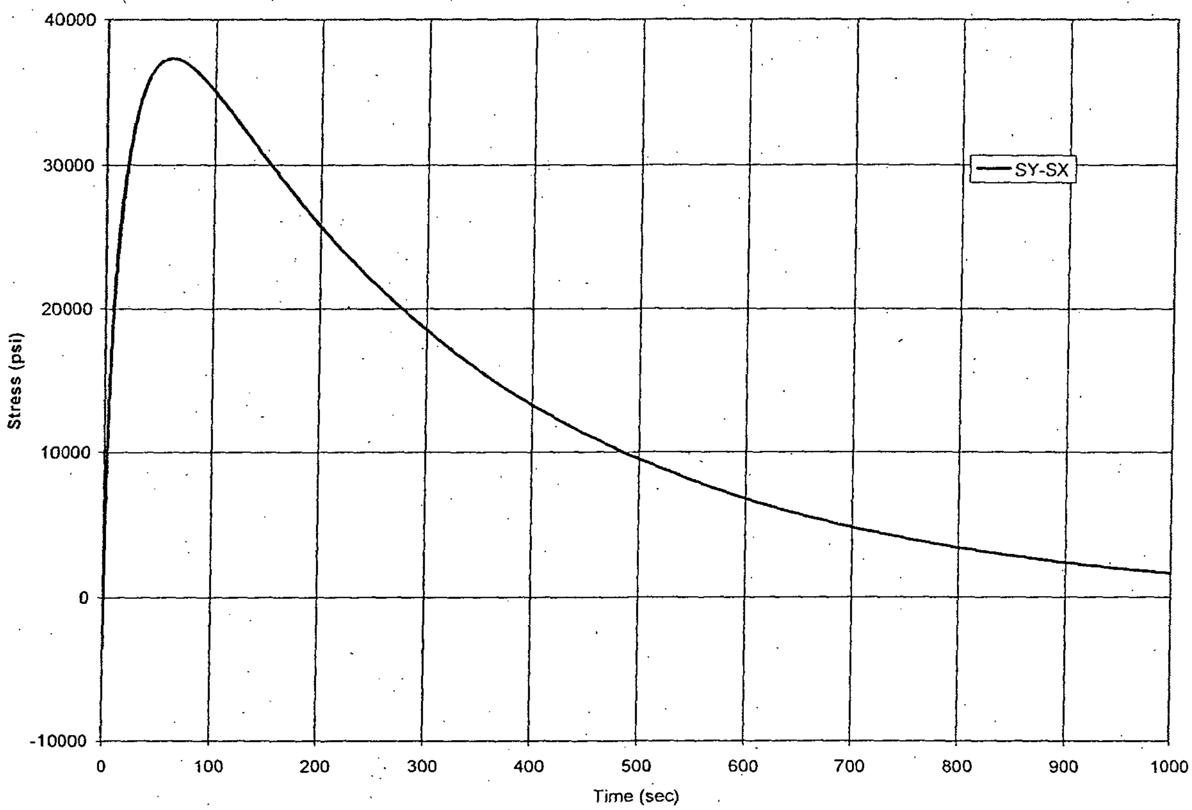



**Figure 3-7: Safe End Total Stress Intensity Green's Function for 0% Flow**

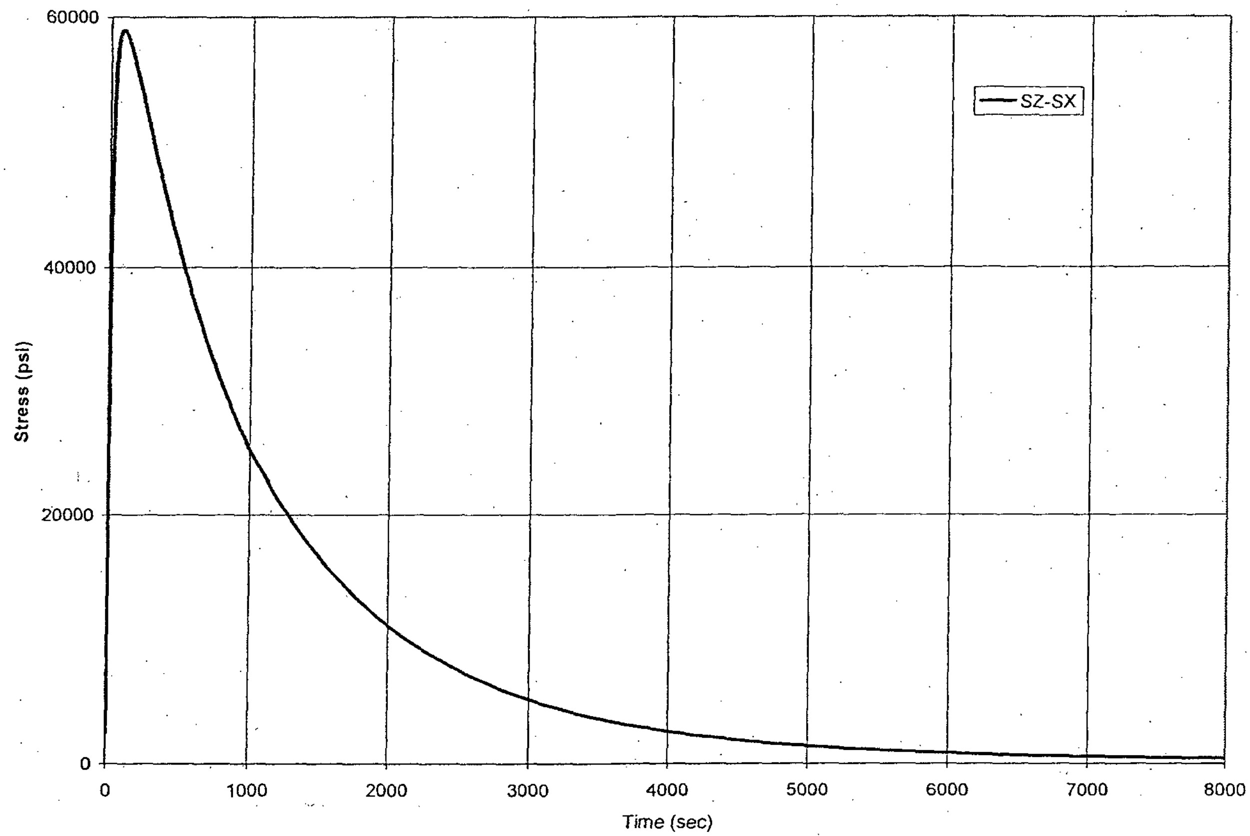



**Figure 3-8: Blend Radius Total Stress Intensity Green's Function for 100% Flow**

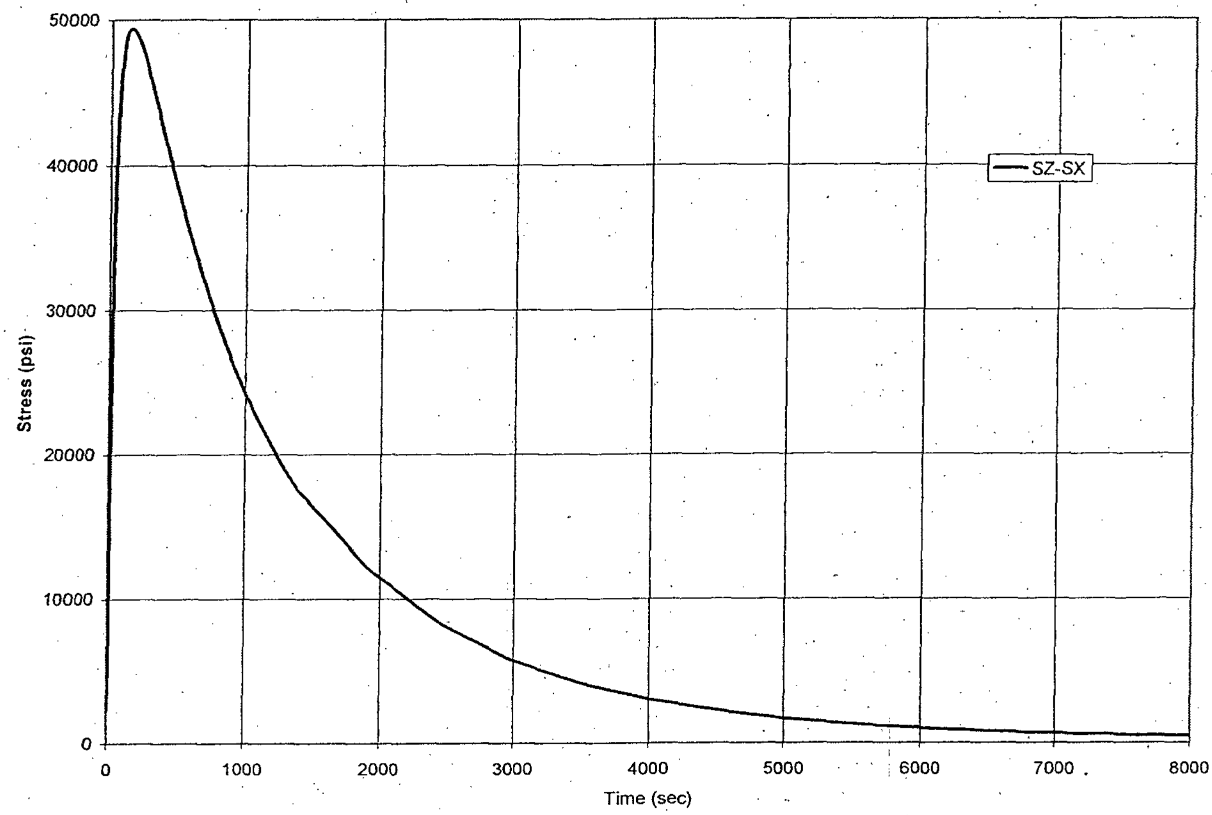



**Figure 3-9: Blend Radius Total Stress Intensity Green's Function for 50% Flow**

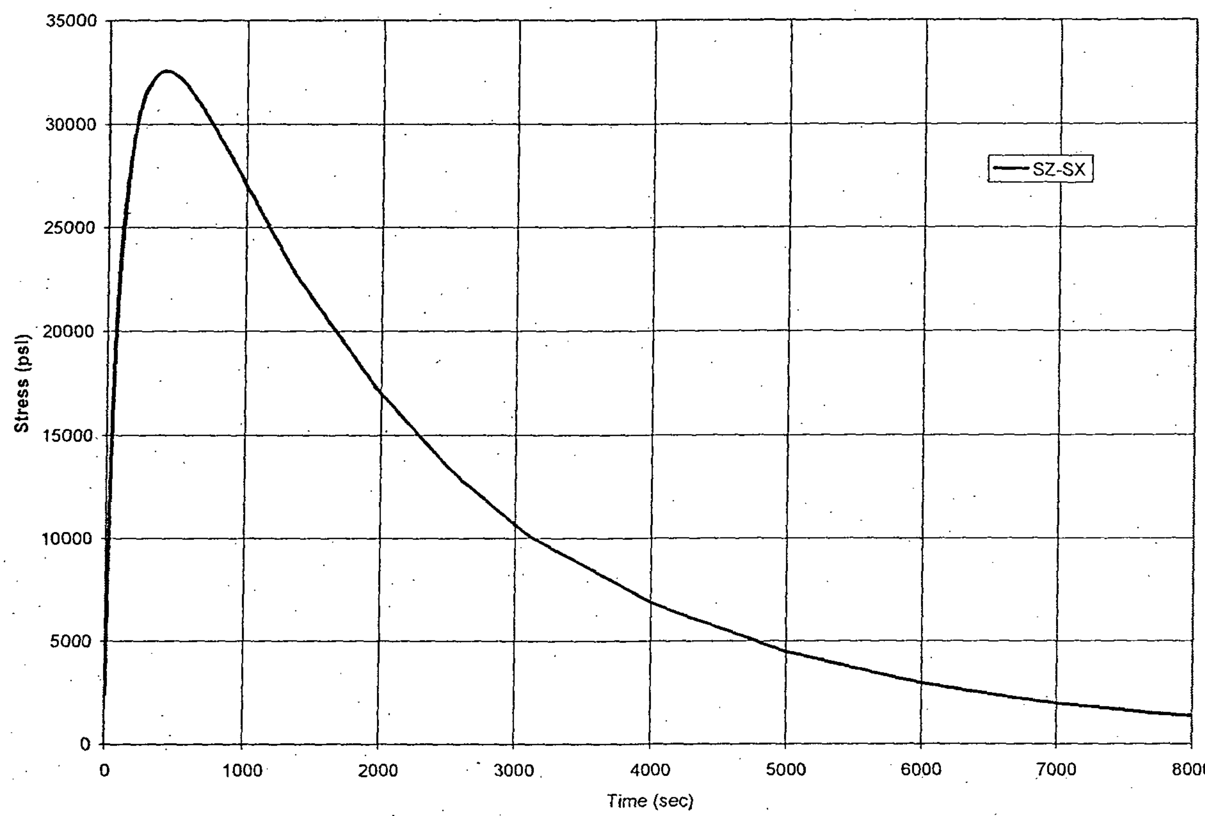



**Figure 3-10: Blend Radius Total Stress Intensity Green's Function for 0% Flow**

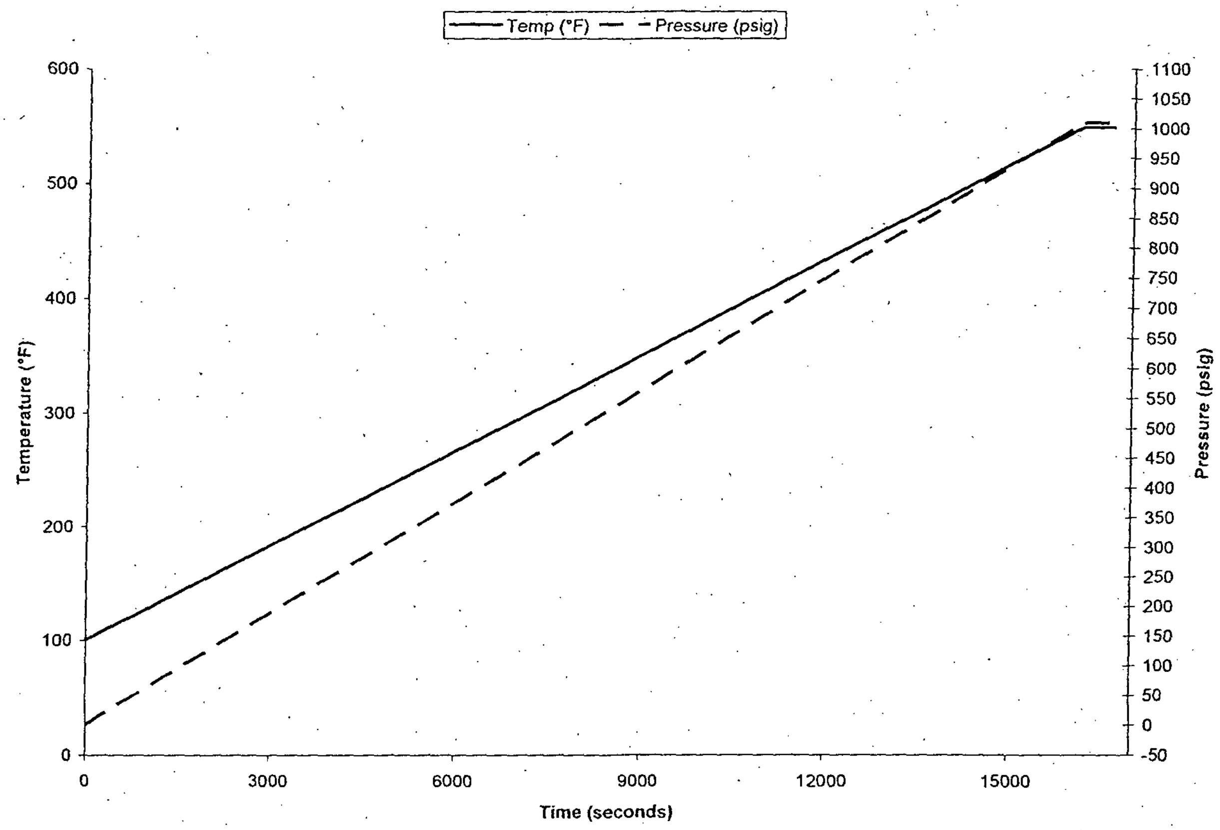



**Figure 3-11: Transient 1: Normal Startup at 100°F/hr**

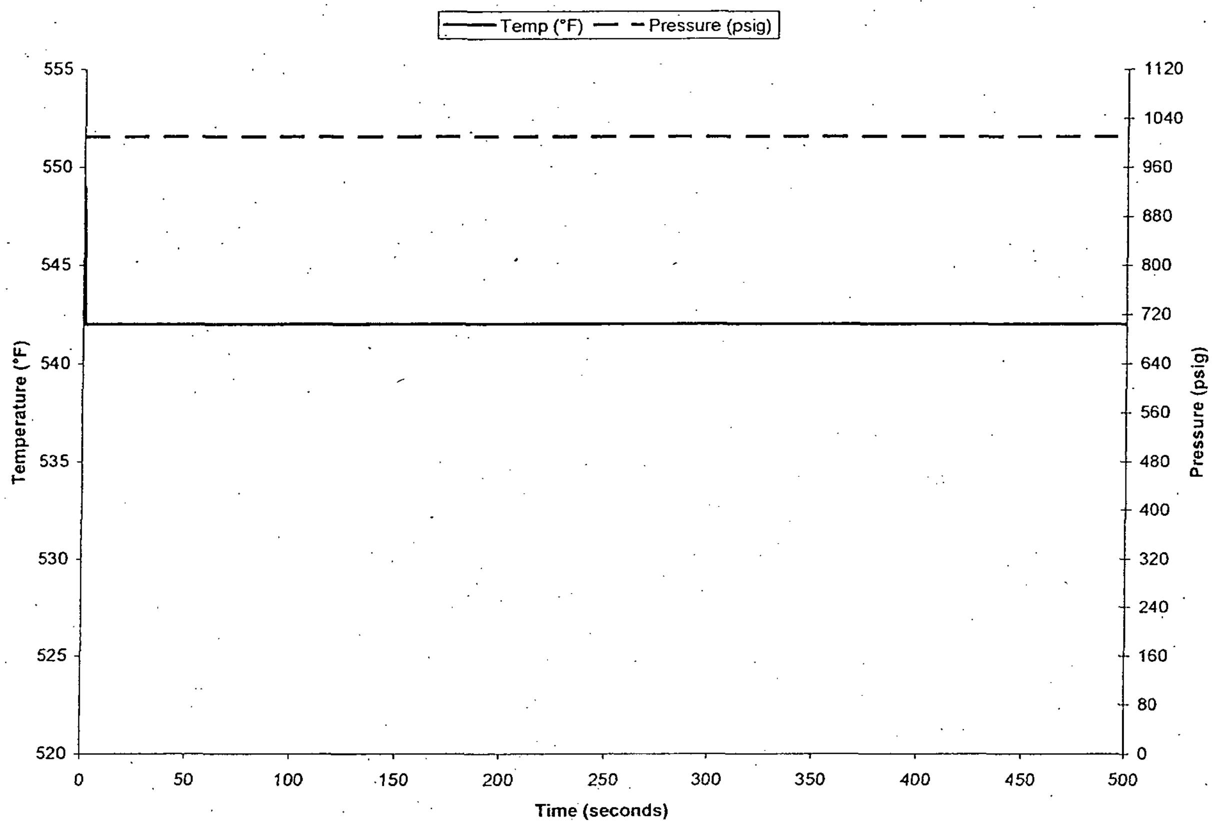



**Figure 3-12: Transient 2: Turbine Roll and Increase to Rated Power**

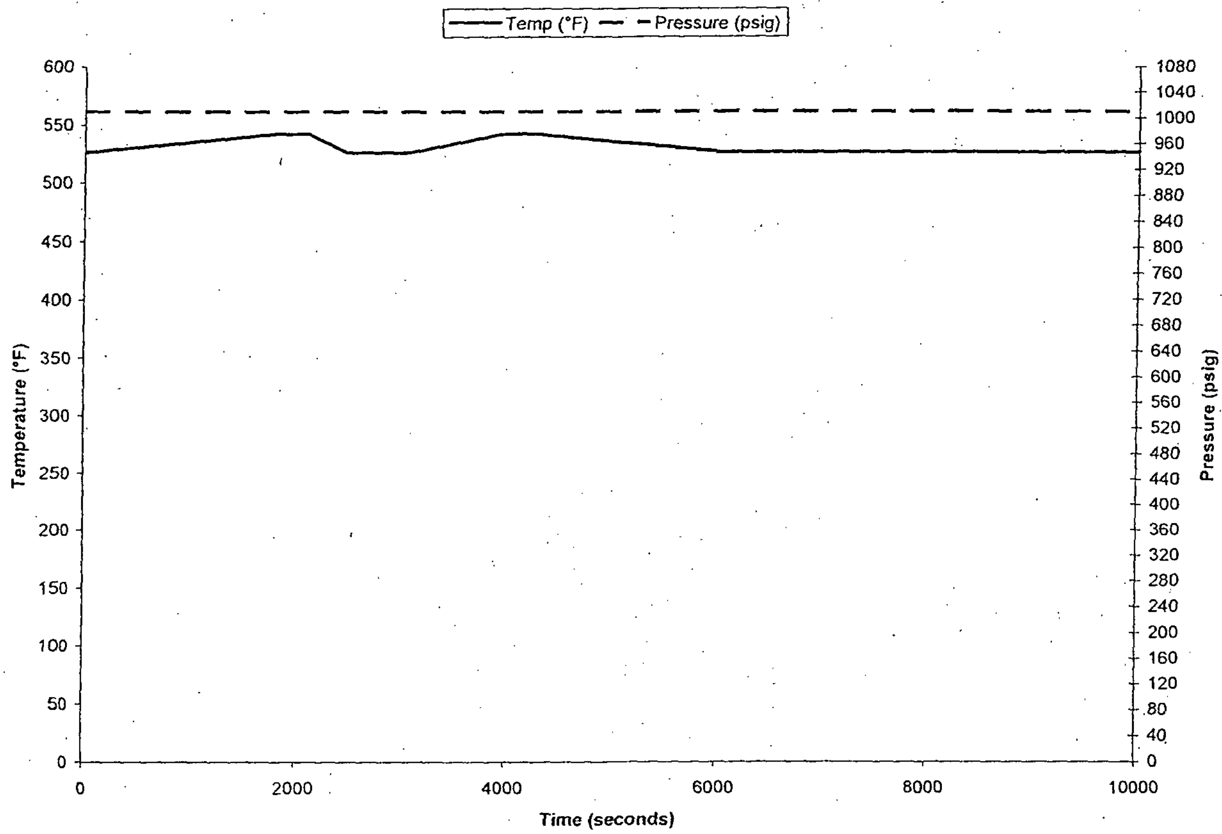



**Figure 3-13: Transient 3: Loss of Feedwater Heaters and Turbine Trip at 25% Power**

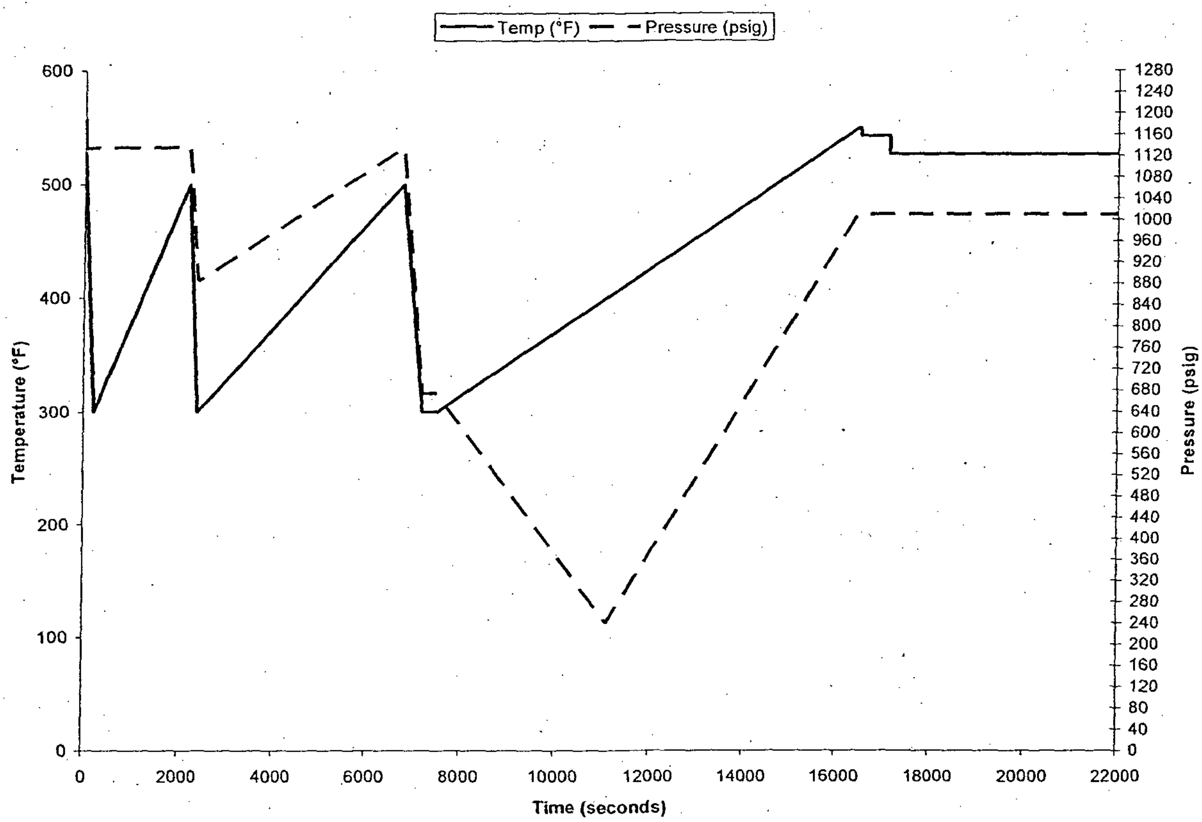



**Figure 3-14: Transient 4: Loss of Feedwater Pumps**

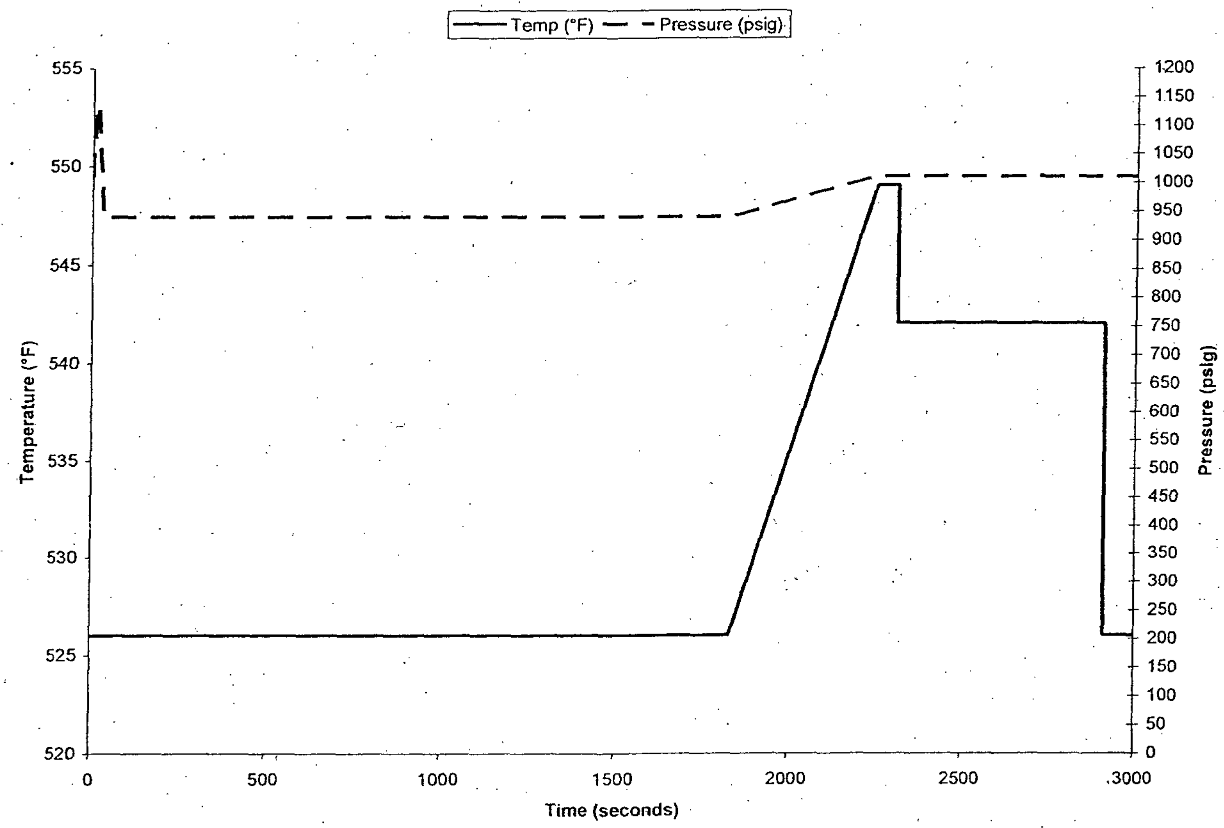



**Figure 3-15: Transient 5: Turbine Generator Trip**

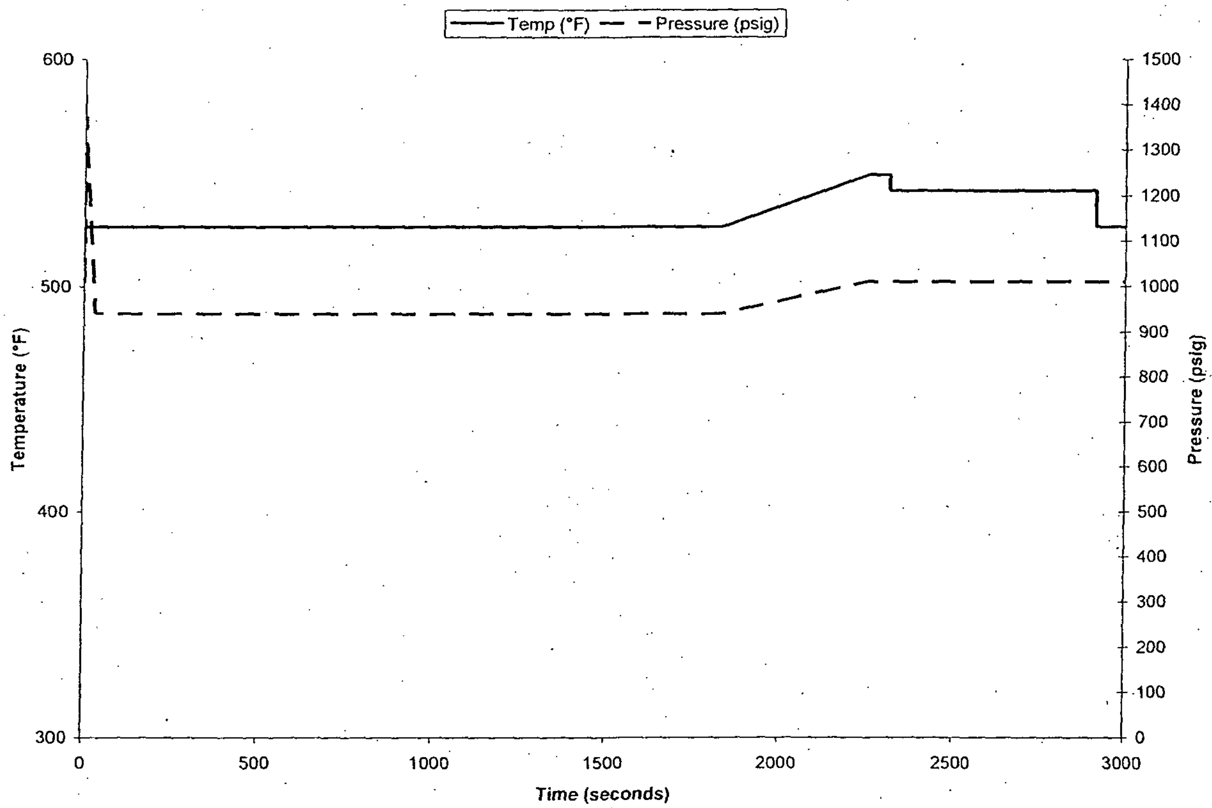



**Figure 3-16: Transient 6: Reactor Overpressure**

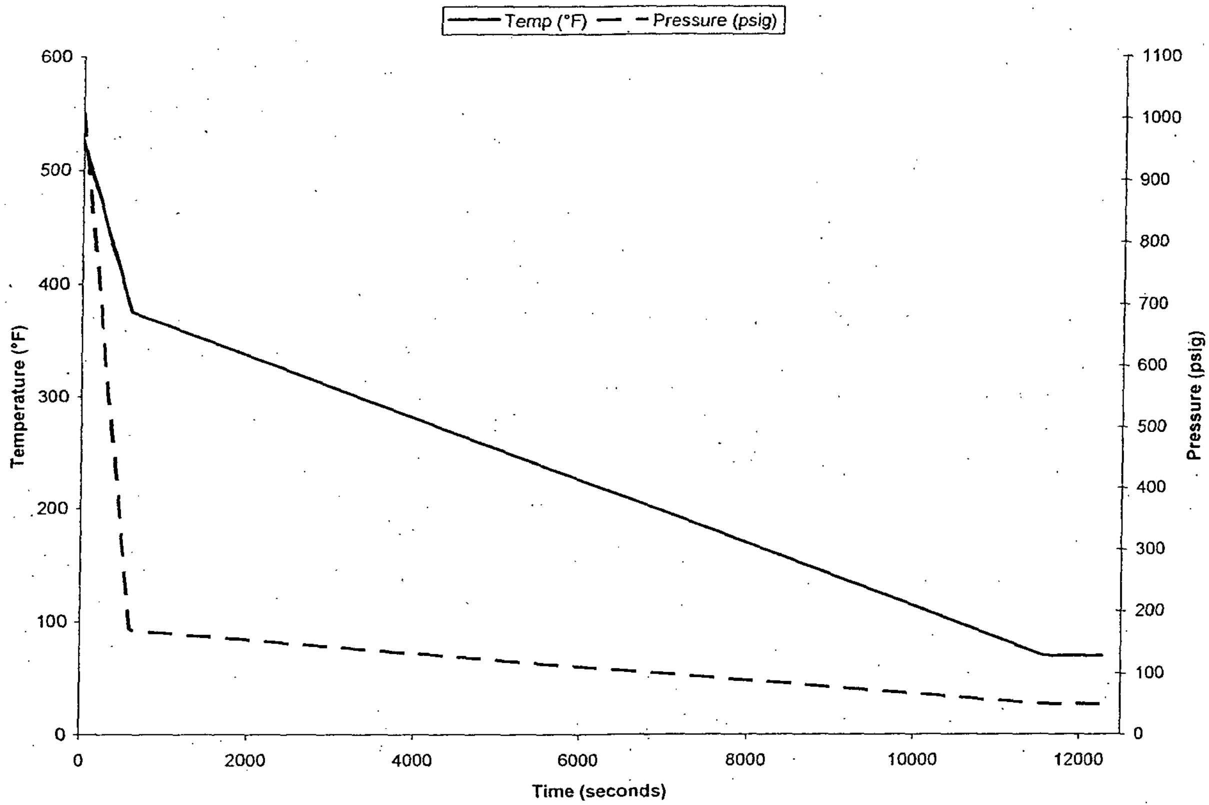



**Figure 3-17: Transient 7: SRV Blowdown**

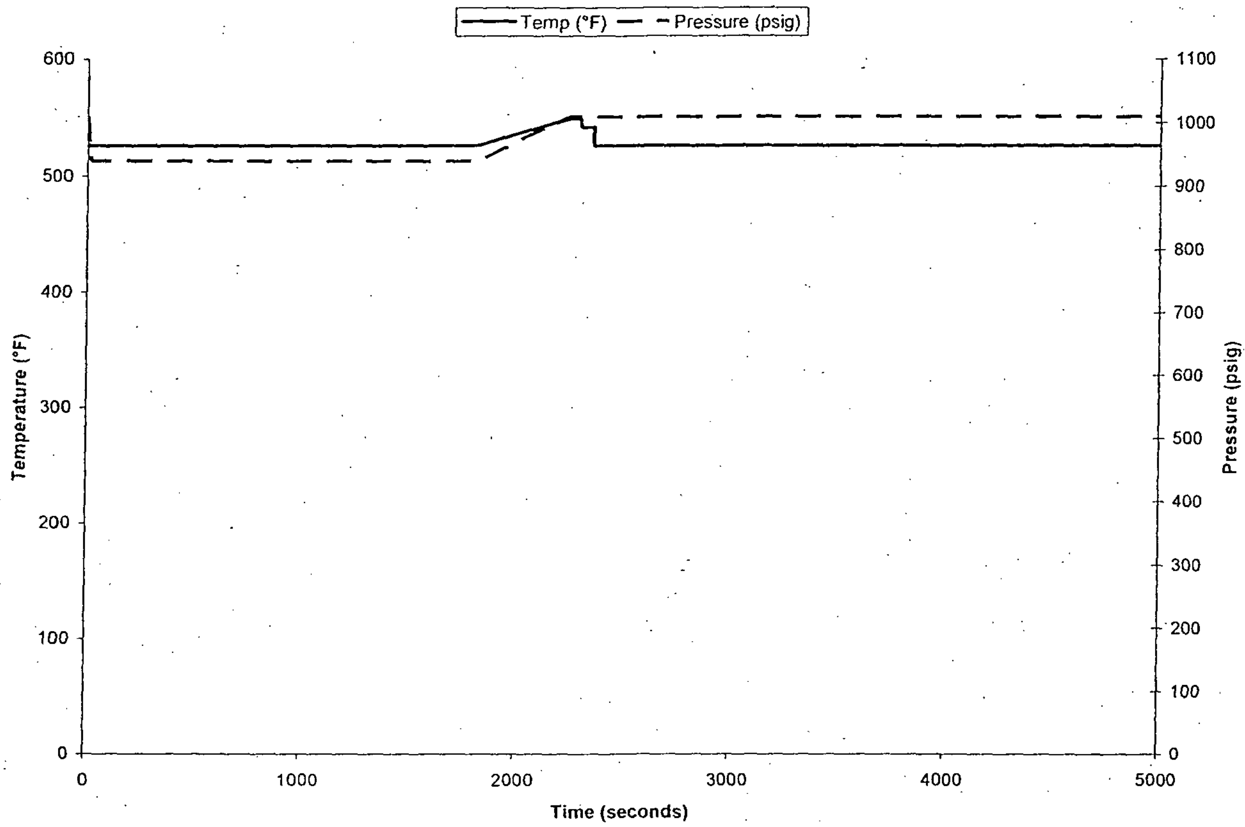



**Figure 3-18: Transient 8: Scram - Other**

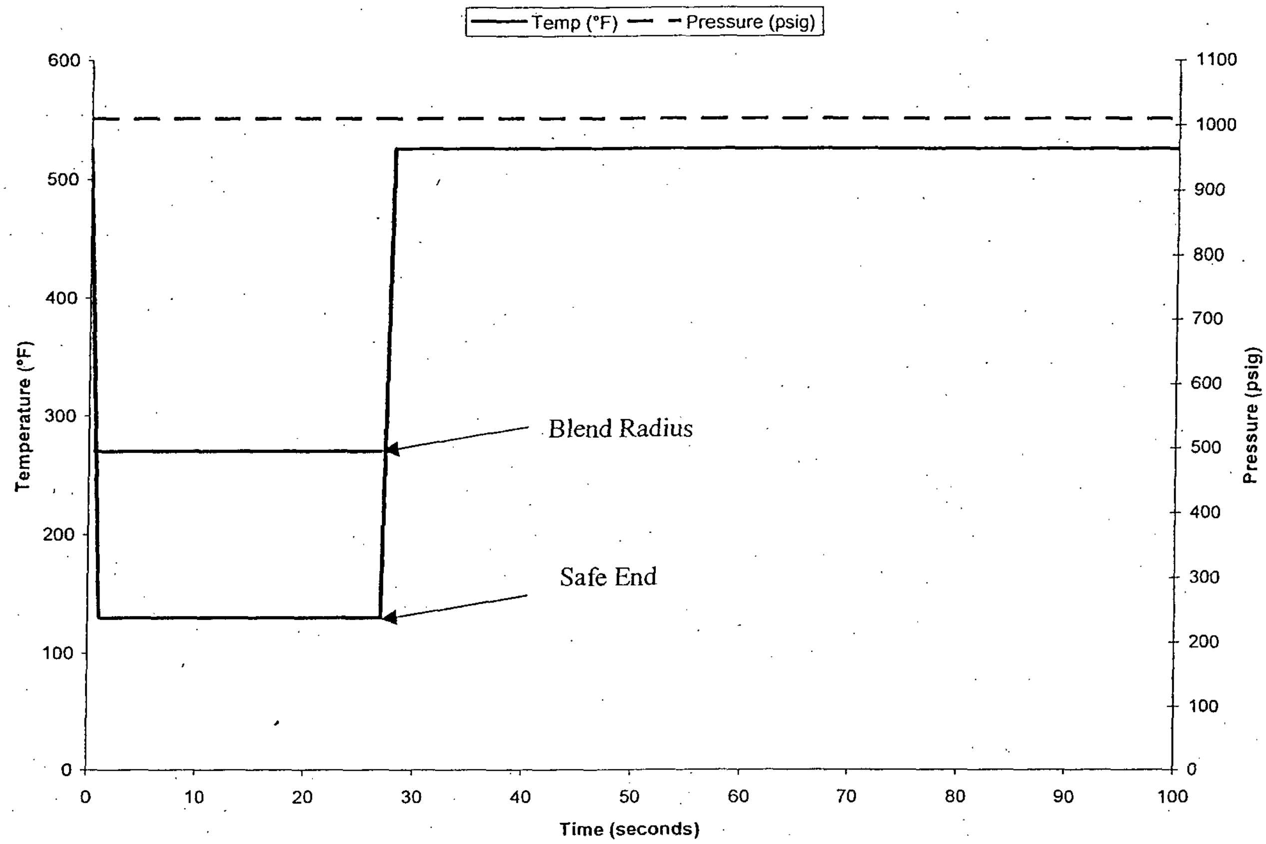



**Figure 3-19: Transient 9: Improper Startup**

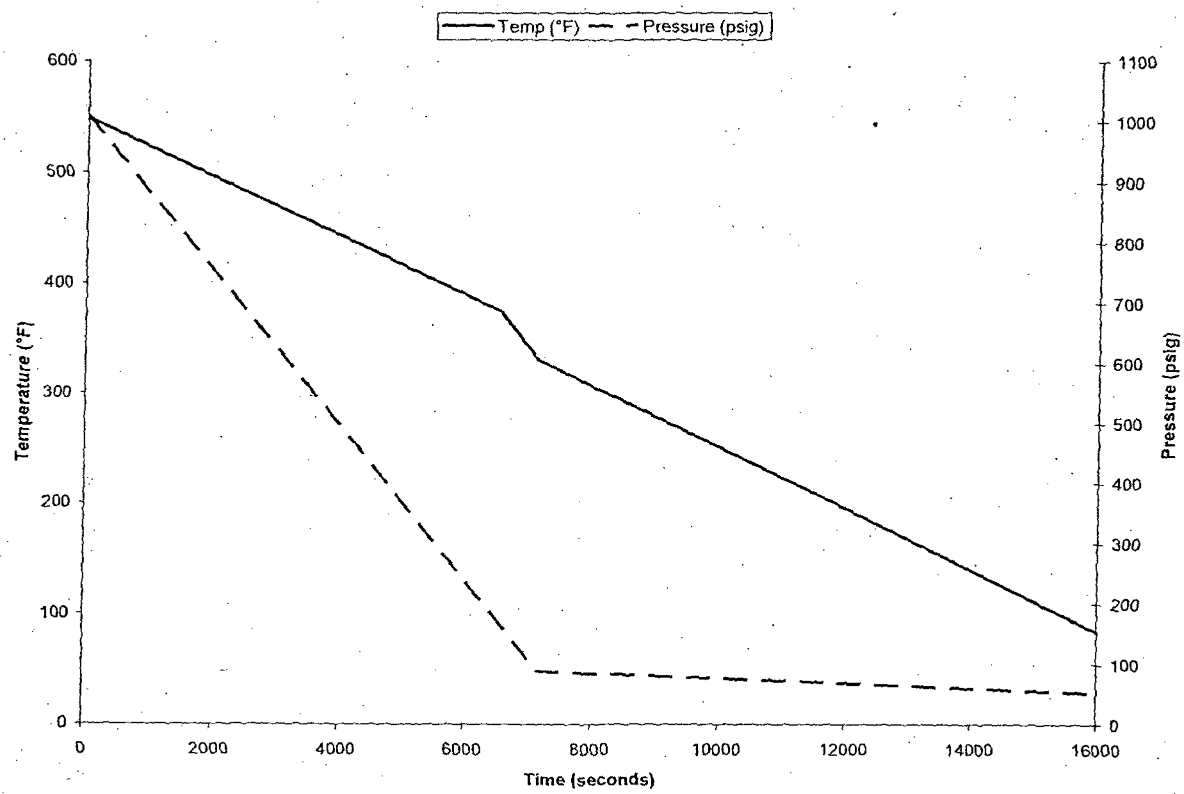



**Figure 3-20: Transient 10: Shutdown**

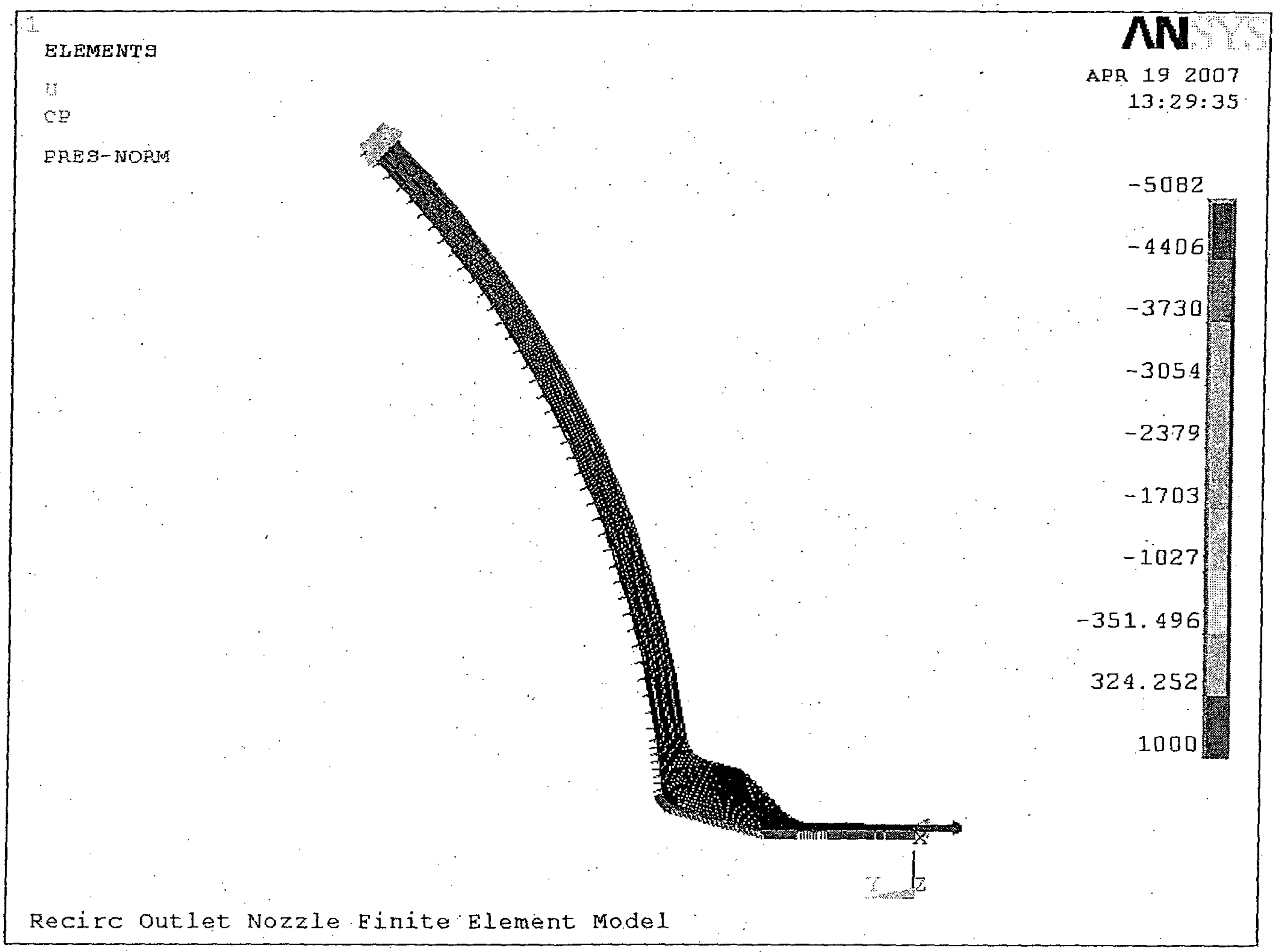



**Figure 3-21: Reactor Recirculation Outlet Nozzle Internal Pressure Distribution**

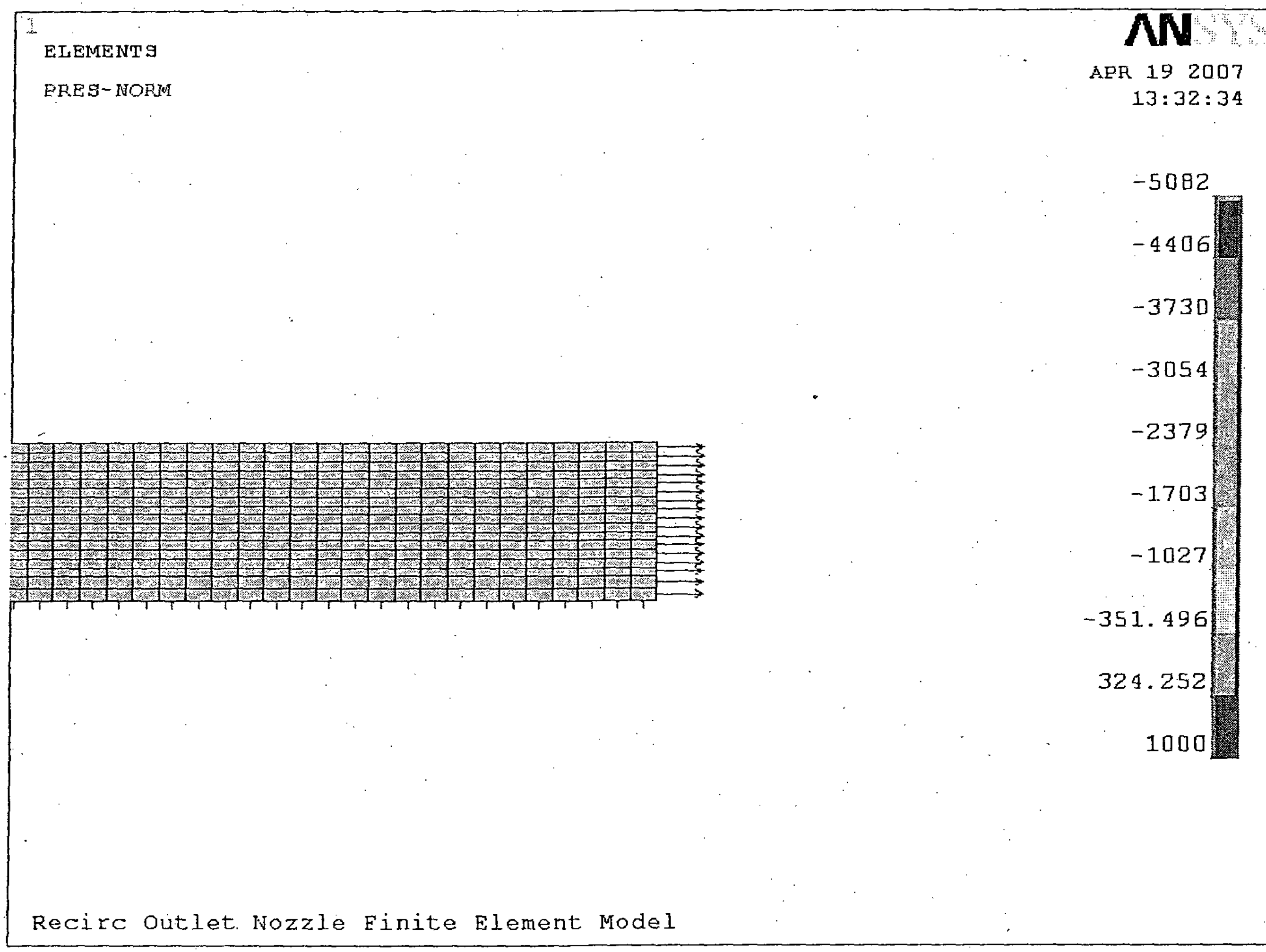



**Figure 3-22: Reactor Recirculation Outlet Nozzle Pressure Cap Load**

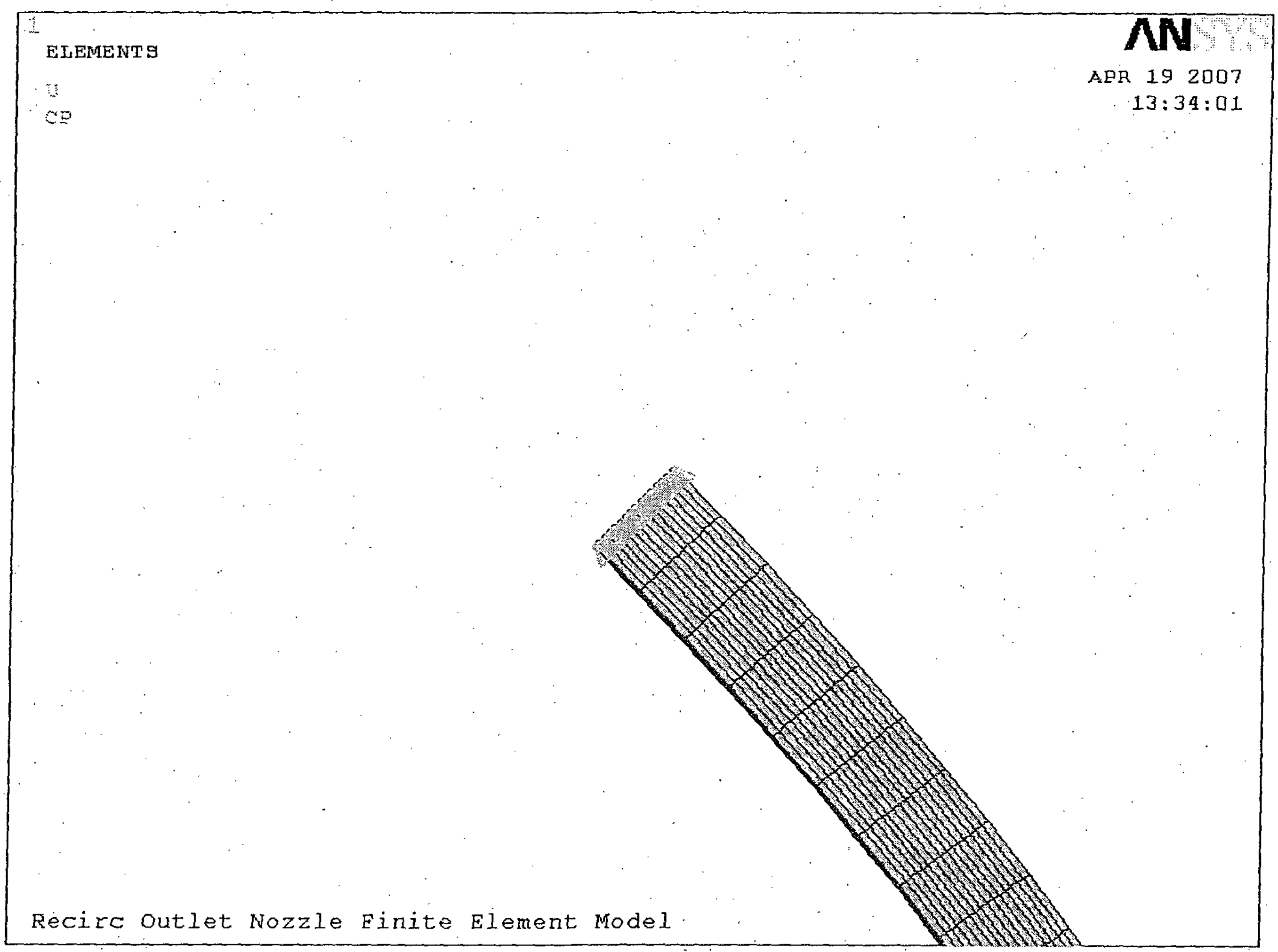



**Figure 3-23: Reactor Recirculation Outlet Nozzle Vessel Boundary Condition**

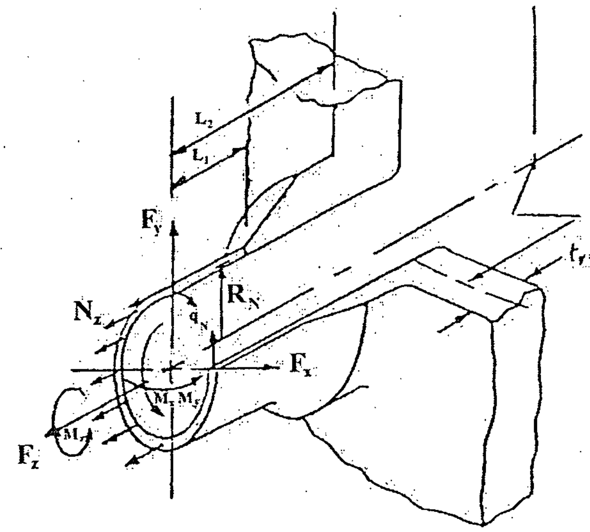



Figure 3-24: Pipe Reactions

## 4.0 STRESS AND FATIGUE ANALYSIS RESULTS

Fatigue calculations for the VY reactor recirculation outlet nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [17]. Fatigue analysis was performed in the Reference [11] calculation for the two locations identified in Section 3.1.2 using the Green's Functions developed for these two locations and the 60-year projected cycle counts from Reference [14].

Three computer programs were used to facilitate the fatigue analysis process: STRESS.EXE, P-V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III methodology. All three programs are explained in detail and were independently verified for use in the Reference [16] calculation.

In order to perform the fatigue analysis, input files with the necessary data were prepared and the three analysis programs were run. The program STRESS.EXE required the following three input files:

- **Green.dat**: This file contains the Green's Function. As discussed above, the reactor recirculation outlet nozzle analyses utilize twelve Green's Functions: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function for both the safe end and blend radius locations for each of three flow conditions.
- **Green.cfg**: A configuration file containing parameters that describe the Green's Function.
- **Transnt.inp**: This file contains the input transient history defined in Tables 3-1 and 3-2.

Tables 4-1 and 4-2 show the stresses for each location that were used in the fatigue analysis. Columns 2 through 5 of Table 4-1 (for the safe end) and Table 4-2 (for the blend radius) show the final peak and valley output after stress history reduction. The pressure values for Columns 6 through 8 in each table were determined from the transient pressures specified in Tables 3-1 and 3-2. The pressure stress intensities from Section 3.2 were scaled appropriately for each transient case. The scaled piping stress values are shown in Columns 9 and 10 of Tables 4-1 and 4-2. The piping stress intensities from Section 3.3 were scaled based on the transient case RPV fluid temperature and assuming no stress occurs at an ambient temperature of 70°F. Both of these stress intensities were then added to the thermal stress intensity peak and valley points to calculate the final stress values used for the fatigue analysis. In the case of the piping load stress intensities, the sign of the stress intensity was conservatively set to the same sign as the thermal stress intensity to ensure bounding fatigue usage results. Columns 11 and 12 of Tables 4-1 and 4-2 show the summation of all stresses for each thermal peak and valley stress point. The last column shows the number of cycles associated with each peak or valley based on the cycle counts shown in Tables 3-1 and 3-2.

The program FATIGUE.EXE performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data for the configuration input file for FATIGUE.EXE, which is named FATIGUE.CFG, is shown in Table 4-3.

The results of the fatigue analysis are presented in Tables 4-4 and 4-5 for the safe end and the blend radius for 60 years, respectively.

## Table 4-1: Reactor Recirculation Outlet Nozzle Safe End Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | -925 | -949 | 100.00 | 0 | 0 | 0 | -339.1419 | -339.1419 | -1264.14 | -1288.14 | 300 |
| | 16164 | -4814 | -4433 | 549.00 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 1375.93 | 1615.53 | 300 |
| | 16864 | -3749 | -3705 | 549.00 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2440.93 | 2343.53 | 300 |
| 2 | 0 | -3838 | -3665 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2351.93 | 2383.53 | 300 |
| | 6 | -1664 | -2263 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 4605.07 | 3864.67 | 300 |
| | 601 | -3773 | -3607 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 2496.07 | 2520.67 | 300 |
| | 606.6 | 1196 | -403 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17955.86 | 5905.54 | 300 |
| | 1302 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 300 |
| 3 | 0 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 10 |
| | 1800.1 | -4165 | -3904 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 2104.07 | 2223.67 | 10 |
| | 2460.2 | -1932 | -2200 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 4517.94 | 4108.54 | 10 |
| | 3960.2 | -4537 | -4185 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 1732.07 | 1942.67 | 10 |
| | 6060.2 | -3315 | -3241 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 3134.94 | 3067.54 | 10 |
| | 6760 | -3687 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2762.94 | 2786.54 | 10 |
| 4 | 0.00 | -3756 | -3716 | 526 | 1020 | 11719.8 | 11577 | -5154.958 | -5154.958 | 2808.84 | 2706.04 | 10 |
| | 3.00 | -3756 | -3716 | 526 | 1190 | 13673.1 | 13506.5 | -5154.958 | -5154.958 | 4762.14 | 4635.54 | 10 |
| | 13.00 | -3756 | -3716 | 526 | 1135 | 13041.15 | 12882.25 | -5154.958 | -5154.958 | 4130.19 | 4011.29 | 10 |
| | 242.30 | 15878 | 10049 | 302.374 | 1135 | 13041.15 | 12882.25 | 2626.926 | 2626.926 | 31546.08 | 25558.18 | 10 |
| | 2213.10 | -6388 | -5428 | 499.889 | 1135 | 13041.15 | 12882.25 | -4859.78 | -4859.78 | 1793.37 | 2594.47 | 10 |
| | 2408.60 | 13203 | 8265 | 301.443 | 885 | 10168.65 | 10044.75 | 2616.401 | 2616.401 | 25988.05 | 20926.15 | 10 |
| | 6773.40 | -4763 | -4312 | 499.809 | 1135 | 13041.15 | 12882.25 | -4858.875 | -4858.875 | 3419.27 | 3711.37 | 10 |
| | 7193.10 | 15374 | 9801 | 300 | 675 | 7755.75 | 7661.25 | 2600.088 | 2600.088 | 25729.84 | 20062.34 | 10 |
| | 16457.50 | -4812 | -5032 | 549 | 240 | 2757.6 | 2724 | -5414.966 | -5414.966 | -7469.37 | -7722.97 | 10 |
| | 16524.70 | -2358 | -2725 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3911.07 | 3402.67 | 10 |
| | 17118.00 | -3778 | -3610 | 541.996 | 1010 | 11604.9 | 11463.5 | -5335.788 | -5335.788 | 2491.11 | 2517.71 | 10 |
| | 17123.60 | 1192 | -406 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17951.86 | 5902.54 | 10 |
| | 17819.00 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 10 |
| 5 | 0.00 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 60 |
| | 10.00 | -3688 | -3522 | 526 | 1135 | 13041.15 | 12882.25 | -5154.958 | -5154.958 | 4198.19 | 4205.29 | 60 |
| | 30.00 | -3688 | -3522 | 526 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 60 |
| | 2250.10 | -6054 | -5337 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 60 |
| | 2319.90 | -2977 | -3123 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 60 |
| | 2911.00 | -3782 | -3613 | 541.999 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 2487.08 | 2514.68 | 60 |
| | 2916.70 | 1188 | -408 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17947.86 | 5900.54 | 60 |
| | 3612.00 | -3670 | -3509 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 60 |
| 6 | 0.00 | -3688 | -3522 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 1 |
| | 2.00 | -3688 | -3522 | 5.26E+02 | 1375 | 15798.75 | 15606.25 | -5154.958 | -5154.958 | 6955.79 | 6929.29 | 1 |
| | 32.00 | -3688 | -3522 | 5.26E+02 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 1 |
| | 2252.10 | -6054 | -5337 | 5.49E+02 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 1 |
| | 2322.20 | -2977 | -3123 | 5.42E+02 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 1 |
| | 2913.00 | -3782 | -3613 | 5.42E+02 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 2487.08 | 2514.68 | 1 |
| | 2918.70 | 1188 | -408 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 17947.86 | 5900.54 | 1 |
| | 3614.00 | -3670 | -3509 | 5.26E+02 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2779.94 | 2799.54 | 1 |
| 7 | 0 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 1 |
| | 600 | 7773 | 5336 | 375 | 170 | 1953.3 | 1929.5 | 3447.943 | 3447.943 | 13174.24 | 10713.44 | 1 |
| | 1367.9 | -1390 | -1567 | 354.172 | 162 | 1861.38 | 1838.7 | -3212.488 | -3212.488 | -2741.11 | -2940.79 | 1 |
| | 11580.1 | 454 | 190 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | 1028.50 | 757.50 | 1 |
| | 12280 | -707 | -689 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | -132.50 | -121.50 | 1 |
| 8 | 0.00 | -3688 | -3522 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2761.94 | 2786.54 | 228 |
| | 15.00 | -3688 | -3522 | 526 | 940 | 10800.6 | 10669 | -5154.958 | -5154.958 | 1957.64 | 1992.04 | 228 |
| | 2235.10 | -6054 | -5337 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 135.93 | 711.53 | 228 |
| | 2305.20 | -2977 | -3123 | 542 | 1010 | 11604.9 | 11463.5 | -5335.833 | -5335.833 | 3292.07 | 3004.67 | 228 |
| | 2356.00 | -3183 | -3151 | 541.999 | 1010 | 11604.9 | 11463.5 | -5335.822 | -5335.822 | 3086.08 | 2976.68 | 228 |
| | 2361.50 | 1761 | -28 | 526 | 1010 | 11604.9 | 11463.5 | 5154.958 | -5154.958 | 18520.86 | 6280.54 | 228 |
| | 3057.00 | -3667 | -3506 | 526 | 1010 | 11604.9 | 11463.5 | -5154.958 | -5154.958 | 2782.94 | 2802.54 | 228 |
| 9 | 0 | -2968 | -2837 | 525.7 | 1010 | 11604.9 | 11463.5 | -5151.566 | -5151.566 | 3485.22 | 3474.82 | 1 |
| | 27 | 68473 | 45303 | 291.3 | 1010 | 11604.9 | 11463.5 | 2501.737 | 2501.737 | 82579.74 | 59268.34 | 1 |
| | 80.7 | -11546 | -8877 | 518.4 | 1010 | 11604.9 | 11463.5 | -5069.042 | -5069.042 | -5010.04 | -2482.14 | 1 |
| | 5200 | -2967 | -2832 | 525.7 | 1010 | 11604.9 | 11463.5 | -5151.566 | -5151.566 | 3486.21 | 3479.78 | 1 |
| 10 | 0 | -3745 | -3709 | 549 | 1010 | 11604.9 | 11463.5 | -5414.966 | -5414.966 | 2444.93 | 2339.53 | 300 |
| | 6864.2 | 501 | -405 | 329.994 | 170 | 1953.3 | 1929.5 | 2939.162 | -2939.162 | 5393.46 | -1414.66 | 300 |
| | 7455.5 | -1183 | -1528 | 314.325 | 88 | 1011.12 | 998.8 | -2762.029 | -2762.029 | -2933.91 | -3291.23 | 300 |
| | 16224.1 | 334 | -35 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | 908.50 | 532.50 | 300 |
| | 16924 | -731 | -763 | 70 | 50 | 574.5 | 567.5 | 0 | 0 | -156.50 | -195.50 | 300 |
| 11 | | 0 | 0 | 100 | 0 | 0 | 0 | 339.1419 | 339.1419 | 339.14 | 339.14 | 120 |
| | | 0 | 0 | 100 | 1100 | 12639 | 12485 | 339.1419 | 339.1419 | 12978.14 | 12824.14 | 120 |
| | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 120 |
| 12 | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 1 |
| | | 0 | 0 | 100 | 1563 | 17958.87 | 17740.05 | 339.1419 | 339.1419 | 18298.01 | 18079.19 | 1 |
| | | 0 | 0 | 100 | 50 | 574.5 | 567.5 | 339.1419 | 339.1419 | 913.64 | 906.64 | 1 |

For notes, see next page.

**Table 4-1: Reactor Recirculation Outlet Nozzle Safe End Stress Summary (concluded)**

| | | |
|---|---|---|
| NOTES: | Column 1: | Transient number identification. |
| | Column 2: | Time during transient where maximum or minimum stress intensity occurs from P-V.OUT output file. |
| | Column 3: | Maximum or minimum total stress intensity from P-V.OUT output file. |
| | Column 4: | Maximum or minimum membrane plus bending stress intensity from P-V.OUT output file. |
| | Column 5: | Temperature per total stress intensity. |
| | Column 6: | Pressure per Table 3-1. |
| | Column 7: | Total pressure stress intensity from the quantity (Column 6 x 11490)/1000. |
| | Column 8: | Membrane plus bending pressure stress intensity from the quantity (Column 6 x 11350)/1000. |
| | Column 9: | Total external stress, 5707.89 psi*(Column 5-70°F)/(549°F -70°F). |
| | Column 10: | Same as Column 9, but for M+B stress. |
| | Column 11: | Sum of total stresses (Columns 3, 7, and 9). |
| | Column 12: | Sum of membrane plus bending stresses (Columns 4, 8, and 10). |
| | Column 13: | Number of cycles for the transient (60 years). |

## Table 4-2: Reactor Recirculation Outlet Nozzle Blend Radius Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 1 | 0 | 459 | 388 | 100.00 | 0 | 0 | 0 | 16.64312 | 16.64312 | 475.64 | 404.64 | 300 |
| | 4303 | -3417 | -1594 | 219.53 | 1010 | 31613 | 33976.4 | -82.95209 | -82.95209 | 28113.05 | 32299.45 | 300 |
| | 22164 | 2713 | 2306 | 549.00 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34591.74 | 36548.14 | 300 |
| 2 | 0.00 | 3094 | 1934 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34972.74 | 36176.14 | 300 |
| | 94.30 | 4079 | 2481 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 35953.85 | 36719.25 | 300 |
| | 601.70 | 3683 | 2435 | 538.8 | 1010 | 31613 | 33976.4 | 260.0765 | 260.0765 | 35556.08 | 36671.48 | 300 |
| | 680.10 | 5891 | 3489 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 37756.98 | 37718.38 | 300 |
| | 6602.00 | 2977 | 1859 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34842.98 | 36088.38 | 300 |
| 3 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 10 |
| | 1807.20 | 1834 | 1043 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 33708.85 | 35281.25 | 10 |
| | 2491.50 | 4425 | 2667 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36290.98 | 36896.38 | 10 |
| | 3974.40 | 1706 | 1060 | 542 | 1010 | 31613 | 33976.4 | 261.8518 | 261.8518 | 33580.85 | 35298.25 | 10 |
| | 6070.80 | 3971 | 2551 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35836.98 | 36780.38 | 10 |
| | 12060.00 | 2965 | 1852 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34830.98 | 36081.38 | 10 |
| 4 | 0 | 2465 | -703 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | -252.9754 | 34330.98 | 33020.42 | 10 |
| | 3 | 2465 | -703 | 526.00 | 1190 | 37247 | 40031.6 | 252.9754 | -252.9754 | 39964.98 | 39075.62 | 10 |
| | 13 | 2465 | -703 | 526.00 | 1135 | 35525.5 | 38181.4 | 252.9754 | -252.9754 | 38243.48 | 37225.42 | 10 |
| | 435.6 | 18138 | 9690 | 356.38 | 1135 | 35525.5 | 38181.4 | 158.8774 | 158.8774 | 53822.38 | 48030.28 | 10 |
| | 2222.5 | -1169 | -2598 | 489.44 | 1135 | 35525.5 | 38181.4 | -232.6952 | -232.6952 | 34123.80 | 35350.70 | 10 |
| | 2665.5 | 12763 | 6695 | 328.40 | 885 | 27700.5 | 29771.4 | 143.3539 | 143.3539 | 40606.85 | 36609.75 | 10 |
| | 6779.2 | -4008 | -2829 | 497.05 | 1010 | 31613 | 33976.4 | -236.9137 | -236.9137 | 27368.09 | 30910.49 | 10 |
| | 7243.8 | 19275 | 9965 | 302.91 | 1010 | 31613 | 33976.4 | 129.2122 | 129.2122 | 51017.21 | 44070.61 | 10 |
| | 13996 | -2135 | 34 | 542.00 | 1010 | 31613 | 33976.4 | -261.8518 | 261.8518 | 29216.15 | 34272.25 | 10 |
| | 17247 | 3413 | 2074 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35278.98 | 36303.38 | 10 |
| | 23119 | 2971 | 1855 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34836.98 | 36084.38 | 10 |
| 5 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 60 |
| | 10.00 | 2959 | 1849 | 526 | 1135 | 35525.5 | 38181.4 | 252.9754 | 252.9754 | 38737.48 | 40283.38 | 60 |
| | 15.00 | 2959 | 1849 | 526 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 60 |
| | 2269.50 | 111 | 295 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 60 |
| | 3010.10 | 4407 | 2579 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36272.98 | 36808.38 | 60 |
| | 8912.00 | 2968 | 1854 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34833.98 | 36083.38 | 60 |
| 6 | 0.00 | 2959 | 1849 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 1 |
| | 2.00 | 2959 | 1849 | 526.00 | 1375 | 43037.5 | 46255 | 252.9754 | 252.9754 | 46249.48 | 48356.98 | 1 |
| | 32.00 | 2959 | 1849 | 526.00 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 1 |
| | 2271.50 | 111 | 295 | 549.00 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 1 |
| | 3022.00 | 4407 | 2579 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 36272.98 | 36808.38 | 1 |
| | 8914.00 | 2968 | 1854 | 526.00 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34833.98 | 36083.38 | 1 |
| 7 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 1 |
| | 615.10 | 20260 | 12980 | 374.581 | 170 | 5321 | 5718.8 | 168.9726 | 168.9726 | 25749.97 | 18867.77 | 1 |
| | 17580.00 | 279 | 179 | 70 | 50 | 1565 | 1682 | 0 | 0 | 1844.00 | 1861.00 | 1 |
| 8 | 0.00 | 2959 | 1849 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34824.98 | 36078.38 | 228 |
| | 15.00 | 2959 | 1849 | 526 | 940 | 29422 | 31621.6 | 252.9754 | 252.9754 | 32633.98 | 33723.58 | 228 |
| | 2254.50 | 111 | 295 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 31989.74 | 34537.14 | 228 |
| | 2491.20 | 3792 | 2234 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 35657.98 | 36463.38 | 228 |
| | 8357.00 | 2963 | 1851 | 526 | 1010 | 31613 | 33976.4 | 252.9754 | 252.9754 | 34828.98 | 36080.38 | 228 |
| 9 | 0 | 2058 | 961 | 525.8 | 1010 | 31613 | 33976.4 | 252.8645 | 252.8645 | 33923.86 | 35190.26 | 1 |
| | 0.52 | 1956 | 734 | 525.6 | 1010 | 31613 | 33976.4 | 252.7535 | 252.7535 | 33821.75 | 34963.15 | 1 |
| | 28 | 23747 | 3188 | 504.5 | 1010 | 31613 | 33976.4 | 241.0479 | 241.0479 | 55601.05 | 37405.45 | 1 |
| | 425 | 1520 | 611 | 525.5 | 1010 | 31613 | 33976.4 | 252.698 | 252.698 | 33385.70 | 34840.10 | 1 |
| | 12400 | 2058 | 879 | 525.8 | 1010 | 31613 | 33976.4 | 252.8645 | 252.8645 | 33923.86 | 35108.26 | 1 |
| 10 | 0 | 2767 | 2176 | 549 | 1010 | 31613 | 33976.4 | 265.7352 | 265.7352 | 34645.74 | 36418.14 | 300 |
| | 4240.8 | 6643 | 4158 | 445.775 | 441 | 13803.3 | 14835.24 | 208.469 | 208.469 | 20654.77 | 19201.71 | 300 |
| | 6268 | 6498 | 3675 | 374.7 | 170 | 5321 | 5718.8 | 169.0386 | 169.0386 | 11988.04 | 9562.84 | 300 |
| | 6891.8 | 9282 | 5241 | 329.228 | 88 | 2754.4 | 2960.32 | 143.8121 | 143.8121 | 12180.21 | 8345.13 | 300 |
| | 22224 | 361 | 120 | 70 | 50 | 1565 | 1682 | 0 | 0 | 1926.00 | 1802.00 | 300 |
| 11 | | 0 | 0 | 100 | 0 | 0 | 0 | 16.64312 | 16.64312 | 16.64 | 16.64 | 120 |
| | | 0 | 0 | 100 | 1100 | 34430 | 37004 | 16.64312 | 16.64312 | 34446.64 | 37020.64 | 120 |
| | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 120 |
| 12 | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 1 |
| | | 0 | 0 | 100 | 1563 | 48921.9 | 52579.32 | 16.64312 | 16.64312 | 48938.54 | 52595.96 | 1 |
| | | 0 | 0 | 100 | 50 | 1565 | 1682 | 16.64312 | 16.64312 | 1581.64 | 1698.64 | 1 |

For notes, see next page.

**Table 4-2: Reactor Recirculation Outlet Nozzle Blend Radius Stress Summary (concluded)**

NOTES:

| | |
|---|---|
| Column 1: | Transient number identification. |
| Column 2: | Time during transient where maximum or minimum stress intensity occurs from P-V.OUT output file. |
| Column 3: | Maximum or minimum total stress intensity from P-V.OUT output file. |
| Column 4: | Maximum or minimum membrane plus bending stress intensity from P-V.OUT output file. |
| Column 5: | Temperature per total stress intensity. |
| Column 6: | Pressure per Table 3-2. |
| Column 7: | Total pressure stress intensity from the quantity (Column 6 x 31300)/1000. |
| Column 8: | Membrane plus bending pressure stress intensity from the quantity (Column 6 x 33640)/1000. |
| Column 9: | Total external stress, 280.16 psi*(Column 5-70°F)/(549°F -70°F). |
| Column 10: | Same as Column 9, but for M+B stress. |
| Column 11: | Sum of total stresses (Columns 3, 7, and 9). |
| Column 12: | Sum of membrane plus bending stresses (Columns 4, 8, and 10). |
| Column 13: | Number of cycles for the transient (60 years). |

**Table 4-3: Fatigue Parameters Used in the Recirculation Outlet Nozzle Fatigue Analysis**

| Parameter | Blend Radius | Safe End |
|---|---|---|
| Parameters *m* and *n* for Computing $K_e$ | 2.0 & 0.2 (low alloy steel) [17] | 1.7 & 0.3 (stainless steel) [17] |
| Design Stress Intensity Values, $S_m$ | 26700 psi [9] @ 600°F | 17000 psi [9] @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi [17] | $28.3 \times 10^6$ psi [17] |
| Elastic Modulus Used in Finite Element Model | $26.7 \times 10^6$ psi [10] | $27.0 \times 10^6$ psi [10] |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 1.53 [20] |

## Table 4-4: Fatigue Results for Reactor Recirculation Outlet Nozzle Safe End

```
      LOCATION = LOCATION NO. 1 -- SAFE END
 FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 1.7
             n =  .3
            Sm = 17000. psi
        Ecurve = 2.830E+07 psi
     Eanalysis = 2.700E+07 psi
            Kt = 1.53
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 82580. | -7469. | 90049. | 66991. | 2.045 | 134573. | 1.000E+00 | 6.765E+02 | .0015 |
| 31546. | -7469. | 39015. | 33281. | 1.000 | 29691. | 9.000E+00 | 6.857E+05 | .0000 |
| 31546. | -5010. | 36556. | 28040. | 1.000 | 26947. | 1.000E+00 | 1.160E+06 | .0000 |
| 25988. | -2934. | 28922. | 24217. | 1.000 | 21884. | 1.000E+01 | 2.383E+06 | .0000 |
| 25730. | -2934. | 28664. | 23354. | 1.000 | 21509. | 1.000E+01 | 2.566E+06 | .0000 |
| 18521. | -2934. | 21455. | 9572. | 1.000 | 13903. | 2.280E+02 | 9.710E+08 | .0000 |
| 18298. | -2934. | 21232. | 21370. | 1.000 | 17063. | 1.000E+00 | 7.876E+06 | .0000 |
| 17956. | -2934. | 20890. | 9197. | 1.000 | 13502. | 5.100E+01 | 1.000E+20 | .0000 |
| 17956. | -2741. | 20697. | 8846. | 1.000 | 13304. | 1.000E+00 | 1.000E+20 | .0000 |
| 17956. | -1264. | 19220. | 7194. | 1.000 | 12071. | 2.480E+02 | 1.000E+20 | .0000 |
| 17952. | -1264. | 19216. | 7191. | 1.000 | 12068. | 1.000E+01 | 1.000E+20 | .0000 |
| 17948. | -1264. | 19212. | 7189. | 1.000 | 12065. | 4.200E+01 | 1.000E+20 | .0000 |
| 17948. | -157. | 18104. | 6096. | 1.000 | 11181. | 1.800E+01 | 1.000E+20 | .0000 |
| 17948. | -157. | 18104. | 6096. | 1.000 | 11181. | 1.000E+00 | 1.000E+20 | .0000 |
| 13174. | -157. | 13331. | 10909. | 1.000 | 10016. | 1.000E+00 | 1.000E+20 | .0000 |
| 12978. | -157. | 13135. | 13020. | 1.000 | 10500. | 1.200E+02 | 1.000E+20 | .0000 |
| 6956. | -157. | 7112. | 7125. | 1.000 | 5706. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | -157. | 5550. | -1219. | 1.000 | 2570. | 1.590E+02 | 1.000E+20 | .0000 |
| 5393. | -133. | 5526. | -1293. | 1.000 | 2537. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 6.000E+01 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 1.000E+00 | 1.000E+20 | .0000 |
| 5393. | 136. | 5258. | -2126. | 1.000 | 2165. | 7.900E+01 | 1.000E+20 | .0000 |
| 4762. | 136. | 4626. | 3924. | 1.000 | 3514. | 1.000E+01 | 1.000E+20 | .0000 |
| 4605. | 136. | 4469. | 3153. | 1.000 | 3218. | 1.390E+02 | 1.000E+20 | .0000 |
| 4605. | 339. | 4266. | 3526. | 1.000 | 3215. | 1.200E+02 | 1.000E+20 | .0000 |
| 4605. | 909. | 3697. | 3332. | 1.000 | 2863. | 4.100E+01 | 1.000E+20 | .0000 |
| 4518. | 909. | 3609. | 3576. | 1.000 | 2885. | 1.000E+01 | 1.000E+20 | .0000 |
| 4198. | 909. | 3290. | 3673. | 1.000 | 2744. | 6.000E+01 | 1.000E+20 | .0000 |
| 4130. | 909. | 3222. | 3479. | 1.000 | 2655. | 1.000E+01 | 1.000E+20 | .0000 |
| 3911. | 909. | 3003. | 2870. | 1.000 | 2371. | 1.000E+01 | 1.000E+20 | .0000 |
| 3486. | 909. | 2578. | 2947. | 1.000 | 2170. | 1.000E+00 | 1.000E+20 | .0000 |
| 3485. | 909. | 2577. | 2942. | 1.000 | 2168. | 1.000E+00 | 1.000E+20 | .0000 |
| 3419. | 909. | 2511. | 3179. | 1.000 | 2199. | 1.000E+01 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 6.000E+01 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 909. | 2384. | 2472. | 1.000 | 1936. | 9.600E+01 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.200E+02 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 914. | 2378. | 2098. | 1.000 | 1829. | 1.000E+00 | 1.000E+20 | .0000 |

**Table 4-4: Fatigue Results for Reactor Recirculation Outlet Nozzle Safe End (concluded)**

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 3292. | 1029. | 2264. | 2247. | 1.000 | 1810. | 1.000E+00 | 1.000E+20 | .0000 |
| 3292. | 1376. | 1916. | 1389. | 1.000 | 1390. | 9.000E+00 | 1.000E+20 | .0000 |
| 3135. | 1376. | 1759. | 1452. | 1.000 | 1325. | 1.000E+01 | 1.000E+20 | .0000 |
| 3086. | 1376. | 1710. | 1361. | 1.000 | 1274. | 2.280E+02 | 1.000E+20 | .0000 |
| 2809. | 1376. | 1433. | 1091. | 1.000 | 1054. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1376. | 1407. | 1187. | 1.000 | 1067. | 4.300E+01 | 1.000E+20 | .0000 |
| 2783. | 1732. | 1051. | 860. | 1.000 | 790. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1793. | 990. | 208. | 1.000 | 576. | 1.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 6.000E+01 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 1.000E+00 | 1.000E+20 | .0000 |
| 2783. | 1958. | 825. | 811. | 1.000 | 658. | 1.040E+02 | 1.000E+20 | .0000 |
| 2780. | 1958. | 822. | 808. | 1.000 | 655. | 1.240E+02 | 1.000E+20 | .0000 |
| 2780. | 2104. | 676. | 576. | 1.000 | 514. | 1.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.660E+02 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 6.000E+01 | 1.000E+20 | .0000 |
| 2780. | 2352. | 428. | 416. | 1.000 | 340. | 1.000E+00 | 1.000E+20 | .0000 |
| 2763. | 2352. | 411. | 403. | 1.000 | 327. | 1.000E+01 | 1.000E+20 | .0000 |
| 2762. | 2352. | 410. | 403. | 1.000 | 327. | 1.000E+01 | 1.000E+20 | .0000 |
| 2762. | 2352. | 410. | 403. | 1.000 | 327. | 4.300E+01 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.700E+01 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.000E+00 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 1.000E+00 | 1.000E+20 | .0000 |
| 2762. | 2441. | 321. | 443. | 1.000 | 291. | 2.280E+02 | 1.000E+20 | .0000 |
| 2496. | 2441. | 55. | 177. | 1.000 | 78. | 5.300E+01 | 1.000E+20 | .0000 |
| 2496. | 2445. | 51. | 181. | 1.000 | 77. | 2.470E+02 | 1.000E+20 | .0000 |
| 2491. | 2445. | 46. | 178. | 1.000 | 74. | 1.000E+01 | 1.000E+20 | .0000 |
| 2487. | 2445. | 42. | 175. | 1.000 | 71. | 4.300E+01 | 1.000E+20 | .0000 |
| 2487. | 2487. | 0. | 0. | 1.000 | 0. | 1.700E+01 | 1.000E+20 | .0000 |

TOTAL USAGE FACTOR = .0015

**Table 4-5: Fatigue Results for the Reactor Recirculation Outlet Nozzle Blend Radius**

```
     LOCATION = LOCATION NO. 2 -- BLEND RADIUS
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
            m = 2.0
            n =  .2
           Sm = 26700. psi
       Ecurve = 3.000E+07 psi
    Eanalysis = 2.670E+07 psi
           Kt = 1.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 55601. | 17. | 55584. | 37389. | 1.000 | 31227. | 1.000E+00 | 1.951E+04 | .0001 |
| 53822. | 17. | 53806. | 48014. | 1.000 | 30228. | 1.000E+01 | 2.161E+04 | .0005 |
| 51017. | 17. | 51001. | 44054. | 1.000 | 28652. | 1.000E+01 | 2.547E+04 | .0004 |
| 48939. | 17. | 48922. | 52579. | 1.000 | 27484. | 1.000E+00 | 2.894E+04 | .0000 |
| 46249. | 17. | 46233. | 48340. | 1.000 | 25974. | 1.000E+00 | 3.443E+04 | .0000 |
| 40607. | 17. | 40590. | 36593. | 1.000 | 22803. | 1.000E+01 | 5.217E+04 | .0002 |
| 39965. | 17. | 39948. | 39059. | 1.000 | 22443. | 1.000E+01 | 5.647E+04 | .0002 |
| 38737. | 17. | 38721. | 40267. | 1.000 | 21753. | 6.000E+01 | 6.592E+04 | .0009 |
| 38243. | 17. | 38227. | 37209. | 1.000 | 21476. | 1.000E+01 | 7.025E+04 | .0001 |
| 37757. | 17. | 37740. | 37702. | 1.000 | 21202. | 7.000E+00 | 7.486E+04 | .0001 |
| 37757. | 476. | 37281. | 37314. | 1.000 | 20945. | 2.930E+02 | 7.954E+04 | .0037 |
| 36291. | 476. | 35815. | 36492. | 1.000 | 20121. | 7.000E+00 | 9.705E+04 | .0001 |
| 36291. | 1582. | 34709. | 35198. | 1.000 | 19500. | 3.000E+00 | 1.096E+05 | .0000 |
| 36273. | 1582. | 34691. | 35110. | 1.000 | 19490. | 6.000E+01 | 1.098E+05 | .0005 |
| 36273. | 1582. | 34691. | 35110. | 1.000 | 19490. | 1.000E+00 | 1.098E+05 | .0000 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 5.600E+01 | 1.135E+05 | .0005 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 1.000E+00 | 1.135E+05 | .0000 |
| 35954. | 1582. | 34372. | 35021. | 1.000 | 19310. | 1.000E+00 | 1.135E+05 | .0000 |
| 35954. | 1844. | 34110. | 34858. | 1.000 | 19163. | 1.000E+00 | 1.167E+05 | .0000 |
| 35954. | 1926. | 34028. | 34917. | 1.000 | 19117. | 2.410E+02 | 1.177E+05 | .0020 |
| 35837. | 1926. | 33911. | 34978. | 1.000 | 19051. | 1.000E+01 | 1.191E+05 | .0001 |
| 35658. | 1926. | 33732. | 34661. | 1.000 | 18951. | 4.900E+01 | 1.214E+05 | .0004 |
| 35658. | 11988. | 23670. | 26901. | 1.000 | 13298. | 1.790E+02 | 5.728E+05 | .0003 |
| 35556. | 11988. | 23568. | 27109. | 1.000 | 13240. | 1.210E+02 | 5.955E+05 | .0002 |
| 35556. | 12180. | 23376. | 28326. | 1.000 | 13133. | 1.790E+02 | 6.411E+05 | .0003 |
| 35279. | 12180. | 23099. | 27958. | 1.000 | 12977. | 1.000E+01 | 7.138E+05 | .0000 |
| 34973. | 12180. | 22793. | 27831. | 1.000 | 12805. | 1.110E+02 | 8.050E+05 | .0001 |
| 34973. | 20655. | 14318. | 16974. | 1.000 | 8044. | 1.890E+02 | 7.421E+07 | .0000 |
| 34843. | 20655. | 14188. | 16887. | 1.000 | 7971. | 1.110E+02 | 7.983E+07 | .0000 |
| 34843. | 25750. | 9093. | 17221. | 1.000 | 5108. | 1.000E+00 | 1.000E+20 | .0000 |
| 34843. | 27368. | 7475. | 5178. | 1.000 | 4199. | 1.000E+01 | 1.000E+20 | .0000 |
| 34843. | 28113. | 6730. | 3789. | 1.000 | 3781. | 1.780E+02 | 1.000E+20 | .0000 |
| 34837. | 28113. | 6724. | 3785. | 1.000 | 3777. | 1.000E+01 | 1.000E+20 | .0000 |
| 34834. | 28113. | 6721. | 3784. | 1.000 | 3776. | 6.000E+01 | 1.000E+20 | .0000 |
| 34834. | 28113. | 6721. | 3784. | 1.000 | 3776. | 1.000E+00 | 1.000E+20 | .0000 |
| 34831. | 28113. | 6718. | 3782. | 1.000 | 3774. | 1.000E+01 | 1.000E+20 | .0000 |
| 34829. | 28113. | 6716. | 3781. | 1.000 | 3773. | 4.100E+01 | 1.000E+20 | .0000 |
| 34829. | 29216. | 5613. | 1808. | 1.000 | 3153. | 1.000E+01 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 6.000E+01 | 1.000E+20 | .0000 |

**Table 4-5: Fatigue Results for Reactor Recirculation Outlet Nozzle Blend Radius (concluded)**

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 1.000E+00 | 1.000E+20 | .0000 |
| 34829. | 31990. | 2839. | 1543. | 1.000 | 1595. | 1.160E+02 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+01 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 6.000E+01 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 31990. | 2835. | 1541. | 1.000 | 1593. | 4.000E+01 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 6.000E+01 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 1.000E+00 | 1.000E+20 | .0000 |
| 34825. | 32634. | 2191. | 2355. | 1.000 | 1231. | 1.270E+02 | 1.000E+20 | .0000 |
| 34646. | 32634. | 2012. | 2695. | 1.000 | 1130. | 1.010E+02 | 1.000E+20 | .0000 |
| 34646. | 33386. | 1260. | 1578. | 1.000 | 708. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33581. | 1065. | 1120. | 1.000 | 598. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 33709. | 937. | 1137. | 1.000 | 526. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 33822. | 824. | 1455. | 1.000 | 463. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33924. | 722. | 1228. | 1.000 | 406. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 33924. | 722. | 1310. | 1.000 | 406. | 1.000E+00 | 1.000E+20 | .0000 |
| 34646. | 34124. | 522. | 1067. | 1.000 | 293. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 34331. | 315. | 3398. | 1.000 | 177. | 1.000E+01 | 1.000E+20 | .0000 |
| 34646. | 34447. | 199. | -603. | 1.000 | 112. | 1.200E+02 | 1.000E+20 | .0000 |
| 34646. | 34592. | 54. | -130. | 1.000 | 30. | 3.500E+01 | 1.000E+20 | .0000 |
| | | | | | | | | ======= |
| | | | | | | TOTAL USAGE FACTOR = | | .0108 |

## 5.0 ENVIRONMENTAL FATIGUE ANALYSIS

Environmental fatigue multipliers were computed for both normal water chemistry (NWC) and hydrogen water chemistry (HWC) conditions in Reference [18] for various regions of the VY RPV and attached piping.

The Recirculation Outlet nozzle has three materials: a Ni-Cr-Fe dissimilar metal weld (DMW), a low alloy steel forging, and a stainless steel safe end. To ensure the maximum CUF considering environmental effects was identified; locations in the safe end and nozzle forging were selected. This selection produces bounding environmental fatigue results for the entire nozzle assembly for the following reasons:

- The highest thermal stresses from the FEM analysis occur in the stainless steel safe end. Stainless steel $F_{en}$ multipliers are significantly higher than Ni-Cr-Fe multipliers ($F_{en}$ values are 2.55 or higher for stainless steel [18] vs. a constant value of 1.49 for Ni-Cr-Fe [19]). Therefore, evaluation of the safe end bounds the Ni-Cr-Fe weld material.
- The highest pressure stresses from the FEM analysis occur in the low alloy steel nozzle forging. Low alloy steel $F_{en}$ multipliers are higher than Ni-Cr-Fe multipliers ($F_{en}$ values are 2.45 or higher for low alloy steel [18] vs. a constant value of 1.49 for Ni-Cr-Fe [19]). Therefore, evaluation of the nozzle forging bounds the Ni-Cr-Fe weld material.

Based on VY-specific dates for plant startup and HWC implementation, as well as past and future predicted HWC system availability, it was determined that overall HWC availability is 47% over the sixty year operating period for VY. Therefore, for the purposes of the EAF assessment of the reactor recirculation outlet nozzle, it was assumed that HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time over the 60-year operating life of the plant. RPV beltline region chemistry was assumed for both the reactor recirculation outlet nozzle safe end and blend radius locations, since both locations experience reactor conditions at all times.

For the safe end location, the environmental fatigue factors for NWC and HWC are 8.36 and 15.35, respectively, from Table 5 of Reference [18] for the RPV beltline region. This results in an EAF adjusted CUF as follows:

60-Year CUF, $U_{60} = 0.0015$

Overall EAF multiplier, $F_{en} = (8.36 \times 53\% + 15.35 \times 47\%) = 11.65$

60-Year EAF CUF, $U_{60\text{-}env} = 0.0015 \times 11.65 = 0.0175$

The EAF CUF value of 0.0175 for 60 years for the safe end is acceptable (i.e., less than the allowable value of 1.0).

The fatigue calculation documented in Section 4.0 for the blend radius location was performed for the nozzle base material since cladding is structurally neglected in modern-day fatigue analyses, per ASME Code, Section III, NB-3122.3 [17]. This is also consistent with Sections 5.7.1 and 5.7.4 of NUREG/CR-6260 [1]. Therefore, the cladding was neglected and EAF assessment of the nozzle base material was performed for the blend radius location.

For the blend radius location, the environmental fatigue factors for NWC and HWC are 12.43 and 2.45, respectively, from Table 5 of Reference [18] for the RPV beltline region. This results in an EAF adjusted CUF as follows:

60-Year CUF, $U_{60} = 0.0108$

Overall EAF multiplier, $F_{en} = (12.43 \times 53\% + 2.45 \times 47\%) = 7.74$

60-Year EAF CUF, $U_{60\text{-}env} = 0.0108 \times 7.74 = 0.0836$

The EAF CUF value of 0.0836 for 60 years for the blend radius is acceptable (i.e., less than the allowable value of 1.0).

## 6.0 CONCLUSIONS

This report documents a refined fatigue evaluation for the VY reactor recirculation outlet nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the reactor recirculation outlet nozzle and safe end are included in the evaluation, to be consistent with NUREG/CR-6260 [1] needs for EAF evaluation for license renewal. The final fatigue results are considered to be a replacement to the values previously reported in the VY LRA.

The fatigue calculations for the VY reactor recirculation outlet nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [17]. The stress evaluation is summarized in Section 3.0, and the fatigue analysis is summarized in Section 4.0. The results in Section 4.0 reveal that the CUF for the limiting safe end location is 0.0015, and the CUF for the limiting blend radius location is 0.0108. Both of these values represent 60 years of plant operation, including all relevant EPU effects.

EAF calculations for the VY reactor recirculation outlet nozzle were also performed, as summarized in Section 5.0. The results in Section 5.0 reveal that the EAF CUF for the limiting safe end location is 0.0175, and the EAF CUF for the limiting blend radius location is 0.0836. Both of these values represent 60 years of plant operation, including all relevant EPU effects.

All fatigue allowables, both with and without EAF effects, are met, thus demonstrating acceptability for 60 years of operation.

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13. Nozzle Thermal Cycles (Recirculation Outlet), Attachment 1, page 4 of Entergy Design Input Record (DIR) EC No. 1773, Rev. 1, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/07, SI File No. VY-16Q-209.
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Revision No.: 0
Project No.: VY-16Q
File No.: VY-16Q-403
July 2007

**Environmental Fatigue Analysis
for the
Vermont Yankee
Reactor Pressure Vessel
Core Spray Nozzle**

*Prepared for:*
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(Contract No. 10150394)

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*Approved by:* T. J. Herrmann P.E. Date: 7/26/2007

## REVISION CONTROL SHEET

Document Number: SIR-07-138-NPS

Title: Environmental Fatigue Analysis for the Vermont Yankee Reactor Pressure Vessel Core Spray Nozzles

Client: Entergy Nuclear Operations, Inc.

SI Project Number: VY-16Q

| Section | Pages | Revision | Date | Comments |
|---|---|---|---|---|
| 1.0 | 1-1 – 1-5 | 0 | 07/26/07 | Initial issue. |
| 2.0 | 2-1 – 2-3 | | | |
| 3.0 | 3-1 – 3-26 | | | |
| 4.0 | 4-1 – 4-8 | | | |
| 5.0 | 5-1 – 5-2 | | | |
| 6.0 | 6-1 | | | |
| 7.0 | 7-1 – 7-3 | | | |

## Table of Contents

## List of Tables



## List of Figures

## 1.0 INTRODUCTION

In Table 4.3-3 of the Vermont Yankee License Renewal Application (LRA), the 60-year cumulative usage factor (CUF) values for the reactor pressure vessel (RPV) core spray nozzle are reported as 0.625 (nozzle) and 0.182 (safe end). The safe end value was reported as a generic value, since no plant-specific value was determined. Application of environmentally assisted fatigue (EAF) multipliers, as required for the license renewal period, resulted in unacceptable EAF CUF values of 1.53 and 2.79 for the nozzle and safe end, respectively. Therefore, further refined analysis was necessitated to show acceptable EAF CUF results for this component.

This report documents a refined fatigue evaluation for the VY core spray nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the core spray nozzle and safe end are included in the evaluation, to be consistent with NUREG/CR-6260 [1] needs for EAF evaluation for license renewal. The EAF effects for the core spray piping, which is also a NUREG/CR-6260 location, are considered to be covered by the nozzle and safe end calculations because the nozzle region bounds the piping[1]. The resulting fatigue results will be used as a replacement to the values previously reported in the VY LRA.

The refined evaluation summarized in this report included the development of a detailed finite element model of the core spray nozzle, including relevant portions of the safe end, thermal sleeve, the RPV wall, and the weld overlay repair documented in Reference [2]. Thermal and pressure stress histories were developed for relevant transients affecting the core spray nozzle, including any effects of Extended Power Uprate (EPU), as specified by the VY RPV Design Specification [3], the VY EPU Design Specification [4] and other boiling water reactor (BWR) operating experience. The thermal and pressure stress histories were used to determine total stress and primary plus secondary stress for use in a subsequent fatigue evaluation. Stresses were also included due to loads from the attached piping for application in the stress/fatigue analysis, based on the bounding reaction loads obtained from the

[1] The nozzle stresses are more severe due to the nozzle discontinuity, and the nozzle thermal transients are more severe due to interaction with the hot RPV.

relevant design documents. The revised fatigue calculation was performed using Section III methodology from the 1998 Edition, 2000 Addenda of the ASME Code, and were performed using actual cycles from past plant operation projected out to 60 years of operation.

## 1.1 Green's Function Methodology

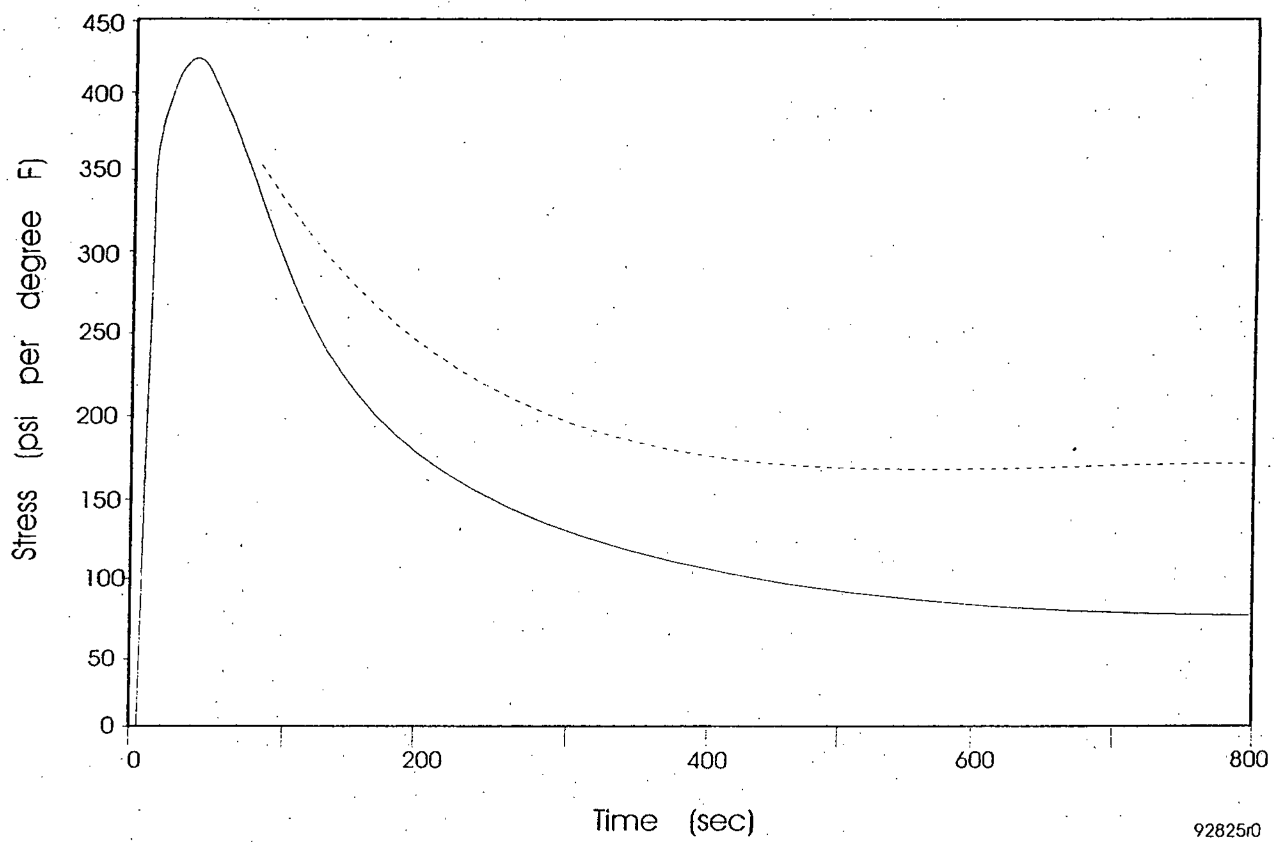
For the core spray nozzle evaluated as a part of this work, stress histories were computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's Function integration scheme is similar in concept to the well-known Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [5]. A general outline is provided in this section.

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 1-1 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 1-2. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 1-2. These five step changes produce the five successive stress responses in the second plot shown in Figure 1-2. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY core spray nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.




Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

**Figure 1-1: Typical Green's Functions for Thermal Transient Stress**

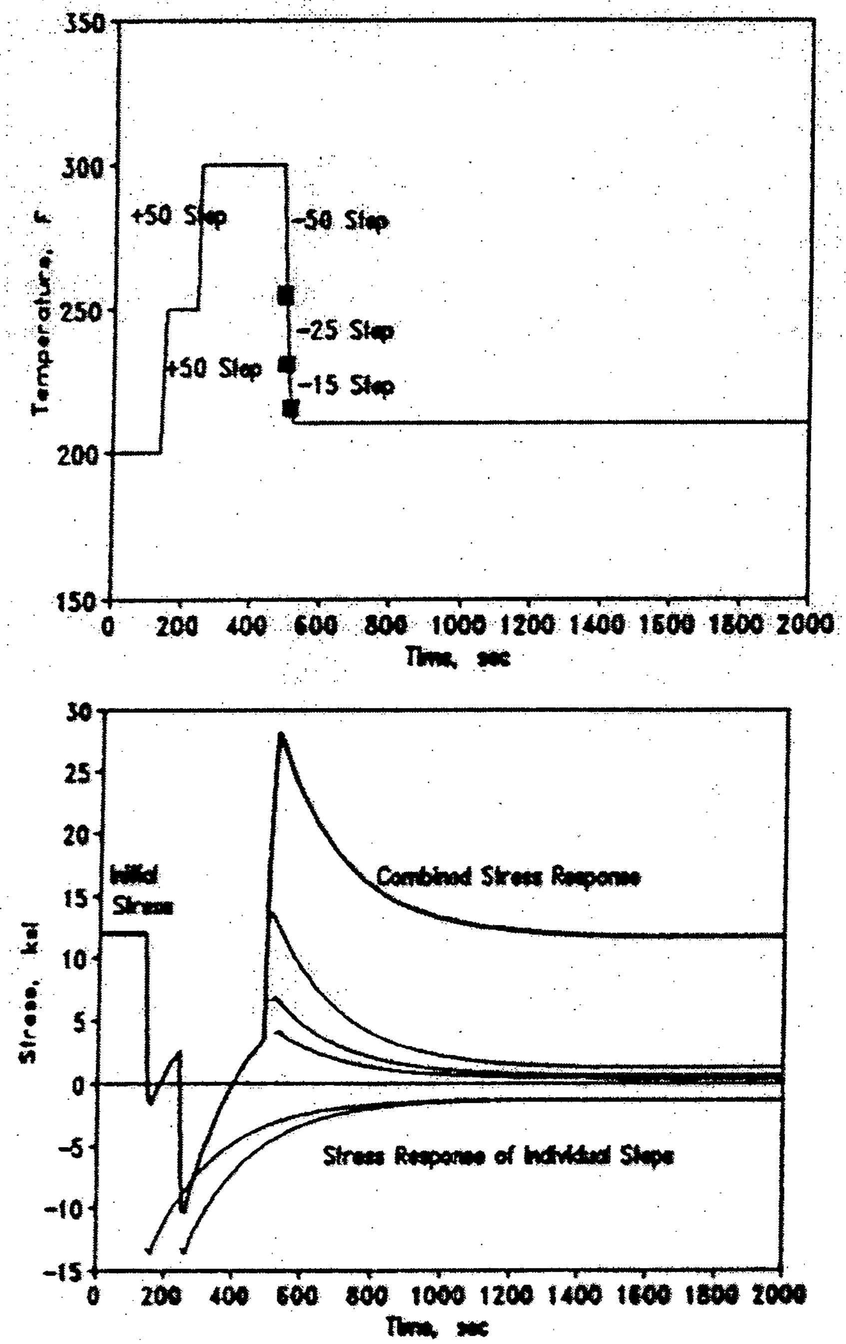



**Figure 1-2: Typical Stress Response Using Green's Functions**

## 2.0 FINITE ELEMENT MODEL

An ANSYS [6] finite element model (FEM) of the VY core spray nozzle and safe end was developed and used to perform the updated stress and fatigue analyses. The details of the model development are documented in the Reference [7] calculation.

The materials of the various components of the model are listed below:

- Safe End – SB 166 (72Ni-15Cr-8Fe, N06600)
- 8Ø x 10Ø Conc. Reduction – SA312 TP304 (18Cr-8Ni)
- Nozzle Forging – SA508 Class II (3/4Ni-1/2Mo-1/3Cr-V)
- Vessel – SA533 Grade B (Mn-1/2Mo-1/2Ni)
- Cladding – SA240 TP 304 (18Cr-8Ni)

In the FEM model, the radius of RPV was increased by a factor of two to account for the fact that the vessel portion of the finite element model is a sphere and the actual geometry is a cylinder.

Material properties were based upon the 1998 ASME Code, Section II, Part D, with 2000 Addenda [8], and are shown in Table 2-1. The properties were evaluated at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F, which was applied to the FEM model for Green's Function development.

The finite element model, which includes the weld overlay, is shown in Figure 2-1.

## Table 2-1: Material Properties @ 300°F [(1)]

| Material ID | Part Description | Material | | Modulus of Elasticity, e+6 psi [EX] | Coefficient of Thermal Expansion, e-6, in/in/°F [ALPX] | Thermal Conductivity, Btu/hr-ft-°F [KXX] | Thermal Diffusivity, ft²/hr | Specific Heat, Btu/lb-°F [C] [(3)] |
|---|---|---|---|---|---|---|---|---|
| 2 | Safe End | SB 166 | 72Ni-15Cr-8Fe N06600 | 29.8 | 7.9 | 9.6 | 0.160 | 0.1157 |
| 2 | Weld Overlay | INCONEL 82 | 72Ni-15Cr-8Fe N06600 | 29.8 | 7.9 | 9.6 | 0.160 | 0.1157 |
| 1 | Nozzle | SA508 Class II | ¾ Ni-1/2Mo-1/3 Cr-V | 26.7 | 7.3 | 23.4 | 0.401 | 0.1193 |
| 3 | Vessel | SA533 Grade B | Mn-1/2Mo-1/2Ni | 28.0 | 7.7 | 23.4 | 0.401 | 0.1193 |
| 4 | 3/16 Clad | SA240 TP 304 | 18Cr-8Ni | 27.0 | 9.8 | 9.8 | 0.160 | 0.1252 |
| 4 | 8Ø x 10Ø Conc. Reduction[(2)] | SA312 [(2)] TP304 | 18Cr-8Ni | 27.0 | 9.8 | 9.8 | 0.160 | 0.1252 |

Note:
1. Material properties are evaluated at 300°F from the 1998 ASME Code, Section II, Part D, with 2000 Addenda [8], Poisson's ratio, which are assumed typical values and specific heat is calculated as [k/ρd]/12$^3$.
2. The 8Ø x 10Ø concentric reduction was modeled as a straight pipe with the material properties of the original desi; was replaced by a new material (SA403 T316L). These two stainless steels have the same modulus of elasticity an properties.

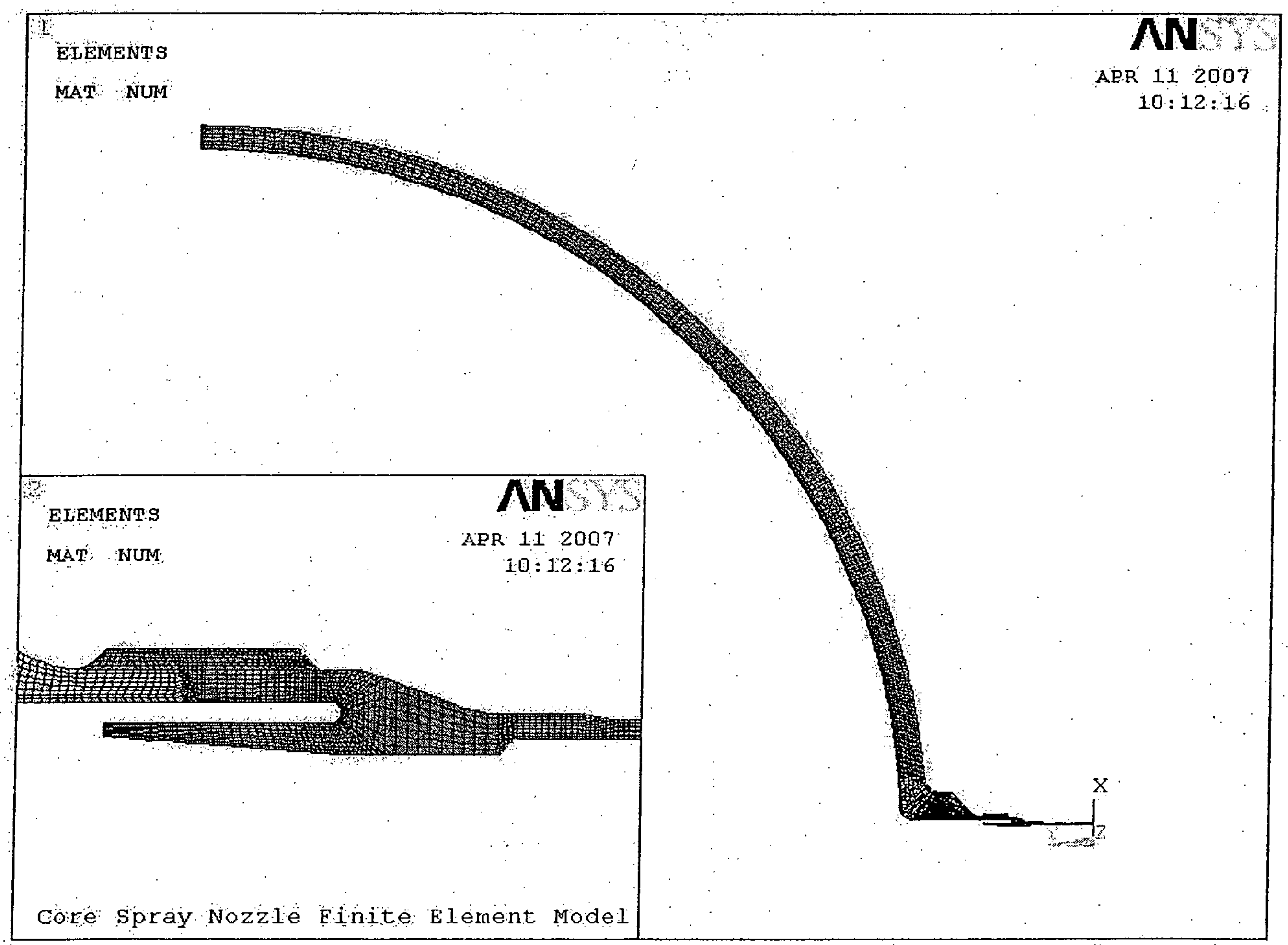



**Figure 2-1: VY Core Spray Nozzle FEM**

## 3.0 LOAD DEFINITIONS

The pressure and thermal stresses for the core spray nozzle for the revised fatigue evaluation were developed using the axisymmetric FEM model, described in Section 2.0 of this report. The details of the Green's function development and associated stress evaluation are documented in the Reference [9] and [10] calculations.

### 3.1 Thermal Loading

Thermal loads were applied to the core spray nozzle model to generate the Green's Function. As a first step in the Green's Function process, heat transfer coefficients were determined for various regions of the core spray FEM for two different flow cases: (1) 0% core spray flow, and (2) 100% core spray flow through the nozzle.

The 0% flow case simulates a stagnant condition of the core spray nozzle when not in operation and the entire core spray nozzle is at the same temperature as the RPV fluid. The heat transfer coefficients for the 0% flow case are for free convection (stagnant) conditions. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the core spray nozzle in the stagnant condition.

The 100% flow case simulates the operational condition of the core spray nozzle (i.e., the entire core spray nozzle experiences 100°F water due to injection). The heat transfer coefficients for the high flow case are for forced and free convection depending on the region of the FEM. The applied boundary fluid temperature is changed to simulate a thermal shock from 500°F to 100°F to develop the stress response on the core spray nozzle due to injection.

The temperature on the exterior of the reactor, nozzle, safe end and pipe was assumed to be 120°F (ambient). Figure 3-4 shows the heat transfer coefficient regions assumed for the core spray nozzle FEM. The applied heat transfer coefficients and the fluid temperatures are summarized in the sections that follow.

### *3.1.1 Heat Transfer Coefficients and Boundary Fluid Temperatures*

Referring to Figure 3-4, heat transfer coefficients were applied as follows:

- The heat transfer coefficient for the outside surfaces of the FEM (Region 12) was a constant value of 0.2 BTU/hr-ft$^2$-°F (3.858x10$^{-7}$ BTU/sec-in$^2$-°F).
- Table 3-1 shows the results of the heat transfer coefficient calculations for all of the thermal regions identified in Figure 3-4. The detailed heat transfer calculations for Regions 1, 3, 5, 7, 9, and 11 are contained in the Reference [9] calculation.
- In Regions 2, 4, 6, 8, and 10, the heat transfer coefficients are interpolated.

For both Green's Functions, a 500°F – 100°F thermal shock was run to determine the stress response. For the 0% flow case, the entire inside surface of the FEM was shocked. For the 100% flow case, only the nozzle flow path was shocked.

### *3.1.2 Green's Functions*

The two flow-dependent thermal load cases outlined in previous section were run on the core spray nozzle FEM with the heat transfer coefficients and the fluid temperature conditions listed in Table 3-1. Two locations were selected for analysis (see Figures 3-5 and 3-6):

1. The critical safe end location was chosen as the node with the highest stress intensity due to thermal loading under nozzle flow conditions. The highest stress intensity due to thermal loading occurred at Node 3719 (see Figure 3-5), on the inside diameter of the nozzle safe end. Therefore, this node was selected for analysis.
2. The critical blend radius location was chosen based upon the highest pressure stress intensity. The critical location was selected as Node 2166, as shown in Figure 3-6.

Two stress intensity Green's Functions were developed for each location and each flow case: (1) total stress intensity, and (2) membrane plus bending stress intensity. The total stress intensity

Green's Functions for the safe end location are shown in Figures 3-7 and 3-8. The total stress intensity Green's Functions for the blend radius location are shown in Figures 3-9 and 3-10.

### *3.1.3 Thermal Transients*

The transients analyzed for the core spray nozzle were developed based on the definitions in the original RPV Design Specification [3], as modified for EPU [4], as well as more recent definitions based on BWR operating experience. For BWR operating experience, the transients described in the thermal cycle diagrams for a BWR-4 plant similar in design and vintage to VY were obtained, and plant data from VY applied to each transient. The resulting thermal cycle diagrams are shown in References [11 and 12]. The final transients evaluated in the stress and fatigue analyses are shown in Figures 3-11 through 3-16.

The number of cycles projected for the 60-year operating life is used for each transient [13]. Tables 3-2 and 3-3 summarize the thermal transients for the safe end and blend radius locations, respectively.

## 3.2 Pressure Loading

A uniform pressure of 1,000 psi was applied along the inside surface of the core spray nozzle and the RPV wall. A pressure load of 1,000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load of 4,774 psi was applied to the piping at the end of the nozzle. This cap load was calculated as follows:

$$P_{cap} = \frac{PD_i^2}{\left(D_o^2 - D_i^2\right)}$$

where: $P_{cap}$ = end cap pressure load (psi)

$P$ = unit pressure load = 1,000 psi

$D_i$ = inside diameter of end of FEM = 9.834"

$D_o$ = outside diameter of end of FEM = 10.815"

The calculated pressure was applied as a negative value so that it would exert tension on the end of the model. The nodes on the end of the FEM were coupled in the axial direction to ensure mutual displacement of the end of the nozzle due to attached piping. Figures 3-1, 3-2, and 3-3 show the internal pressure distribution, cap load, and symmetry condition applied to the vessel end of the model, respectively.

The internal pressure load case for Node 2166 (blend radius) resulted in a total stress intensity of 35,860 psi, and for Node 3719 (safe end) resulted in a total stress intensity of 12,030 psi. The membrane plus bending stress intensity at Node 2166 and Node 3719 are 34,970 psi and 12,020 psi, respectively.

### 3.3 Piping Loading

The piping stress intensities (stress caused by the attached piping) were determined for the two evaluated core spray nozzle locations. The design piping reactions that were used in the stress and fatigue evaluation are defined on the Reference [14] drawing. These loads represent shear and moment loadings on the nozzle resulting from thermal expansion of the attached piping and seismic loads. The loads are applicable at the piping end of the safe end, as shown in Figure 3-17. The stresses resulting from these loads were calculated by hand using classical structural mechanics formulas, as documented in Reference [10], and are shown in Tables 3-4 and 3-5 for the safe end and blend radius locations, respectively.

Table 3-1: Summary of Heat Transfer Coefficients

| Regions | 0% Flow | | 100% Flow | |
|---|---|---|---|---|
| | Initial Temperature °F | HTC Btu/hr-ft$^2$-°F | Initial Temperature °F | HTC Btu/hr-ft$^2$-°F |
| R1 | 500 | 143 | 500 | 2693 |
| R2 | 500 | Interpolated | 500 | Interpolated |
| R3 (1) | 500 | 39 | 500 | 52 |
| R4 | 500 | Interpolated | 500 | Interpolated |
| R5 (1) | 500 | 47 | 500 | 66 |
| R6 | 500 | Interpolated | 500 | Interpolated |
| R6B | 500 | 97 | 500 | 97 |
| R7A (1) | 500 | 38 | 500 | 50 |
| R7B (1) | 500 | 20 | 500 | 23 |
| R8 | 500 | Interpolated | 500 | Interpolated |
| R9 (1) | 500 | 33 | 500 | 41 |
| R10 | 500 | Interpolated | 500 | Interpolated |
| R11 | 500 | 500 | 500 | 500 |
| R12 | 120 | 0.20 | 120 | 0.2 |

## Table 3-2: Safe End Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 2. Design HYD Test | --- | 100 | --- | 0 | |
| 120 Cycles | | | | 1100 | |
| | | | | 50 | |
| 3. Startup | 0 | 100 | | 0 | 0 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 | (0%) |
| | 17164 | 549 | 1000 | 1010 | |
| 11. Loss of Feedwater | 0 | 526 | | 1010 | 0 |
| Pumps | 3 | 526 | 3 | 1190 | (0%) |
| 10 Cycles | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6893 | 500 | 4500 | 1135 | |
| | 7313 | 300 | 420 | 675 | |
| | 7613 | 300 | 300 | 675 | |
| | 11213 | 400 | 3600 | 240 | |
| | 16577 | 549 | 5364 | 1010 | |
| | 16637 | 549 | 60 | 1010 | |
| | 16638 | 542 | 1 | 1010 | |
| | 16698 | 542 | 60 | 1010 | |
| | 16699 | 526 | 1 | 1010 | |
| | 17699 | 526 | 1000 | 1010 | |
| 14. SRV Blowdown | 0 | 526 | | 1010 | 0 |
| 1 Cycle | 600 | 375 | 600 | 400 | (0%) |
| | 11580 | 70 | 10980 | 50 | |
| | 12580 | 70 | 1000 | 50 | |
| 21-23. Shutdown | 0 | 549 | | 1010 | 0 |
| 300 Cycles | 6264 | 375 | 6264 | 50 | (0%) |
| | 6864 | 330 | 600 | 50 | |
| | 16224 | 100 | 9360 | 50 | |
| | 17224 | 100 | 1000 | 50 | |
| 12. Hydrostatic Test | --- | 100 | --- | 50 | |
| 1 cycle | | | | 1563 | |
| | | | | 50 | |
| 30. Emergency Shut Down | 0 | 549 | | 1010 | 3200 |
| 1 Cycle | 10 | 406 | 10 | 250 | (100%) |
| | 11 | 70 | 1 | 250 | |
| | 1011 | 70 | 1000 | 0 | |

## Table 3-3: Blend Radius Transients

| Transient Number | Time (s) | Temp (°F) | Time Step (s) | Pressure (psig) | Flow Rate (GPM) |
|---|---|---|---|---|---|
| 2. Design HYD Test | --- | 100 | --- | 0 | |
| | | | | 1100 | |
| 120 Cycles | | | | 50 | |
| 3. Startup | 0 | 100 | | 0 | 0 |
| 300 Cycles | 16164 | 549 | 16164 | 1010 | (0%) |
| | 24164 | 549 | 8000 | 1010 | |
| 11. Loss of Feedwater | 0 | 526 | | 1010 | 0 |
| Pumps | 3 | 526 | 3 | 1190 | (0%) |
| 10 Cycles | 13 | 526 | 10 | 1135 | |
| | 233 | 300 | 220 | 1135 | |
| | 2213 | 500 | 1980 | 1135 | |
| | 2393 | 300 | 180 | 885 | |
| | 6893 | 500 | 4500 | 1135 | |
| | 7313 | 300 | 420 | 675 | |
| | 7613 | 300 | 300 | 675 | |
| | 11213 | 400 | 3600 | 240 | |
| | 16577 | 549 | 5364 | 1010 | |
| | 16637 | 549 | 60 | 1010 | |
| | 16638 | 542 | 1 | 1010 | |
| | 16698 | 542 | 60 | 1010 | |
| | 16699 | 526 | 1 | 1010 | |
| | 24699 | 526 | 8000 | 1010 | |
| 14. SRV Blowdown | 0 | 526 | | 1010 | 0 |
| 1 Cycle | 600 | 375 | 600 | 400 | (0%) |
| | 11580 | 70 | 10980 | 50 | |
| | 19580 | 70 | 8000 | 50 | |
| 21-23. Shutdown | 0 | 549 | | 1010 | 0 |
| 300 Cycles | 6264 | 375 | 6264 | 50 | (0%) |
| | 6864 | 330 | 600 | 50 | |
| | 16224 | 100 | 9360 | 50 | |
| | 24224 | 100 | 8000 | 50 | |
| 24. Hydrostatic Test | --- | 100 | --- | 50 | |
| 1 Cycle | | | | 1563 | |
| | | | | 50 | |
| 30. Emergency Shut Down | 0 | 549 | | 1010 | 3200 |
| 1 Cycle | 10 | 406 | 10 | 250 | (100%) |
| | 11 | 70 | 1 | 250 | |
| | 8011 | 70 | 8000 | 0 | |

**Table 3-4: Stresses Due to Piping Loads for Safe End Location**

| Safe End External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 2.50 | kips |
| $F_y$ = | 4.60 | kips |
| $F_Z$ = | 1.70 | kips |
| $M_x$ = | 264.00 | in-kips |
| $M_y$ = | 85.20 | in-kips |
| $M_Z$ = | 105.60 | in-kips |
| OD= | 10.82 | in |
| ID= | 9.834 | in |
| $R_N$ = | 5.16 | in |
| L = | 0.30 | in |
| $t_N$ = | 0.49 | in |
| $(M_x)_1$ = | 262.60 | in-kips |
| $(M_y)_1$ = | 85.96 | in-kips |
| $M_{xy}$ = | 276.31 | in-kips |
| $F_{xy}$ = | 5.24 | kips |
| $N_Z$ = | 3.35 | kips/in |
| $q_N$ = | -0.31 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 6.84 | ksi |
| $\tau$ = | -0.63 | ksi |
| $SI_{max}$ = | 6.95 | ksi |
| $SI_{max}$ = | 6949.94 | psi |

**Table 3-5: Stresses Due to Piping Loads for Blend Radius Location**

| Blend Radius External Piping Loads | | |
|---|---|---|
| Parameters | | |
| $F_x$ = | 2.50 | kips |
| $F_y$ = | 4.60 | kips |
| $F_Z$ = | 1.70 | kips |
| $M_x$ = | 264.00 | in-kips |
| $M_y$ = | 85.20 | in-kips |
| $M_Z$ = | 105.60 | in-kips |
| OD= | 18.87 | in |
| ID= | 11.750 | in |
| $R_N$ = | 7.65 | in |
| L = | 30.82 | in |
| $t_N$ = | 3.56 | in |
| $(M_x)_2$ = | 122.24 | in-kips |
| $(M_y)_2$ = | 162.24 | in-kips |
| $M_{xy}$ = | 203.14 | in-kips |
| $F_{xy}$ = | 5.24 | kips |
| $N_Z$ = | 1.14 | kips/in |
| $q_N$ = | -0.07 | kips/in |
| **Primary Membrane Stress Intensity** | | |
| $PM_Z$ = | 0.32 | ksi |
| $\tau$ = | -0.02 | ksi |
| $SI_{max}$ = | 0.32 | ksi |
| $SI_{max}$ = | 322.52 | psi |

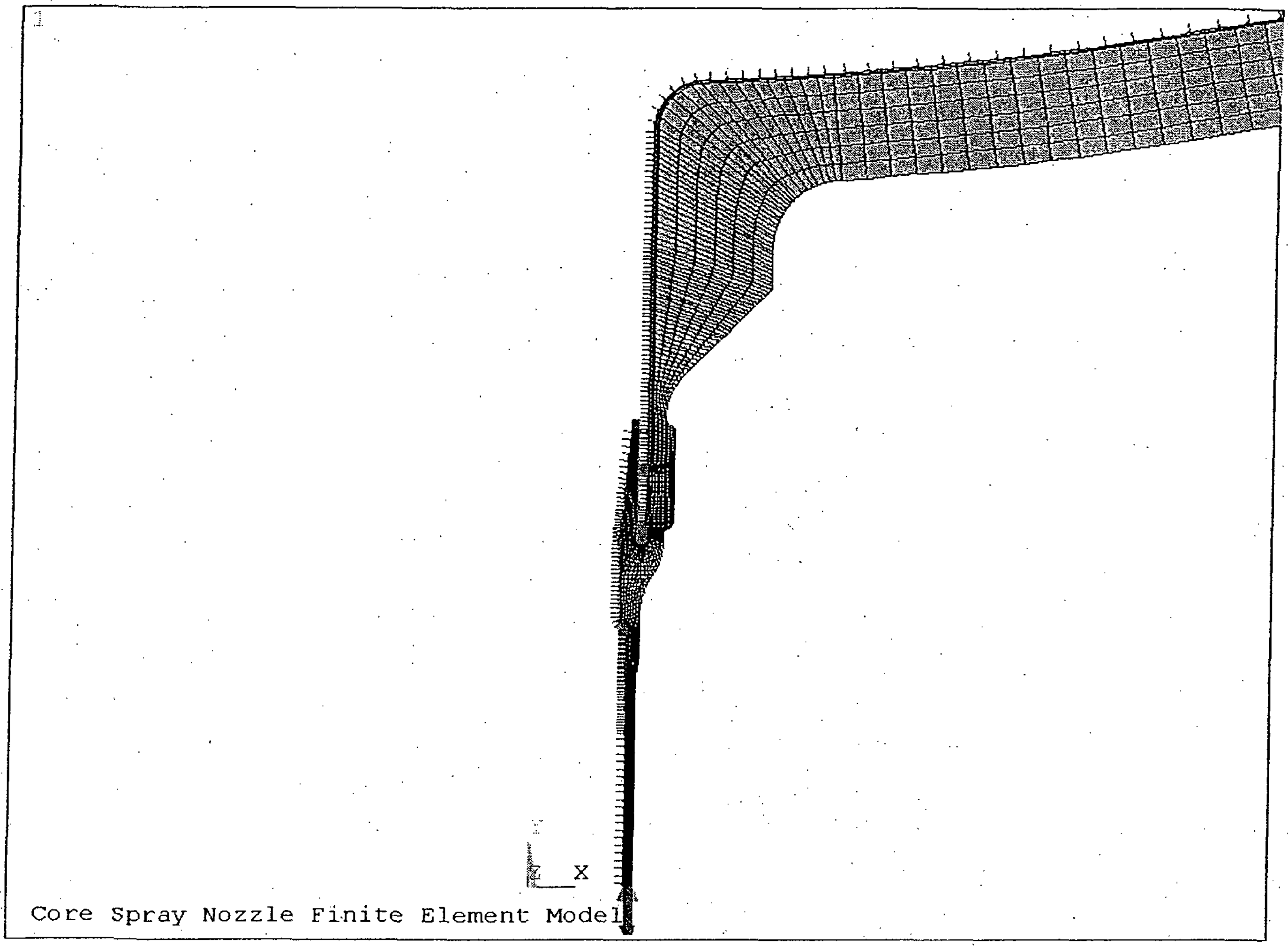



**Figure 3-1: Core Spray Nozzle Internal Pressure Distribution**

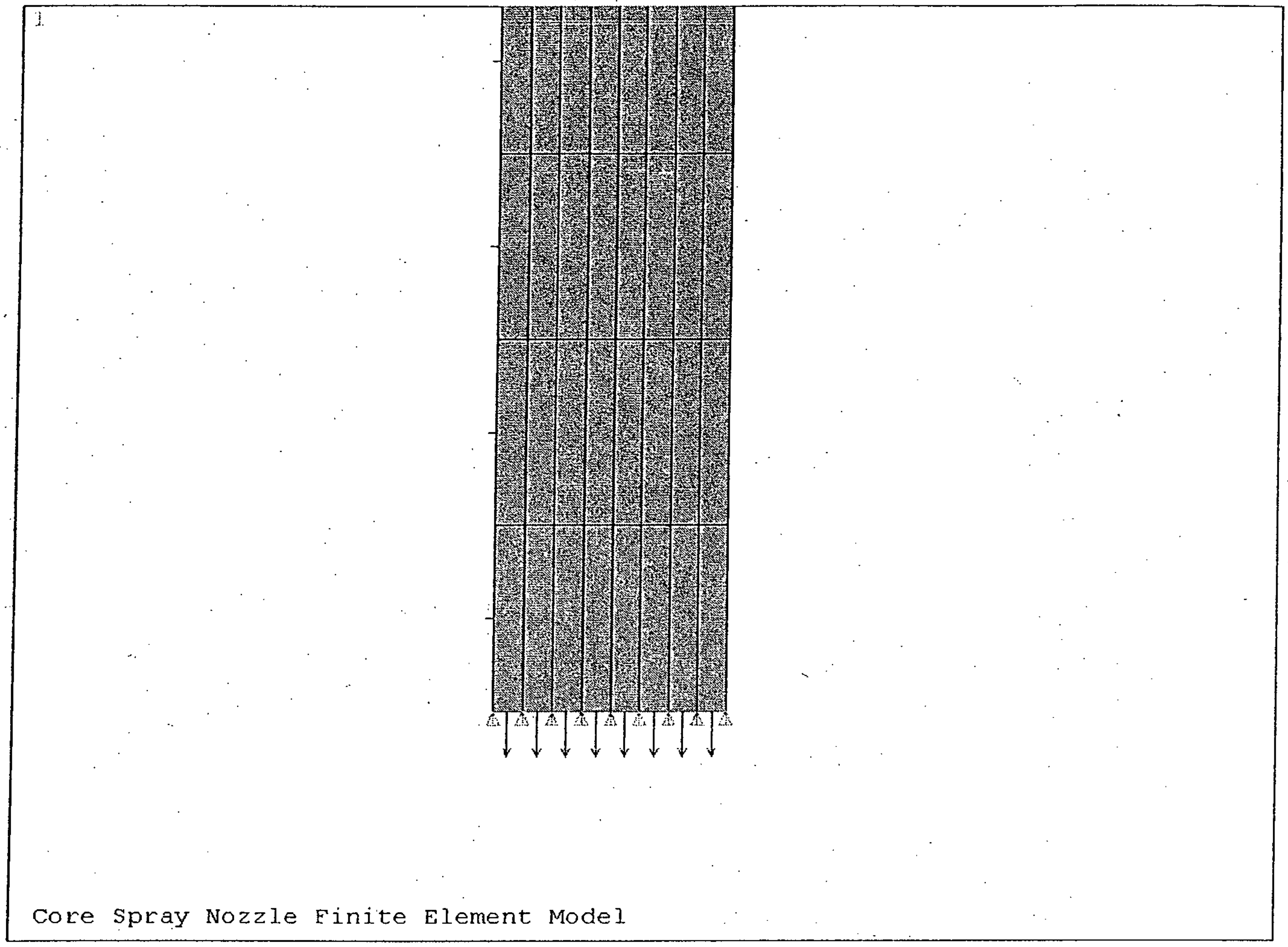



**Figure 3-2: Core Spray Nozzle Pressure Cap Load**

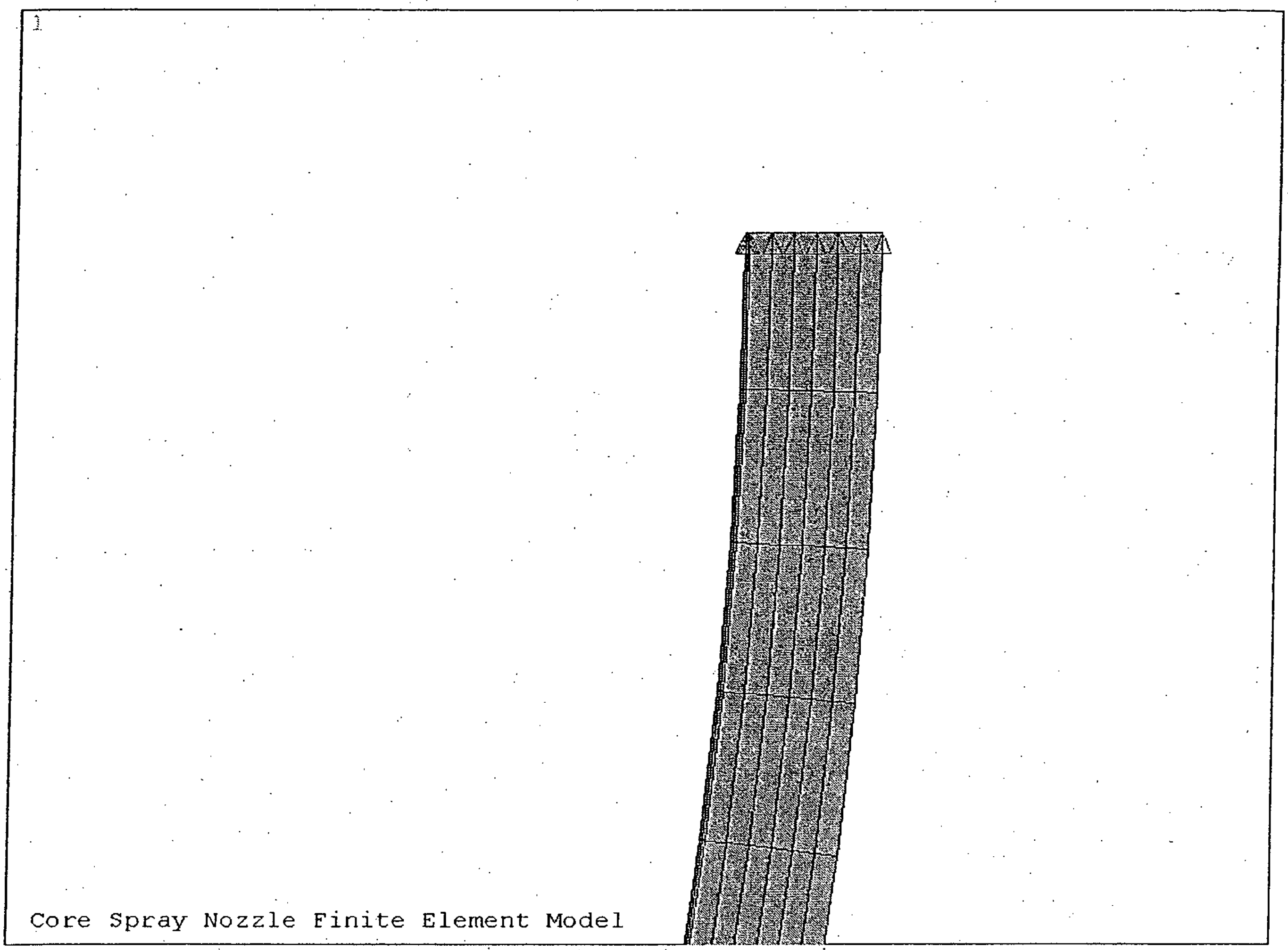



**Figure 3-3: Core Spray Nozzle Vessel Boundary Condition**

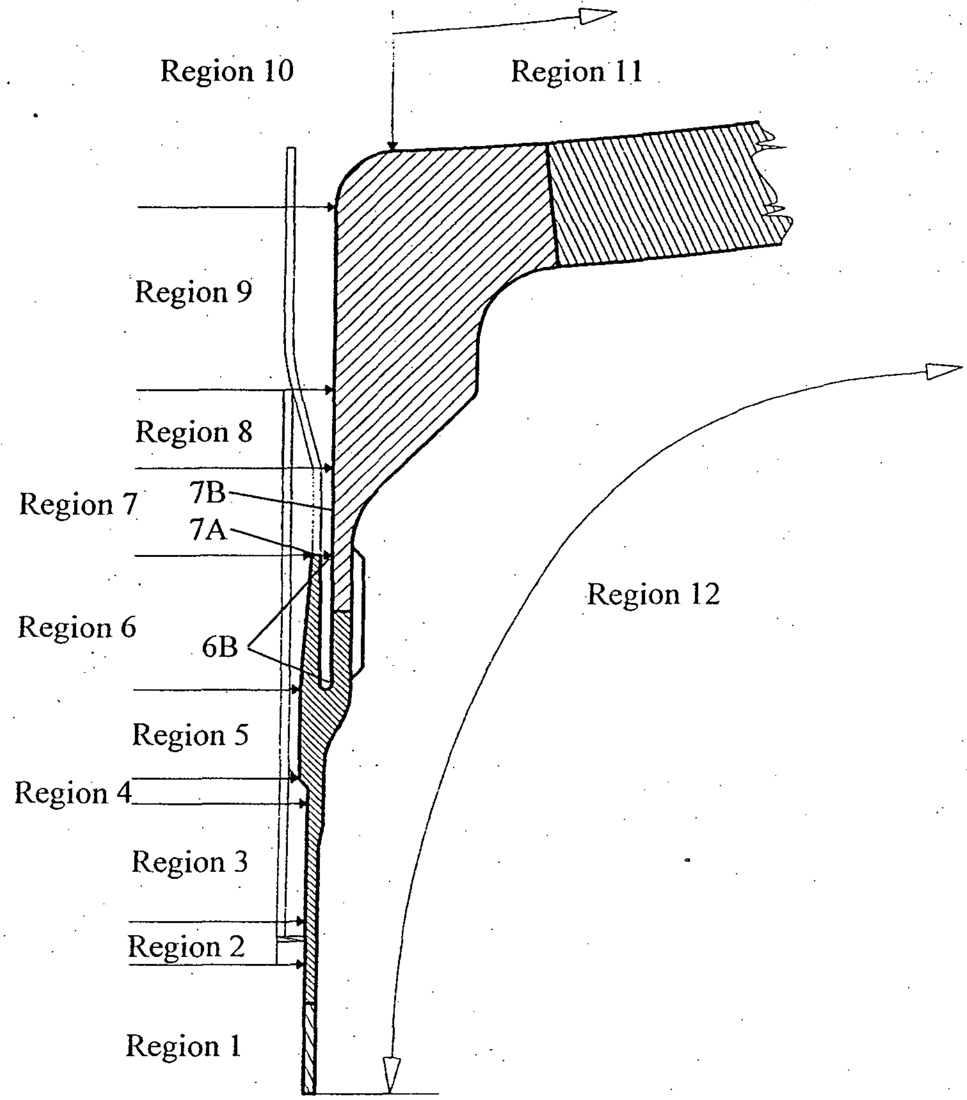



**Figure 3-4: Thermal Regions**

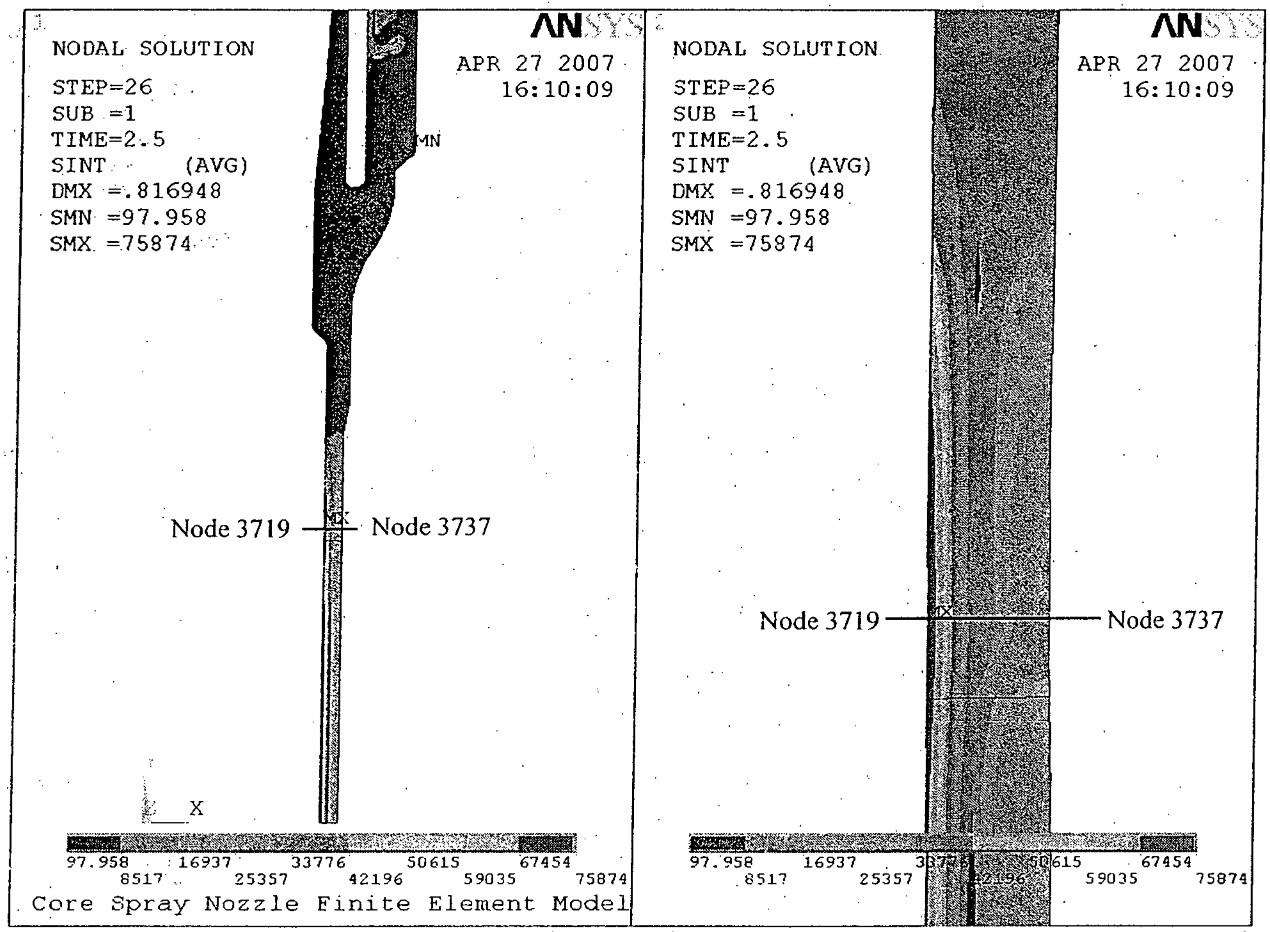



**Figure 3-5: Safe End Critical Thermal Stress Location**

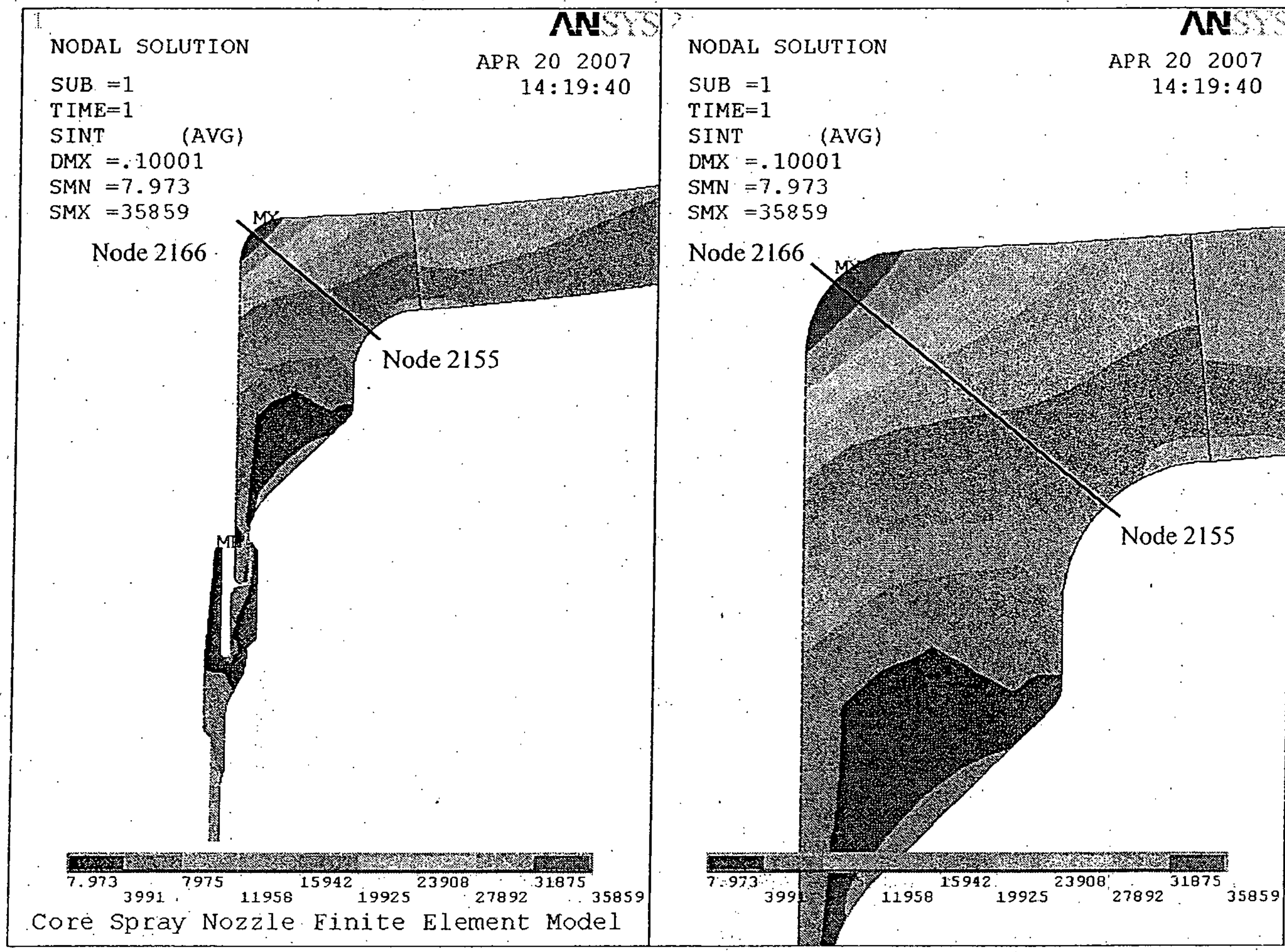



**Figure 3-6: Blend Radius Critical Thermal Stress Location**

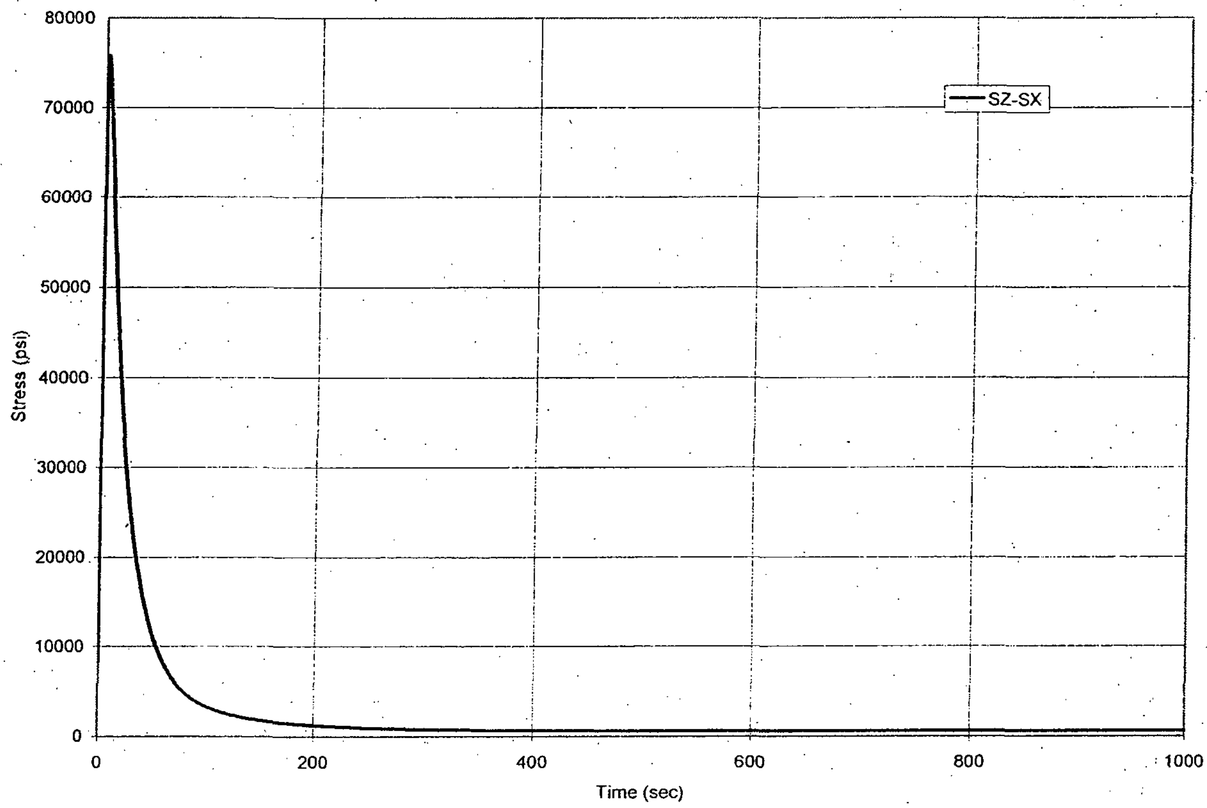



**Figure 3-7: Safe End Green's Function for 100% Flow**

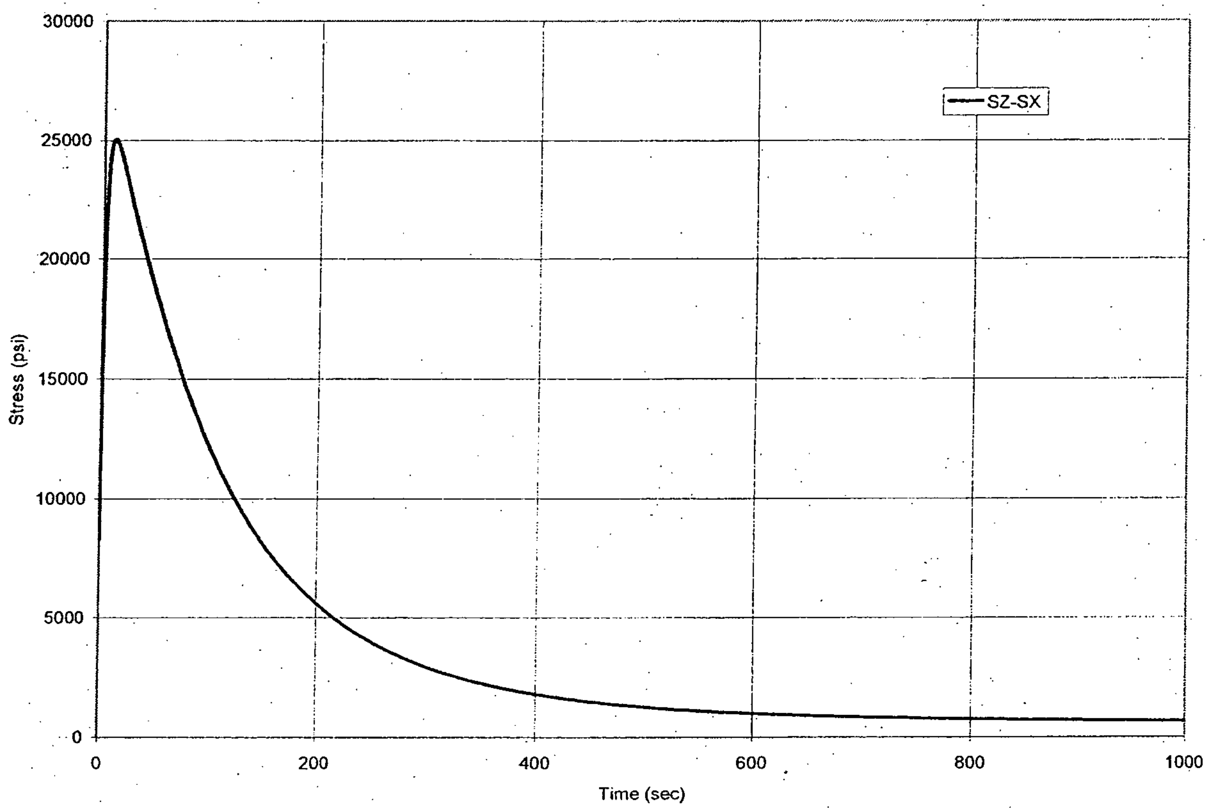



**Figure 3-8: Safe End Green's Function for 0% Flow**

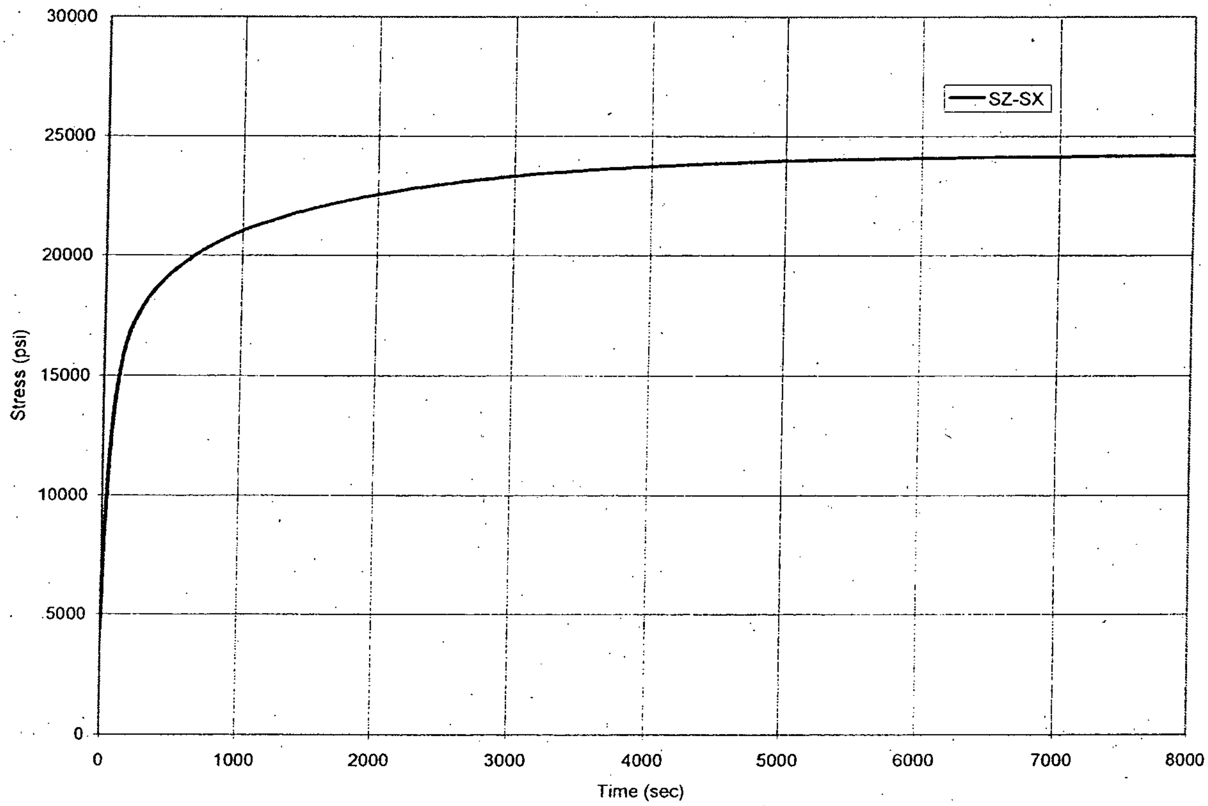



**Figure 3-9: Blend Radius Green's Function for 100% Flow**

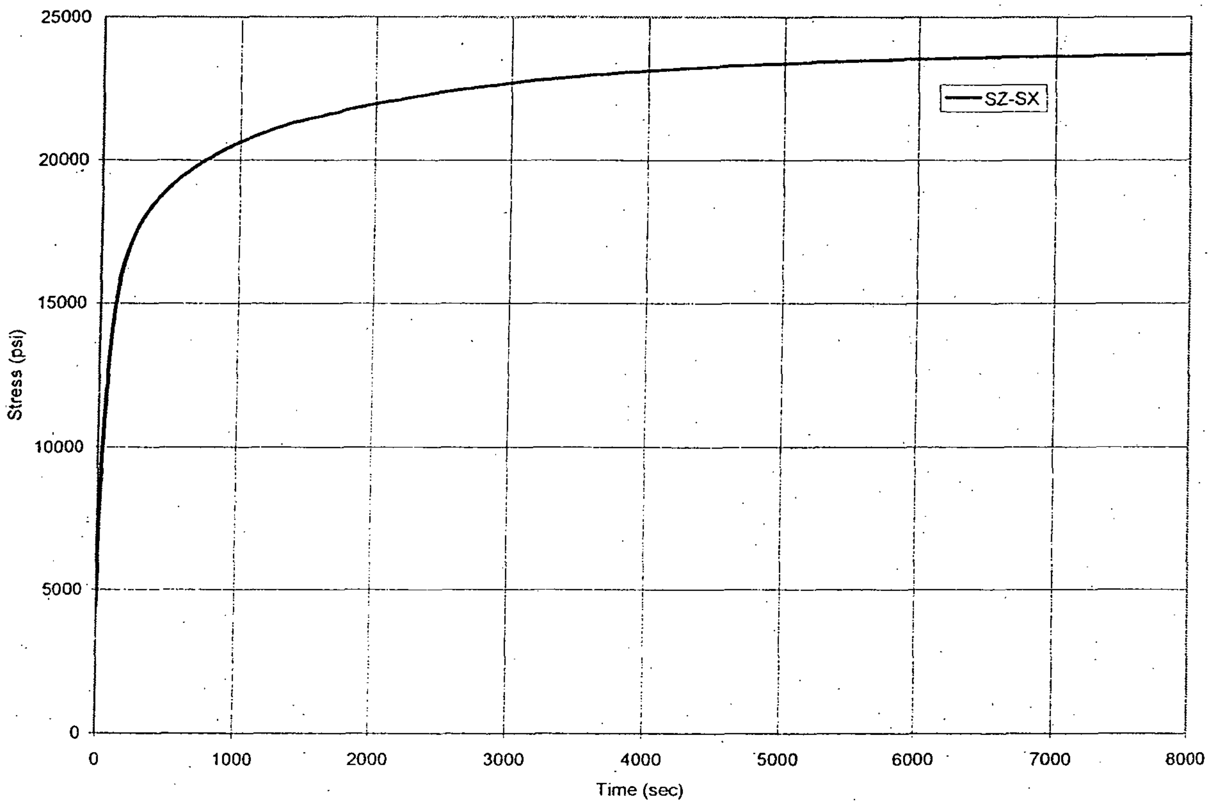



**Figure 3-10: Blend Radius Green's Function for 0% Flow**

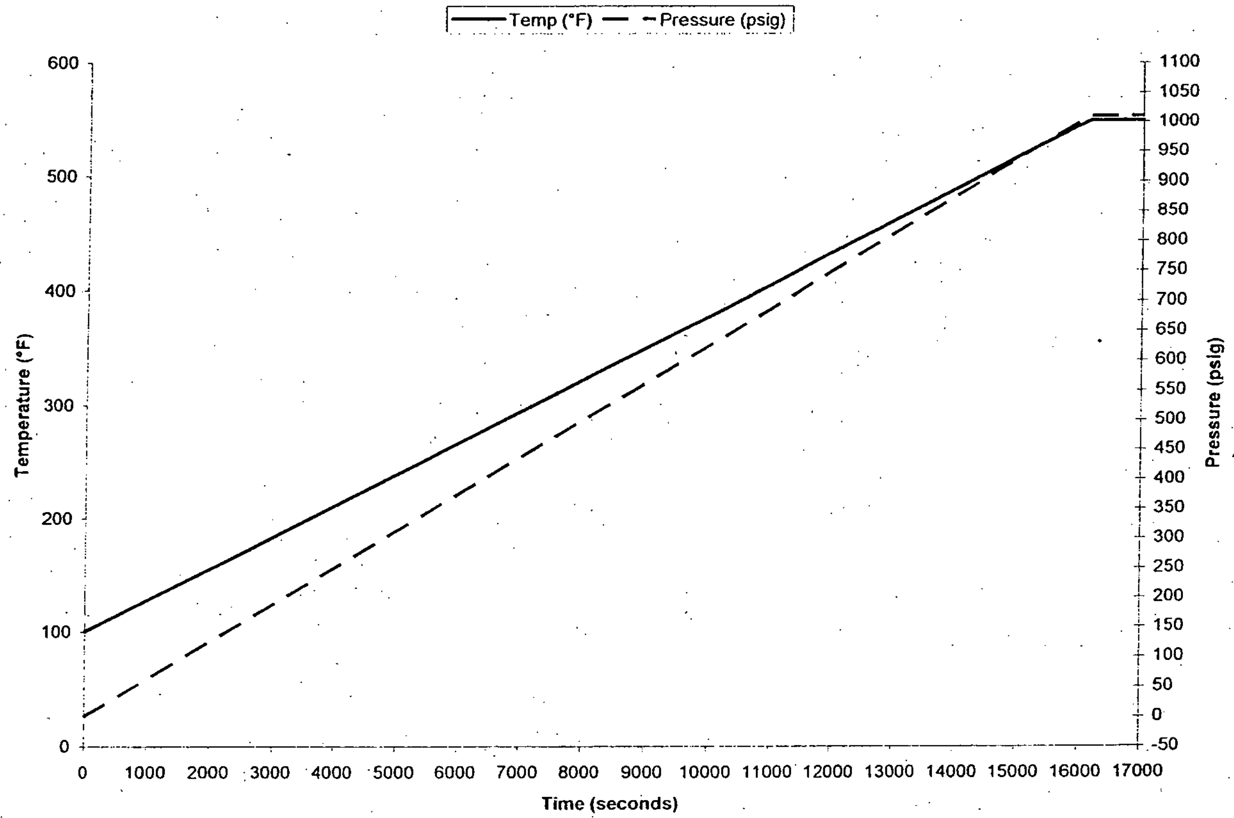



**Figure 3-11: Transient 03: Startup**

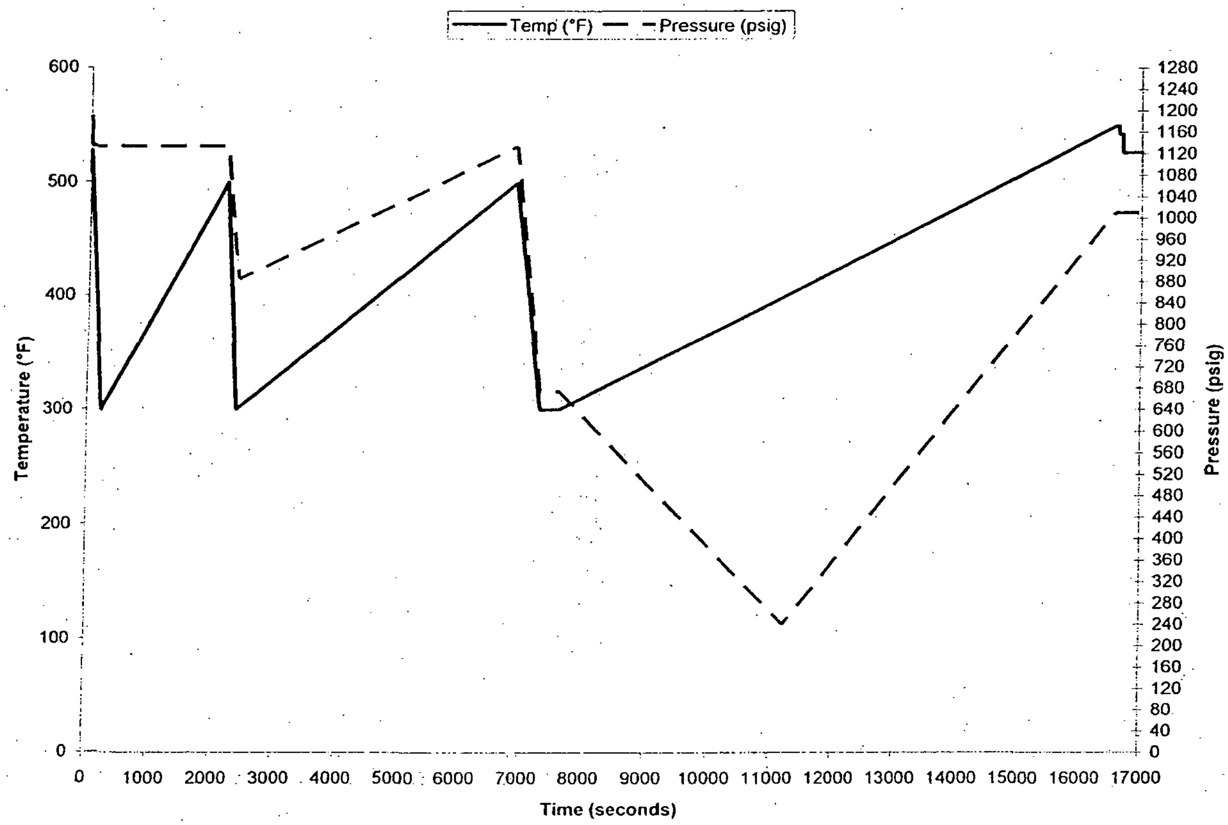



**Figure 3-12: Transient 11: Loss of Feedwater Pumps, Isolation Valves Close**

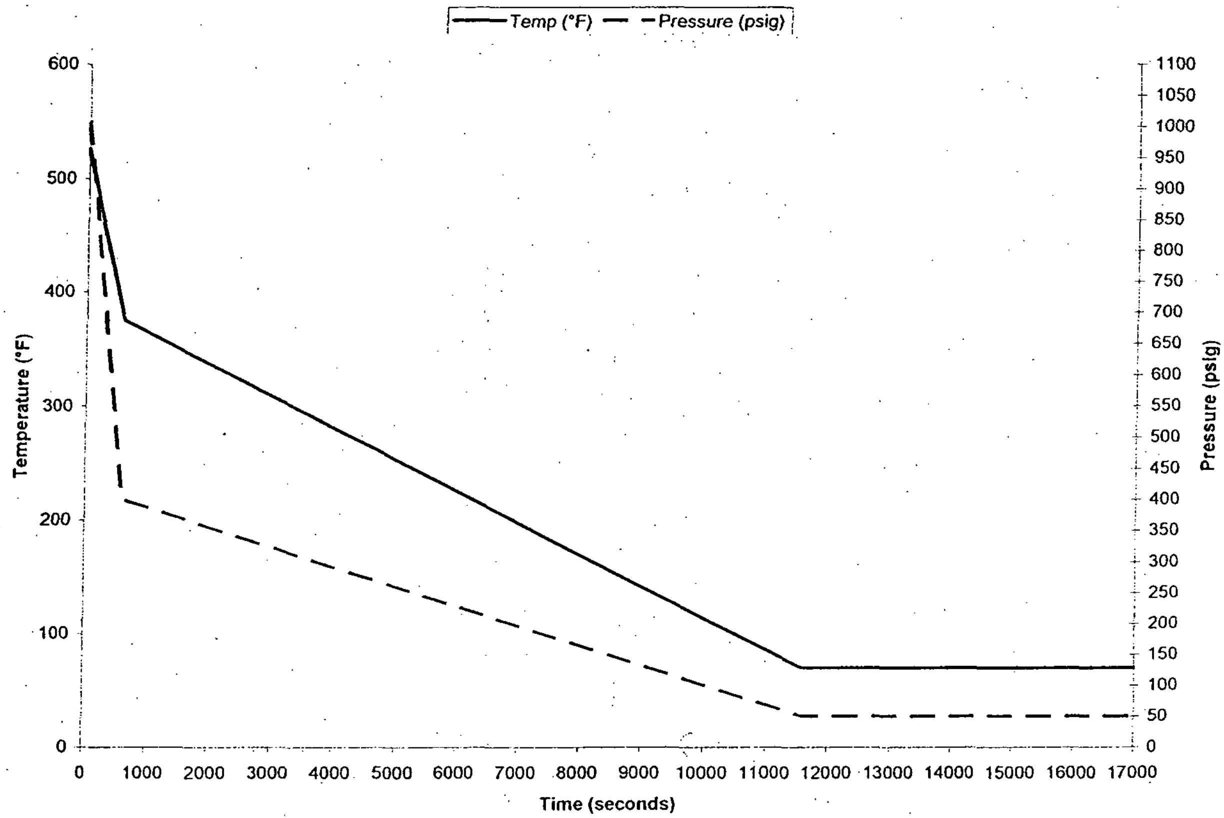



**Figure 3-13: Transient 14: Single Relief of Safety Valve Blow Down**

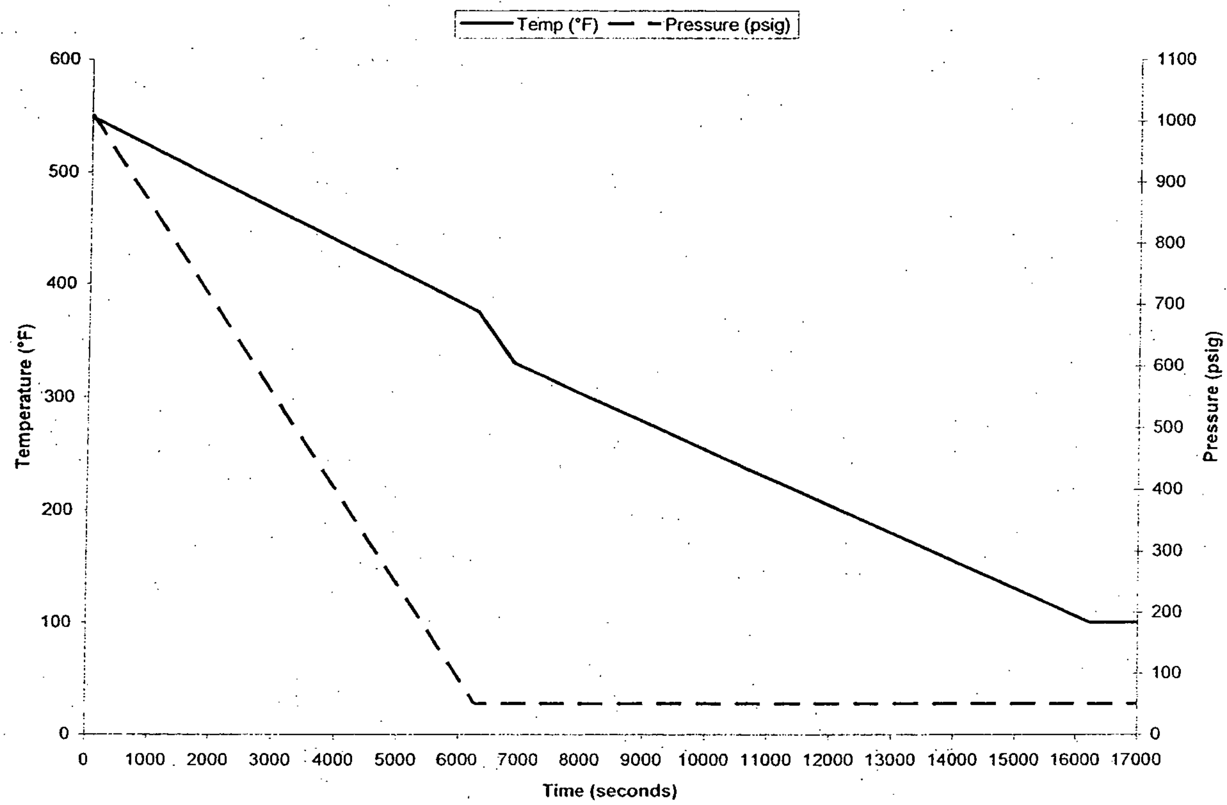



**Figure 3-14: Transient 21-23: Shutdown Vessel Flooding**

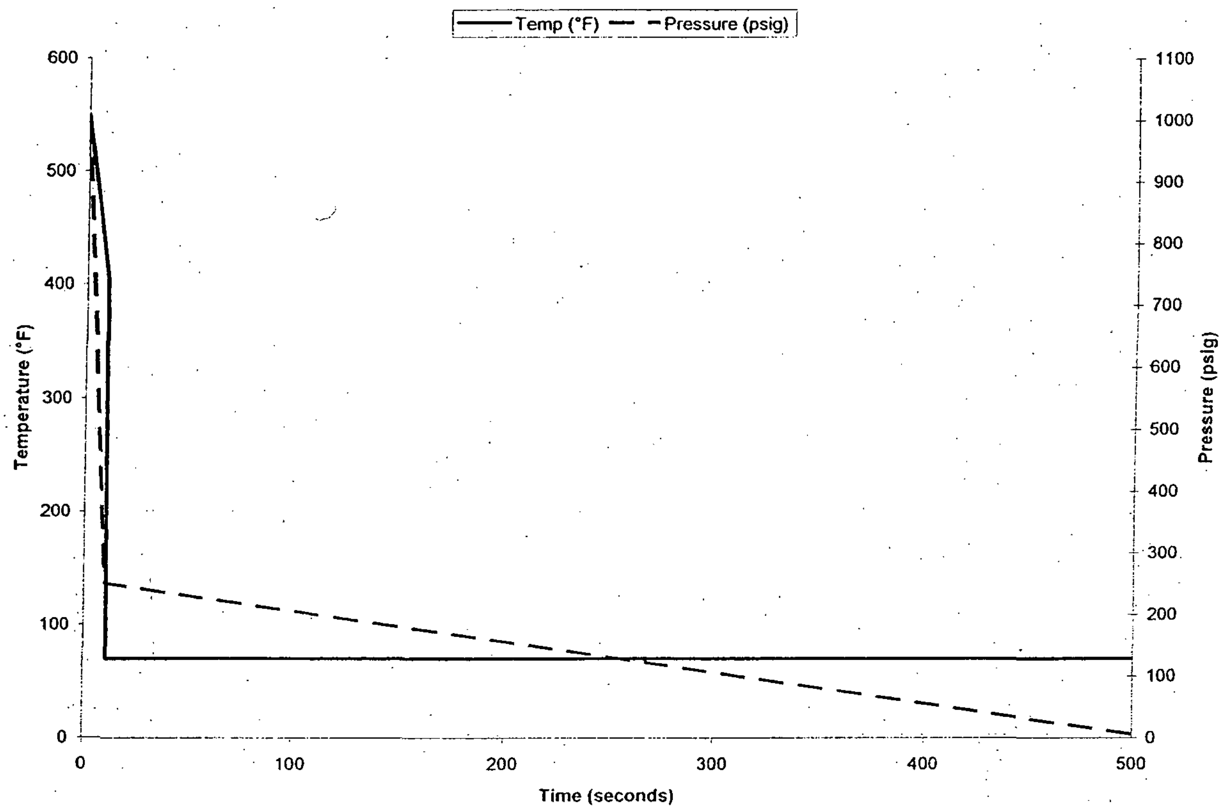



**Figure 3-15: Transient 30: Emergency Shutdown 100% Flow (Safe End)**

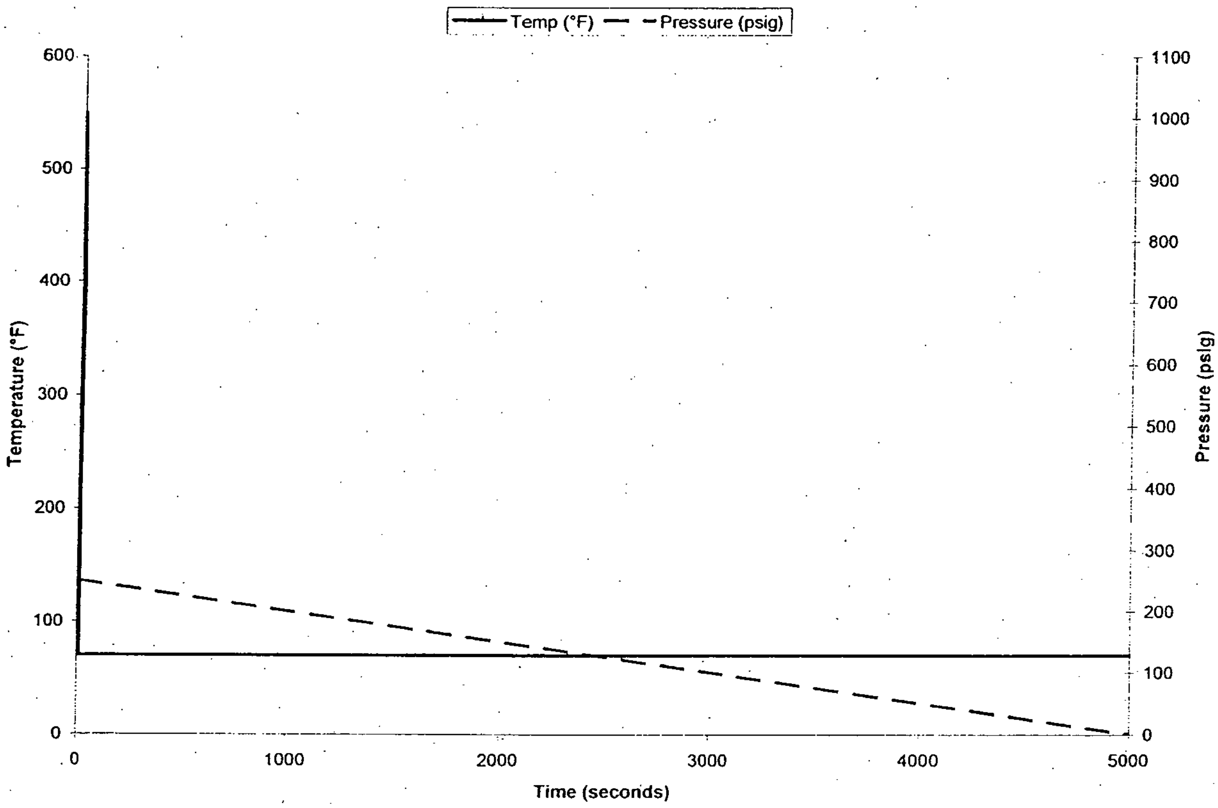



**Figure 3-16: Transient 30: Emergency Shut Down 100% Flow (Blend Radius)**

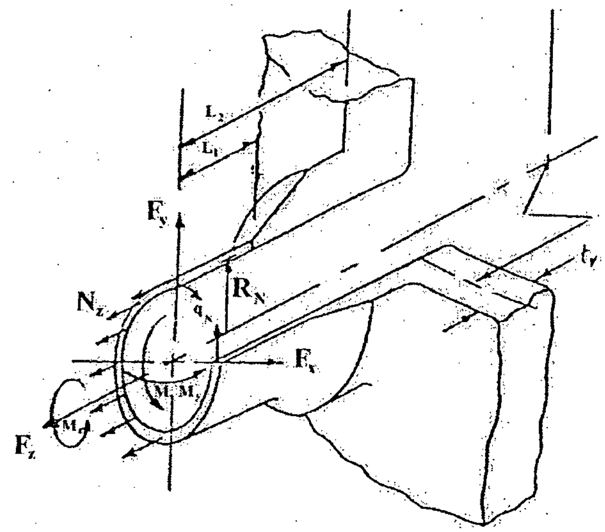



**Figure 3-17: Pipe Reactions**

## 4.0 STRESS AND FATIGUE ANALYSIS RESULTS

Fatigue calculations for the VY core spray nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [16]. Fatigue analysis was performed in the Reference [10] calculation for the two locations identified in Section 3.1.2, using the Green's Functions developed for these two locations and the 60-year projected cycle counts from Reference [13].

Three computer programs were used to facilitate the fatigue analysis process: STRESS.EXE, P-V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III methodology. All three programs are explained in detail and were independently verified for use in the Reference [15] calculation.

In order to perform the fatigue analysis, input files with the necessary data were prepared and the three analysis programs were run. The program STRESS.EXE required the following three input files:

- **Green.dat**: This file contains the Green's Function. As discussed above, the core spray nozzle analyses utilize four Green's Functions: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function for both the safe end and blend radius locations.
- **Green.cfg**: A configuration file containing parameters that describe the Green's Function.
- **Transnt.inp:** This file contains the input transient history defined in Tables 3-2 and 3-3.

Tables 4-1 and 4-2 show the stresses for each location that were used in the fatigue analysis. Columns 2 through 5 of Table 4-1 (for the safe end) and Table 4-2 (for the blend radius) show the final peak and valley output. The pressure values for Column 6 in each table were determined from the transient pressures, specified in Tables 3-2 and 3-3. The pressure stress intensities from Section 3.2 were scaled appropriately for each transient case. The scaled piping stress values are shown in columns 9 and 10 of Tables 4-1 and 4-2. The piping stress intensities from Section 3.3 were scaled based on the transient case RPV fluid temperature and assuming no stress occurs at an ambient temperature of 70°F. Both of these stress intensities were then added to the thermal stress intensity peak and valley points to calculate the final stress values used for the fatigue analysis. In the case of the piping load stress intensities, the sign of the stress intensity was conservatively set to the same sign as the thermal stress intensity to ensure bounding fatigue usage results. Columns 11 and 12 of Tables 4-1 and 4-2 show the summation of all stresses for each thermal peak and valley stress point. The last column shows the number of cycles associated with each peak or valley based on the cycle counts shown in Tables 3-2 and 3-3.

The program FATIGUE.EXE performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data for the configuration input file for FATIGUE.EXE, which is named FATIGUE.CFG, is shown in Table 4-3.

The core spray piping adjacent to the safe end was also analyzed because of its proximity to the maximum safe end thermal stress location. For this fatigue analysis, the stress results of the safe end were used with stainless steel material properties and a value of 1.8 was selected for $K_t$ at the weld location, based on the maximum value given in ASME Code, Section III, Table NB-3681(a)-1 [16].

The results of the fatigue analysis are presented in Tables 4-4, 4-5 and 4-6 for the safe end, blend radius, and piping for 60 years, respectively.

## Table 4-1: Core Spray Nozzle Safe End Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| 2 | | | | 100 | 0 | 0 | 0 | 413 | 413 | 413 | 413 | 120 |
| | | | | 100 | 1100 | 13233 | 13222 | 413 | 413 | 13646 | 13635 | 120 |
| | | | | 100 | 50 | 602 | 601 | 413 | 413 | 1014 | 1014 | 120 |
| 3 | 0 | 661 | 759 | 100 | 0 | 0 | 0 | 413 | 413 | 1074 | 1172 | 300 |
| | 17164 | 9240 | 10700 | 549 | 1010 | 12150 | 12140 | 6592 | 6592 | 27982 | 29432 | 300 |
| 11 | 0 | 8802 | 10236 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 27228 | 28652 | 10 |
| | 3 | 8802 | 10236 | 526 | 1190 | 14316 | 14304 | 6276 | 6276 | 29393 | 30815 | 10 |
| | 13 | 8802 | 10236 | 526 | 1135 | 13654 | 13643 | 6276 | 6276 | 28732 | 30154 | 10 |
| | 164 | 11645 | 11598 | 408 | 1135 | 13654 | 13643 | 4657 | 4657 | 29956 | 29898 | 10 |
| | 672 | 4808 | 5791 | 344 | 1135 | 13654 | 13643 | 3775 | 3775 | 22237 | 23209 | 10 |
| | 2374 | 11140 | 10841 | 361 | 912 | 10971 | 10962 | 4005 | 4005 | 26116 | 25808 | 10 |
| | 2955 | 4722 | 5577 | 325 | 916 | 11019 | 11010 | 3509 | 3509 | 19250 | 20096 | 10 |
| | 7054 | 9518 | 10162 | 441 | 959 | 11537 | 11527 | 5100 | 5100 | 26155 | 26789 | 10 |
| | 7930 | 4491 | 5276 | 309 | 637 | 7663 | 7657 | 3287 | 3287 | 15441 | 16219 | 10 |
| | 16709 | 9960 | 11116 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 28386 | 29532 | 10 |
| | 17699 | 8802 | 10236 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 27228 | 28652 | 10 |
| 14 | 0 | 8802 | 10236 | 526 | 1010 | 12150 | 12140 | 6276 | 6276 | 27228 | 28652 | 1 |
| | 152 | 9499 | 10570 | 497 | 855 | 10286 | 10277 | 5880 | 5880 | 25664 | 26727 | 1 |
| | 12580 | 91 | 95 | 70 | 50 | 602 | 601 | 0 | 0 | 693 | 696 | 1 |
| 21-23 | 0 | 9242 | 0 | 549 | 1010 | 12150 | 12140 | 6592 | 6592 | 27984 | 18732 | 300 |
| | 17224 | 664 | 0 | 100 | 50 | 602 | 601 | 413 | 413 | 1678 | 1014 | 300 |
| 24 | | | | 100 | 50 | 602 | 601 | 413 | 413 | 1014 | 1014 | 1 |
| | | | | 100 | 1563 | 18803 | 18787 | 413 | 413 | 19216 | 19200 | 1 |
| | | | | 100 | 50 | 602 | 601 | 413 | 413 | 1014 | 1014 | 1 |
| 30 | 0 | 9280 | 10800 | 549 | 1010 | 12150 | 12140 | 6592 | 6592 | 28022 | 29532 | 1 |
| | 13 | 85600 | 44694 | 162 | 250 | 3002 | 3000 | 1260 | 1260 | 89862 | 48953 | 1 |
| | 1011 | -12 | -10 | 70 | 0 | 0 | 0 | 0 | 0 | -12 | -10 | 1 |

NOTES:
- Column 1: Transient number identification.
- Column 2: Time during transient where a maximum or minimum stress intensity occurs from P-V.OUT output file.
- Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
- Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
- Column 5: Temperature per total stress intensity.
- Column 6: Pressure per Table 3-4.
- Column 7: Total pressure stress intensity from the quantity (Column 6 x 12,030)/1000.
- Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 12,020)/1000.
- Column 9: Calculated using the total external stress from Table 3-4 as 6949.94 psi*(Column 5-70°F)/(575°F -70°F).
- Column 10: Same as Column 9, but for M+B stress.
- Column 11: Sum of total stresses (Columns 3, 7, and 9).
- Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
- Column 13: Number of cycles for the transient (60 years).

## Table 4-2: Core Spray Nozzle Blend Radius Stress Summary

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transient Number | Time (s) | Total Stress (psi) | M+B Stress (psi) | Temperature F | Pressure (psig) | Total Pressure Stress (psi) | M+B Pressure Stress (psi) | Total Piping Stress (psi) | M+B Piping Stress (psi) | Total Total Stress (psi) | Total M+B Stress (psi) | Number of Cycles (60 years) |
| *2* | | | | 100 | 0 | 0 | 0 | 19 | 19 | 19 | 19 | 120 |
| | | | | 100 | 1100 | 39446 | 38467 | 19 | 19 | 39465 | 38486 | 120 |
| | | | | 100 | 50 | 1793 | 1749 | 19 | 19 | 1812 | 1768 | 120 |
| *3* | 0 | 23700 | 12600 | 100 | 0 | 0 | 0 | 19 | 19 | 23719 | 12619 | 300 |
| | 24164 | 2100 | 3180 | 549 | 1010 | 36219 | 35320 | 306 | 306 | 38625 | 38806 | 300 |
| *11* | 0 | 3209 | 3644 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39719 | 39255 | 10 |
| | 3 | 3209 | 3644 | 526 | 1190 | 42673 | 41614 | 291 | 291 | 46174 | 45550 | 10 |
| | 526 | 10458 | 5374 | 330 | 1135 | 40701 | 39691 | 166 | 166 | 51325 | 45231 | 10 |
| | 2222 | 5488 | 1664 | 490 | 1122 | 40235 | 39236 | 268 | 268 | 45991 | 41168 | 10 |
| | 2860 | 11776 | 7444 | 321 | 911 | 32668 | 31858 | 160 | 160 | 44605 | 39462 | 10 |
| | 6903 | 5435 | 3621 | 495 | 1124 | 40307 | 39306 | 272 | 272 | 46013 | 43199 | 10 |
| | 8012 | 12577 | 6791 | 390 | 627 | 22484 | 21926 | 204 | 204 | 35265 | 28921 | 10 |
| | 16640 | 2772 | 4370 | 542 | 1010 | 36219 | 35320 | 301 | 301 | 39292 | 39991 | 10 |
| | 16991 | 3389 | 4115 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39899 | 39726 | 10 |
| | 24699 | 3209 | 3644 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39719 | 39255 | 10 |
| *14* | 0 | 3209 | 3644 | 526 | 1010 | 36219 | 35320 | 291 | 291 | 39719 | 39255 | 1 |
| | 19580 | 25122 | 13197 | 70 | 50 | 1793 | 1749 | 0 | 0 | 26915 | 14946 | 1 |
| *21-23* | 0 | 2103 | 3161 | 549 | 1010 | 36219 | 35320 | 306 | 306 | 38628 | 38787 | 300 |
| | 24224 | 23680 | 12568 | 100 | 50 | 1793 | 1749 | 19 | 19 | 25492 | 14336 | 300 |
| *24* | | | | 100 | 50 | 1793 | 1749 | 19 | 19 | 1812 | 1768 | 1 |
| | | | | 100 | 1563 | 56049 | 54658 | 19 | 19 | 56068 | 54677 | 1 |
| | | | | 100 | 50 | 1793 | 1749 | 19 | 19 | 1812 | 1768 | 1 |
| *30* | 0 | 2040 | 2950 | 549 | 1010 | 36219 | 35320 | 306 | 306 | 38565 | 38576 | 1 |
| | 8011 | 25700 | 14900 | 70 | 0 | 0 | 0 | 0 | 0 | 25700 | 14900 | 1 |

NOTES:
- Column 1: Transient number identification.
- Column 2: Time during transient where a maximum or minimum stress intensity occurs from P-V.OUT output file.
- Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
- Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
- Column 5: Temperature per total stress intensity.
- Column 6: Pressure per Table 3-5.
- Column 7: Total pressure stress intensity from the quantity (Column 6 x 35,860)/1000.
- Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 34,970)/1000.
- Column 9: Calculated using the total external stress from Table 3-5 as 322.52 psi*(Column 5-70°F)/(575°F -70°F).
- Column 10: Same as Column 9, but for M+B stress.
- Column 11: Sum of total stresses (Columns 3, 7, and 9).
- Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
- Column 13: Number of cycles for the transient (60 years).

**Table 4-3: Fatigue Parameters Used in the Core Spray Nozzle Fatigue Analysis**

| | Blend Radius (SA508 Class II) | Safe End (N06600) | Piping (Stainless Steel) |
|---|---|---|---|
| Parameters $m$ and $n$ for Computing $K_e$ | 2.0 & 0.2 (low alloy steel) | 1.7 & 0.3 | 1.7 & 0.3 |
| Design Stress Intensity Values, $S_m$ | 26,700 psi @ 600°F | 23,300 psi @ 600°F | 17,000 psi @ 600°F |
| Elastic Modulus from Applicable Fatigue Curve | $30.0 \times 10^6$ psi | $28.3 \times 10^6$ psi | $28.3 \times 10^6$ psi |
| Elastic Modulus Used in Finite Element Model (300°F) | $26.7 \times 10^6$ psi | $29.8 \times 10^6$ psi | $27.0 \times 10^6$ psi |
| The Geometric Stress Concentration Factor $K_t$ | 1.0 | 4.0 See Note 1 | 1.8 |

Note: 1. Conservative bounding value per ASME Code, Subsection NB-3600 to conservatively cover adjacent thread and weld regions.

## Table 4-4: Fatigue Results for Core Spray Nozzle Safe End

```
        LOCATION = LOCATION NO. 1 -- SAFE END
   FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
               m = 1.7
               n =  .3
              Sm = 23300. psi
          Ecurve = 2.830E+07 psi
       Eanalysis = 2.980E+07 psi
              Kt = 4.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 89862. | -12. | 89874. | 48963. | 1.000 | 112423. | 1.000E+00 | 1.213E+03 | .0008 |
| 29956. | 413. | 29543. | 29485. | 1.000 | 56029. | 1.000E+01 | 1.910E+04 | .0005 |
| 29393. | 413. | 28980. | 30402. | 1.000 | 57068. | 1.000E+01 | 1.746E+04 | .0006 |
| 28732. | 413. | 28319. | 29741. | 1.000 | 55813. | 1.000E+01 | 1.946E+04 | .0005 |
| 28386. | 413. | 27973. | 29119. | 1.000 | 54762. | 1.000E+01 | 2.140E+04 | .0005 |
| 28022. | 413. | 27609. | 29119. | 1.000 | 54590. | 1.000E+00 | 2.174E+04 | .0000 |
| 27984. | 413. | 27571. | 18319. | 1.000 | 39187. | 7.900E+01 | 1.244E+05 | .0006 |
| 27984. | 693. | 27291. | 18036. | 1.000 | 38651. | 1.000E+00 | 1.341E+05 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 38045. | 1.200E+02 | 1.460E+05 | .0008 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 38045. | 1.000E+00 | 1.460E+05 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 38045. | 1.000E+00 | 1.460E+05 | .0000 |
| 27984. | 1074. | 26910. | 17560. | 1.000 | 37792. | 9.800E+01 | 1.514E+05 | .0006 |
| 27982. | 1074. | 26908. | 28260. | 1.000 | 53033. | 2.020E+02 | 2.517E+04 | .0080 |
| 27982. | 1678. | 26304. | 28418. | 1.000 | 52971. | 9.800E+01 | 2.532E+04 | .0039 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 51502. | 1.000E+01 | 2.919E+04 | .0003 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 51502. | 1.000E+01 | 2.919E+04 | .0003 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 51502. | 1.000E+00 | 2.919E+04 | .0000 |
| 26155. | 1678. | 24477. | 25775. | 1.000 | 48339. | 1.000E+01 | 4.021E+04 | .0002 |
| 26116. | 1678. | 24438. | 24794. | 1.000 | 46923. | 1.000E+01 | 4.673E+04 | .0002 |
| 25664. | 1678. | 23986. | 25713. | 1.000 | 48017. | 1.000E+00 | 4.159E+04 | .0000 |
| 22237. | 1678. | 20559. | 22195. | 1.000 | 41379. | 1.000E+01 | 9.257E+04 | .0001 |
| 19250. | 1678. | 17572. | 19082. | 1.000 | 35526. | 1.000E+01 | 2.135E+05 | .0000 |
| 19216. | 1678. | 17538. | 18186. | 1.000 | 34234. | 1.000E+00 | 2.691E+05 | .0000 |
| 15441. | 1678. | 13763. | 15205. | 1.000 | 28195. | 1.000E+01 | 1.001E+06 | .0000 |
| 13646. | 1678. | 11968. | 12621. | 1.000 | 23661. | 1.200E+02 | 1.772E+06 | .0001 |

TOTAL USAGE FACTOR = .0184

## Table 4-5: Fatigue Results for the Core Spray Nozzle Blend Radius

```
      LOCATION = LOCATION NO. 2 -- BLEND RADIUS
 FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 2.0
             n =  .2
            Sm = 26700. psi
        Ecurve = 3.000E+07 psi
     Eanalysis = 2.670E+07 psi
            Kt = 1.00
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 56068. | 19. | 56049. | 54658. | 1.000 | 31488. | 1.000E+00 | 1.896E+04 | .0001 |
| 51325. | 19. | 51306. | 45212. | 1.000 | 28824. | 1.000E+01 | 2.501E+04 | .0004 |
| 46174. | 19. | 46155. | 45531. | 1.000 | 25930. | 1.000E+01 | 3.460E+04 | .0003 |
| 46013. | 19. | 45994. | 43180. | 1.000 | 25839. | 1.000E+01 | 3.498E+04 | .0003 |
| 45991. | 19. | 45972. | 41149. | 1.000 | 25827. | 1.000E+01 | 3.503E+04 | .0003 |
| 44605. | 19. | 44586. | 39443. | 1.000 | 25048. | 1.000E+01 | 3.848E+04 | .0003 |
| 39899. | 19. | 39880. | 39707. | 1.000 | 22404. | 1.000E+01 | 5.695E+04 | .0002 |
| 39719. | 19. | 39700. | 39236. | 1.000 | 22303. | 1.000E+01 | 5.824E+04 | .0002 |
| 39719. | 19. | 39700. | 39236. | 1.000 | 22303. | 1.000E+01 | 5.824E+04 | .0002 |
| 39719. | 19. | 39700. | 39236. | 1.000 | 22303. | 1.000E+00 | 5.824E+04 | .0000 |
| 39465. | 19. | 39446. | 38467. | 1.000 | 22161. | 3.800E+01 | 6.012E+04 | .0006 |
| 39465. | 1812. | 37653. | 36718. | 1.000 | 21153. | 8.200E+01 | 7.572E+04 | .0011 |
| 39292. | 1812. | 37480. | 38223. | 1.000 | 21056. | 1.000E+01 | 7.747E+04 | .0001 |
| 38628. | 1812. | 36816. | 37019. | 1.000 | 20683. | 2.800E+01 | 8.466E+04 | .0003 |
| 38628. | 1812. | 36816. | 37019. | 1.000 | 20683. | 1.000E+00 | 8.466E+04 | .0000 |
| 38628. | 1812. | 36816. | 37019. | 1.000 | 20683. | 1.000E+00 | 8.466E+04 | .0000 |
| 38628. | 23719. | 14909. | 26168. | 1.000 | 8376. | 2.700E+02 | 5.366E+07 | .0000 |
| 38625. | 23719. | 14906. | 26187. | 1.000 | 8374. | 3.000E+01 | 5.375E+07 | .0000 |
| 38625. | 25492. | 13133. | 24470. | 1.000 | 7378. | 2.700E+02 | 3.042E+08 | .0000 |
| 38565. | 25492. | 13073. | 24240. | 1.000 | 7344. | 1.000E+00 | 3.374E+08 | .0000 |
| 35265. | 25492. | 9773. | 14585. | 1.000 | 5490. | 1.000E+01 | 1.000E+20 | .0000 |
| 26915. | 25492. | 1423. | 610. | 1.000 | 799. | 1.000E+00 | 1.000E+20 | .0000 |
| 25700. | 25492. | 208. | 564. | 1.000 | 117. | 1.000E+00 | 1.000E+20 | .0000 |
| | | | | | | | TOTAL USAGE FACTOR = | .0043 |

## Table 4-6: Fatigue Results for the Core Spray Stainless Steel Piping

```
      LOCATION = LOCATION NO. 1 -- SS Piping
 FATIGUE CURVE = 2 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
             m = 1.7
             n = .3
            Sm = 17000. psi
        Ecurve = 2.830E+07 psi
     Eanalysis = 2.700E+07 psi
            Kt = 1.80
```

| MAX | MIN | RANGE | MEM+BEND | Ke | Salt | Napplied | Nallowed | U |
|---|---|---|---|---|---|---|---|---|
| 89862. | -12. | 89874. | 48963. | 1.000 | 67629. | 1.000E+00 | 8.006E+03 | .0001 |
| 29956. | 413. | 29543. | 29485. | 1.000 | 27845. | 1.000E+01 | 1.042E+06 | .0000 |
| 29393. | 413. | 28980. | 30402. | 1.000 | 27934. | 1.000E+01 | 1.031E+06 | .0000 |
| 28732. | 413. | 28319. | 29741. | 1.000 | 27310. | 1.000E+01 | 1.110E+06 | .0000 |
| 28386. | 413. | 27973. | 29119. | 1.000 | 26868. | 1.000E+01 | 1.171E+06 | .0000 |
| 28022. | 413. | 27609. | 29119. | 1.000 | 26678. | 1.000E+00 | 1.198E+06 | .0000 |
| 27984. | 413. | 27571. | 18319. | 1.000 | 22130. | 7.900E+01 | 2.272E+06 | .0000 |
| 27984. | 693. | 27291. | 18036. | 1.000 | 21864. | 1.000E+00 | 2.392E+06 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 21563. | 1.200E+02 | 2.539E+06 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 21563. | 1.000E+00 | 2.539E+06 | .0000 |
| 27984. | 1014. | 26970. | 17718. | 1.000 | 21563. | 1.000E+00 | 2.539E+06 | .0000 |
| 27984. | 1074. | 26910. | 17560. | 1.000 | 21465. | 9.800E+01 | 2.588E+06 | .0000 |
| 27982. | 1074. | 26908. | 28260. | 1.000 | 25950. | 2.020E+02 | 1.311E+06 | .0002 |
| 27982. | 1678. | 26304. | 28418. | 1.000 | 25700. | 9.800E+01 | 1.354E+06 | .0001 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 24978. | 1.000E+01 | 1.485E+06 | .0000 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 24978. | 1.000E+01 | 1.485E+06 | .0000 |
| 27228. | 1678. | 25550. | 27638. | 1.000 | 24978. | 1.000E+00 | 1.485E+06 | .0000 |
| 26155. | 1678. | 24477. | 25775. | 1.000 | 23634. | 1.000E+01 | 1.779E+06 | .0000 |
| 26116. | 1678. | 24438. | 24794. | 1.000 | 23202. | 1.000E+01 | 1.889E+06 | .0000 |
| 25664. | 1678. | 23986. | 25713. | 1.000 | 23351. | 1.000E+00 | 1.850E+06 | .0000 |
| 22237. | 1678. | 20559. | 22195. | 1.000 | 20080. | 1.000E+01 | 3.442E+06 | .0000 |
| 19250. | 1678. | 17572. | 19082. | 1.000 | 17209. | 1.000E+01 | 7.481E+06 | .0000 |
| 19216. | 1678. | 17538. | 18186. | 1.000 | 16816. | 1.000E+00 | 8.600E+06 | .0000 |
| 15441. | 1678. | 13763. | 15205. | 1.000 | 13588. | 1.000E+01 | 1.000E+20 | .0000 |
| 13646. | 1678. | 11968. | 12621. | 1.000 | 11564. | 1.200E+02 | 1.000E+20 | .0000 |
| | | | | | | | TOTAL USAGE FACTOR = | .0005 |

## 5.0 ENVIRONMENTAL FATIGUE ANALYSIS

Environmental fatigue multipliers were computed for both normal water chemistry (NWC) and hydrogen water chemistry (HWC) conditions in Reference [17] for various regions of the VY RPV and attached piping. Based on VY-specific dates for plant startup and HWC implementation, as well as past and future predicted HWC system availability, it was determined that overall HWC availability is 47% over the sixty year operating period for VY. Therefore, for the purposes of the EAF assessment of the core spray nozzle, it was assumed that HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time over the 60-year operating life of the plant. RPV upper region chemistry was assumed for both the core spray nozzle safe end and blend radius locations, since both locations experience reactor conditions for all times except during core spray injections, (which are rare occurrences).

For the safe end location, the environmental fatigue factors for pre-HWC and post-HWC are both 1.49 from Reference [18]. This results in an EAF adjusted CUF as follows:

60-Year CUF, $U_{60} = 0.0184$ (from Table 4-4)
Overall EAF multiplier, $F_{en} = 1.49$
60-Year EAF CUF, $U_{60\text{-evn}} = 0.0184 \times 1.49 = 0.0274$

The EAF CUF value of 0.0274 for 60 years for the safe end is acceptable (i.e., less than the allowable value of 1.0).

For the stainless steel piping, the environmental fatigue factors for pre-HWC and post-HWC are both 8.36 from Table 4 of Reference [17] for the RPV upper region. This results in an EAF adjusted CUF as follows:

60-Year CUF, $U_{60} = 0.0005$ (from Table 4-6)
Overall EAF multiplier, $F_{en} = 8.36$
60-Year EAF CUF, $U_{60\text{-evn}} = 0.0005 \times 8.36 = 0.0042$

The EAF CUF value of 0.0042 for 60 years for the blend radius is acceptable (i.e., less than the allowable value of 1.0).

The fatigue calculation documented in Section 4.0 for the blend radius location was performed for the nozzle base material, since cladding is structurally neglected in modern-day fatigue analyses, per ASME Code, Section III, NB-3122.3 [16]. This is also consistent with Sections 5.7.1 and 5.7.4 of NUREG/CR-6260 [1]. Therefore, the cladding was neglected and EAF assessment of the nozzle base material was performed for the blend radius location.

For the blend radius location, the environmental fatigue factors for pre-HWC and post-HWC are 11.14 and 8.82, respectively, from Table 4 of Reference [17] for the RPV upper region. This results in an EAF adjusted CUF as follows:

60-Year CUF, $U_{60}$ = 0.0043 (from Table 4-5)
Overall EAF multiplier, $F_{en}$ = (11.14 x 53% + 8.82 x 47%) = 10.05
60-Year EAF CUF, $U_{60\text{-}evn}$ = 0.0043 x 10.05 = 0.0432

The EAF CUF value of 0.0432 for 60 years for the blend radius is acceptable (i.e., less than the allowable value of 1.0).

## 6.0 CONCLUSIONS

This report documents a refined fatigue evaluation for the VY core spray nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the core spray nozzle, safe end, and piping are included in the evaluation, to be consistent with NUREG/CR-6260 [1] needs for EAF evaluation for license renewal. The final fatigue results are considered to be a replacement to the values previously reported in the VY LRA.

The fatigue calculations for the VY core spray nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [16]. The stress evaluation is summarized in Section 3.0, and the fatigue analysis is summarized in Section 4.0. The results in Section 4.0 reveal that the CUF for the limiting safe end location is 0.0184, the CUF for the limiting blend radius location is 0.0043, and the CUF for the stainless steel piping is 0.0005. All of these values represent 60 years of plant operation, including all relevant EPU effects.

EAF calculations for the VY core spray nozzle were also performed, as summarized in Section 5.0. The results in Section 5.0 reveal that the EAF CUF for the limiting safe end location is 0.0274, the EAF CUF for the limiting blend radius location is 0.0432, and the EAF CUF for the stainless steel piping is 0.0042. All of these values represent 60 years of plant operation, including all relevant EPU effects.

All fatigue allowables, both with and without EAF effects, are met, thus demonstrating acceptability for 60 years of operation.

## 7.0 REFERENCES


1. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

2. Structural Integrity Associates Report No. SIR-86-037, Revision 0, "Evaluation of Modifications to Vermont Yankee Core Spray Nozzle and Safe End," January 1987, SI Project No. YAEC-08.

3. GE Design Specification No. 21A1115, Revision 4, "Vermont Yankee Reactor Pressure Vessel," October 21, 1969, SI File No. VY-05Q-210.

4. GE Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," August 29, 2003, SI File No. VY-05Q-236.

5. Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green's Functions," ASME PVP Conference, Chicago, 1986.

6. ANSYS, Release 8.1A1 (w/Service Pack 1), ANSYS, Inc., June 2004.

7. Structural Integrity Associates Calculation No. VY-16Q-308, Revision 0, "Core Spray Nozzle Finite Element Model."

8. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, <u>Materials</u>, Part D, "Properties (Customary)," 1998 Edition, 2000 Addenda.

9. Structural Integrity Associates Calculation No. VY-16Q-309, Revision 0, "Core Spray Nozzle Green's Functions."

10. Structural Integrity Associates Calculation No. VY-16Q-310, Revision 0, "Fatigue Analysis of Core Spray Nozzle."

11. Reactor Thermal Cycles, Attachment 1 of Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Rev. 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/07, SI File No. VY-16Q-209.

12. Nozzle Thermal Cycles (Drain, Core Spray & Head Spray), Attachment 1 of Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Rev. 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/07, SI File No. VY-16Q-209.

13. Reactor Thermal Cycles for 60 Years of Operation, Attachment 1 of Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Rev. 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/07, SI File No. VY-16Q-209.

14. Vermont Yankee Drawing 5920-00024, Rev. 11, (GE Drawing No. 919D294, Sheet No. 7), "Reactor Vessel," SI File No. VY-05Q-241.

15. Structural Integrity Associates Calculation No. SW-SPVF-01Q-301, Revision 0, "STRESS.EXE, P-V.EXE, and FATIGUE.EXE Software Verification."

16. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, 1998 Edition, 2000 Addenda.

17. Structural Integrity Associates Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head."

18. EPRI Report No. TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," December 1995.

**NEC-JH_18**

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# Summary Report of Plant-Specific Environmental Fatigue Analyses for the Vermont Yankee Nuclear Power Station

*Prepared for:*
Entergy Nuclear Operations. Inc.
*(Contract Order No. 10150394)*

*Prepared by:*
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Table of Contents

## LIST OF TABLES

## 1.0 INTRODUCTION

This report provides the results of plant-specific environmental fatigue calculations for the Vermont Yankee Nuclear Power Station (VYNPS). These calculations are performed to satisfy Nuclear Regulatory Commission (NRC) requirements for Entergy Nuclear Vermont Yankee's (ENVY's) License Renewal Application for VYNPS, submitted to the NRC in 2006.

Generic Safety Issue (GSI) 166 [1], later renumbered as GSI-190 [2], was identified by the NRC staff because of concerns about the effects of reactor water environments on fatigue life during the period of extended operation [3]. GSI-190 was closed in December 1999, based on a memorandum from NRC-RES to NRC-NRR [4]. Timing of issue closure required the first two license renewal applicants – Baltimore Gas & Electric Company for the Calvert Cliffs Nuclear Power Plant and Duke Energy for the Oconee Nuclear Station – to address GSI-190 in their applications prior to issue closure. Each of the applicants developed responses to the NRC staff without the benefit of information from GSI-190 closure. Subsequent license renewal applicants have had the benefit of this information that could be used to guide the resolution of the fatigue design basis and time limited aging analyses (TLAA) issues.

This report addresses VYNPS reactor water environmental effects on the fatigue life of selected fatigue-sensitive reactor coolant system (RCS) components, in accordance with the resolution of GSI-190, as required by Chapter X, "Time Limited Aging Analyses Evaluation of Aging Management Programs Under 10CFR54.21(c)(1)(iii), Section X.M1 "Metal Fatigue of Reactor Coolant Pressure Boundary", of the Generic Aging Lessons Learned (GALL) Report [5]. Consistent with the requirements of the GALL report, the method chosen for this environmentally-assisted fatigue (EAF) evaluation is based on evaluation of the locations identified in NUREG/CR-6260 [6] and the NRC-accepted EAF relationships generated from laboratory data, as documented in References [7] and [8].

## 2.0 BACKGROUND

As a part of the NRC's Fatigue Action Plan [3], incorporation of environmental fatigue effects originally involved a reduced set of fatigue design curves, such as those proposed by Argonne National Laboratory (ANL) in NUREG/CR-5999 [9]. As a part of the effort to close GSI-166 (later GSI-190) for operating nuclear power plants during the current 40-year licensing term, Idaho National Engineering Laboratory (INEL) evaluated fatigue-sensitive component locations at plants designed by all four U. S. nuclear steam supply system (NSSS) vendors. The ANL fatigue curves were used by INEL to recalculate the cumulative usage factors (CUFs) for fatigue-sensitive component locations in early and late vintage Combustion Engineering (CE) pressurized water reactors (PWRs), early and late vintage Westinghouse PWRs, early and late vintage General Electric (GE) boiling water reactors (BWRs), and Babcock & Wilcox Company (B&W) PWRs. The results of the INEL calculations were published in NUREG/CR-6260 [6]. The INEL calculations took advantage of conservatisms present in governing ASME Code fatigue calculations, including the numbers of actual plant transients relative to the numbers of design-basis transients, but did not recalculate stress ranges based on actual plant transient profiles. The BWR calculations, especially the early-vintage GE BWR calculations, are directly relevant to VYNPS.

The fatigue-sensitive component locations chosen for the older-vintage GE BWR plant were: (1) the reactor vessel shell and lower head, (2) the reactor vessel feedwater nozzle, (3) the reactor recirculation piping (including the reactor inlet and outlet nozzles), (4) the core spray line reactor vessel nozzle and associated Class 1 piping, (5) the residual heat removal (RHR) return line Class 1 piping, and (6) the feedwater line Class 1 piping. For the recirculation, RHR, and feedwater piping locations, INEL performed representative design-basis fatigue calculations. This is because no CUF calculations had originally been performed since the piping systems for the selected BWR plant were initially designed and analyzed in accordance with the criteria of USAS B31.1-1967 [10].

The six RCS component locations described above are evaluated for EAF effects for VYNPS in this report through separate plant-specific analyses of nine VY component locations (with report section numbers indicated): the reactor pressure vessel (RPV) shell and lower head (3.1); the RPV shell at the shroud support junction (3.1); the feedwater nozzle (3.2); the recirculation / residual heat removal Class 1 piping (3.3.1 and 3.5); the recirculation inlet nozzle forging (3.3.2); the recirculation inlet nozzle safe end (3.3.2); the recirculation outlet nozzle forging (3.3.3); the core spray nozzle, safe end, and Class 1 piping (3.4); and the feedwater Class 1 piping (3.6).

The calculations reported in NUREG/CR-6260 were based on the interim reduced fatigue design curves given in NUREG/CR-5999 [9]. Such an approach penalizes the component location fatigue analysis unnecessarily, because research has shown that a combination of environmental conditions is required before reactor water environmental effects become pronounced. The strain rate must be sufficiently low and the strain range must be sufficiently high to cause continuing rupture of the passivation layer that protects the exposed surface area. Temperature, dissolved oxygen content, metal sulfur content, and water flow rate are additional variables to be considered. In order to take these parameters into consideration, EPRI and GE jointly developed a method, called the $F_{en}$ approach [11], which permits reactor water environmental effects to be applied selectively, as justified by parameter combinations.

In 1999, the NRC staff raised a number of issues relative to the use of the EPRI/GE methodology in various industry applications. Those issues, coupled with more recent laboratory fatigue data in simulated LWR reactor water environments generated by ANL for carbon and low-alloy steels and stainless steels, resulted in a revised $F_{en}$ methodology, as published in NUREG/CR-6583 [7] for carbon and low alloy steels, and NUREG/CR-5704 [8] for stainless steels. The methodology documented in these reports was used to evaluate environmental effects for VYNPS components, as described in Section 3.0 of this report.

## 3.0 ENVIRONMENTAL FATIGUE CALCULATIONS

Section 2.0 identifies the locations evaluated in NUREG/CR-6260 for the older vintage GE plant, which corresponds to VYNPS. NUREG/CR-6260 provided an assessment of these six selected component locations with respect to environmental fatigue using the older reduced environmental fatigue curves. Potential reactor water environmental effects are evaluated using the updated $F_{en}$ methodology on a plant-specific basis in this subsection, in order to address the associated effects on fatigue as required by the GALL Report [5].

For each of the components identified in Section 2.0, environmental fatigue calculations were performed. The details of these calculations are documented in the Reference [12, 17, 18, 21, 22 and 24] calculations. The calculations were carried out using the appropriate methodology contained in NUREG/CR-6583 for carbon/low alloy steel material, and in NUREG/CR-5704 for stainless steel material. This methodology is as follows:

*For Carbon Steel [7]:*

$$F_{en} = \exp(0.585 - 0.00124T' - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$
$$= \exp(0.554 - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$

*For Low Alloy Steel [7]:*

$$F_{en} = \exp(0.929 - 0.00124T' - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$
$$= \exp(0.898 - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$

*Note that the above expressions have been corrected as summarized in Reference [23].*

where:

| | | |
|---|---|---|
| $F_{en}$ | = | fatigue life correction factor |
| T' | = | 25°C (NUREG/CR-6583, Section 6, $F_{en}$ relative to air) |
| S* | = | S for 0 < sulfur content, S ≤ 0.015 wt. % |
| | = | 0.015 for S > 0.015 wt. % |
| T* | = | 0 for T < 150°C |
| | = | (T - 150) for 150 ≤ T ≤ 350°C |
| T | = | fluid service temperature (°C) |
| O* | = | 0 for dissolved oxygen, DO < 0.05 parts per million (ppm) |
| | = | ln(DO/0.04) for 0.05 ppm ≤ DO ≤ 0.5 ppm |
| | = | ln(12.5) for DO > 0.5 ppm |

$\dot{\varepsilon}^*$ = 0 for strain rate, $\dot{\varepsilon}$ > 1%/sec
= ln($\dot{\varepsilon}$) for 0.001 ≤ $\dot{\varepsilon}$ ≤ 1%/sec
= ln(0.001) for $\dot{\varepsilon}$ < 0.001%/sec

*For Types 304 and 316 Stainless Steel [8]*: $F_{en} = \exp(0.935 - T^* \dot{\varepsilon}^* O^*)$

where:
$F_{en}$ = fatigue life correction factor
T = fluid service temperature (°C)
T* = 0 for T < 200°C
= 1 for T ≥ 200°C
$\dot{\varepsilon}^*$ = 0 for strain rate, $\dot{\varepsilon}$ > 0.4%/sec
= ln($\dot{\varepsilon}$/0.4) for 0.0004 ≤ $\dot{\varepsilon}$ ≤ 0.4%/sec
= ln(0.0004/0.4) for $\dot{\varepsilon}$ < 0.0004%/sec
O* = 0.260 for dissolved oxygen, DO < 0.05 parts per million (ppm)
= 0.172 for DO ≥ 0.05 ppm

Bounding $F_{en}$ values are determined or, where necessary, computed for each load pair in a detailed fatigue calculation. The environmental fatigue is then determined as $U_{env}$ = (U) ($F_{en}$), where U is the original fatigue usage, and $U_{env}$ is the EAF usage factor.

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Since implementation of HWC in 2003, VYNPS's availability has exceeded 98.5% and the objective for future HWC system availability is a minimum of 99% [12]. With these considerations, the overall availability for HWC since implementation at VYNPS until the end of the 60-year operating period was estimated at 98.5%.

Some nozzles, (e.g., recirculation outlet nozzle) have three materials: a Ni-Cr-Fe dissimilar metal weld (DMW), a low alloy steel forging, and a stainless steel safe end. To ensure the maximum CUF considering environmental effects was identified, locations in both the safe end and nozzle forging were selected. This selection produces bounding environmental fatigue results for the entire nozzle assembly for the following reasons:

- The highest thermal stresses from the finite-element model (FEM) analysis occur in the stainless steel safe end. Stainless steel $F_{en}$ multipliers at VYNPS are significantly higher than Ni-Cr-Fe multipliers ($F_{en}$ values are 2.55 or higher for stainless steel [12] vs. a constant value of 1.49 for Ni-Cr-Fe [11]). Therefore, evaluation of the safe end bounds the Ni-Cr-Fe weld material.
- The highest pressure stresses from the FEM analysis occur in the low alloy steel nozzle forging. Low alloy steel $F_{en}$ multipliers at VYNPS are higher than Ni-Cr-Fe multipliers ($F_{en}$ values are 2.45 or higher for low alloy steel [12] vs. a constant value of 1.49 for Ni-Cr-Fe [11]). Therefore, evaluation of the nozzle forging bounds the Ni-Cr-Fe weld material.

The number of cycles for forty years was adjusted based on the number of cycles actually experienced by the plant, projected out to 60 years of operation [14]. In addition, VYNPS has implemented extended power uprate (EPU). These effects have been incorporated into the evaluations documented in this report. With the use of this information, the CUF values documented in this report are applicable for 60 years of operation.

The environmental fatigue calculations are shown in Tables 3-1 through 3-9 and summarized in Table 3-10. Component-specific details are provided in the subsections that follow.

## 3.1 Reactor Vessel Shell and Lower Head

The environmental fatigue calculations for the reactor vessel shell and lower head location are shown in Table 3-1. The limiting CUF value reported in the VY LRA for the RPV shell/bottom head location corresponds to a point located on the outside surface of the RPV bottom head at the junction with the support skirt. Therefore, this location is not exposed to the reactor coolant, and EAF effects do not apply. Based on this, evaluation of the limiting location along the inside surface of the RPV bottom head was performed.

The calculations shown in Table 3-1 are for the RPV lower head at the area with the highest alternating stress, which represents the limiting RPV bottom head location [12]. Reference [15] is the governing stress report for this low alloy steel location. The design fatigue calculation for the limiting RPV lower head location is reproduced in Table 3-1. The effects of EPU as well as conservative cycle counts for 60 years of plant operation are incorporated in this table. The final results in Table 3-1 show an EAF adjusted CUF of 0.0809 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

The calculations shown in Table 3-2 are for the RPV shell at the RPV shell junction to the shroud support plate, which represents the limiting RPV shell location exposed to the reactor coolant [12]. Reference [16] is the governing stress report for this low alloy steel location. The design fatigue calculation for the limiting RPV shell location is reproduced in Table 3-2, which considers the effects of EPU and conservative cycle counts were used for 60 years of plant operation. The final results in Table 3-2 show an EAF adjusted CUF of 0.7364 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

## 3.2 Reactor Vessel Feedwater Nozzle

The environmental fatigue calculations for the reactor vessel feedwater nozzle location are summarized in Table 3-3. The calculations summarized in Table 3-3 show both the blend radius, which represents the limiting feedwater nozzle location, and the safe end. Reference [17] contains the governing fatigue calculation for this location. Upper RPV region chemistry was assumed for the feedwater nozzle blend radius location, since this location is exposed to the reactor water chemistry in this region, whereas feedwater line chemistry was assumed for the safe end location.

The governing fatigue calculation for the limiting feedwater nozzle locations includes the effects of EPU and cycle counts for 60 years of operation obtained from Attachment 1 of Reference [14]. The blend radius cumulative usage factor (CUF) from system cycling is 0.0636 for 60 years. The safe end CUF is 0.1471 for 60 years. Although the carbon steel safe end has a higher CUF prior to considering environmental effects, the environmental multiplier from Table 3-3 results in a higher CUF at the low alloy steel blend radius. For the safe end location, the EAF adjusted CUF is 0.2560 for 60 years. For the blend radius location, EAF adjusted CUF is 0.6392 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

## 3.3 Reactor Recirculation Piping (Including the Reactor Inlet and Outlet Nozzles)

Three locations were identified for the reactor recirculation piping in NUREG/CR-6260: the reactor vessel nozzle (includes both the inlet and outlet nozzles), and the recirculation piping. The evaluations for each of these components are described in the following subsections.

### 3.3.1 Reactor Recirculation Piping

Two locations (both stainless steel) were identified for VY for the reactor recirculation/RHR piping that correspond to the equivalent locations to those identified in NUREG/CR-6260: the RHR return tee connection to the recirculation piping, and the valve to pipe weld at the RHR isolation valve. Reference [18] contains the governing fatigue calculations for these locations. These analyses determined the limiting location to be at the RHR return tee.

The environmental fatigue calculations for the limiting recirculation/RHR piping location is summarized in Table 3-4, which includes the effects of EPU and cycle counts for 60 years of plant operation.

A review of the shutdown cooling mode of operation since the time of recirculation piping replacement in 1986 was performed by VYNPS, and the number of cycles per loop was conservatively estimated to be 150 through Year 60 [14]. Based on this, the cycle counts for the

Recirculation piping were reduced by a factor of 150/300 (50%) for all transients with the exception of transients that have fewer than 10 transient cycles. To ensure this cycle reduction adequately considered the potential impact on the RHR piping, the full number of transient cycles listed in Attachment 1 of Reference [14] was initially applied to the PIPESTRESS model and the highest CUF for the RHR piping was lower than the value obtained for the recirculation piping with reduced cycles.

Due to replacement of the recirculation piping, HWC conditions exist for 39% of the time, and NWC conditions exist for 61% of the time. This is based on 17.5 years of operation with NWC between March 1986 when the piping was replaced and November 2003 when HWC was implemented, and 46 years of operation from March 1986 to the end of the period of extended operation in March 2032. Using the bounding EAF multipliers (8.36 for HWC and 15.35 for NWC) [12], the overall multiplier is 12.62. Applying this to the 60-Year CUF of 0.0590 results in a total environmentally assisted CUF of 0.7446.

### 3.3.2 Reactor Recirculation Inlet Nozzle

References [15, 19 and 20] are the applicable stress reports for this location. An evaluation was performed for both the inlet nozzle forging (low alloy steel) and the safe end (stainless steel).

The environmental fatigue calculations for the recirculation inlet nozzle forging location are shown in Table 3-5. The governing fatigue calculation for the recirculation inlet nozzle location is reproduced in Table 3-5 [12], which includes the effects of EPU and cycle counts for 60 years of plant operation from Attachment 1 of Reference [14]. The final results show an EAF adjusted CUF of 0.5034 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

The environmental fatigue calculations for the recirculation inlet nozzle safe end location are shown in Table 3-6. The governing fatigue calculation for the recirculation inlet nozzle location is reproduced in Table 3-6 [12], which includes the effects of EPU and cycle counts for 60 years of plant operation from Attachment 1 of Reference [14]. The final results show an EAF adjusted CUF of 0.0199 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

### 3.3.3 Reactor Recirculation Outlet Nozzle

The recirculation outlet nozzle was evaluated for environmental fatigue effects. Reference [24] is the fatigue calculation for this location. An evaluation was performed for both the outlet nozzle safe end (stainless steel) and the nozzle inner corner blend radius (low alloy steel). The results for the limiting nozzle forging location are reported here.

The environmental fatigue calculations for the limiting recirculation outlet nozzle forging blend radius location are shown in Table 3-7 [24], which includes the effects of EPU and cycle counts for 60 years of plant operation from Attachment 1 of Reference [14]. The final results in Table 3-7 show an EAF adjusted CUF of 0.0836 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

## 3.4 Core Spray Line Reactor Vessel Nozzle and Associated Class 1 Piping

Locations that were evaluated in NUREG/CR-6260 included the reactor vessel nozzle blend radius (low alloy steel), the reactor vessel nozzle safe end (Alloy 600) and the core spray piping (stainless steel).

Reference [21] is the applicable fatigue calculation for these locations, which shows the nozzle limiting location to be the blend radius. The design fatigue calculations for the limiting location at the core spray nozzle, safe end, and piping are summarized in Table 3-8 [21], which include the effects of EPU and cycle counts for 60 years of plant operation from Attachment 1 of Reference [14]. The cumulative fatigue usage, prior to considering environmental effects for the blend radius, is 0.0166. Factoring in the environmental multiplier from Table 3-8 [12], the EAF adjusted CUF is 0.1668 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

### 3.5 RHR Return Line Class 1 Piping

The environmental fatigue calculations for the RHR return line Class 1 piping are covered by the calculations in Subsection 3.3.1 above.

### 3.6 Feedwater Line Class 1 Piping

The environmental fatigue calculation for the limiting feedwater Class 1 piping location (carbon steel) is summarized in Table 3-9. The calculations shown in Table 3-9 are for the limiting feedwater Class 1 piping location. Per Reference [22], the limiting total fatigue usage for the analyzed feedwater/high pressure coolant injection (HPCI) piping system occurs on the riser to the RPV feedwater nozzle N4B. The limiting fatigue usage value for the feedwater Class 1 piping location is 0.1661, which includes the effects of EPU and cycle counts for 60 years of plant operation from Attachment 1 of Reference [14]. The final results in Table 3-9 show the EAF adjusted CUF of 0.2890 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

### 3.7 Summary of Results

The results of the calculations contained in Tables 3-1 through 3-9 are summarized in Table 3-10.

It is noteworthy that the CUF results presented in this section include uniformly applied environmental effects without consideration of threshold criteria that might indicate an absence of conditions that would lead to environmental fatigue effects. Furthermore, conservative values were applied for temperature, strain rate and metal sulfur content in calculating environmental multipliers. Therefore, the environmental adjustments to the CUF results are considered to be conservative.

Table 3-1. Environmental Fatigue Evaluation for the Reactor Vessel Shell

Component: RPV Shell/Bottom Head
NUREG/CR-6260 CUF: 0.032 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-102
Stress Report CUF: 0.0057 *(for Point 14, see below)*
Material: Low Alloy Steel *(Material = A-533 Gr. B)*

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.149 | *Conservatively used minimum E of 26.1 from Section S2 Appendix of RPV Stress Report.* |
| Power Uprate = | 1.0067 | *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1* |
| $K_t$ = | 1.000 | *stress concentration factor* |
| m = | 2.0 | *NB-3228.5 of ASME Code, Section III* |
| n = | 0.2 | *NB-3228.5 of ASME Code, Section III* |
| $S_m$ = | 26,700 | psi *(ASME Code, Section II, Part D)* |

| $P_L+P_B+Q$ *(see Note 1)* | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 4)* | N *(see Note 5)* | U |
|---|---|---|---|---|---|
| 44,526 | 1.00 | 25,762 | 200 | 35,300 | 0.0057 |
| | | | | **Total, $U_{40}$ =** | **0.0057** |

*Notes:*
1. *$P_L+P_B+Q$ is obtained for Point 14 from p. A52 of VYC-378, Rev. 0.*
2. *$K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.*
3. *$S_{alt} = 0.5 * K_e * K_t * E_{fatigue\ curve}/E_{analysis}$ * Power Uprate * $(P_L+P_B+Q)$.*
4. *n for 40 years is the number of Heatup-Cooldown cycles, per p. B8 of VYC-378, Rev. 0.*
5. *N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.*
6. *n for 60 years is the projected number of Heatup-Cooldown cycles.*

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 6)* | N *(see Note 4)* | U |
|---|---|---|---|---|---|
| 44,526 | 1.00 | 25,762 | 300 | 35,300 | 0.0085 |
| | | | | **Total, $U_{60}$ =** | **0.0085** |

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = 5.39
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = 13.17

**$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ = 0.0809**
**Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = 9.51**

# Table 3-2. Environmental Fatigue Evaluation for the Reactor Vessel Shell at Shroud Support

| | | |
|---|---|---|
| Component: | RPV Shell at Shroud Support | |
| NUREG/CR-6260 CUF: | 0.032 | *(for reference only)* |
| Reference: | NUREG/CR-6260, p. 5-102 | |
| Stress Report CUF: | 0.0549 | *(for Point 9, see below)* |
| Material: | Low Alloy Steel | *(Material = A-533 Gr. B)* |

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| Hydrotest $H_H$ = | 26,240 | psi *(p. S3-97 of RPV Stress Report)* |
| Hydrotest $H_t$ = | -1,250 | psi *(p. S3-97 of RPV Stress Report)* |
| Stress Concentration Factor, $K_t$ = | 2.40 | *(p. S3-99d of RPV Stress Report)* |
| Hydrotest $K_tH_H$ = | 62,976 | psi *(p. S3-97 of RPV Stress Report)* |
| Improper Startup $H_H$ = | 28,060 | psi *(p. S3-98 of RPV Stress Report)* |
| Improper Startup $H_t$ = | -1,025 | psi *(p. S3-98 of RPV Stress Report)* |
| Improper Startup Skin Stress = | 156,099 | psi *(p. S3-98 of RPV Stress Report)* |
| Improper Startup $K_tH_H$ + Skin Stress = | 223,443 | psi *(p. S3-98 of RPV Stress Report)* |
| Warmup $H_H$ = | -5,707 | psi *(p. S3-99a of RPV Stress Report)* |
| Warmup $H_t$ = | -102 | psi *(p. S3-99a of RPV Stress Report)* |
| Warmup $K_tH_H$ = | -13,696 | psi *(p. S3-99a of RPV Stress Report)* |
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.0417 | *30.0 / 28.8 per S3-99f of RPV Stress Report and ASME Code fatigue curve* |
| Power Uprate = | 1.0067 | *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1* |
| m = | 2.0 | *NB-3228.5 of ASME Code, Section III* |
| n = | 0.2 | *NB-3228.5 of ASME Code, Section III* |
| $S_m$ = | 26,700 | psi *(ASME Code, Section II, Part D)* |

| $P_L+P_B+Q$ *(see Note 1)* | Events | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 4)* | N *(see Note 5)* | U |
|---|---|---|---|---|---|---|
| 34,690 | Improper Startup - Warmup | 1.00 | 124,825 | 5 | 332 | 0.0151 |
| 33,095 | Hydrotest - Warmup | 1.00 | 40,804 | 322 | 8,095 | 0.0398 |
| | | | | | **Total, $U_{40}$ =** | **0.0549** |

*Notes:*
1. *$P_L+P_B+Q$ is computed for Point 9 based on the $[(H_H - H_t)_{Event\ 1} - (H_H - H_t)_{Event\ 2}]$ stress intensity.*
2. *$K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.*
3. *$S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis} *$ Power Uprate $* [(K_tH_H - H_t)_{Event\ 1} - (K_tH_H - H_t)_{Event\ 2}]$.*
4. *n for 40 years is the number of cycles as follows per p. S3-99e and S3-99f of the RPV Stress Report:*

| | | |
|---|---|---|
| *Improper Startup =* | *5* | *cycles* |
| *Hydrotest =* | *2* | *cycles* |
| *Isothermal at 70°F and 1,000 psi =* | *120* | *cycles (same as number of Startup events)* |
| *Warmup-Cooldown =* | *199* | *cycles* |
| *Warmup-Blowdown =* | *1* | *cycle* |
| *TOTAL =* | *327* | *cycles* |

5. *N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.*
6. *n for 60 years is the projected number of cycles as follows:*

| | | |
|---|---|---|
| *Improper Startup =* | *1* | *cycles* |
| *Hydrotest =* | *1* | *cycles* |
| *Isothermal at 70°F and 1,000 psi =* | *300* | *cycles (same as number of Startup events)* |
| *Warmup-Cooldown =* | *300* | *cycles* |
| *Warmup-Blowdown =* | *1* | *cycle* |
| *TOTAL =* | *603* | *cycles* |

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | | $K_e$ *(see Note 2)* | $S_{alt}$ *(see Note 3)* | n *(see Note 6)* | N *(see Note 4)* | U |
|---|---|---|---|---|---|---|
| 34,690 | Improper Startup - Warmup | 1.00 | 124,825 | 1 | 332 | 0.0030 |
| 33,095 | Hydrotest - Warmup | 1.00 | 40,804 | 602 | 8,095 | 0.0744 |
| | | | | | **Total, $U_{60}$ =** | **0.0774** |

Environmental CUF Calculation for 60 Years:

| | |
|---|---|
| Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = | 5.39 |
| Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = | 13.17 |
| **$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ =** | **0.7364** |
| **Overall Multiplier = $U_{env\text{-}60}/U_{60}$ =** | **9.51** |

## Table 3-3. Environmental Fatigue Evaluation for the Reactor Vessel Feedwater Nozzle Forging Blend Radius

*Low Alloy Steel:*

$F_{en}$ = exp(0.898 - 0.101S*T*O*□)

Assume S* = 0.015 (maximum)
Assume □ = ln(0.001) = -6.908 (minimum)

**For a BWR with HWC environment (post-HWC implementation):**
DO = 97 ppb = 0.097 ppm, so O* = ln(0.097/0.04) = 0.886

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 3.90 |
| 250 | 482 | 6.20 |
| 288 | 550 | 8.82 |

Thus, maximum $F_{en}$ = 8.82

**For a BWR with NWC environment (pre-HWC implementation):**
DO = 114 ppb = 0.114 ppm, so O* = ln(0.114/0.04) = 1.047

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.25 |
| 250 | 482 | 7.35 |
| 288 | 550 | 11.14 |

Thus, maximum $F_{en}$ = 11.14

[T* = (T-150) for T > 150°C]

*Carbon Steel:*

$F_{en}$ = exp(0.554 - 0.101S*T*O*□)

Assume S* = 0.015 (maximum)
Assume □ = ln(0.001) = -6.908 (minimum)

**For a BWR with HWC environment (post-HWC implementation):**
DO = 40 ppb = 0.040 ppm < 0.050 ppm so O* = 0
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

**For a BWR with NWC environment (pre-HWC implementation):**
DO = 40 ppb = 0.040 ppm < 0.050 ppm so O* = 0
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

[T* = (T-150) for T > 150°C]

| No. | Component | Material | 60-Year CUF | Overall Environmental Multiplier | 60-Year Environmental CUF (1,2) |
|---|---|---|---|---|---|
| 1 | Feedwater Nozzle Forging Blend Radius | Low Alloy Steel | 0.0636 | 10.05 | 0.6392 |
| 2 | Feedwater Nozzle Forging Safe End | Carbon Steel | 0.1471 | 1.74 | 0.2560 |

Notes:
1. An Fen Multiplier was used for each respective component with the following conditions:
   + 47% HWC conditions and 53% NWC conditions
2. Results using updated ASME Code fatigue calculations and actual cycles accumulated to-date and projected to 60 years.

Table 3-4. Environmental Fatigue Evaluation for the Recirculation/RHR Piping Tee

| | | | | | |
|---|---|---|---|---|---|
| *Stainless Steel:* | | $F_{en} = \exp(0.935 - T^*\varepsilon^*O^*)$ | | | |
| **For a BWR with HWC environment (post-HWC implementation):**<br>DO = 46 ppb = 0.046 ppm < 0.050 ppm, so $O^* = 0.260$<br>Conservatively use $T^* = 1$ for T > 200°C<br>Thus: | | | **For a BWR with NWC environment (pre-HWC implementation):**<br>DO = 123 ppb = 0.123 ppm > 0.05 ppm, so $O^* = 0.172$<br>Conservatively use $T^* = 1$ for T > 200°C<br>Thus: | | |
| $\varepsilon^* = 0$ for $\varepsilon > 0.4\%$/sec | so $F_{en}$ = | 2.55 | | so $F_{en}$ = | 2.55 |
| $\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4\%$/sec | *so $F_{en}$ ranges from* | 2.55 | | *so $F_{en}$ ranges from* | 2.55 |
| | to | 15.35 | | to | 8.36 |
| $\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004\%$/sec | so $F_{en}$ = | 15.35 | | so $F_{en}$ = | 8.36 |
| | Thus, maximum $F_{en}$ = | 15.35 | | Thus, maximum $F_{en}$ = | 8.36 |

| No. | Component | Material | 60-Year CUF | Overall Environmental Multiplier | 60-Year Environmental CUF (1,2) |
|---|---|---|---|---|---|
| 1 | Recirculation /RHR Piping Return Tee | Stainless Steel | 0.0590 | 12.62 | 0.7446 |

Notes: 1. An $F_{en}$ multiplier was used for each respective component with the following conditions:
+ 39% HWC conditions and 61% NWC conditions
2. Results using updated ASME Code fatigue calculations and actual cycles accumulated to-date and projected to 60 years.

## Table 3-5. Environmental Fatigue Evaluation for the Reactor Recirculation Inlet Nozzle Forging

Component: Recirculation Inlet Nozzle Forging
NUREG/CR-6260 CUF: 0.310 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-105
Stress Report CUF: 0.0433 *(updated for Point 12, see below)*
Material: Low Alloy Steel *(Material = A-508 Cl. II per p. I-S8-4 of CBIN Stress Report Section S8)*

Design Basis CUF Calculation for 40 years:

$E_{fatigue\ curve}/E_{analysis}$ = 1.1278 = 30.0 / 26.6 (per p. I-S8-24 of CBIN Stress Report Section S8 and ASME Code fatigue curve)
Power Uprate = 1.0067 =(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1
$K_t$ = 1.660 stress concentration factor (p. A270 of VYC-378, Rev. 0)
m = 2.0 NB-3228.5 of ASME Code, Section III
n = 0.2 NB-3228.5 of ASME Code, Section III
$S_m$ = 26,700 psi (ASME Code, Section II, Part D)

| $P_L+P_B+Q$ *(see Note 1)* | Skin Stress *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 6)* | U |
|---|---|---|---|---|---|---|
| 43,110 | 15,145 | 1.00 | 49,224 | 200 | 4,614 | 0.0433 |
| | | | | | **Total, $U_{40}$ =** | **0.0433** |

*Notes:*
1. *$P_L+P_B+Q$ is obtained for Point 12 from p. A270 of VYC-378, Rev. 0.*
2. *Skin Stress is obtained for Point 12 from p. A270 of VYC-378, Rev. 0.*
3. *$K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.*
4. *$S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis} *$ Power Uprate $* [ (P_L+P_B+Q)\ K_t$ + Skin Stress ].*
5. *n for 40 years is the number of Heatup-Cooldown cycles, per p. B28 of VYC-378, Rev. 0.*
6. *N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.*
7. *n for 60 years is the projected number of Heatup-Cooldown cycles.*

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | Skin Stress *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 7)* | U |
|---|---|---|---|---|---|---|
| 43,110 | 15,145 | 1.00 | 49,224 | 300 | 4,614 | 0.0650 |
| | | | | | **Total, $U_{60}$ =** | **0.0650** |

Environmental CUF Calculation for 60 Years:

Maximum $F_{en-HWC}$ Multiplier for HWC Conditions = 2.45
Maximum $F_{en-NWC}$ Multiplier for NWC Conditions = 12.43

**$U_{env-60} = U_{60} \times F_{en-NWC} \times 0.53 + U_{60} \times F_{en-HWC} \times 0.47$ =** 0.5034
**Overall Multiplier = $U_{env-60}/U_{60}$ =** 7.74

## Table 3-6. Environmental Fatigue Evaluation for Reactor Recirculation Inlet Nozzle Safe End

Component: Recirculation Inlet Nozzle Safe End
NUREG/CR-6260 CUF: 0.310 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-105
Stress Report CUF: 0.0017 *(updated for Location 6-I, see below)*
Material: Stainless Steel *(316L per p. 8 of 23A4292, Rev. 4)*

Design Basis CUF Calculation for 40 years:

| | | |
|---|---|---|
| $E_{fatigue\ curve}/E_{analysis}$ = | 1.1076 | = 28.3 / 25.55 (per p. 62 of Reference [18] and ASME Code fatigue curve) |
| Power Uprate = | 1.0067 | =(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 |
| $K_t$ = | 1.280 | stress concentration factor (p. B27 of VYC-378, Rev. 0) |
| m = | 1.7 | NB-3228.5 of ASME Code, Section III |
| n = | 0.3 | NB-3228.5 of ASME Code, Section III |
| $S_m$ = | 16,600 | psi (ASME Code, Section II, Part D) |

| $P_L+P_B+Q$ *(see Note 1)* | P+Q+F *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 6)* | U |
|---|---|---|---|---|---|---|
| 47,183 | 36,972 | 1.00 | 26,385 | 2,076 | 1,242,266 | 0.0017 |
| | | | | | **Total, $U_{40}$ =** | **0.0017** |

*Notes:*
1. $P_L+P_B+Q$ is obtained for Surface I (after weld overlay) from p. 117 of Reference [18].
2. P+Q+F is obtained for Point 6-I from p. 118 of Reference [18] (BEFORE weld overlay).
3. $K_e$ computed in accordance with NB-3228.5 of ASME Code, Section III.
4. $S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis}$ * Power Uprate * [ (P+Q+F) $K_t$ ].
5. n for 40 years is the number of cycles as follows per p. B26 of VYC-378, Rev. 0:

| | | |
|---|---|---|
| Design Hydrotest = | 130 | |
| Loss of Feedpumps Composite: | | |
| Startup/Shutdown = | 290 | |
| SRV Blowdown = | 8 | |
| Loss of Feedwater Pumps | 30 | 10 events x 3 up/down cycles per event |
| SCRAM = | 270 | |
| Normal +/- Seismic = | 11 | 10 cycles of upset seismic, plus 1 Level C seismic event |
| Normal = | 739 | = Sum of all of above events |
| Zeroload = | 598 | = Startup/Shutdown + SRV Blowdown + Scram + LOFP |
| Total number of cycles = | 2,076 | |

6. N obtained from Figure I-9.2 of Appendix I of ASME Code, Section III.
7. n for 60 years is the projected number of cycles as follows:

| | | |
|---|---|---|
| Design Hydrotest = | 120 | |
| Loss of Feedpumps Composite: | | |
| Startup/Shutdown = | 300 | |
| SRV Blowdown = | 1 | |
| Loss of Feedwater Pumps | 30 | 10 events x 3 up/down cycles per event |
| SCRAM = | 289 | All remaining scrams |
| Normal +/- Seismic = | 11 | Assume the same |
| Normal = | 751 | = Sum of all of above events |
| Zeroload = | 620 | = Startup/Shutdown + SRV Blowdown + Scram + LOFP |
| Total number of cycles = | 2,122 | |

Revised CUF Calculation for 60 Years:

| $P_L+P_B+Q$ *(see Note 1)* | P+Q+F *(see Note 2)* | $K_e$ *(see Note 3)* | $S_{alt}$ *(see Note 4)* | n *(see Note 5)* | N *(see Note 7)* | U |
|---|---|---|---|---|---|---|
| 47,183 | 36,972 | 1.00 | 26,385 | 2,122 | 1,242,266 | 0.0017 |
| | | | | | **Total, $U_{60}$ =** | **0.0017** |

Environmental CUF Calculation for 60 Years:

| | |
|---|---|
| Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = | 15.35 |
| Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = | 8.36 |
| $U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ = | **0.0199** |
| **Overall Multiplier = $U_{env\text{-}60}/U_{60}$ =** | **11.64** |

Table 3-7. Environmental Fatigue Evaluation for Recirculation Outlet Nozzle Forging

*Low Alloy Steel:*

$F_{en} = \exp(0.898 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

**For a BWR with HWC environment (post-HWC implementation):**
DO = 46 ppb = 0.046 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 2.45 |
| 269.45 | 517.01 | 2.45 |
| 288 | 550 | 2.45 |

Thus, maximum $F_{en}$ = 2.45

[$T^* = (T-150)$ for $T > 150°C$]

**For a BWR with NWC environment (pre-HWC implementation):**
DO = 123 ppb = 0.123 ppm, so $O^* = \ln(0.123/0.04) = 1.123$

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.42 |
| 269.45 | 517.01 | 10.00 |
| 288 | 550 | 12.43 |

Thus, maximum $F_{en}$ = 12.43

| No. | Component | Material | 60-Year CUF | Overall Environmental Multiplier | 60-Year Environmental CUF (1,2) |
|---|---|---|---|---|---|
| 1 | Recirculation Outlet Nozzle Forging Blend Radius | Low Alloy Steel | 0.0108 | 7.74 | 0.0836 |

Notes: 1. An $F_{en}$ multiplier was used for each respective component with the following conditions:
+ 47% HWC conditions and 53% NWC conditions
2. Results using updated ASME Code fatigue calculations and actual cycles accumulated to-date and projected to 60 years.

# Table 3-8. Environmental Fatigue Evaluation for Core Spray Reactor Vessel Nozzle Forging Blend Radius, Safe End, and Piping

*Low Alloy Steel:*

$F_{en}$ = exp(0.898 - 0.101S*T*O*□*)

Assume S* = 0.015 (maximum)
Assume □*= ln(0.001) = -6.908 (minimum)

**For a BWR with HWC environment (post-HWC implementation):**
DO = 97 ppb = 0.097 ppm, so O* = ln(0.097/0.04) = 0.886

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 3.90 |
| 250 | 482 | 6.20 |
| 288 | 550 | 8.82 |

Thus, maximum $F_{en}$ = 8.82

[T*= (T-150) for T > 150°C]

**For a BWR with NWC environment (pre-HWC implementation):**
DO = 114 ppb = 0.114 ppm, so O* = ln(0.114/0.04) = 1.047

Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 2.45 |
| 50 | 122 | 2.45 |
| 100 | 212 | 2.45 |
| 150 | 302 | 2.45 |
| 200 | 392 | 4.25 |
| 250 | 482 | 7.35 |
| 288 | 550 | 11.14 |

Thus, maximum $F_{en}$ = 11.14

*Stainless Steel:*

$F_{en}$ = exp(0.935 - T*°*O*)

**For a BWR with HWC environment (post-HWC implementation):**
DO = 97 ppb = 0.097 ppm > 0.050 ppm, so O* = 0.172
Conservatively use T* = 1 for T > 200°C
Thus:

| | | | |
|---|---|---|---|
| °* = 0 for ° > 0.4%/sec | so $F_{en}$ = | 2.55 | |
| °* = ln(°/0.4) for 0.0004 <= ° <= 0.4%/sec | so $F_{en}$ ranges from | 2.55 | |
| | to | 8.36 | |
| °* = ln(0.0004/0.4) for ° < 0.0004%/sec | so $F_{en}$ = | 8.36 | |
| | Thus, maximum $F_{en}$ = | 8.36 | |

**For a BWR with NWC environment (pre-HWC implementation):**
DO = 114 ppb = 0.114 ppm > 0.05 ppm, so O* = 0.172
Conservatively use T* = 1 for T > 200°C
Thus:

| | |
|---|---|
| so $F_{en}$ = | 2.55 |
| so $F_{en}$ ranges from | 2.55 |
| to | 8.36 |
| so $F_{en}$ = | 8.36 |
| Thus, maximum $F_{en}$ = | 8.36 |

| No. | Component | Material | 60-Year CUF | Overall Environmental Multiplier | 60-Year Environmental CUF (1,2) |
|---|---|---|---|---|---|
| 1 | Core Spray Nozzle Forging Blend Radius | Low Alloy Steel | 0.0166 | 10.05 | 0.1668 |
| 2 | Core Spray Nozzle Safe End | Ni-Cr-Fe | 0.0398 | 1.49 | 0.0593 |
| 3 | Core Spray Piping | Stainless Steel | 0.0011 | 8.36 | 0.0092 |

Notes:
1. An Fen Multiplier was used for each respective component with the following conditions:
   + 47% HWC conditions and 53% NWC conditions
2. Results using updated ASME Code fatigue calculations and actual cycles accumulated to-date and projected to 60 years.

Table 3-9. Environmental Fatigue Evaluation for the Feedwater Line Class 1 Piping

*Carbon Steel:*

$F_{en} = \exp(0.554 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

**For a BWR with HWC environment (post-HWC implementation):**
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

($T^* = (T-150)$ for $T > 150°C$)

**For a BWR with NWC environment (pre-HWC implementation):**
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

| T (°C) | T (°F) | $F_{en}$ |
|---|---|---|
| 0 | 32 | 1.74 |
| 50 | 122 | 1.74 |
| 100 | 212 | 1.74 |
| 150 | 302 | 1.74 |
| 200 | 392 | 1.74 |
| 250 | 482 | 1.74 |
| 288 | 550 | 1.74 |

Thus, maximum $F_{en}$ = 1.74

| No. | Component | Material | 60-Year CUF | Overall Environmental Multiplier | 60-Year Environmental CUF (1,2) |
|---|---|---|---|---|---|
| 1 | Feedwater Piping Riser to RPV Nozzle N4B | Carbon Steel | 0.1661 | 1.74 | 0.2890 |

Notes: 1. An $F_{en}$ multiplier was used for each respective component with the following conditions:
+ 47% HWC conditions and 53% NWC conditions
2. Results using updated ASME Code fatigue calculations and actual cycles accumulated to-date and projected to 60 years.

Table 3-10. Summary of Environmental Fatigue Calculations for VYNPS

| No. | Component | Material | 40-Year Design CUF (1) | 60-Year CUF (2) | Overall Environmental Multiplier (3) | 60-Year Environmental CUF |
|---|---|---|---|---|---|---|
| 1 | RPV Shell/Bottom Head | Low Alloy Steel | 0.0057 | 0.0085 | 9.51 | 0.0809 |
| 2 | RPV Shell at Shroud Support | Low Alloy Steel | 0.0549 | 0.0774 | 9.51 | 0.7364 |
| 3 | Feedwater Nozzle Blend Radius | Low Alloy Steel | (4) | 0.0636 | 10.05 | 0.6392 |
| 4 | Recirculation/RHR Class 1 Piping (Return Tee) | Stainless Steel | (4) | 0.0590 | 12.62 | 0.7446 |
| 5 | Recirculation Inlet Nozzle Forging | Low Alloy Steel | 0.0433 | 0.0650 | 7.74 | 0.5034 |
| 6 | Recirculation Inlet Nozzle Safe End | Stainless Steel | 0.0017 | 0.0017 | 11.64 | 0.0199 |
| 7 | Recirculation Outlet Nozzle Forging | Low Alloy Steel | (4) | 0.0108 | 7.74 | 0.0836 |
| 8 | Core Spray Nozzle Forging Blend Radius (5) | Low Alloy Steel | (4) | 0.0166 | 10.05 | 0.1668 |
| 9 | Feedwater Class 1 Piping | Carbon Steel | (4) | 0.1661 | 1.74 | 0.2890 |

Notes:
1. Updated 40-year CUF calculation based on recent ASME Code methodology and design basis cycles.
2. CUF results using updated ASME Code methodology and actual cycles accumulated to-date and projected to 60 years.
3. An $F_{en}$ multiplier was used for each respective component with the following conditions:
   - 47% HWC conditions and 53% NWC conditions
4. 40 year values were not calculated for these locations
5. Only the highest CUF from Table 3-8 is shown

## 4.0 SUMMARY AND CONCLUSIONS

The results of Tables 3-1 through 3-9, as summarized in Table 3-10, demonstrate that the fatigue usage factor, including environmental effects, remains within the allowable value of 1.0 for 60 years of operation for the following component locations:

- ✓ Reactor vessel shell, bottom head and shroud support
- ✓ Reactor vessel feedwater nozzle
- ✓ Reactor recirculation piping (including the reactor inlet and outlet nozzles)
- ✓ Core spray line reactor vessel nozzle and associated Class 1 piping
- ✓ Feedwater line Class 1 piping

Therefore, the environmental fatigue assessment results for all of the NUREG/CR-6260 locations associated with the older vintage BWR plant are acceptable for 60 years of operation for VYNPS.

## 5.0 REFERENCES


1. U. S. Nuclear Regulatory Commission, Generic Safety Issue 166, "Adequacy of Fatigue Life of Metal Components."

2. U. S. Nuclear Regulatory Commission, Generic Safety Issue 190, "Fatigue Evaluation of Metal Components for 60-Year Plant Life."

3. SECY-95-245, "Completion of the Fatigue Action Plan," James M. Taylor, Executive Director for Operations, U. S. Nuclear Regulatory Commission, Washington, DC, September 25, 1995.

4. Memorandum, Ashok C. Thadani, Director, Office of Nuclear Regulatory Research, to William D. Travers, Executive Director for Operations, Closeout of Generic Safety Issue 190, "Fatigue Evaluation of Metal Components for 60 Year Plant Life," U. S. Nuclear Regulatory Commission, Washington, DC, December 26, 1999.

5. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U.S. Nuclear Regulatory Commission, September 2005.

6. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

7. NUREG/CR-6583 (ANL-97/18), "Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels," March 1998.

8. NUREG/CR-5704 (ANL-98/31), "Effects of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steels," April 1999.

9. NUREG/CR-5999 (ANL-93/3), "Interim Fatigue Design Curves for Carbon, Low-Alloy, and Austenitic Stainless Steels in LWR Environments," April 1993.

10. USAS B31.1 - 1967, USA Standard Code for Pressure Piping, "Power Piping," American Society of Mechanical Engineers, New York.

11. EPRI Report No. TR-105759, "An Environmental Factor Approach to Account for Reactor Water Effects in Light Water Reactor Pressure Vessel and Piping Fatigue Evaluations," December 1995.

12. Structural Integrity Associates Calculation No. VY-16Q-303, Revision 0, " Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head."

13. INFORMATION REDACTED

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16. Chicago Bridge & Iron RPV Stress Report, Section S3, Revision 4, "Stress Analysis, Shroud Support, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," 2/3/70, SI File No. VY-16Q-203.

17. Structural Integrity Associates Calculation No. VY-16Q-302, Revision 0, "Fatigue Analysis of Feedwater Nozzle."

18. Structural Integrity Associates Calculation No. VY-16Q-307, Revision 0, "Recirculation Class 1 Piping Fatigue and EAF Analysis."

19. CB&I RPV Stress Report, Section S8, Revision 4, "Stress Analysis, Recirculation Inlet Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," 2/3/70, SI File No. VY-16Q-203.

20. GE Nuclear Energy Certified Stress Report No. 23A4292, Revision 0, "Reactor Vessel – Recirculation Inlet Safe End Nozzle," January 21, 1985, SI File No. VY-16Q-203.

21. Structural Integrity Associates Calculation No. VY-16Q-310, Revision 1, "Fatigue Analysis of Core Spray Nozzle."

22. Structural Integrity Associates Calculation No. VY-16Q-311, Revision 0, "Feedwater Class 1 Piping Fatigue Analysis."

23. EPRI/BWRVIP Memo. No. 2005-271, "Potential Error in Existing Fatigue Reactor Water Environmental Effects Analyses," July 1, 2005

24. Structural Integrity Associates Calculation No. VY-16Q-306, Revision 0, "Fatigue Analysis of Recirculation Outlet Nozzle."

| Structural Integrity Associates, Inc. CALCULATION PACKAGE | File No.: VY-19Q-301<br>Project No.: VY-19Q |
|---|---|

**PROJECT NAME:**

Provide VY Support for Questions Related to Environmental Fatigue Analyses

**CONTRACT NO.:**

10163217

| CLIENT: | PLANT: |
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| Entergy Nuclear Operations, Inc. | Vermont Yankee |

**CALCULATION TITLE:**

Design Inputs and Methodology for ASME Code Confirmatory Fatigue Usage Analysis of Reactor Feedwater Nozzle

| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
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## Table of Contents



## List of Tables



## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation package is to establish the design inputs and methodology to be used for an ASME Code, Section III fatigue usage calculation of the reactor pressure vessel (RPV) feedwater (FW) nozzle at Vermont Yankee Nuclear Power Station (VYNPS).

## 2.0 METHODOLOGY

A detailed fatigue usage analysis of the FW nozzle will be performed using the methodology of Subarticle NB-3200 of Section III of the ASME Code [1]. The analysis will be used as a confirmatory analysis for comparison with a previous fatigue usage analysis that was done using simplified methods. Therefore, only the fatigue portion of the ASME Code methodology will be used, and the analysis will be a fatigue assessment only, and not a complete ASME Code analysis.

Finite element analysis will be performed using a previously-developed axisymmetric finite element model (FEM) of the FW nozzle. Thermal transient analysis will be performed using the FEM for each defined transient. Concurrent with the thermal transients are pressure and piping interface loads; for these loads, unit load analyses (finite element analysis for pressure, and manual calculations for piping loads) will be performed. The stresses from these analyses will be scaled appropriately based on the magnitude of the pressure and piping loads during each thermal transient, and combined with stresses from the thermal transients. Additional scaling of pressure stresses will be performed to account for nozzle corner contour effects (i.e., the effects of approximating the nozzle-to-RPV intersection of two cylinders with an axisymmetric model). Other stress concentration factors (SCFs) will be applied as appropriate.

All six components of the stress tensor will be used for stress calculations. The stress components for the non-axisymmetric loads (shear and moment piping loads) can have opposite signs depending upon which side of the nozzle is being examined. Therefore, when combining stress components from these loads with stress components from thermal transients and other loads, the signs of the stress components will be adjusted to maximize the magnitude of the stress component ranges.

The fatigue analysis will be performed at previously-examined locations for direct comparison of results. Stresses will be linearized at these locations. The linearized primary plus secondary membrane plus bending stress will be used to determine the value of $K_e$ to be used in the simplified elastic-plastic analysis in accordance with ASME Code NB-3200 methodology. Environmental fatigue multipliers will be applied in accordance with NUREG/CR-6583 [15].

# 3.0 ASSUMPTIONS/DESIGN INPUTS

## 3.1 Assumptions

*3.1.1 Power uprate effects are considered as being applied to the entire period of operation. The higher pressures, flows, and temperatures at uprate conditions are used in determining and applying heat transfer coefficients [3, Section 3.2] [2, Section 3.1].*

*3.1.2 The Boltup transient [2, Tables 1 and 2] analysis does not affect the FW nozzle and is therefore excluded from the transients analyzed.*

*3.1.3 Where the flow rates in the thermal cycle diagram are at a value not calculated in Table 2, the next highest flow rate heat transfer coefficient will be used. This results in a higher heat transfer coefficient and is therefore conservative.*

*3.1.4 The effect of non-uniform geometries is judged to be insignificant for flow inside the safe end, because of the smooth transition and small geometry changes as shown in Figure 6. The smaller inner diameter (9.669") at the safe end was used to calculate heat transfer coefficients, resulting in a higher flow velocity and therefore conservative values.*

*3.1.5 The annulus leakage flow rate used is 31 GPM for EPU conditions [3, Section 3.2].*

*3.1.6 Density and Poisson's ratio used in the FEM are assumed typical values of $\rho = 0.283$ lb/in$^3$ and 0.3, respectively.*

*3.1.7 For purposes of linearizing stress at the nozzle corner, the effect of the cladding is conservatively neglected.*

*3.1.8 Stress components due to piping loads are scaled assuming no stress occurs at an ambient temperature of 70°F and the full values are reached at reactor design temperature, 575°F, as was done in the previous analysis [2, Section 3.4].*

## 3.2 ASME Code Edition

The analysis will be performed in a manner consistent with the fatigue usage rules in NB-3200 of Section III of the ASME Code; the 1998 Edition with Addenda through 2000 [1] will be used, for consistency with the previous analysis [2].

## 3.3 Transients

Previously developed thermal and pressure transients [2, Section 3.1 and Tables 1 and 2] are used for this analysis. The transients to be evaluated are shown in Table 1. For each transient, the time, nozzle fluid temperature ($T_{noz}$), RPV pressure, percent FW flow rate, and number of cycles are included. In some cases, flow rates and $T_{noz}$ values from the nozzle thermal cycle diagram [10, Attachment 1, p. 3] are used to reduce excess conservatism. Note that the only difference between the nozzle corner and the safe end transients in the referenced document is the length of the steady state time increment used at the end of the transients. These steady state periods are not included in Table 1; the analyst will use a value greater than or equal to the largest steady time increment from the referenced document.

At the inside surface of the RPV, the Region A temperature from the reactor thermal cycle diagram [10, Attachment 1, p. 2] shall be applied. Table 1 also includes these values as $T_{RPV}$.

## Table 1: Transients

| Transient | Time, sec | $T_{noz}$, °F | $T_{RPV}$, °F | P, psig | FW Flow, % | Cycles |
|---|---|---|---|---|---|---|
| 1. Boltup | 0 | 70 | 70 | 0 | 0% | 123 |
| 2. Design Hydrotest | 0 | 70 | 70 | 0 | 0% | 120 |
| | 1080 | 100 | 100 | 0 | 0% | |
| | 1680 | 100 | 100 | 1100 | 0% | |
| | 5280 | 100 | 100 | 1100 | 0% | |
| | 5880 | 100 | 100 | 50 | 0% | |
| 3. Startup | 0 | 100 | 100 | 50 | 0% | 300 |
| | 16164 | 549 | 549 | 1010 | 0% | |
| 4. Turbine Roll and Increased to Rated Power | 0 | 549 | 549 | 1010 | 0% | 300 |
| | 1 | 100 | 549 | 1010 | 25%* | |
| | 1801 | 100 | 549 | 1010 | 25%* | |
| | 1802 | 260 | 549 | 1010 | 25%* | |
| | 3602 | 392 | 549 | 1010 | 100% | |
| 5. Daily Reduction 75% Power | 0 | 392 | 549 | 1010 | 100% | 10,000 |
| | 900 | 310 | 549 | 1010 | 100%* | |
| | 2700 | 310 | 549 | 1010 | 100%* | |
| | 3600 | 392 | 549 | 1010 | 100% | |
| 6. Weekly Reduction 50% Power | 0 | 392 | 549 | 1010 | 100% | 2,000 |
| | 1800 | 280 | 549 | 1010 | 100%* | |
| | 3600 | 280 | 549 | 1010 | 100%* | |
| | 5400 | 392 | 549 | 1010 | 100% | |
| 9. Turbine Trip at 25% Power | 0 | 392 | 549 | 1010 | 100% | 10 |
| | 1800 | 265 | 549 | 1010 | 100% | |
| | 1980 | 265 | 549 | 1010 | 25%* | |
| | 2340 | 90 | 549 | 1010 | 25%* | |
| | 2520 | 90 | 549 | 1010 | 25%* | |
| | 3420 | 265 | 549 | 1010 | 25%* | |
| | 3600 | 265 | 549 | 1010 | 100% | |
| | 5400 | 392 | 549 | 1010 | 100% | |
| 10. FW Heater Bypass | 0 | 392 | 549 | 1010 | 100% | 70 |
| | 90 | 265 | 549 | 1010 | 100% | |
| | 1890 | 265 | 549 | 1010 | 100% | |
| | 2070 | 392 | 549 | 1010 | 100% | |

| Transient | Time, sec | $T_{noz}$, °F | $T_{RPV}$, °F | P, psig | FW Flow, % | Cycles |
|---|---|---|---|---|---|---|
| 11. Loss of FW Pumps | 0 | 392 | 549 | 1010 | 100% | 10 |
| | 1 | 565 | 565 | 1010 | 0% | |
| | 3.5 | 565 | 565 | 1190 | 0% | |
| | 4.5 | 50 | 565 | 1184.5 | 40% | |
| | 13.5 | 50 | 565 | 1135 | 40% | |
| | 184.5 | 50 | 565 | 1135 | 40% | |
| | 1564.5 | 440 | 565 | 1135 | 0% | |
| | 1565.5 | 565 | 565 | 1135 | 0% | |
| | 2165.5 | 565 | 565 | 1135 | 0% | |
| | 2166.5 | 50 | 565 | 1135 | 40%* | |
| | 2346.5 | 50 | 532 | 885 | 40%* | |
| | 5406.5 | 440 | 549 | 1055 | 0% | |
| | 5407.5 | 549 | 549 | 1055 | 0% | |
| | 6727.5 | 565 | 565 | 1135 | 0% | |
| | 6728.5 | 50 | 565 | 1135 | 25%* | |
| | 7148.5 | 50 | 502 | 675 | 25%* | |
| | 7448.5 | 300 | 502 | 675 | 0% | |
| | 11048.5 | 400 | 400 | 232 | 0% | |
| | 16411.5 | 549 | 549 | 885 | 0% | |
| | 16412.5 | 549 | 549 | 1010 | 0% | |
| | 18212.5 | 549 | 549 | 1010 | 0% | |
| | 18213.5 | 100 | 549 | 1010 | 25%* | |
| | 20013.5 | 100 | 549 | 1010 | 25%* | |
| | 20014.5 | 260 | 549 | 1010 | 25%* | |
| | 21814.5 | 392 | 549 | 1010 | 100% | |
| 12/13/15. Turbine Generator Trip, Reactor Overpressure, Other SCRAMs | 0 | 392 | 549 | 1010 | 100% | 289 |
| | 10 | 392 | 565/600** | 1135/1375** | 100% | |
| | 15 | 392 | 565/600** | 1135/1375** | 100% | |
| | 30 | 392 | 539 | 940 | 100% | |
| | 90 | 275 | 539 | 940 | 25%* | |
| | 990 | 100 | 539 | 940 | 25%* | |
| | 2790 | 100 | 539 | 940 | 25%* | |
| | 2791 | 260 | 539 | 940 | 100% | |
| | 3210 | 291 | 549 | 1010 | 100% | |
| | 4591 | 392 | 549 | 1010 | 100% | |
| 14. SRV Blowdown | 0 | 392 | 549 | 1010 | 100% | 1 |
| | 60 | 275 | 531.6 | 885 | 100% | |
| | 960 | 100 | 365 | 50 | 25%* | |
| 19. Reduction to 0% Power | 0 | 392 | 549 | 1010 | 100% | 300 |
| | 1800 | 265 | 549 | 1010 | 25%* | |
| 20. Hot Standby (Heatup Portion) | 0 | 265 | 549 | 1010 | 25%* | 300 |
| | 1 | 440 | 549 | 1010 | 0% | |
| | 3925 | 549 | 549 | 1010 | 0% | |
| 20A. Hot Standby (FW Injection Portion) | 0 | 549 | 549 | 1010 | 0% | 300 |
| | 1 | 100 | 549 | 1010 | 25% | |
| | 181 | 100 | 549 | 1010 | 25% | |
| | 241 | 290 | 549 | 1010 | 0% | |
| | 451 | 549 | 549 | 1010 | 25% | |
| 21-23. Shutdown | 0 | 549 | 549 | 1010 | 25%* | 300 |
| | 6264 | 375 | 375 | 50 | 25%* | |
| | 6864 | 330 | 330 | 50 | 25%* | |
| | 15144 | 100 | 100 | 50 | 0% | |

| Transient | Time, sec | $T_{noz}$, °F | $T_{RPV}$, °F | P, psig | FW Flow, % | Cycles |
|---|---|---|---|---|---|---|
| 24. Hydrostatic Test | 0 | 100 | 100 | 50 | 0% | 1 |
| | 600 | 100 | 100 | 1563 | 0% | |
| | 1200 | 100 | 100 | 1563 | 0% | |
| | 1800 | 100 | 100 | 50 | 0% | |
| 25. Unbolt | 0 | 100 | 100 | 0 | 0% | 123 |
| | 1080 | 70 | 70 | 0 | 0% | |

* Flow rate is conservatively rounded up to one of the three flow rates considered (25%, 40%, 100%).
** The second value applies for one cycle; the first value applies for the rest of the cycles.

### 3.4 Heat Transfer Coefficients, Condensation

When steam floods a relatively cold component, the steam condenses on the component surface. Holman [5, p. 413] gives the following equation for average heat transfer coefficient:

$$\bar{h} = 0.555\ \{\rho(\rho - \rho_v)gk^3h'_{fg}/[\mu D(T_g - T_w)]\}^{1/4}$$ , where

$\rho$ = mass density of liquid,
$\rho_v$ = mass density of vapor,
g = acceleration of gravity,
k = conductivity of liquid at average temperature,
$h'_{fg} = h_{fg} + 0.68c(T_g - T_w)$,
$h_{fg}$ = heat of condensation at vapor temperature,
c = specific heat of liquid at average temperature,
$T_g$ = saturated vapor temperature = $T_{final}$,
$T_w$ = pipe inner wall temperature = $T_{initial}$,
$\mu$ = viscosity of liquid at average temperature
D = inner diameter of pipe

The portion of the equation inside the brackets, $\rho(\rho - \rho_v)gk^3h'_{fg}/[\mu D(T_g - T_w)]$, has the following units:

$$\frac{\cancel{(lbm)^2}}{(ft^3)^2}\ \frac{\cancel{(ft)}}{(sec^2)}\ \frac{(Btu)^3}{(hr\text{-}ft\text{-}°F)^3}\ \frac{(Btu)}{\cancel{(lbm)}}\ \frac{(ft\text{-}hr)}{\cancel{(lbm)}\ \cancel{(ft)}\ (°F)}$$

$$\frac{(Btu^4)}{(ft^6)\ \cancel{(sec^2)}\ (hr^3\text{-}ft^3\text{-}°F^3)}\ \frac{(ft\text{-}\cancel{hr})}{(°F)}\ \frac{(3600^2\ \cancel{sec^2})}{(hr^{\cancel{2}})}$$

$$\frac{12960000\ Btu^4}{hr^4\text{-}ft^8\text{-}°F^4}$$

After taking the fourth root, this becomes 60 Btu/hr-ft²-°F. Steam properties are interpolated at $T_g$, and water properties are interpolated at $T_f$, which is taken as the average of $T_g$ and $T_w$. Then, $h'_{fg}$ and heat transfer coefficient $\bar{h}$ are calculated for each set of steam properties, water properties, $T_g$ and $T_w$. Tables 2 and 3 list selected properties of liquid water [12, Table 1-8] and saturated steam [13], respectively.

**Table 2: Properties of Liquid Water**

| T, °F | ρ, lbm/ft³ | c, Btu/lbm-°F | μ, lbm/ft-hr | ν, ft²/sec | k, Btu/hr-ft-°F |
|---|---|---|---|---|---|
| 300 | 57.3 | 1.03 | 0.468 | 2.27E-06 | 0.395 |
| 400 | 53.6 | 1.08 | 0.335 | 1.74E-06 | 0.382 |
| 500 | 49.0 | 1.19 | 0.252 | 1.43E-06 | 0.349 |
| 600 | 42.4 | 1.51 | 0.208 | 1.37E-06 | 0.293 |

**Table 3: Properties of Saturated Steam**

| $T_g$, °F | $v_g$, ft³/lbm | $h_{fg}$, Btu/lbm |
|---|---|---|
| 545 | 0.4449 | 649.6 |
| 550 | 0.4249 | 641.6 |
| 565 | 0.3703 | 616.4 |

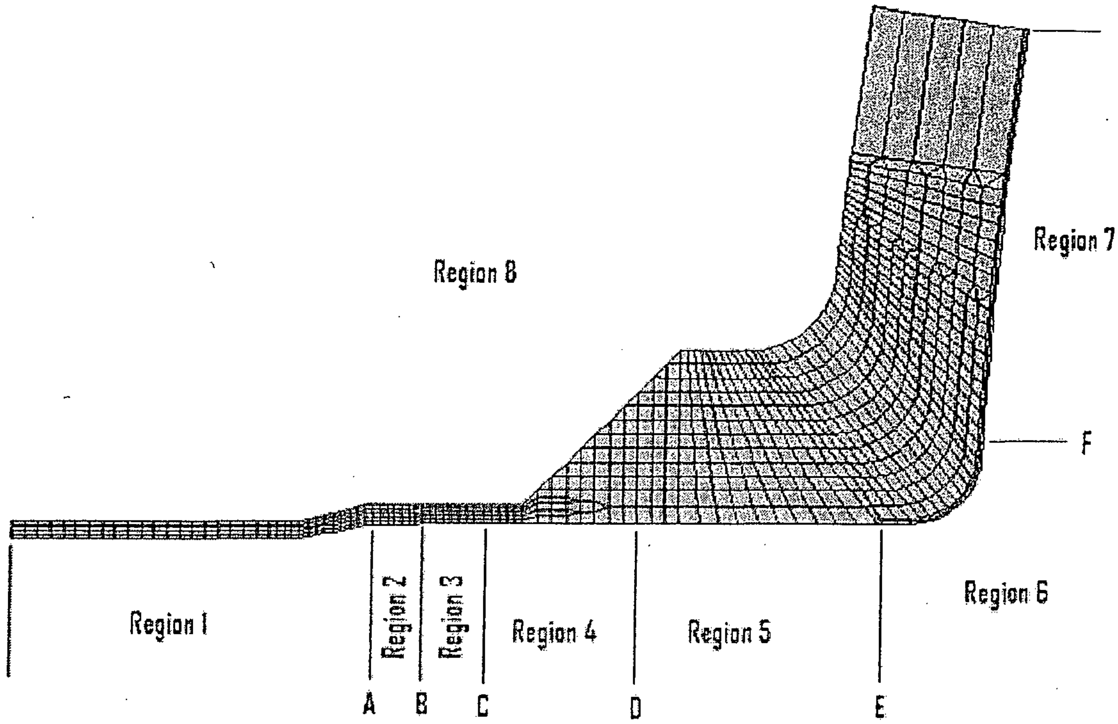
### 3.5 Heat Transfer Coefficients, Forced Flow and Natural Circulation

Table 4 summarizes the force flow and natural circulation heat transfer coefficients to be used in the analysis [3, Section 3.2.1]. For each flow rate, values are taken at 300°F as in the previous analysis. These values are within 11% of the maximum values for a given flow rate, and are more than 30% greater than the minimum values for a given flow rate [3, Table 4] [4, Tables 4 and 5]. Therefore, the use of heat transfer coefficients at 300°F is bounding for the most severe transients, which occur at a wide range of temperatures. Figure 1 illustrates the heat transfer coefficient regions [4, Figure 6].

**Table 4: Forced Flow and Natural Circulation Heat Transfer Coefficients, Btu/hr-ft²-°F**

| Region | 100% flow | 40% flow | 25% flow | 0% flow, water |
|---|---|---|---|---|
| 1 | 3705 | 1780 | 1222 | 144 |
| 2 | * | * | * | * |
| 3 | 1489 | 743 | 504 | 109 |
| 4 | * | * | * | * |
| 5 | 177 | 89 | 60 | 12 |
| 6 | * | * | * | * |
| 7 | 864 | 864 | 864 | 864 |
| 8 | 0.2 | 0.2 | 0.2 | 0.2 |

* Linearly transition between the values for the adjacent regions.




Notes: Point A: End of thermal sleeve = Node 204 = 0.25" from feedwater inlet side of thermal sleeve flat.
Point B: Beginning of annulus = Node 252.
Point C: Beginning of thermal sleeve transition = approximately 4.0" from Point A = Node 294.
Point D: End of thermal sleeve transition = approximately 9.5" from Point A = Node 387.
Point E: End of inner nozzle corner (nozzle side) = Node 553.
Point F: End of inner nozzle corner (vessel wall side) = Node 779.

**Figure 1: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries**

### 3.6 Finite Element Model

The ANSYS program [6] will be used to perform the finite element analysis. A previously-developed axisymmetric model will be used [4, file FW.INP], except that temperature-dependent material properties will be used. Table 5 shows the applicable material properties [14].

## Table 5: Temperature-Dependent Material Properties

| Material No. | Description | Temperature, °F | Young's Modulus, E x $10^6$ (psi) | Mean Coefficient of Thermal Expansion, $\alpha$ x $10^{-6}$ (in/in-°F) | Conductivity, k (BTU/hr-ft-°F) (see Note 1) | Diffusivity, d (ft²/hr) | Specific Heat, $c_p$ (BTU/lbm-°F) (see Note 5) |
|---|---|---|---|---|---|---|---|
| 1 | SA533 Grade B, | 70 | 27.8 | 6.4 | 23.5 | 0.458 | 0.105 |
| | A508 Class II | 200 | 27.1 | 6.7 | 23.6 | 0.425 | 0.114 |
| | (see Note 2) | 300 | 26.7 | 6.9 | 23.4 | 0.401 | 0.119 |
| | | 400 | 26.1 | 7.1 | 23.1 | 0.378 | 0.125 |
| | | 500 | 25.7 | 7.3 | 22.7 | 0.356 | 0.130 |
| | | 600 | 25.2 | 7.4 | 22.2 | 0.336 | 0.135 |
| 2 | SS Clad | 70 | 28.3 | 8.5 | 8.6 | 0.151 | 0.116 |
| | (see Note 3) | 200 | 27.6 | 8.9 | 9.3 | 0.156 | 0.122 |
| | | 300 | 27.0 | 9.2 | 9.8 | 0.160 | 0.125 |
| | | 400 | 26.5 | 9.5 | 10.4 | 0.165 | 0.129 |
| | | 500 | 25.8 | 9.7 | 10.9 | 0.170 | 0.131 |
| | | 600 | 25.3 | 9.8 | 11.3 | 0.174 | 0.133 |
| 3 | A508 Class I | 70 | 29.3 | 6.4 | 35.1 | 0.695 | 0.103 |
| | (see Note 4) | 200 | 28.6 | 6.7 | 33.6 | 0.613 | 0.112 |
| | | 300 | 28.1 | 6.9 | 32.3 | 0.561 | 0.118 |
| | | 400 | 27.5 | 7.1 | 30.9 | 0.512 | 0.123 |
| | | 500 | 27.1 | 7.3 | 29.5 | 0.472 | 0.128 |
| | | 600 | 26.5 | 7.4 | 28.0 | 0.433 | 0.132 |
| 4 | A106 Grade B | 70 | 29.3 | 6.4 | 35.1 | 0.695 | 0.103 |
| | (see Note 4) | 200 | 28.6 | 6.7 | 33.6 | 0.613 | 0.112 |
| | | 300 | 28.1 | 6.9 | 32.3 | 0.561 | 0.118 |
| | | 400 | 27.5 | 7.1 | 30.9 | 0.512 | 0.123 |
| | | 500 | 27.1 | 7.3 | 29.5 | 0.472 | 0.128 |
| | | 600 | 26.5 | 7.4 | 28.0 | 0.433 | 0.132 |

Notes:
1. Convert to BTU/sec-in-°F for input to ANSYS.
2. Properties of A508 Class II are used (3/4Ni-1/2Mo-1/3Cr-V).
3. Properties of 18Cr - 8Ni austenitic stainless steel are used.
4. Composition = C-Si; k and d for plain carbon steel are used [11].
5. Calculated as $[k/(\rho d)]/12^3$.

Stresses will be extracted and linearized at two locations, both on the inside surface. The critical safe end location is Node 192, which has the highest stress intensity due to thermal loading under high flow conditions [3, Section 4.0 and Figures 6 and 7]. The corresponding linearization path is from Node 192 to Node 187 (Figure 2 [3, Figure 7]).

The critical nozzle corner location is Node 657 at the base metal of the nozzle, chosen based upon the highest pressure stress [3, Section 4.0 and Figures 8 and 9]. The corresponding linearization path is from Node 657 to Node 645 (Figure 3 [3, Figure 9]).

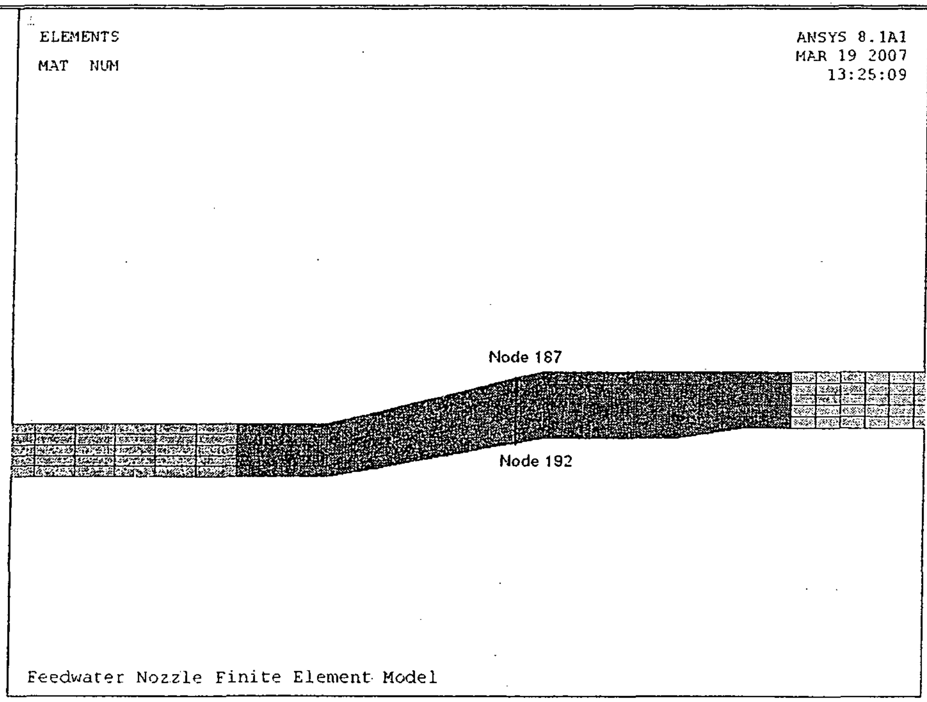



**Figure 2: Safe End Linearization Path**

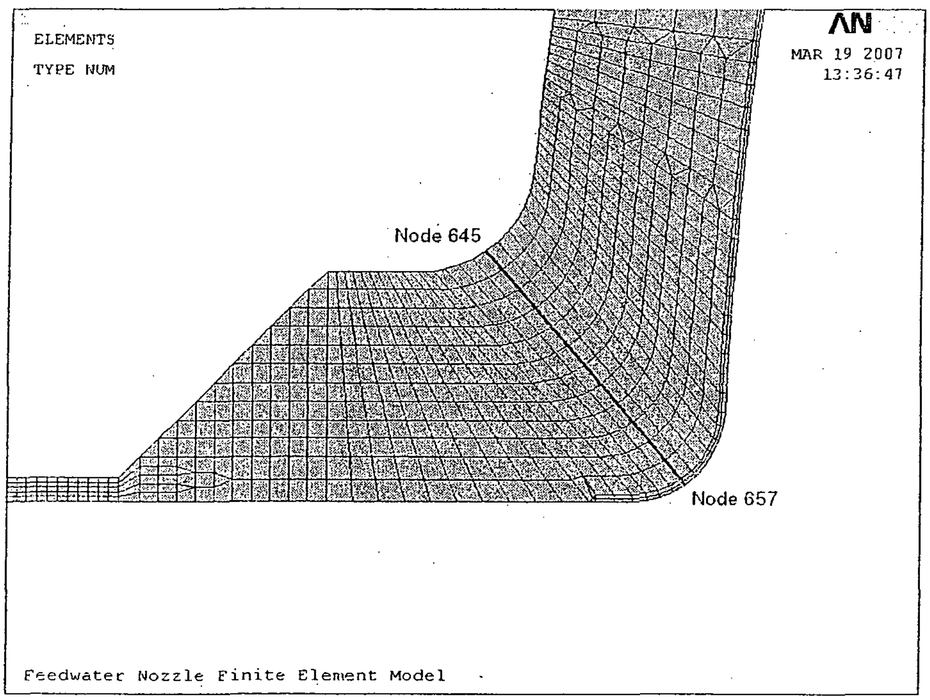



**Figure 3: Nozzle Corner Linearization Path**

### 3.7 Nozzle Corner Effects

The axisymmetric model has the effect of modeling the cylindrical RPV as spherical. To partially counter the resulting reduction in stress in the RPV wall, the radius in the model was increased by a factor of 1.5 [3, p. 8]. This yields a general membrane stress that equals the average of the hoop and axial stress for the cylinder.

Stresses from the axisymmetric analysis will need to be increased to account for the three-dimensional (3-D) geometry. A factor of 1.333 has been established in a previous calculation package that modeled the nozzle [3, p. 9], to achieve an overall pressure multiplication of 2.0. This is consistent with the maximum value used in prior VYNPS analyses [7, Appendix A, p. 4-10].

No other SCF is required at the nozzle corner inside surface, since this location has no stress riser.

### 3.8 Piping Interface Loads

The previous analysis of the FW nozzle calculated membrane axial and shear stresses due to the piping interface loads by closed form solution, then combined them into stress intensities for the two locations of interest [2, Section 3.4]. All shear stresses were treated as existing in the same plane.

In this analysis, the stress components are recalculated in Section 4.3 taking into account through-wall distribution. Forces and moments are taken from the same reference as before [8, Table 3].

### 3.9 SCFs, Safe End

In the previous analysis, an SCF of 1.34 was used for the safe end location for all load conditions [2]. That value was obtained from the original design basis evaluation for the FW nozzle. For the current analysis, the SCF is updated to reflect modern-day ASME Code fatigue usage analysis methodology for consistency with the rest of the evaluation.

At the safe end inside surface, guidance is taken from the piping analysis rules in Subarticle NB-3600 of Section III of the ASME Code [1]. These rules specify stress indices $C_1$, $C_2$, and $C_3$, which are applied to nominal stress to yield primary plus secondary membrane plus bending stress (P+Q); and $K_1$, $K_2$, and $K_3$, which are applied to nominal stress along with the C factors to yield total stress (P+Q+F). The subscripts indicate the type of loading: 1 for pressure, 2 for moments, and 3 for thermal transients. Stress indices for a reducer are used.

Section 4.3 contains calculations of the safe end SCFs. For stresses due to piping loads, the moment stress indices $C_2$ and $K_2$ are applied to the nominal stress components at the safe end. For pressure stresses, the ANSYS model is sufficient to account for the effects of gross structural discontinuity such that $C_1$ is not needed. To account for the effects of local structural discontinuity, $K_1$ is applied to the linearized P+Q stress to yield P+Q+F. These factors are conservatively applied to all six components of the stress tensor.

For thermal stresses, $C_3$ and $K_3$ are given as 1.0 [1, Table NB-3681(a)-1]; therefore, no SCF is required.

### 3.10 Environmental Fatigue Multipliers

The environmental fatigue multipliers for the safe end and nozzle corner will be calculated in accordance with NUREG/CR-6583 methodology [15].

## 4.0 CALCULATIONS

### 4.1 Heat Transfer Coefficients, Condensation

Condensation heat transfer coefficients are calculated with the formula shown in Section 3.4 for times during which the nozzle is filled with steam at Region A temperature [10, Attachment 1, p. 3]. This is done in the sheet labeled "Condensation" in Excel workbook *VY-19Q-301.xls* in the project computer files. The highest heat transfer coefficient values for the transient temperature range are used. These are provided in Table 6.

**Table 6: Condensation Heat Transfer Coefficients, Btu/hr-ft²-°F**

| Region | 0% flow, steam |
|---|---|
| 1 | 598 |
| 2 | * |
| 3 | 1515 |
| 4 | * |
| 5 | 874 |
| 6 | * |
| 7 | ** |
| 8 | ** |

* Linearly transition between the values for the adjacent regions.
** Use values from Table 4, since these are bounding and there is no change in temperature.

### 4.2 Piping Interface Loads

From general structural mechanics, the membrane plus bending stresses at the inside surface of a thick-walled cylinder are:

$\sigma_{z1}$ = axial stress due to axial force = $F_z/A$
$\sigma_{z2}$ = axial stress due to bending moment = $M_{xy}(ID/2)/I$
$\sigma_z = \sigma_{z1} + \sigma_{z2}$
$\tau_{r\theta}$ = shear stress due to torsion = $M_z(ID/2)/J$
$\tau_{rz}$ = shear stress due to shear force = $2F_{xy}/A$, where

$F_x$, $F_y$, $F_z$, $M_x$, $M_y$, and $M_z$ are forces and moments at the pipe-to-safe end weld
$M_{xL}$ = moment about x axis translated by length z = -L = $M_x - F_y L$
$M_{yL}$ = moment about y axis translated by length z = -L = $M_y + F_x L$
$M_{xy}$ = resultant bending moment = $(M_{xL}^2 + M_{yL}^2)^{0.5}$
$F_{xy}$ = resultant shear force = $(F_x^2 + F_y^2)^{0.5}$

ID, OD = inside and outside diameters
A = area of cross section = $(\pi/4)(OD^2 - ID^2)$

I = moment of inertia = $(\pi/64)(OD^4 - ID^4)$
J = polar moment of inertia = $(\pi/32)(OD^4 - ID^4)$

Figure 4 shows the coordinate system for the forces and moments [8, Figure 1]. The shear stresses are expressed in a local coordinate system with r radial (X in ANSYS coordinates), θ circumferential (Z in ANSYS coordinates), and Z axial (Y in ANSYS coordinates). Table 7 shows the calculation of stresses; ID, OD, and L are taken from the previous piping load stress calculations [2, Section 3.4]. Forces and moments are taken from the same reference as before, except that signs are chosen to maximize stress [8, Table 3].

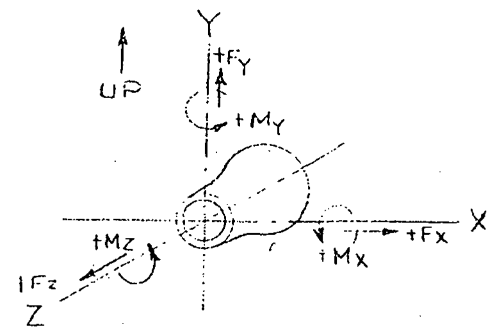



**Figure 4: Coordinate System for Forces and Moments**

**Table 7: Membrane Plus Bending Stresses Due to Piping Loads**

| | Safe End | Nozzle Corner |
|---|---|---|
| $F_x$, kip | 3.00 | 3.00 |
| $F_y$, kip | -15.00 | -15.00 |
| $F_z$, kip | 3.20 | 3.20 |
| $M_x$, kip-in | 336.00 | 336.00 |
| $M_y$, kip-in | 156.00 | 156.00 |
| $M_z$, kip-in | 480.00 | 480.00 |
| L, in | 12.09 | 27.57 |
| $M_{xL}$, kip-in | 517.31 | 749.58 |
| $M_{yL}$, kip-in | 192.26 | 238.72 |
| $M_{xy}$, kip-in | 551.88 | 786.67 |
| $F_{xy}$, kip-in | 15.30 | 15.30 |
| OD, in | 11.86 | 22.67 |
| ID, in | 10.409 | 10.750 |
| A, $in^2$ | 25.28 | 312.73 |
| I, $in^4$ | 393.28 | 12300.41 |
| J, $in^4$ | 786.55 | 24600.82 |
| $\sigma_{z1}$, ksi | 0.127 | 0.010 |
| $\sigma_{z2}$, ksi | 7.304 | 0.344 |
| $\sigma_z$, ksi | 7.430 | 0.354 |
| $\tau_{r\theta}$, ksi | 3.176 | 0.105 |
| $\tau_{rz}$, ksi | 1.210 | 0.098 |

### 4.3 SCFs, Safe End

Figure 5 shows the geometry parameters used in calculating stress indices for reducers [1, Figure NB-3683.6-1], and Figure 6 shows the feedwater nozzle safe end geometry [9]. Comparing the two figures gives the following values:

$L_1$ = 0", $r_1$ = 0.75", $D_1$ = 12.000", $t_1$ = (12 – 10.515)/2 = 0.7425"
$L_2$ = 0", $r_2$ = 0.75", $D_2$ = 10.840", $t_2$ = (10.840 – 9.669)/2 = 0.5855"
$\alpha$ = 10°
($L_1$ and $L_2$ are taken as zero because the location of interest is on the radius of curvature.)

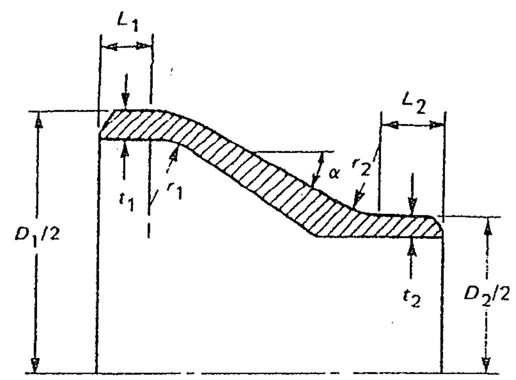



**Figure 5: Reducer Geometry Parameters**

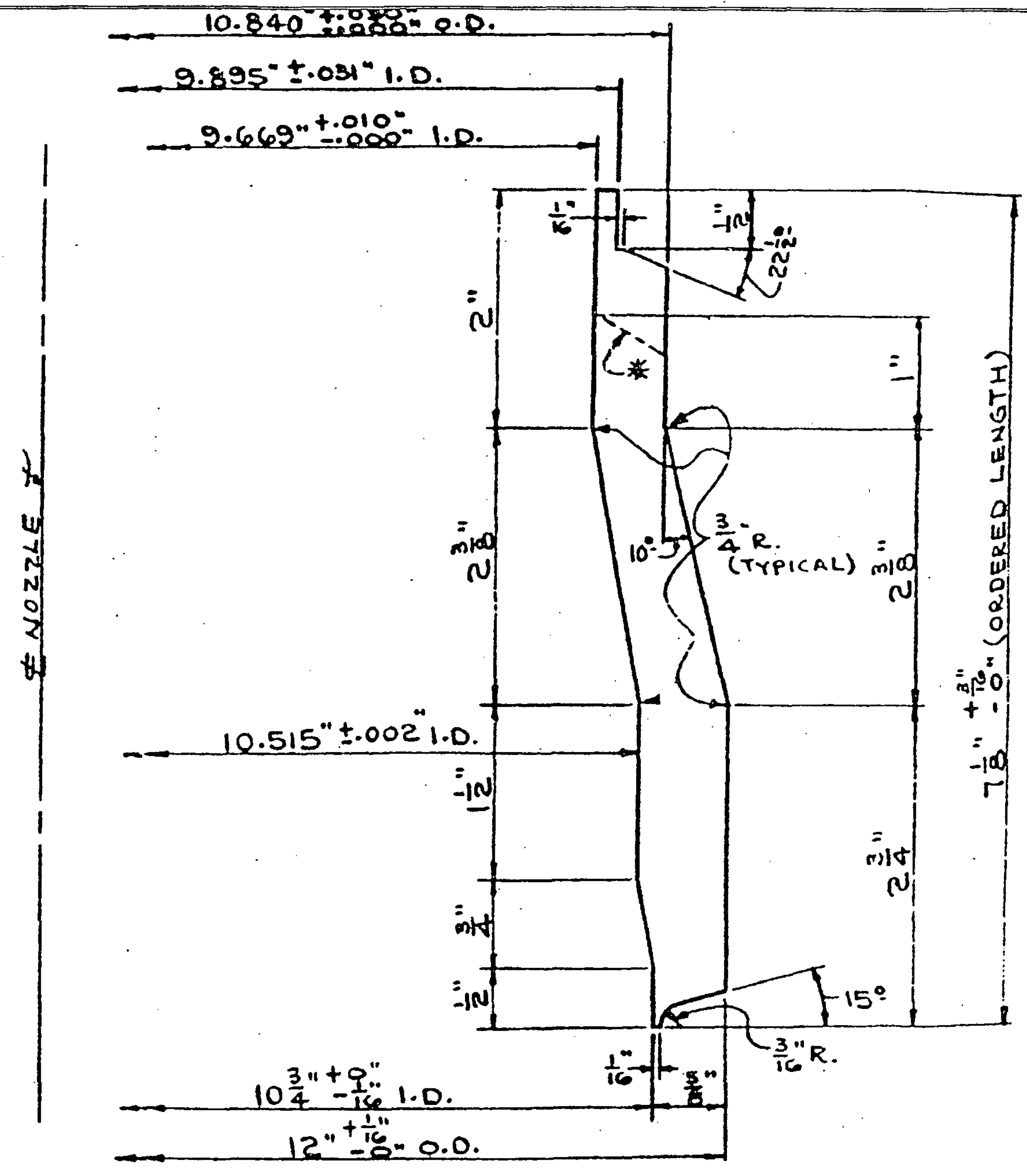



Figure 6: FW Nozzle Safe End Geometry

Equations for stress indices are taken from the ASME Code [1, NB-3683.6]. For $K_1$ and $K_2$, since the location of interest is not on a weld, the equation for flush welds is used:

$$K_1 = K_2 = 1.1 - 0.1\ L_m/(D_m\ t_m)^{0.5}, \text{ where}$$

$$L_m/(D_m\ t_m)^{0.5} = \text{the lesser of } L_1/(D_1\ t_1)^{0.5} \text{ and } L_2/(D_2\ t_2)^{0.5}$$

Since $L_1 = L_2 = 0$, one finds:

$$K_1 = K_2 = 1.1 - 0.1\ (0) = 1.1$$

Since $r_1$ and $r_2$ are less than $0.1D_1$, $C_2$ is given as:

$$C_2 = 1.0 + 0.0185\ \alpha\ (D_n/t_n)^{0.5}, \text{ where}$$

$$D_n/t_n = \text{the larger of } D_1/t_1 \text{ and } D_2/t_2$$

The bounding D/t value is $D_2/t_2 = 10.840/0.5855 = 18.514$, so that:

$$C_2 = 1.0 + 0.0185\ (10)\ (18.514)^{0.5} = 1.796$$
$$C_2\ K_2 = 1.796\ (1.1) = 1.976$$

## 5.0 RESULTS OF ANALYSIS

This calculation package specifies the ASME Code edition, finite element model, thermal and pressure transients (Table 1), and heat transfer coefficients (Tables 4 and 6) to be used in a fatigue usage analysis of the FW nozzle at VYNPS. Thermal transient and pressure stress components will be calculated using ANSYS, and piping load stress components are calculated herein using closed form solutions (Table 7).

Linearized stress components at Nodes 192 (safe end inside surface) and 657 (nozzle corner inside surface) will be used for the fatigue usage analysis. At the nozzle corner, P+Q and P+Q+F pressure stress components will be increased by a factor of 1.333. For the nozzle corner location, the stresses used in the evaluation shall be for the base metal only; that is, the cladding material should be unselected prior to stress extraction. At the safe end, linearized P+Q pressure stress components will be multiplied by 1.1 to yield P+Q+F pressure stress components, and nominal stress components due to piping loads are multiplied by 1.796 to yield P+Q stress components and 1.976 to yield P+Q+F stress components.

The fatigue usage analysis will consider all six stress components, and will be performed using the NB-3200 rules of Section III of the ASME Code [1]. Calculated fatigue usage factors will be multiplied by the overall $F_{en}$ of 1.74 for the safe end [2, Section 5.0] and values to be developed in a subsequent calculation package, to be assigned file number VY-19Q-303, for the nozzle corner.

## 6.0 REFERENCES


1. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection NB, 1998 Edition with Addenda through year 2000.

2. SI Calculation Package, *Fatigue Analysis of Feedwater Nozzle*, Revision 0, SI File No. VY-16Q-302.

3. SI Calculation Package, *Feedwater Nozzle Stress History Development for Greens Functions*, Revision 0, SI File No. VY-16Q-301.

4. SI Calculation Package, *Feedwater Nozzle Finite Element Model and Heat Transfer Coefficients*, Revision 0, SI File No. VY-10Q-301.

5. Holman, J.P., *Heat Transfer*, Fifth Edition, McGraw-Hill, 1981.

6. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004. (Listed for reference only; this program is not used in this calculation package.)

7. Entergy Document VYC-378, Revision 0, *Vermont Yankee Reactor Cyclic Limits for Transient Events*, SI File No. VY-05Q-211.

8. GE Drawing No. 919D294, Revision 11, Sheet 7, *Reactor Vessel, Spec. Control*, SI File No. VY-05Q-241.

9. Ebasco Drawing 5920-234R1, 08/03/67, *Safe End Detail for Nozzles MK. N4A THRU N4D*, (CB&I Contract 9-6201, Drawing #M14, Revision 0, 05/02/67), SI File No. VY-05Q-215.

10. Entergy Document EC No. 1773, Revision 0 (Design Input Revision 1), *Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station*, SI File No. VY-16Q-209.

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| Structural Integrity Associates, Inc. CALCULATION PACKAGE | File No.: VY-19Q-302 Project No.: VY-19Q |
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**PROJECT NAME:**

Provide VY Support for Questions Related to Environmental Fatigue Analyses

**CONTRACT NO.:**

10163217

| CLIENT: | PLANT: |
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| Entergy Nuclear Operations, Inc. | Vermont Yankee Nuclear Power Station |

**CALCULATION TITLE:**

ASME Code Confirmatory Fatigue Evaluation of Reactor Feedwater Nozzle

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## Table of Contents



## List of Tables



## List of Figures

## 1.0 OBJECTIVE

The objective of this calculation package is to perform an ASME Code, Section III fatigue usage calculation for the reactor pressure vessel (RPV) feedwater (FW) nozzle at Vermont Yankee Nuclear Power Station (VYNPS).

## 2.0 METHODOLOGY

The methodology to be used for this evaluation was established in a previous calculation package [1], and is summarized herein. A previously-developed finite element model (FEM) is analyzed using the ANSYS program [2]. Thermal transient analysis is performed for each defined transient, and the thermal stresses are added to stresses due to pressure and piping loads, which are scaled based on the magnitudes of the pressure and piping loads. Stress concentration factors (SCFs) are applied as appropriate. All six components of the stress tensor are used for stress calculations.

The fatigue calculation is performed at previously-examined locations, and uses the methodology of Subarticle NB-3200 of Section III of the ASME Code [3]. Environmental fatigue usage analysis will be performed in a separate calculation package.

## 3.0 DESIGN INPUTS

### 3.1 Finite Element Analysis

A previous calculation package specifies all design input [1]. The FEM input file is taken from the previous analysis of the FW nozzle [4, file *FW.INP*], and modified to include temperature-dependent properties [1, Table 5]. The modified file is named *FW-GEOM.INP*, and is used as input to the files in which the thermal transient and stress analyses are performed. Figure 1 shows the FEM [4, Figure 4].

For the thermal transient ANSYS analysis, previously defined thermal transients [1, Table 1] are analyzed, applying heat transfer coefficients [1, Tables 4 and 6] as appropriate based on flow rate. Bounding reactor temperature is used for Transients 12/13/15 [1, Table 1], called Transient 13 herein. (In VESLFAT, Transient 13 is run separately since it has a higher reactor pressure.) For ramps during which the flow rate undergoes a ramp change [5, Attachment 1, p. 3], the set of heat transfer coefficients with the largest values is used. This is done because ANSYS always applies changes to the heat transfer coefficients as step changes, even if the temperature undergoes a ramp change.

Note that, for three time periods during Transient 11 [1, Table 1], the nozzle is filled with steam at Region A temperature [5, Attachment 1, p. 3, Note 1], such that heat transfer coefficients for condensation apply [1, Table 6]. Since it takes a finite amount of time for the water to drain and condensation to begin, the condensation heat transfer coefficients are not applied until the load step after the Region A temperature is reached.

Stress analysis is performed using the temperature distributions calculated in the thermal transient ANSYS analysis as input. At the vessel wall, Y displacement is set to zero, and X displacement is unconstrained, as was previously done [6, Figure 4]. At the FW pipe, Y displacement is coupled to account for the adjacent piping, as was previously done [6, files *FWS_VY_25.INP*, *FWS_VY_40.INP*, and *FWS_VY_100.INP*]. Figure 1 shows the locations of these boundary conditions.

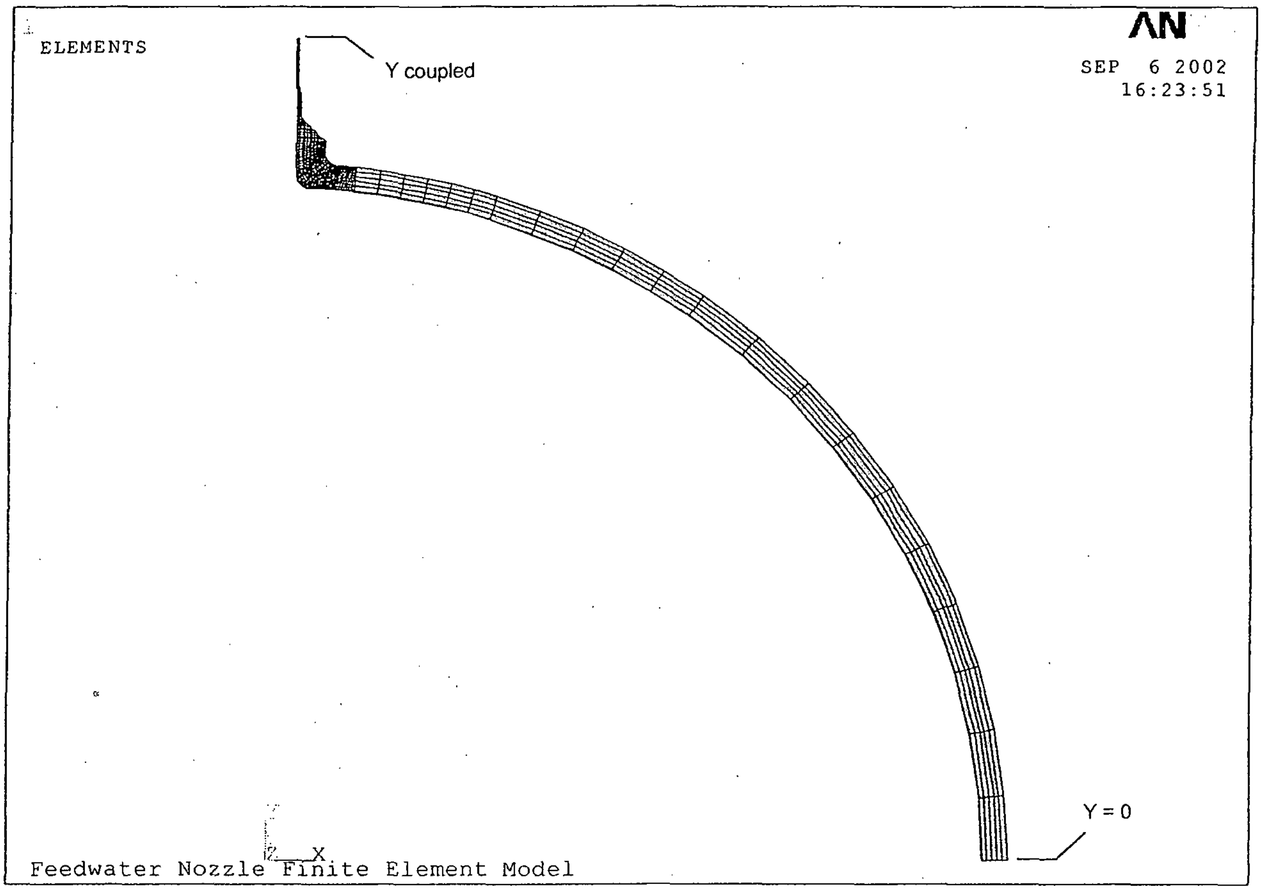


**Figure 1: ANSYS Finite Element Model**

All ANSYS input files, listed below, are saved in the project computer files:

*FW-GEOM.INP*: Geometry and material properties
*FW-HTBC.INP*: Set heat transfer boundary conditions
*TRAN02-T.INP, TRAN02-S.INP*: Transient 2, thermal and stress analysis
*TRAN03-T.INP, TRAN03-S.INP*: Transient 3, thermal and stress analysis
*TRAN04-T.INP, TRAN04-S.INP*: Transient 4, thermal and stress analysis
*TRAN05-T.INP, TRAN05-S.INP*: Transient 5, thermal and stress analysis
*TRAN06-T.INP, TRAN06-S.INP*: Transient 6, thermal and stress analysis
*TRAN09-T.INP, TRAN09-S.INP*: Transient 9, thermal and stress analysis
*TRAN10-T.INP, TRAN10-S.INP*: Transient 10, thermal and stress analysis
*TRAN11-T.INP, TRAN11-S.INP*: Transient 11, thermal and stress analysis
*TRAN13-T.INP, TRAN13-S.INP*: Transient 12/13/15, thermal and stress analysis

*TRAN14-T.INP, TRAN14-S.INP*: Transient 14, thermal and stress analysis
*TRAN19-T.INP, TRAN19-S.INP*: Transient 19, thermal and stress analysis
*TRAN20-T.INP, TRAN20-S.INP*: Transient 20, thermal and stress analysis
*TRAN20AT.INP, TRAN20AS.INP*: Transient 20A, thermal and stress analysis
*TRAN21-T.INP, TRAN21-S.INP*: Transient 21, thermal and stress analysis
*TRAN25-T.INP, TRAN25-S.INP*: Transient 25, thermal and stress analysis

### 3.2 Stress Calculation

Linearized stress components at Nodes 192 (safe end inside surface) and 657 (nozzle corner inside surface) are used for the fatigue usage analysis [1, Section 3.6], as shown in Figure 2 [6, Figures 7 and 9]. For the nozzle corner location, the stresses used in the evaluation are for the base metal only; that is, the cladding material is unselected prior to stress extraction. The stress components from the thermal stress analyses are combined with stress components due to pressure and piping loads. A unit pressure stress analysis was performed using ANSYS in a previous calculation package [6], and stress component results are taken from that analysis [6, files *PSE.OUT* and *PBLEND.OUT*]. Piping load stress components are taken from previous calculations using closed form solutions [1, Table 7].

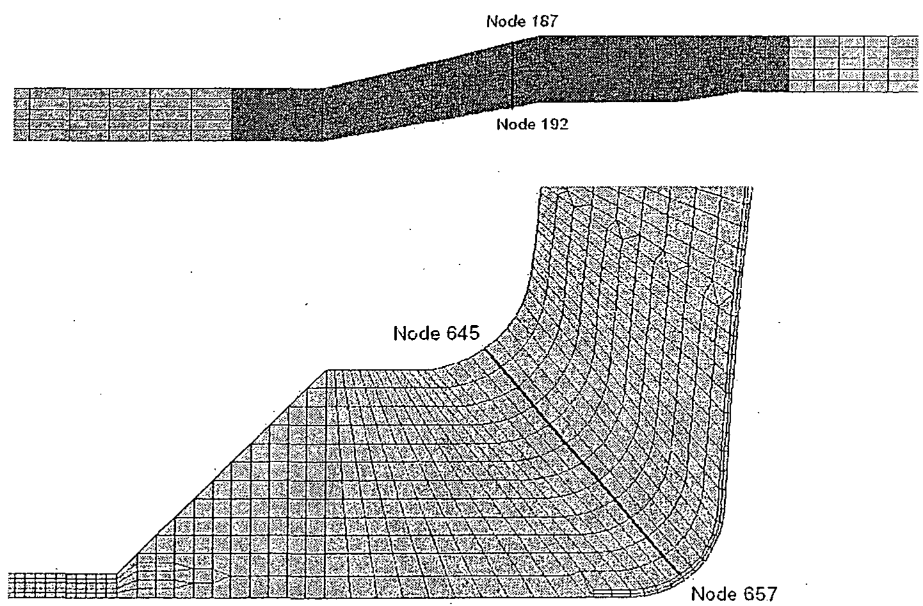


**Figure 2: Linearization Paths**

SCFs are applied to the pressure and piping load stress components to yield primary plus secondary membrane plus bending stress components (P+Q) and the total (primary plus secondary plus peak) stress components (P+Q+F) as specified in the methodology calculation package [1].

### 3.3 Fatigue Usage Analysis, General

The VESLFAT program [7] is used to perform the fatigue usage analysis in accordance with the fatigue usage portion of NB-3200 [3]. VESLFAT performs the analysis required by NB-3222.4(e) [3] for Service Levels A and B conditions defined by the user. The VESLFAT program computes the primary plus secondary and total stress ranges for all events and performs a correction for elastic-plastic analysis, if appropriate.

The program computes the stress intensity range based on the stress component ranges for all event pairs [3, NB-3216.2]. The program evaluates the stress ranges for primary plus secondary and primary plus secondary plus peak stress based upon six components of stress (3 direct and 3 shear stresses). If the primary plus secondary stress intensity range is greater than $3S_m$, then the total stress range is increased by the factor $K_e$, as described in NB-3228.5 [3]. The value of $S_m$ is specified as a function of temperature. The input maximum temperature for both states of a load set pair is used to determine the temperature upon which $S_m$ is determined from the user-defined values.

When more than one load set is defined for either of the event pair loadings, the stress differences are determined for all of the potential loadings, saving the maximum for the event pair, based on the pair producing the largest alternating total stress intensity ($S_{alt}$), including the effects of $K_e$. The principal stresses for the stress ranges are determined by solving for the roots of the cubic equation:

$$S^3 - (\sigma_x + \sigma_y + \sigma_z)S^2 + (\sigma_x \sigma_y + \sigma_y \sigma_z + \sigma_z \sigma_x - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2)S - (\sigma_x \sigma_y \sigma_z + 2\tau_{xy} \tau_{xz} \tau_{yz} - \sigma_z \tau_{xy}^2 - \sigma_y \tau_{xz}^2 - \sigma_x \tau_{yz}^2) = 0$$

The stress intensities for the event pairs are reordered in decreasing order of $S_{alt}$, including a correction for the ratio of modulus of elasticity (E) from the fatigue curve divided by E from the analysis. This allows a fatigue table to be created to eliminate the number of cycles available for each of the events of an event pair, allowing determination of fatigue usage per NB-3222.4(e) [3]. For each load set pair in the fatigue table, the allowable number of cycles is determined based on $S_{alt}$.

For the VYNPS FW nozzle analysis, transients that consist of both upward and downward temperature and pressure ramps are split so that each successive ramp is treated separately. Table 1 shows the transients as input to VESLFAT [1, Table 1]. The numbers of cycles in Table 1 are entered in VESLFAT input files *VFAT-1I.CYC* (safe end) and *VFAT-2I.CYC* (nozzle corner).

**Table 1: Transients as Input to VESLFAT**

| VESLFAT Load Set | Transient | Start Time, sec** | Temp. Change | Pressure Change | Cycles |
|---|---|---|---|---|---|
| 1 | 1_Boltup | 0 | None | None | * |
| 2 | 2_DesHydro1 | 0 | Upward | Upward | 120 |
| 3 | 2_DesHydro2 | 5280 | None | Downward | 120 |
| 4 | 3_Startup | 0 | Upward | Upward | 300 |
| 5 | 4_TurbRoll1 | 0 | Downward | None | 300 |
| 6 | 4_TurbRoll2 | 1801 | Upward | None | 300 |
| 7 | 5_DailyRed1 | 0 | Downward | None | 10,000 |
| 8 | 5_DailyRed2 | 2700 | Upward | None | 10,000 |
| 9 | 6_WklyRed1 | 0 | Downward | None | 2,000 |
| 10 | 6_WklyRed2 | 3600 | Upward | None | 2,000 |
| 11 | 9_TurbTrip1 | 0 | Downward | None | 10 |
| 12 | 9_TurbTrip2 | 2520 | Upward | None | 10 |
| 13 | 10_FWHByp1 | 0 | Downward | None | 70 |
| 14 | 10_FWHByp2 | 1890 | Upward | None | 70 |
| 15 | 11_LoFP1 | 0 | Upward | Upward | 10 |
| 16 | 11_LoFP2 | 3.5 | Downward | Downward | 10 |
| 17 | 11_LoFP3 | 184.5 | Upward | None | 10 |
| 18 | 11_LoFP4 | 2165.5 | Downward | Downward | 10 |
| 19 | 11_LoFP5 | 2346.5 | Upward | Upward | 10 |
| 20 | 11_LoFP6 | 6727.5 | Downward | Downward | 10 |
| 21 | 11_LoFP7 | 7148.5 | Upward | Downward | 10 |
| 22 | 11_LoFP8 | 11048.5 | Upward | Upward | 10 |
| 23 | 11_LoFP9 | 18212.5 | Downward | None | 10 |
| 24 | 11_LoFP10 | 20013.5 | Upward | None | 10 |
| 25 | 12_TGTrip1 | 0 | None | Upward | 288 |
| 26 | 12_TGTrip2 | 15 | Downward | Downward | 288 |
| 27 | 12_TGTrip3 | 2790 | Upward | Upward | 288 |
| 28 | 13_Overpr1 | 0 | None | Upward | 1 |
| 29 | 13_Overpr2 | 15 | Downward | Downward | 1 |
| 30 | 13_Overpr3 | 2790 | Upward | Upward | 1 |
| 31 | 14_SRVBlwdn | 0 | Downward | Downward | 1 |
| 32 | 19_RedTo0pct | 0 | Downward | None | 300 |
| 33 | 20_HSHeatup | 0 | Upward | None | 300 |
| 34 | 20A_HSFWInj1 | 0 | Downward | None | 300 |
| 35 | 20A_HSFWInj2 | 181 | Upward | None | 300 |
| 36 | 21_Shutdown | 0 | Downward | Downward | 300 |
| 37 | 24_HydroTest1 | 0 | None | Upward | 1 |
| 38 | 24_HydroTest2 | 1200 | None | Downward | 1 |
| 39 | 25_Unbolt | 0 | Downward | None | 123 |

* Since this transient does not affect the FW nozzle, it is not considered in the cyclic evaluation.

** Note that stress peaks may occur after the start of the subsequent ramp.

### 3.4 Material Properties, VESLFAT

Material properties are entered in VESLFAT input files *VFAT-1I.FDT* (safe end) and *VFAT-2I.FDT* (nozzle corner). Table 2 lists the temperature-dependent material properties used in the analysis [1, Table 5] [8], and Table 3 lists the fatigue curve for the nozzle and safe end materials [3, Appendix I, Table I-9.1 and Figure I-9.1]. VESLFAT automatically scales the stresses by the ratio of E on the fatigue curve to E in the analysis, for purposes of determining allowable numbers of cycles, as required by the ASME Code.

Other material properties are input as follows:

m = 3.0, n = 0.2, parameters used to calculate factor $K_e$, safe end [9]
m = 2.0, n = 0.2, parameters used to calculate factor $K_e$, nozzle corner [9]
E from fatigue curve = 30,000 ksi [3, Appendix I, Table I-9.1 and Figure I-9.1] [9]

**Table 2: Temperature-Dependent Material Properties, VESLFAT**

| Material | T, °F | E, psi | $S_m$, ksi | $S_y$, ksi |
|---|---|---|---|---|
| A508 Class I | 70 | $29.3(10)^6$ | 23.3 | 36.0 |
| (safe end) | 200 | $28.6(10)^6$ | 21.9 | 33.0 |
| | 300 | $28.1(10)^6$ | 21.3 | 31.8 |
| | 400 | $27.5(10)^6$ | 20.6 | 30.8 |
| | 500 | $27.1(10)^6$ | 19.4 | 29.3 |
| | 600 | $26.5(10)^6$ | 17.8 | 27.6 |
| A508 Class II | 70 | $27.8(10)^6$ | 26.7 | 50.0 |
| (nozzle) | 200 | $27.1(10)^6$ | 26.7 | 47.0 |
| | 300 | $26.7(10)^6$ | 26.7 | 45.5 |
| | 400 | $26.1(10)^6$ | 26.7 | 44.2 |
| | 500 | $25.7(10)^6$ | 26.7 | 43.2 |
| | 600 | $25.2(10)^6$ | 26.7 | 42.1 |

**Table 3: Carbon/Low Alloy Steel Fatigue Curve**

| Number of Cycles | $S_a$, ksi |
|---|---|
| 10 | 580 |
| 20 | 410 |
| 50 | 275 |
| 100 | 205 |
| 200 | 155 |
| 500 | 105 |
| 1,000 | 83 |
| 2,000 | 64 |
| 5,000 | 48 |
| 10,000 | 38 |
| 20,000 | 31 |
| 50,000 | 23 |
| 100,000 | 20 |
| 200,000 | 16.5 |
| 500,000 | 13.5 |
| 1,000,000 | 12.5 |

## 4.0 CALCULATIONS

Table 4 contains the stress components at the locations of interest for the 1,000 psi pressure case [6, files *PSE.OUT* and *PBLEND.OUT*] and for the piping loads [1, Table 7], corresponding to a reactor temperature of 575°F [1, Section 3.1.8].

**Table 4: Stress Components Before SCF, psi**

| Loading | Type | Node | $S_x$ | $S_y$ | $S_z$ | $S_{xy}$ | $S_{xz}$ | $S_{yz}$ |
|---|---|---|---|---|---|---|---|---|
| Unit | Membrane | 192 | -810.7 | 6116 | 7853 | -450.1 | 0 | 0 |
| Pressure, | plus Bending | 657 | -705.2 | 1198 | 24020 | -3590 | 0 | 0 |
| 1,000 psi | Total | 657 | -705.2 | 985.5 | 27590 | -121.1 | 0 | 0 |
| Piping Loads | Nominal | 192 | 0 | 7430 | 0 | 1210 | 3176 | 0 |
| at 575°F | | 657 | 0 | 354 | 0 | 98 | 105 | 0 |

SCFs are applied to the pressure and piping load stress components to yield P+Q and P+Q+F stress components as follows [1]:

Pressure:

Safe end (Node 192):

Membrane plus bending from ANSYS equals P+Q

Membrane plus bending from ANSYS is multiplied by 1.1 to yield P+Q+F

Nozzle corner (Node 657):

Membrane plus bending from ANSYS is multiplied by 1.333 to yield P+Q

Total stress from ANSYS is multiplied by 1.333 to yield P+Q+F

Piping Loads:

Safe end (Node 192):

Nominal stresses are multiplied by 1.796 to yield P+Q

Nominal stresses are multiplied by 1.976 to yield P+Q+F

Nozzle corner (Node 657):

Nominal stresses are used as is for P+Q and P+Q+F

Table 5 shows the stress components with SCFs. The piping load stress components are applied as having negative signs, to yield the largest stress component ranges.

**Table 5: Stress Components With SCF, psi**

| | | Membrane plus Bending | | | | | | Total | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | Node | $S_x$ | $S_y$ | $S_z$ | $S_{xy}$ | $S_{xz}$ | $S_{yz}$ | $S_x$ | $S_y$ | $S_z$ | $S_{xy}$ | $S_{xz}$ | $S_{yz}$ |
| Pressure | 192 | -811 | 6116 | 7853 | -450 | 0 | 0 | -892 | 6728 | 8638 | -495 | 0 | 0 |
| | 657 | -940 | 1597 | 32019 | -4785 | 0 | 0 | -940 | 1314 | 36777 | -161 | 0 | 0 |
| Piping | 192 | 0 | 13344 | 0 | 2173 | 5704 | 0 | 0 | 14682 | 0 | 2391 | 6276 | 0 |
| | 657 | 0 | 354 | 0 | 98 | 105 | 0 | 0 | 354 | 0 | 98 | 105 | 0 |

The calculations of VESLFAT stress input are automated in Excel workbooks *VFAT-1I.XLS* (safe end) and *VFAT-2I.XLS* (nozzle). These files are organized with sheets labeled as follows:

- Overview: Contains general information.

- Other Stresses: Contains calculation of pressure and piping load as shown in Tables 4 and 5.
- Rearranger: There are 16 Rearranger sheets, one for each transient as analyzed by ANSYS. In these sheets, thermal stresses are copied from Excel workbook *StressResults.xls*, which contains the results of the ANSYS stress linearization for each transient, and rearranged to conform to VESLFAT input format (including switching the shear stress components $S_{xz}$ and $S_{yz}$ as required by VESLFAT). Time-varying scale factors for the piping loads (based on FW nozzle fluid temperature) and pressure are determined, and used to scale the unit load stresses, which are then added to the thermal stresses. Time-varying pressure is also included in the VESLFAT stress input. The VESLFAT stress input also includes time-varying metal temperature, from the ANSYS output, which is used to determine temperature-dependent properties from the values in Table 2.
- VESLFAT: Contains the VESLFAT stress input, obtained from sheets named Rearranger. Load set numbers are entered on this sheet, as defined in Table 1. These sheets are saved to VESLFAT input files *VFAT-1I.STR* (safe end) and *VFAT-2I.STR* (nozzle corner). To avoid double counting of stress states, the initial time steps of each load set before the first stress peak are not included.

The files with extension STR are edited if necessary to remove some intermediate stress points, since VESLFAT has a limit of 3,000 total stress states.

## 5.0 RESULTS OF ANALYSIS

Tables 6 and 7 give the detailed fatigue usage results for the safe end and the nozzle corner, respectively, from VESLFAT output files *VFAT-1I.FAT* (safe end) and *VFAT-2I.FAT* (nozzle corner). All VESLFAT input and output files are saved in the project computer files.

**Table 6: Fatigue Usage Results for Safe End**

| Load Set A | Load Set B | n | $S_n$, psi | $K_e$ | $S_{alt}$, psi | N | Usage |
|---|---|---|---|---|---|---|---|
| 15 11_LoFP1 | 18 11_LoFP4 | 10 | 61435 | 1.115 | 57352 | 2836.19 | 0.0035 |
| 20 11_LoFP6 | 27 12_TGTrip3 | 10 | 49698 | 1 | 40800 | 8098.01 | 0.0012 |
| 27 12_TGTrip3 | 34 20A_HSFWInj1 | 278 | 42194 | 1 | 37182 | 10769 | 0.0258 |
| 30 13_Overpr3 | 34 20A_HSFWInj1 | 1 | 42194 | 1 | 37182 | 10769 | 0.0001 |
| 33 20_HSHeatup | 34 20A_HSFWInj1 | 21 | 42563 | 1 | 35966 | 12060 | 0.0017 |
| 5 4_TurbRoll1 | 33 20_HSHeatup | 279 | 43986 | 1 | 35597 | 12491 | 0.0223 |
| 6 4_TurbRoll2 | 23 11_LoFP9 | 10 | 39882 | 1 | 32197 | 17579 | 0.0006 |
| 5 4_TurbRoll1 | 6 4_TurbRoll2 | 21 | 39842 | 1 | 32178 | 17615 | 0.0012 |
| 16 11_LoFP2 | 35 20A_HSFWInj2 | 10 | 40708 | 1 | 31762 | 18413 | 0.0005 |
| 35 20A_HSFWInj2 | 37 24_HydroTest1 | 1 | 20956 | 1 | 13081 | 664055 | 0.0000 |
| 17 11_LoFP3 | 35 20A_HSFWInj2 | 10 | 20399 | 1 | 12667 | 887275 | 0.0000 |
| 19 11_LoFP5 | 35 20A_HSFWInj2 | 10 | 19602 | 1 | 12135 | infinite | 0.0000 |
| | | | | | | TOTAL = | 0.0571 |

**Table 7: Fatigue Usage Results for Nozzle Corner**

| Load Set A | Load Set B | n | $S_n$, psi | $K_e$ | $S_{alt}$, psi | N | Usage |
|---|---|---|---|---|---|---|---|
| 2 2_DesHydro1 | 16 11_LoFP2 | 10 | 65109 | 1 | 46047 | 5655.78 | 0.0018 |
| 2 2_DesHydro1 | 20 11_LoFP6 | 10 | 50344 | 1 | 43990 | 6477.19 | 0.0015 |
| 2 2_DesHydro1 | 18 11_LoFP4 | 10 | 50150 | 1 | 43205 | 6832.83 | 0.0015 |
| 2 2_DesHydro1 | 11 9_TurbTrip1 | 10 | 65712 | 1 | 43011 | 6924.58 | 0.0014 |
| 2 2_DesHydro1 | 5 4_TurbRoll1 | 80 | 64296 | 1 | 43008 | 6925.97 | 0.0116 |
| 5 4_TurbRoll1 | 39 25_Unbolt | 123 | 63308 | 1 | 41430 | 7738.36 | 0.0159 |
| 3 2_DesHydro2 | 5 4_TurbRoll1 | 97 | 61437 | 1 | 40391 | 8343.98 | 0.0116 |
| 3 2_DesHydro2 | 23 11_LoFP9 | 10 | 63138 | 1 | 40101 | 8524.36 | 0.0012 |
| 3 2_DesHydro2 | 34 20A_HSFWInj1 | 13 | 49069 | 1 | 39657 | 8810.73 | 0.0015 |
| 34 20A_HSFWInj1 | 38 24_HydroTest2 | 1 | 49097 | 1 | 39622 | 8833.38 | 0.0001 |
| 34 20A_HSFWInj1 | 36 21_Shutdown | 286 | 49111 | 1 | 39616 | 8837.88 | 0.0324 |
| 26 12_TGTrip2 | 36 21_Shutdown | 14 | 60379 | 1 | 38556 | 9578.4 | 0.0015 |
| 21 11_LoFP7 | 26 12_TGTrip2 | 10 | 49395 | 1 | 33091 | 16015 | 0.0006 |
| 26 12_TGTrip2 | 31 14_SRVBlwdn | 1 | 42902 | 1 | 27518 | 28831 | 0.0000 |
| 22 11_LoFP8 | 26 12_TGTrip2 | 10 | 32212 | 1 | 24687 | 40237 | 0.0002 |
| 4 3_Startup | 26 12_TGTrip2 | 253 | 30212 | 1 | 23513 | 46728 | 0.0054 |
| 4 3_Startup | 29 13_Overpr2 | 1 | 30212 | 1 | 23513 | 46728 | 0.0000 |
| 4 3_Startup | 28 13_Overpr1 | 1 | 28966 | 1 | 19423 | 111118 | 0.0000 |
| 4 3_Startup | 32 19_RedTo0pct | 45 | 24083 | 1 | 17665 | 156402 | 0.0003 |
| 32 19_RedTo0pct | 33 20_HSHeatup | 255 | 18765 | 1 | 12883 | 761835 | 0.0003 |
| 13 10_FWHByp1 | 33 20_HSHeatup | 45 | 19637 | 1 | 12679 | 879615 | 0.0001 |
| 13 10_FWHByp1 | 35 20A_HSFWInj2 | 25 | 20388 | 1 | 12624 | 914934 | 0.0000 |
| 35 20A_HSFWInj2 | 37 24_HydroTest1 | 1 | 19850 | 1 | 12359 | infinite | 0.0000 |
| 9 6_WklyRed1 | 35 20A_HSFWInj2 | 274 | 19341 | 1 | 11952 | infinite | 0.0000 |
| | | | | | | TOTAL = | 0.0889 |

## 6.0 CONCLUSIONS AND DISCUSSIONS

A previously-developed FEM was analyzed using the ANSYS program. Thermal transient analysis was performed for each defined transient, and the thermal stresses were added to stresses due to pressure and piping loads, which were scaled based on the magnitudes of the pressure and piping loads. SCFs were applied as appropriate. All six components of the stress tensor were used for stress calculations. The fatigue calculation was performed at previously-examined locations, and used the methodology of Subarticle NB-3200 of Section III of the ASME Code.

The 60-year CUF for the safe end location was determined to be 0.0571, and the CUF for the nozzle corner location was determined to be 0.0889. Both values are less than the ASME Code allowable value of 1.0.

Environmental fatigue usage analysis will be performed in a separate calculation package.

## 7.0 REFERENCES


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| Document Revision | Affected Pages | Revision Description | Project Manager Approval Signature & Date | Preparer(s) & Checker(s) Signatures & Date |
|---|---|---|---|---|
| 0 | 1 - 7 | Initial issue. | Terry J. Herrmann 01/30/2008 [signature] | Gary L. Stevens 01/30/2008 [signature] Terry J. Herrmann 01/30/2008 [signature] |

## Table of Contents



## List of Tables

## 1.0 INTRODUCTION

The purpose of this calculation is to perform a plant-specific evaluation of reactor water environmental effects for the reactor pressure vessel (RPV) feedwater nozzle identified in NUREG/CR-6260 [1] for the older vintage General Electric (GE) plant for the Vermont Yankee Nuclear Power Station (VY).

## 2.0 APPROACH

Per Chapter X, "Time-Limited Aging Analyses Evaluation of Aging Management Programs Under 10 CFR 54.21(c)(1)(iii)," Section X.M1, "Metal Fatigue of Reactor Coolant Pressure Boundary," of the Generic Aging Lessons Learned (GALL) Report [2], detailed, vintage-specific, fatigue calculations are required for plants applying for license renewal for the locations identified for the appropriate vintage plant in NUREG/CR-6260.

In this calculation, detailed environmentally assisted fatigue (EAF) calculations are performed for VY for one of the locations associated with the older vintage GE plant in NUREG/CR-6260. The older-vintage GE plant is the appropriate comparison to VY since the original piping design at VY was in accordance with USAS B31.1 [3], as well as the fact that the older-vintage boiling water reactor (BWR) in NUREG/CR-6260 was a BWR-4 plant, which is the same as VY.

Entergy performed an initial assessment of EAF effects for VY in their License Renewal Application (LRA) that was submitted to the NRC in January 2006. Table 4.3-3 of the VY LRA provides the results of those evaluations. All but two of the VY locations evaluated for EAF in the LRA did not yield acceptable results for 60 years of operation, as they were based on generic analysis results from NUREG/CR-6260 that were not VY-specific. Plant-specific analyses have been recently completed to address those components for VY. Relevant chemistry input for this calculation is contained in Reference [5]. This calculation documents the EAF evaluation for the feedwater nozzle locations.

## 3.0 METHODOLOGY

Per Section X.M1 of the GALL Report [2], the EAF evaluation must use the appropriate $F_{en}$ relationships from NUREG/CR-6583 [4] (for carbon/low alloy steels), which are the materials under consideration for the feedwater nozzle. Per Figure 2 and Table 2 of Reference [6], the two locations being evaluated are the feedwater nozzle safe end (carbon steel) and the feedwater nozzle forging corner (low alloy steel). Based on the materials of these locations, the appropriate expressions are:

*For Carbon Steel [4, p. 69]:* $$F_{en} = \exp(0.585 - 0.00124T' - 0.101 S^* T^* O^* \dot{\varepsilon}^*) \quad (1)$$

Substituting T' = 25°C in the above expression, as required by NUREG/CR-6583 to relate room temperature air data to service temperature data in water [7], the following is obtained:

$$F_{en} = \exp(0.585 - 0.00124(25°C) - 0.101\, S^*\, T^*\, O^* \dot{\varepsilon}^*) \quad (2)$$

$$= \exp(0.554 - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*) \quad (3)$$

*For Low Alloy Steel [4, p. 69]:* $$F_{en} = \exp(0.929 - 0.00124T' - 0.101 S^* T^* O^* \dot{\varepsilon}^*) \quad (4)$$

Substituting T' = 25°C in the above expression, as required by NUREG/CR-6583 to relate room temperature air data to service temperature data in water [7], the following is obtained:

$$F_{en} = \exp(0.929 - 0.00124(25°C) - 0.101\, S^*\, T^*\, O^* \dot{\varepsilon}^*) \quad (5)$$

$$= \exp(0.898 - 0.101\, S^*\, T^*\, O^* \dot{\varepsilon}^*) \quad (6)$$

where [4, pp. 60 and 65]:

| | | |
|---|---|---|
| $F_{en}$ | = | fatigue life correction factor |
| $S^*$ | = | S for 0 < sulfur content, S ≤ 0.015 wt. % |
| | = | 0.015 for S > 0.015 wt. % |
| $T^*$ | = | 0 for T < 150°C |
| | = | (T - 150) for 150 ≤ T ≤ 350°C |
| T | = | fluid service temperature (°C) |
| $O^*$ | = | 0 for dissolved oxygen, DO < 0.05 parts per million (ppm) |
| | = | ln(DO/0.04) for 0.05 ppm ≤ DO ≤ 0.5 ppm |
| | = | ln(12.5) for DO > 0.5 ppm |
| $\dot{\varepsilon}^*$ | = | 0 for strain rate, $\dot{\varepsilon}^*$ > 1%/sec |
| | = | ln($\dot{\varepsilon}^*$) for 0.001 ≤ $\dot{\varepsilon}^*$ ≤ 1%/sec |
| | = | ln(0.001) for $\dot{\varepsilon}^*$ < 0.001%/sec |

Bounding $F_{en}$ values were determined in Reference [5]. The values determined in Table 3 of Reference [5] will be used for the carbon steel feedwater nozzle safe end location, where feedwater DO levels are low and the $F_{en}$ value is a constant value of 1.74 for all temperatures for both hydrogen water chemistry (HWC) and normal water chemistry (NWC) conditions. For the low alloy steel nozzle corner location, the applicable $F_{en}$ values are shown in Table 4 of Reference [5]. Since there is a significant variation in values with temperature, $F_{en}$ values will be computed for each load pair in the detailed fatigue calculation for this location.

The environmental fatigue is determined as $U_{env}$ = (U) ($F_{en}$), where U is the original fatigue usage and $U_{env}$ is the environmentally assisted fatigue (EAF) usage factor. All calculations can be found in Excel spreadsheet "*VY-19Q-303 (Env. Fat. Calcs).xls*" associated with this calculation.

From Table 1 of Reference [5], the following water chemistry input applies for the low alloy steel nozzle corner location:

- Over the 60-year operating life of the plant, HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time.
- For the RPV Upper Region, which is applicable to the nozzle corner location, DO is 114 ppb pre-HWC and 97 ppb post-HWC.

With these assumptions, the cumulative usage factor (CUF) values documented in this calculation are considered applicable for sixty years of operation including all relevant EAF and EPU effects.

## 4.0 CALCULATIONS

From Table 6 of Reference [6], the CUF for the safe end for 60 years of operation is 0.0571. Thus, the EAF CUF for 60 years is 0.0571 x 1.74 = 0.0994, which is less than the allowable value of 1.0 and is therefore acceptable.

The CUF for the nozzle corner for 60 years of operation is shown in Table 7 of Reference [6], and has a value of 0.0889. This calculation is reproduced in Table 1, along with EAF calculations on a load pair basis using the $F_{en}$ expression in Equation (6) above for low alloy steel. The final EAF CUF for 60 years is 0.3531, which is less than the allowable value of 1.0 and is therefore acceptable. The overall Fen multiplier for this location is 3.97.

## 5.0 CONCLUSIONS

In this calculation, EAF calculations were performed in accordance with the GALL Report [2] for the feedwater nozzle safe end (carbon steel) and nozzle corner (low alloy steel) locations. These locations were selected based on the locations identified in NUREG/CR-6260 for the older vintage GE plant and plant-specific fatigue calculations that determined the limiting locations for VY. Calculations for the remaining NUREG/CR-6260 locations are documented in other calculations.

The EAF results for the locations identified above indicate that the fatigue usage factors, including environmental effects, are within the allowable value for 60 years of operation. The calculations for both locations make use of the 60-year projected cycles for VY and incorporate EPU effects (conservatively assumed to apply for all 60 years of operation). Therefore, no additional evaluation is required for these components, and the GALL requirements are satisfied.

## 6.0 REFERENCES


1. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.
2. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.
3. USAS B31.1.0 – 1967, USA Standard Code for Pressure Piping, "Power Piping," American Society of Mechanical Engineers, New York.
4. NUREG/CR-6583 (ANL-97/18), "Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels," March 1998.
5. SI Calculation Package, *Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head*, Revision 0, SI File No. VY-16Q-303.
6. SI Calculation Package, *ASME Code Confirmatory Fatigue Evaluation of Reactor Feedwater Nozzle*, Revision 0, SI File No. VY-19Q-302.
7. EPRI/BWRVIP Memo No. 2005-271, "Potential Error in Existing Fatigue Reactor Water Environmental Effects Analyses," July 1, 2005.

# Table 1: EAF Calculations for the Feedwater Nozzle Corner

CUF Calculation from Table 7 of Reference [6]:

| Index | Load #1 | Description #1 | $n_1$ (cycles) | Load #2 | Description #2 | $n_2$ (cycles) | n (cycles) | $S_n$ (psi) | $K_e$ | $S_{alt}$ (psi) | $N_{allow}$ | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2_DesHydro1 | 120 | 16 | 11_LoFP2 | 10 | 10 | 65,109 | 1.000 | 46,047 | 5,655.78 | 0.00177 |
| 2 | 2 | 2_DesHydro1 | 110 | 20 | 11_LoFP6 | 10 | 10 | 50,344 | 1.000 | 43,990 | 6,477.19 | 0.00154 |
| 3 | 2 | 2_DesHydro1 | 100 | 18 | 11_LoFP4 | 10 | 10 | 50,150 | 1.000 | 43,204 | 6,632.83 | 0.00146 |
| 4 | 2 | 2_DesHydro1 | 90 | 11 | 9_TurbTrip1 | 10 | 10 | 55,712 | 1.000 | 43,011 | 6,924.58 | 0.00144 |
| 5 | 2 | 2_DesHydro1 | 80 | 5 | 4_TurbRoll1 | 300 | 80 | 64,296 | 1.000 | 43,008 | 6,925.97 | 0.01155 |
| 6 | 5 | 4_TurbRoll1 | 220 | 39 | 25_Unbolt | 123 | 123 | 63,306 | 1.000 | 41,430 | 7,738.36 | 0.01589 |
| 7 | 3 | 2_DesHydro2 | 120 | 5 | 4_TurbRoll1 | 97 | 97 | 61,437 | 1.000 | 40,391 | 8,343.98 | 0.01163 |
| 8 | 3 | 2_DesHydro2 | 23 | 23 | 11_LoFP9 | 10 | 10 | 63,138 | 1.000 | 40,101 | 8,524.36 | 0.00117 |
| 9 | 3 | 2_DesHydro2 | 13 | 34 | 20A_HSFWInj1 | 300 | 13 | 49,069 | 1.000 | 39,957 | 8,810.73 | 0.00148 |
| 10 | 34 | 20A_HSFWInj1 | 287 | 38 | 24_HydroTest2 | 1 | 1 | 49,097 | 1.000 | 39,522 | 8,833.38 | 0.00011 |
| 11 | 34 | 20A_HSFWInj1 | 285 | 36 | 21_Shutdown | 300 | 286 | 49,111 | 1.000 | 39,616 | 8,837.88 | 0.03236 |
| 12 | 26 | 12_TGTrip2 | 288 | 36 | 21_Shutdown | 14 | 14 | 60,379 | 1.000 | 38,556 | 9,579.40 | 0.00146 |
| 13 | 21 | 11_LoFP7 | 10 | 26 | 12_TGTrip2 | 274 | 10 | 49,395 | 1.000 | 33,991 | 16,015.00 | 0.00062 |
| 14 | 26 | 12_TGTrip2 | 264 | 31 | 14_SRVBlwdn | 1 | 1 | 42,902 | 1.000 | 27,518 | 28,831.00 | 0.00003 |
| 15 | 22 | 11_LoFP8 | 10 | 26 | 12_TGTrip2 | 263 | 10 | 32,212 | 1.000 | 24,667 | 40,237.00 | 0.00025 |
| 16 | 4 | 3_Startup | 300 | 26 | 12_TGTrip2 | 253 | 253 | 30,212 | 1.000 | 23,513 | 46,728.00 | 0.00541 |
| 17 | 4 | 3_Startup | 47 | 29 | 13_Overpr2 | 1 | 1 | 30,212 | 1.000 | 23,513 | 46,728.00 | 0.00002 |
| 18 | 4 | 3_Startup | 46 | 28 | 13_Overpr1 | 1 | 1 | 28,966 | 1.000 | 19,423 | 111,113.00 | 0.00001 |
| 19 | 4 | 3_Startup | 45 | 32 | 19_RedTo0pct | 300 | 45 | 24,083 | 1.000 | 17,665 | 156,402.00 | 0.00029 |
| 20 | 32 | 19_RedTo0pct | 255 | 33 | 20_HSHeatup | 300 | 255 | 18,765 | 1.000 | 12,683 | 761,835.00 | 0.00033 |
| 21 | 13 | 10_FWHByp1 | 70 | 33 | 20_HSHeatup | 45 | 45 | 19,637 | 1.000 | 12,679 | 879,615.00 | 0.00005 |
| 22 | 13 | 10_FWHByp1 | 25 | 35 | 20A_HSFWInj2 | 300 | 25 | 20,388 | 1.000 | 12,624 | 914,934.00 | 0.00003 |
| 23 | 35 | 20A_HSFWInj2 | 275 | 37 | 24_HydroTest1 | 1 | 1 | 19,850 | 1.000 | 12,359 | infinite | 0.00000 |
| 24 | 9 | 6_WklyRed1 | 2000 | 35 | 20A_HSFWInj2 | 274 | 274 | 19,341 | 1.000 | 11,952 | infinite | 0.00000 |
| | | | | | | | | | | | Total, $U_{59}$ = | 0.08893 |

EAF Calculations:

| | HWC DO | NWC DO | |
|---|---|---|---|
| | 97 | 114 | ppb |
| % HWC = | 47% | 53% | = % NWC |

| $T_{MAX}$ (°F) [1] | $T_{MAX}$ (°C) | HWC $F_{en}$ [2] | NWC $F_{en}$ [2] | $U_{env}$ [3] |
|---|---|---|---|---|
| 356.0 | 180.0 | 3.242 | 3.410 | 0.00589 |
| 381.0 | 193.9 | 3.687 | 3.971 | 0.00592 |
| 389.0 | 198.3 | 3.842 | 4.169 | 0.00588 |
| 351.0 | 177.2 | 3.159 | 3.308 | 0.00468 |
| 360.0 | 182.2 | 3.309 | 3.494 | 0.03936 |
| 360.0 | 182.2 | 3.309 | 3.494 | 0.05415 |
| 360.0 | 182.2 | 3.309 | 3.494 | 0.03961 |
| 353.0 | 178.3 | 3.192 | 3.349 | 0.00384 |
| 388.0 | 197.8 | 3.823 | 4.144 | 0.00589 |
| 388.0 | 197.8 | 3.823 | 4.144 | 0.00045 |
| 388.0 | 197.8 | 3.823 | 4.144 | 0.12921 |
| 349.0 | 176.1 | 3.127 | 3.268 | 0.00468 |
| 424.0 | 217.8 | 4.601 | 5.160 | 0.00305 |
| 349.0 | 176.1 | 3.127 | 3.266 | 0.00011 |
| 538.0 | 281.1 | 8.277 | 10.330 | 0.00233 |
| 503.0 | 261.7 | 6.912 | 8.347 | 0.04154 |
| 503.0 | 261.7 | 6.912 | 8.347 | 0.00016 |
| 503.0 | 261.7 | 6.912 | 8.347 | 0.00007 |
| 503.0 | 261.7 | 6.912 | 8.347 | 0.00221 |
| 543.0 | 283.9 | 8.493 | 10.649 | 0.00323 |
| 548.0 | 286.7 | 8.714 | 10.978 | 0.00051 |
| 549.0 | 287.2 | 8.759 | 11.045 | 0.00027 |
| 548.0 | 286.7 | 8.714 | 10.978 | 0.00000 |
| 548.0 | 286.7 | 8.714 | 10.976 | 0.00000 |
| | | | Total, $U_{59\text{-}env}$ = | 0.35306 |
| | | | Overall $F_{en}$ = | 3.970 |

Transient Maximum Temperatures:

From "Mat-2i ALL":

| Index | Load #1 | Description #1 | $n_1$ (cycles) | Load #2 | Description #2 | Index | T1 [4] | s1 [4] | T2 [4] | s2 [4] | $S_n$ (psi) | T (°F) [1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2_DesHydro1 | 120 | 16 | 11_LoFP2 | 1 | 2 | 30 | 16 | 14 | 65,109 | 356 |
| 2 | 2 | 2_DesHydro1 | 110 | 20 | 11_LoFP6 | 2 | 2 | 30 | 20 | 3 | 50,344 | 381 |
| 3 | 2 | 2_DesHydro1 | 100 | 18 | 11_LoFP4 | 3 | 2 | 30 | 18 | 7 | 50,150 | 389 |
| 4 | 2 | 2_DesHydro1 | 90 | 11 | 9_TurbTrip1 | 4 | 2 | 30 | 11 | 6 | 65,712 | 351 |
| 5 | 2 | 2_DesHydro1 | 80 | 5 | 4_TurbRoll1 | 5 | 2 | 30 | 5 | 12 | 64,296 | 360 |
| 6 | 5 | 4_TurbRoll1 | 220 | 39 | 25_Unbolt | 6 | 5 | 12 | 39 | 23 | 63,306 | 360 |
| 7 | 3 | 2_DesHydro2 | 120 | 5 | 4_TurbRoll1 | 7 | 3 | 1 | 5 | 12 | 61,437 | 360 |
| 8 | 3 | 2_DesHydro2 | 23 | 23 | 11_LoFP9 | 8 | 3 | 1 | 23 | 7 | 63,138 | 353 |
| 9 | 3 | 2_DesHydro2 | 13 | 34 | 20A_HSFWInj1 | 9 | 3 | 1 | 34 | 21 | 49,069 | 388 |
| 10 | 34 | 20A_HSFWInj1 | 287 | 38 | 24_HydroTest2 | 10 | 34 | 21 | 38 | 1 | 49,097 | 388 |
| 11 | 34 | 20A_HSFWInj1 | 286 | 36 | 21_Shutdown | 11 | 34 | 21 | 36 | 156 | 49,111 | 388 |
| 12 | 26 | 12_TGTrip2 | 288 | 36 | 21_Shutdown | 12 | 26 | 6 | 36 | 156 | 60,379 | 349 |
| 13 | 21 | 11_LoFP7 | 10 | 26 | 12_TGTrip2 | 13 | 21 | 68 | 26 | 7 | 49,395 | 424 |
| 14 | 26 | 12_TGTrip2 | 264 | 31 | 14_SRVBlwdn | 14 | 26 | 6 | 31 | 41 | 42,902 | 349 |
| 15 | 22 | 11_LoFP8 | 10 | 26 | 12_TGTrip2 | 15 | 22 | 1 | 26 | 7 | 32,212 | 538 |
| 16 | 4 | 3_Startup | 300 | 26 | 12_TGTrip2 | 16 | 4 | 1 | 26 | 7 | 30,212 | 503 |
| 17 | 4 | 3_Startup | 47 | 29 | 13_Overpr2 | 17 | 4 | 1 | 29 | 7 | 30,212 | 503 |
| 18 | 4 | 3_Startup | 46 | 28 | 13_Overpr1 | 18 | 4 | 1 | 28 | 1 | 28,966 | 503 |
| 19 | 4 | 3_Startup | 45 | 32 | 19_RedTo0pct | 19 | 4 | 1 | 32 | 45 | 24,083 | 503 |
| 20 | 32 | 19_RedTo0pct | 255 | 33 | 20_HSHeatup | 20 | 32 | 45 | 33 | 26 | 18,765 | 543 |
| 21 | 13 | 10_FWHByp1 | 70 | 33 | 20_HSHeatup | 21 | 13 | 23 | 33 | 26 | 19,637 | 548 |
| 22 | 13 | 10_FWHByp1 | 25 | 35 | 20A_HSFWInj2 | 22 | 13 | 23 | 35 | 14 | 20,388 | 549 |
| 23 | 35 | 20A_HSFWInj2 | 275 | 37 | 24_HydroTest1 | 23 | 35 | 14 | 37 | 1 | 19,850 | 548 |
| 24 | 9 | 6_WklyRed1 | 2000 | 35 | 20A_HSFWInj2 | 24 | 9 | 10 | 35 | 14 | 19,341 | 548 |

Notes:
1. $T_{MAX}$ is the maximum temperature of the two paired load states, and represents the metal (nodal) temperature at the location being analyzed. This is determined from the VESLFAT output from Reference [6], which is included as "T" in the "Transient Maximum Temperatures" table above.
2. $F_{en}$ values computed using Equation (6) with S* conservatively set to a maximum value of 0.015, and the transformed strain rate conservatively set to a minimum value of ln (0.001) = -6.908 for all load pairs.
3. $U_{env}$ = [U x HWC $F_{en}$ x % HWC] + [U x NWC $F_{en}$ x % NWC].
4. T1 and T2 represent the load number for Load #1 and Load #2, respectively, and s1 and s2 represent the state number for each of those loads.

LICENSEE: Entergy Nuclear Operations, Inc.

FACILITY: Vermont Yankee Nuclear Power Station

SUBJECT: SUMMARY OF MEETING HELD ON JANUARY 8, 2008, BETWEEN THE U.S. NUCLEAR REGULATORY COMMISSION STAFF AND ENTERGY NUCLEAR OPERATIONS, INC. REPRESENTATIVES TO DISCUSS THE RESPONSE TO A REQUEST FOR ADDITIONAL INFORMATION PERTAINING TO THE VERMONT YANKEE NUCLEAR POWER STATION LICENSE RENEWAL APPLICATION

On January 8, 2008, the Nuclear Regulatory Commission staff (the staff) met with members of Entergy Nuclear Operations, Inc. (the applicant) in a public meeting to discuss the response to a request for additional information (RAI) made by the staff pertaining to the Vermont Yankee Nuclear Power Station (VYNPS) license renewal application. The applicant had an opportunity to comment on this summary.

A list of attendees is provided in Enclosure 1. The meeting agenda is provided in Enclosure 2. Comments made by the public during the meeting are provided in Enclosure 3. A copy of the slides presented by the applicant is provided as Enclosure 4. A summary of the discussion follows:

Background

In a letter dated November 27, 2007, the staff issued RAI 4.3.3-2 to the applicant. The purpose of the request was to gather additional information on the calculations used at VYNPS to reanalyze their time-limited aging analysis (TLAA) that addresses environmentally-assisted fatigue. In a letter dated December 11, 2007, the applicant provided its response to RAI 4.3.3-2 to the staff. The staff reviewed the response and further questioned the methodology described in the submittal and statements made that shear stresses are negligible during a conference call with the applicant on December 18, 2007. During the call, the applicant requested a face-to-face meeting to ensure that its position pertaining to this highly technical issue was properly and effectively communicated.

Discussion

During the meeting, the applicant made a slide presentation of the reactor vessel nozzle environmental fatigue analyses for license renewal at VYNPS. The applicant reviewed the terminology used in the response to RAI 4.3.3-2. The applicant reviewed the analyzed vessel nozzle configurations to identify where the shear stresses in the nozzles were negligible, where they were not, and the effects on the fatigue analysis at the locations where shear stresses were not negligible.

The applicant explained that nozzle corner, blend radius, and inner radius are interchangeable terms for locations with geometrical discontinuities; that is, locations where stresses are maximum. The applicant explained that the methodology employed incorporates the use of axisymmetric modeling rather than an exact configuration 3-Dimensional (3-D) or 2-Dimensional (2-D) modeling. They explained that axisymmetric modeling is a 3-D model except that it models the nozzle/vessel interface as a sphere with a multiplier to account for pressure stress effects, rather than a pipe joined to a cylinder. With the aid of colored graphs, the applicant demonstrated specific nozzles where shear stresses are negligible. The applicant also discussed the various conservatisms used in their analysis.

Conclusion

1. Based on the analyses performed, the applicant presented its conclusion that the effects of shear stresses were negligible or were separately addressed for all nozzles analyzed.

2. Based on its interaction with the NRR staff during the meeting, the applicant agreed to perform additional confirmatory work and submit results to the staff for review and acceptance. This work effort will include:

1) Performing benchmarking calculations on the feedwater nozzle, which is the most limiting component, using the axisymmetric finite element model, taking fully into account all stress components on the nozzle and using the ANSYS FEM computer code to model all defined transients;
2) Demonstrating that the Vermont Yankee specific benchmarking calculations bound the results for the Core Spray and Recirculation outlet nozzles.
3) Calculating fatigue usage factors (CUFs) using NRC approved ASME Section III NB-3200 methods; and
4) Comparing the resulting CUFs to the previous environmental assisted fatigue calculations to establish whether the previous calculations are adequate.

Jonathan G. Rowley, Project Manager
Projects Branch 2
Division of License Renewal
Office of Nuclear Reactor Regulation

Docket No. 50-271

Enclosures:
1. Attendance List
2. Agenda
3. Public Comments
4. Presentation slides

cc w/encls: See next page

Jonathan G. Rowley, Project Manager
Projects Branch 2
Division of License Renewal
Office of Nuclear Reactor Regulation

Docket No. 50-271

Enclosures:
1. Attendance List
2. Agenda
3. Public Comments
4. Presentation slides

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|---|---|---|---|---|
| NAME | | JRowley | RFranovich | KChang |
| DATE | / / | / / | / / | / / |

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MEETING BETWEEN THE NRC STAFF AND ENTERGY NUCLEAR OPERATIONS, INC.
VERMONT YANKEE NUCLEAR POWER STATION
LICENSE RENEWAL APPLICATION

6003 EXECUTIVE BOULEVARD
ROOM EBB1B15
ROCKVILLE, MARYLAND

MEETING ATTENDANCE LIST
JANUARY 8, 2008

| PARTICIPANTS | AFFILIATIONS |
|---|---|
| Jonathan Rowley | U.S. Nuclear Regulatory Commission (NRC) |
| Samson Lee | NRC |
| John Fair | NRC |
| Kenneth Chang | NRC |
| PT Kuo | NRC |
| Rani Franovich | NRC |
| Robert Sun | NRC |
| Qi Gan | NRC |
| Kaihwa Hsu | NRC |
| Ricardo Rodriguez | NRC |
| Mary Baty | NRC |
| Perry Buckberg | NRC |
| Evelyn Gettys | NRC |
| Yeon-Ki Chung | NRC |
| Peter Wen | NRC |
| On Yee | NRC |
| Gary Hammer | NRC |
| David Mannai | Entergy Nuclear Operations, Inc. (Entergy) |
| John McCann | Entergy |
| Jay Thayer | Entergy |
| Matias Travieso-Diaz | Entergy |
| Michael Metell | Entergy |
| Garry Young | Entergy |
| Norm Rademacher | Entergy |

Enclosure 1

| | |
|---|---|
| Alan Cox | Entergy |
| PARTICIPANTS | AFFILIATIONS |
| James Fitzpatrick | Entergy |
| Scott Goodwin | Entergy |
| John Dreyfuss | Entergy |
| Gary L. Stevens | Structural Integrity Associates |
| Terry. J. Herrmann | Structural Integrity Associates |
| Joe Hopenfeld | New England Coalition (NEC) |
| David Lochbaum | Union of concerned Scientist |
| **THE FOLLOWING PARTICAPATED** | **VIA TELEPHONE BRIDGELINE** |
| Sarah Hoffman | Vermont Department of Public Service |
| John Sipos | New York Office of the Attorney General |
| Paul Eddy | New York Office of the Attorney General |
| Joan Leary Matthews | New York Office of the Attorney General |
| Blaise Constantakes | New York Office of the Attorney General |
| Rudolf Hausler | New York Office of the Attorney General |
| Raymond Shadis | NEC |
| Claire Chang | NEC |
| Ulrich Witte | NEC |
| Ed Anthes | Nuclear Free Vermont |
| Rich Schaller | Strategic Teaming and Resource Sharing |
| Chalmer Myer | Southern Nuclear Operating Company |
| Bob Audette | The Brattleboro Reformer |
| Susan Smallheer | The Rutland Herald |
| Sally Shaw | |
| Fred Mogolesko | Entergy |

MEETING BETWEEN THE NRC STAFF AND ENTERGY NUCLEAR OPERATIONS, INC.
VERMONT YANKEE NUCLEAR POWER STATION
LICENSE RENEWAL APPLICATION

6003 EXECUTIVE BOULEVARD
ROOM EBB1B15
ROCKVILLE, MARYLAND

AGENDA

JANUARY 8, 2008

| | | |
|---|---|---|
| I. | Introduction and opening remarks | 10 minutes |
| II. | Discussion of Response to Request for Additional Information (Response to RAI 4.3.3-2) | 80 minutes |
| III. | Public Comments | 30 minutes |
| IV. | Adjourn | |

Enclosure 2

MEETING BETWEEN THE NRC STAFF AND ENTERGY NUCLEAR OPERATIONS, INC.
VERMONT YANKEE NUCLEAR POWER STATION
LICENSE RENEWAL APPLICATION
ROCKVILLE, MARYLAND
ROOM EBB1B15

MEETING MINUTES
JANUARY 8, 2008

In a letter dated November 27, 2007, the staff issued RAI 4.3.3-2 to the applicant. The purpose of the request was to gather additional information on the calculations used at VYNPS to reanalyze their time-limited aging analysis (TLAA) that addresses environmentally-assisted fatigue. In a letter dated December 11, 2007, the applicant provided its response to RAI 4.3.3-2 to the staff. The staff reviewed the response and further questioned the methodology described in the submittal and statements made that shear stresses are negligible during a conference call with the applicant on December 18, 2007. During the call, the applicant requested a face-to-face meeting to ensure that its position pertaining to this highly technical issue was properly and effectively communicated.

Discussion

During the meeting, the applicant made a slide presentation of the reactor vessel nozzle environmental fatigue analyses for license renewal at VYNPS. The applicant reviewed the terminology used in the response to RAI 4.3.3-2. The applicant reviewed the analyzed vessel nozzle configurations to identify where the shear stresses in the nozzles were negligible, where they were not, and the effects on the fatigue analysis at the locations where shear stresses were not negligible.

The applicant explained that nozzle corner, blend radius, and inner radius are interchangeable terms for locations with geometrical discontinuities; that is, locations where stresses are a maximum. The applicant explained that their methodology incorporates the use of axisymmetric modeling rather than an exact configuration 3-Dimensional (3-D) or 2-Dimensional (2-D) modeling. They explained that axisymmetric modeling is a 3-D model except that it models the nozzle/vessel interface as a sphere with a multiplier to account for pressure stress effects, rather than a pipe joined to a cylinder. With the aid of colored graphs, the applicant demonstrated specific nozzles where shear stresses are negligible. The applicant also discussed the various conservatisms used in their analysis.

Conclusion

1. Based on the analyses performed, the applicant presented its conclusion that the effects of shear stresses were negligible or were separately addressed for all nozzles analyzed.

Enclosure 3

2. Based on its interaction with the NRR staff during the meeting, the applicant agreed to perform additional confirmatory work and submit results to the staff for review and acceptance. This work effort will include:

1) Performing benchmarking calculations on the feedwater nozzle, which is the most limiting component, using the axisymmetric finite element model, taking fully into account all stress components on the nozzle and using the ANSYS FEM computer code to model all defined transients;
2) Demonstrating that the Vermont Yankee specific benchmarking calculations bound the results for the core spray and recirculation outlet nozzles.
3) Calculating fatigue usage factors (CUFs) using NRC approved ASME Section III NB-3200 methods; and
4) Comparing the resulting CUFs to the previous environmental assisted fatigue calculations to establish whether the previous calculations are adequate

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, DC 20555-0001

April 11, 2008

**NRC REGULATORY ISSUE SUMMARY 2008-10**
**FATIGUE ANALYSIS OF NUCLEAR POWER PLANT COMPONENTS**

## ADDRESSEES

All holders of operating licenses for nuclear power reactors, except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

## INTENT

The U.S. Nuclear Regulatory Commission (NRC) is issuing this regulatory issue summary (RIS) to inform licensees of an analysis methodology used to demonstrate compliance with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) fatigue acceptance criteria that could be nonconservative if not correctly applied.

## BACKGROUND INFORMATION

Title 10 of the *Code of Federal Regulations* (10 CFR) Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," requires that applicants for license renewal perform an evaluation of time-limited aging analyses relevant to structures, systems, and components within the scope of license renewal. The fatigue analysis of the reactor coolant pressure boundary components is an issue that involves time-limited assumptions. In addition, the staff has provided guidance in NUREG-1800, Rev. 1, "Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants," issued September 2005. NUREG-1800, Rev. 1, specifies that the effects of the reactor water environment on fatigue life be evaluated for a sample of components to provide assurance that cracking because of fatigue will not occur during the period of extended operation. Since the reactor water environment has a significant impact on the fatigue life of components, many license renewal applicants have performed supplemental detailed analyses to demonstrate acceptable fatigue life for these components.

10 CFR 50.55a, "Codes and Standards," specifies the ASME Code requirements for operating reactors. Some operating facilities may have performed supplemental detailed analysis of components because of new loading conditions identified after the plant began operation.

**SUMMARY OF ISSUE**

The staff identified a concern regarding the methodology used by some license renewal applicants to demonstrate the ability of nuclear power plant components to withstand the cyclic loads associated with plant transient operations for the period of extended operation. This particular analysis methodology involves the use of the Green's function to calculate the fatigue usage during plant transient operations such as startups and shutdowns.

The Green's function approach involves performing a detailed stress analysis of a component to calculate its response to a step change in temperature. This detailed analysis is used to establish an influence function, which is subsequently used to calculate the stresses caused by the actual plant temperature transients. This methodology has been used to perform fatigue calculations and as input for on-line fatigue monitoring programs. The Green's function methodology is not in question. The concern involves a simplified input for applying the Green's function in which only one value of stress is used for the evaluation of the actual plant transients. The detailed stress analysis requires consideration of six stress components, as discussed in ASME Code, Section III, Subsection NB, Subarticle NB-3200. Simplification of the analysis to consider only one value of the stress may provide acceptable results for some applications; however, it also requires a great deal of judgment by the analyst to ensure that the simplification still provides a conservative result.

The staff has requested that recent license renewal applicants that have used this simplified Green's function methodology perform confirmatory analyses to demonstrate that the simplified Green's function analyses provide acceptable results. The confirmatory analyses retain all six stress components. To date, the confirmatory analysis of one component, a boiling-water reactor feedwater nozzle, indicated that the simplified input for the Green's function did not produce conservative results in the nozzle bore area when compared to the detailed analysis. However, the confirmatory analysis still demonstrated that the nozzle had acceptable fatigue usage.

Licensees may have also used the simplified Green's function methodology in operating plant fatigue evaluations for the current license term. For plants with renewed licenses, the staff is considering additional regulatory actions if the simplified Green's function methodology was used.

**BACKFIT DISCUSSION**

This RIS informs addressees of a potential nonconservative calculation methodology and reminds them that the ASME Code fatigue analysis should be performed properly. For license renewal, metal fatigue is evaluated as a time-limited aging analysis in accordance with 10 CFR 54.21(c). The associated staff review guidance appears in Section 4.3, "Metal Fatigue Analysis," of NUREG-1800, Rev. 1. For operating reactors, the ASME Code requirements appear in 10 CFR 50.55a. This RIS does not impose a new or different regulatory staff position. It requires no action or written response and, therefore, is not a backfit under 10 CFR 50.109, "Backfitting." Consequently, the NRC staff did not perform a backfit analysis.

***FEDERAL REGISTER* NOTIFICATION**

A notice of opportunity for public comment on this RIS was not published in the *Federal Register* because the RIS is informational.

**CONGRESSIONAL REVIEW ACT**

The NRC has determined that this RIS is not a rule as designated by the Congressional Review Act (5 U.S.C. §§801–808) and; therefore, is not subject to the Act.

**PAPERWORK REDUCTION ACT STATEMENT**

This RIS does not contain information collection requirements that are subject to the requirements of the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et seq.).

Public Protection Notification

The NRC may not conduct or sponsor, and a person is not required to respond to, a request for information or an information collection requirement unless the requesting document displays a currently valid Office of Management and Budget control number.

**CONTACT**

Please direct any questions about this matter to the technical contacts listed below.

*/RA/*

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Note: The NRC's generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

NEC-JH_24

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICE OF THE
GENERAL COUNSEL

April 3, 2008

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In the Matter of
AMERGEN ENERGY COMPANY, LLC
(License Renewal for Oyster Creek Nuclear Generating Station)
Docket No. 50-219-LR

Dear Administrative Judges:

Enclosed for your information is a copy of the April 3, 2008 Notification of Information in the Matter of Oyster Creek Nuclear Generating Station License Renewal Application, which the Staff has provided to the Commission.

Sincerely,

James E. Adler
Counsel for the NRC Staff

Enclosure: As Stated

cc w/enclosure: Service List

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 3, 2008

Board Notification 2008-01

MEMORANDUM TO: Chairman Klein
Commissioner Jaczko
Commissioner Lyons
Commissioner Svinicki
Atomic Safety and Licensing Board
All Parties

FROM: Samson S. Lee, Acting Director
Division of License Renewal
Office of Nuclear Reactor Regulation

SUBJECT: NOTIFICATION OF INFORMATION IN THE MATTER OF OYSTER CREEK NUCLEAR GENERATING STATION LICENSE RENEWAL APPLICATION

In conformance with the Commission's policy on notification to the Commission and the Atomic Safety Licensing Board (ASLB) regarding significant new information, this memorandum provides the following information.

The staff is reviewing the use of a simplified method to calculate cumulative usage factors (CUF) that may not be conservative. Oyster Creek Nuclear Generating Station (Oyster Creek) used this simplified fatigue calculation method for one type of nozzle, the recirculation nozzle at the plant. This type of calculation was not applicable to the drywell shell analysis, which is the subject of the appealed contention pending before the Commission. Although, this simplified calculation is not relevant to the contention in the proceeding that was before the ASLB, we are providing this information, because this may be an issue of public interest.

The staff plans to ask Oyster Creek to perform a confirmatory analysis consistent with the methodology in Section III of the ASME Code. However, the staff believes that the safety significance of using the simplified analysis method is low based on the risk assessments performed by the staff in resolving generic safety issues (GSI)-166 and GSI-190.

Docket No. 50-219

cc: See next page

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