WOLF CREEK
NUCLEAR OPERATING CORPORATION

July 26, 2007

Terry J. Garrett
Vice President, Engineering

ET 07-0032

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

Reference: 1) Letter ET 06-0038, dated September 27, 2006, from T. J. Garrett, WCNOC, to USNRC
2) Letter WM 07-0051, dated June 7, 2007, from M. W. Sunseri, WCNOC, to USNRC
3) Letter dated June 22, 2007, from V. Rodriguez, USNRC, to T. J. Garrett, WCNOC (ML071730352)

Subject: Docket No. 50-482: Response to NRC Requests for Additional Information Related to Wolf Creek Generating Station License Renewal Application Time–Limited Aging Analysis Audit Question

Gentlemen:

Reference 1 provided Wolf Creek Nuclear Operating Corporation's (WCNOC) License Renewal Application (LRA) for the Wolf Creek Generating Station (WCGS). As part of the review for license renewal, the Nuclear Regulatory Commission (NRC) staff conducted two audits at WCGS. The LRA Aging Management Program audit was conducted during the week of March 26, 2007 and the LRA Aging Management Review during the week of May 7, 2007. During the course of these audits the NRC staff also audited Time Limited Aging Analyses (TLAA).

A TLAA question and answer database was complied during the audits. WCNOC submitted this database in Reference 2. Reference 3 requested additional information (RAI) concerning the response provided for audit question TLAA025.

A121
NRR

Attachment I provides the response to RAI 4.3-1 and Attachment II provides the response to RAI 4.3-2.

If you have any questions concerning this matter, please contact me at (620) 364-4084, or Mr. Kevin Moles at (620) 364-4126.

Sincerely,

Terry J. Garrett

TJG/rlt

Attachment I Response to RAI 4.3-1
II Response to RAI 4.3-2

cc: J. N. Donohew (NRC), w/a
V. G. Gaddy (NRC), w/a
B. S. Mallett (NRC), w/a
V. Rodriguez (NRC), w/a
Senior Resident Inspector (NRC), wo/a

S TATE OF KANSAS)
) SS
COUNTY OF COFFEY)

Terry J. Garrett, of lawful age, being first duly sworn upon oath says that he is Vice President Engineering of Wolf Creek Nuclear Operating Corporation; that he has read the foregoing document and knows the contents thereof; that he has executed the same for and on behalf of said Corporation with full power and authority to do so; and that the facts therein stated are true and correct to the best of his knowledge, information and belief.

By____________________
Terry J. Garrett
Vice President Engineering

SUBSCRIBED and sworn to before me this 26th day of July, 2007.

NOTARY PUBLIC OFFICIAL SEAL STATE OF KANSAS
RHONDA L. TIEMEYER
MY COMMISSION EXPIRES
January 11, 2010

Rhonda L. Tiemeyer
Notary Public

Expiration Date January 11, 2010

Wolf Creek Nuclear Operating Corporation (WCNOC) Response to NRC Requests for Additional Information RAI 4.3-1

Metal Fatigue Analysis

During the Wolf Creek Generating Station (WCGS) onsite audits the staff reviewed the applicant's license renewal basis document which states that the cumulative usage factors for 24 locations were evaluated using the transfer function method in FatiguePro. FatiguePro performs stress calculations as a function of the time-varying mechanical and thermal boundary conditions.

The transfer function (i.e., Green's function) quantifies component stresses due to temperature change, pressure variation, and external mechanical loading change. The transfer function method correlates time-dependent behavior of a component in terms of input and output.

The staff reviewed the FatiguePro user's manual for the transfer function input and calculated output. The staff could not determine if the program appropriately implemented the transfer function methodology to meet the requirements of ASME Code Section III. The staff requested that the applicant demonstrate the validity of its input and output by providing the benchmarking results for pressure, temperature, and moment loadings.

In a letter dated June 7, 2007, WCGS stated that the developer of the FatiguePro, Structural Integrity Associates (SIA), has never benchmarked the transfer functions to an independent standard. The applicant also states that 1D virtual stress was used for its calculation, which was designed to bound the actual stress intensity ranges for all fatigue significant transients. Furthermore, the applicant also states that this type of stress value does not have a name in the professional literature. Based on the discussion with the applicant, the staff indicated that this response requires clarification.

RAI 4.3-1

In its response to audit question TLAAA025 dated June 7, 2007, the applicant stated that the transfer function report defines a 1D virtual stress value that is designed to bound the actual stress intensity ranges for all fatigue significant transients and this type of stress value does not have a name in the professional literature.

(1) Since it cannot be found in the professional literature, the staff requests that the applicant describe in detail how the 1D virtual stress is derived.

(2) The staff requests that the applicant demonstrate how the virtual stress bounds the actual stress intensity ranges for any thermal transient. Show that the stress difference between any two thermal transients is also conservative since the fatigue evaluation is based on stress difference of two events.

WCNOC Response RAI 4.3- 1

1) The 1D virtual stress is derived by considering the stress as several individual stress contributors, developing separate expressions for each contributor that bound the stress intensity range for that contributor, and then adding the stress contributors algebraically. Each contributor is a signed value; the signs for each term are defined in such a way that for the controlling transient(s), the resultant virtual stress range is maximized.

For example, the Wolf Creek Charging Nozzle location is governed by three terms:

$$\sigma_{\text{thermal}} = \int \frac{Green's}{Function} * T_{Loc}\, dt, \quad \text{[ksi]}$$

$$\sigma_{\text{pressure}} = 0.0047 * P_{chg}, \quad \text{[ksi]}$$

$$\sigma_{\text{piping}} = 0.039 * (\text{CL\_TEMP}) - 0.017 * (T_{chg}) - 1.54, \quad \text{[ksi]}$$

$$\sigma_{\text{total}} = \sigma_{\text{thermal}} + \sigma_{\text{pressure}} + \sigma_{\text{piping}}$$

These equations give a conservative bound for the peak stress intensity, and the differences between maximum and minimum peaks in σ_{total} give conservative bounds for peak stress range. σ_{thermal} is typically biaxial (hoop and axial directions) and may be positive or negative depending on the direction of the temperature change. σ_{pressure} is always positive and is maximum in the hoop direction. σ_{piping} is treated as an axial stress from the bending moments and a shear stress from the torsional moment. σ_{piping} is also computed on the OD of the piping where it has maximum absolute value, while σ_{thermal} typically has maximum absolute value on the pipe ID where temperature changes are most rapid. Adding these three stresses together as though they are all in the same direction at the same location is shown in relevant examples to produce stress ranges greater than or equal to the precise computation of stress intensity range.

(2) For thermal transients that contribute significantly to the fatigue usage of components and piping, the σ_{thermal} and σ_{pressure} terms and their variations are much larger than the σ_{piping} term and its variation. For pressure and temperature transients, the FatiguePro methodology produces conservative bounding results for stress range and fatigue usage. This is demonstrated for the example of the charging nozzles by the Case Study described in the following section. For locations, such as the pressurizer surge line and its nozzles (e.g., the hot leg surge line nozzle) where variations in piping loads resulting from thermal stratification may be important, additional calculations are performed by FatiguePro to include these effects. Therefore, FatiguePro produces conservative estimates for the design transients in component design specifications.

In a general sense, it is very difficult, if not impossible, to mathematically prove that the 1D virtual stress differences will bound the actual stress intensity ranges for all hypothetical transient pairings that could be devised. For a given set of transfer functions one can always construct two transients where the stress range computed using the 1D virtual stress methodology is not an upper bound for the stress range computed using the stress tensor methodology from the ASME Code. However, with the exception of an Operating Basis Earthquake (OBE) seismic event, which is explicitly excluded from the FatiguePro monitoring program, there are no identified transients for which FatiguePro is not expected to produce conservative results. If an earthquake occurs, a supplemental analysis of the fatigue usage from the event will be required. Should an unlikely series of events occur for which FatiguePro is non-conservative the (relatively small) unconservatism that would arise is not significant compared to the conservatisms in the FatiguePro methodology for the more important pressure-temperature transients.

To illustrate this, a case study was performed comparing the FatiguePro 1D stress approach to a more precise three dimensional (3D) approach consistent with ASME Code NB-3200. The study used the Wolf Creek charging nozzle location; a complete write-up of the study is attached.

The results show significant conservatism inherent in the FatiguePro analysis. Systematic conservatisms in FatiguePro come from several sources; the collective effect overwhelms any small effect from treating stress as a 1D value. The study concludes that for those transients, which contribute significantly to fatigue, the FatiguePro 1D stress approach bounds the stress intensity ranges computed from a more precise 3D analysis.

Case Study: A Comparison of FatiguePro 1D Stress Analysis to ASME Six Tensor Component Stress Intensity Analysis for Fatigue Usage Factor Calculations

Objective:

The objective of this calculation is to quantify conservatism of the FatiguePro 1D virtual stress method compared to a more precise 3D stress analysis. This comparison will be performed using the Wolf Creek charging nozzle (CHRG_NOZ) Stress-Based Fatigue (SBF) location, and using two transients (one fast, one slow) that produce significant fatigue usage at that location.

Approach:

The Wolf Creek charging nozzle location was chosen for this study, since this is one of the key locations with respect to determining acceptable margins for environmental fatigue.

Two transients were identified as representative of the range of transients that affect the charging nozzle. It was desired to select one "fast" transient (i.e., where thermal shock is the primary component), and one "slow" transient (i.e., thermal shock is negligible), to cover the range of possibilities.

A finite-element based stress analysis of the Wolf Creek charging nozzle was performed for the two example transients. Applied loadings included thermal, pressure and moment stresses in all three directions. The resulting stresses were evaluated to determine (a) the primary-plus-secondary and membrane-plus-bending stress intensity ranges, (b) the resulting simplified elastic-plastic stress factor Ke (when necessary), and (c) the final peak stress intensity range at the critical fatigue location (i.e., around the ID surface of the charging nozzle safe end).

Independently, a FatiguePro analysis of the same two transients was performed, using the Wolf Creek FatiguePro software.

The stress-intensity range results from the finite-element analysis were compared to the peak stress range results from the FatiguePro analysis, to determine the relative conservatism of the two methodologies.

Transient Definitions:

Two transients were desired for this study: a fast transient, involving significant temperature change over a short period of time, and a slow transient, that involves temperature changes occurring over a protracted period. The transients selected were 'Loss of Letdown with Delayed Return to Service' (fast transient) and 'Plant Heatup/Cooldown' (slow transient). Fatigue usage at the charging nozzles is principally attributable to loss of charging (LOC) and loss of letdown (LOL) transients with smaller contributions from plant heat up and cool down.

Finite Element Analysis (FEA):

A new three-dimensional (3D) FEA model of the Wolf Creek charging nozzle was developed using input from a previously developed axisymmetric model [1]. (The same Reference [1] model was used to produce the FatiguePro stress transfer functions for the charging nozzle location). The ANSYS finite element software package was used to develop and evaluate the model. The model consists of a local portion of the cold leg piping (modeled as a partial sphere for simplicity), the charging nozzle, a portion of the charging piping, the thermal sleeve, and the water in the annular region between the thermal sleeve and nozzle. The resulting finite element model is illustrated in Figure 1.

Fast Transient:

For the fast transient (Loss of Letdown with Delayed Return to Service), a time-history of internal pressure and local fluid temperatures were extracted from the FatiguePro analysis of the same transient. Heat transfer coefficients at the inside surfaces of the cold leg and the charging nozzle were the same as used in Reference 7. A time-history of moment loads, in three orthogonal directions on the nozzle, was computed based on the cold leg and local charging flow fluid temperatures. (Moment terms were computed based on the various load cases analyzed in a piping analysis provided by Westinghouse [8]).

A transient thermal and stress analysis, using the above described loads, was performed using the 3D model. A set of linearized stress paths were then extracted at various locations around the circumference of the nozzle at the longitudinal location of the critical section, as indicated in Figure 2.

The resulting stresses were evaluated using the vendor internal program VESLFAT [2], which determines the maximum membrane-plus-bending stress intensity range, calculates an ASME Code Section III simplified elastic-plastic factor Ke (when necessary) and then determines the final peak stress intensity range. The resulting variation around the circumference for the Loss of Letdown with Delayed Return to Service is shown in Figures 3 through 5.

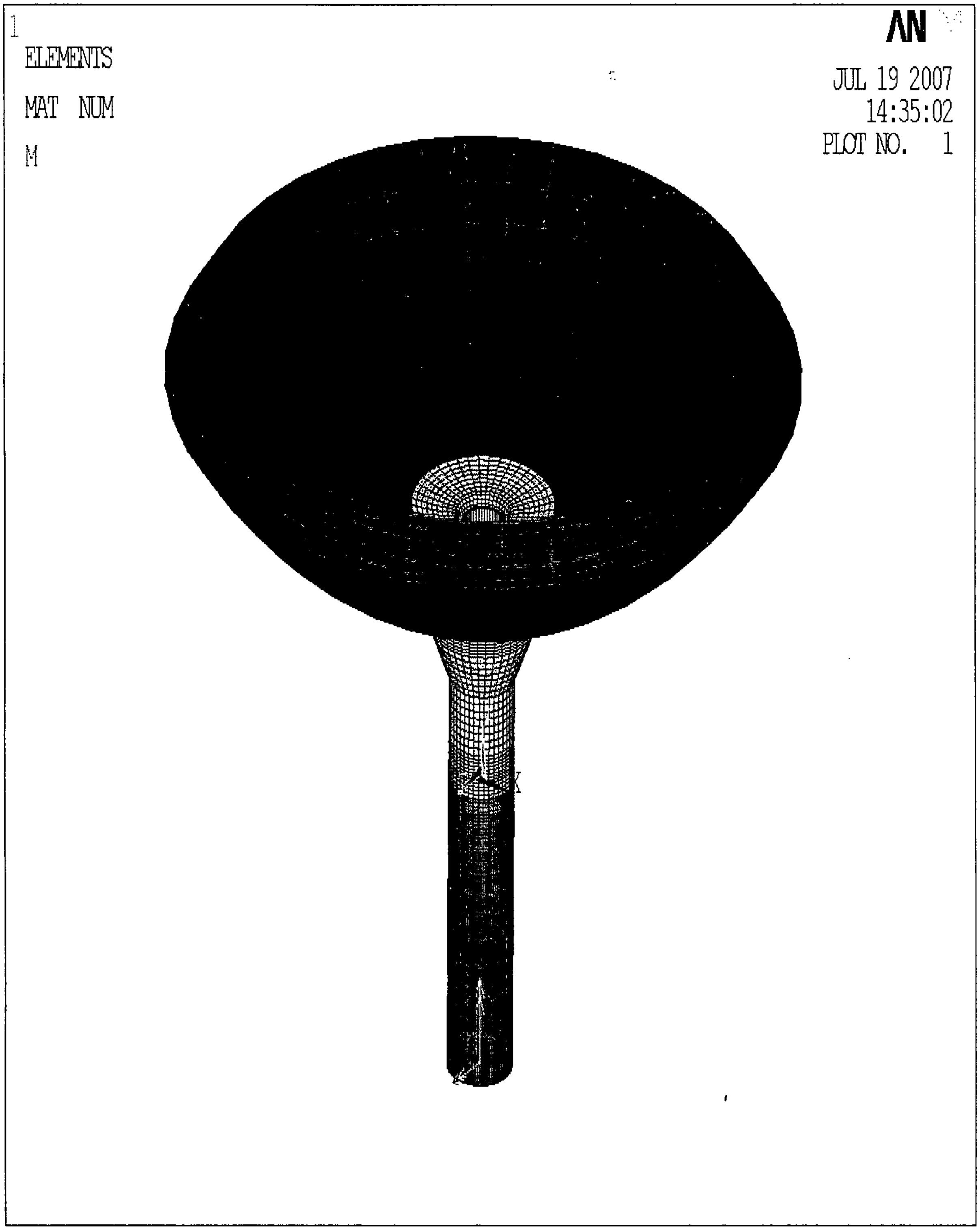

Figure 1: Wolf Creek Charging Nozzle Finite Element Model

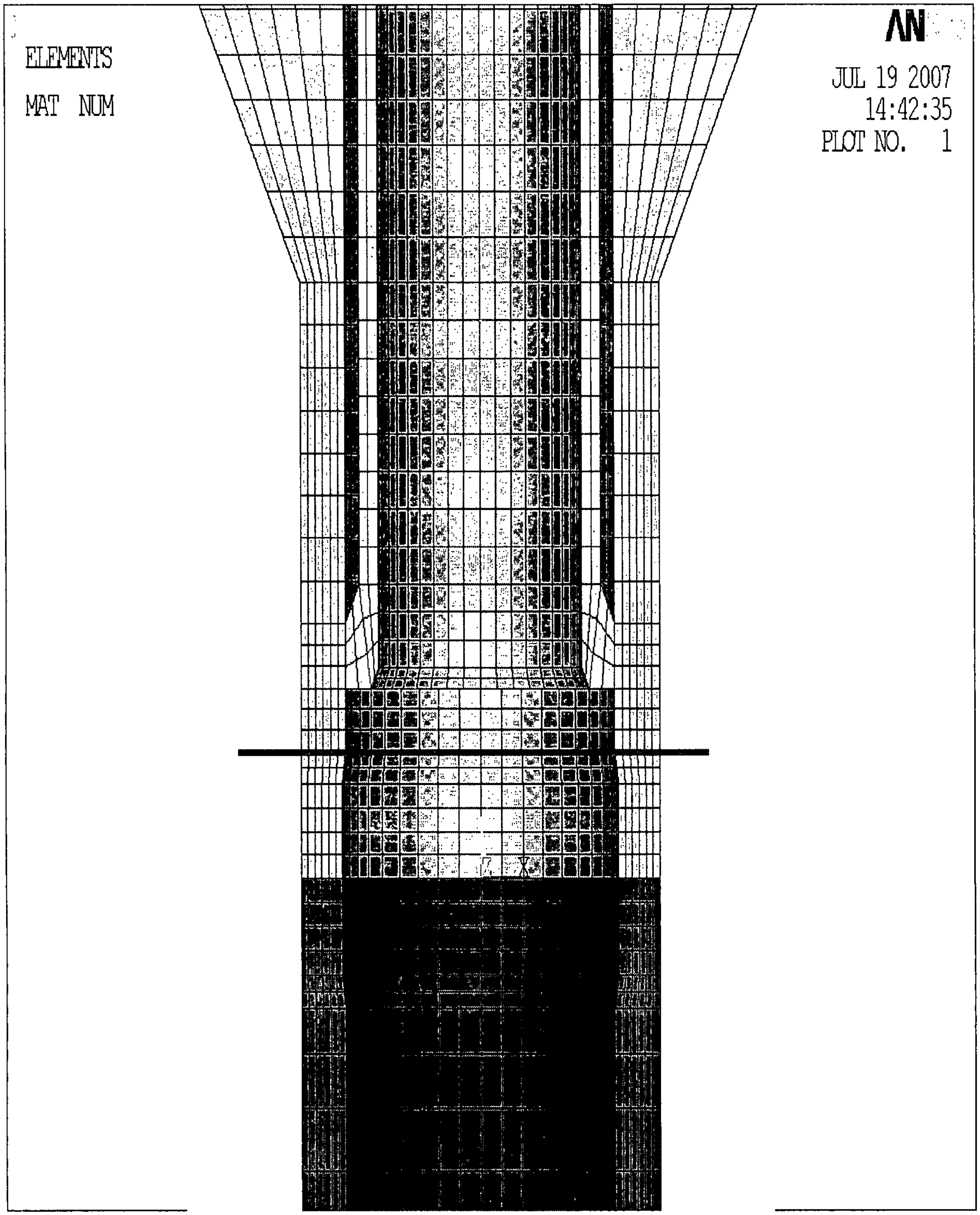

Figure 2: Location for Set of Linearized Stress Path around Circumference

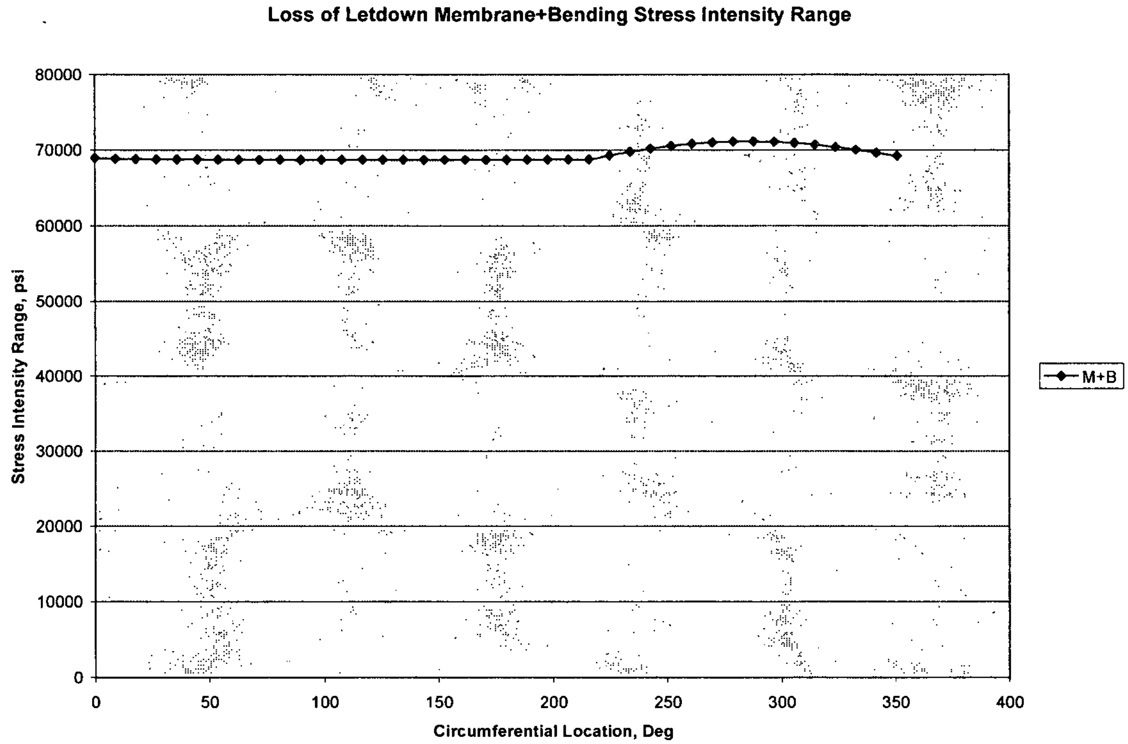

Figure 3: Membrane-plus-Bending Stress Intensity Range

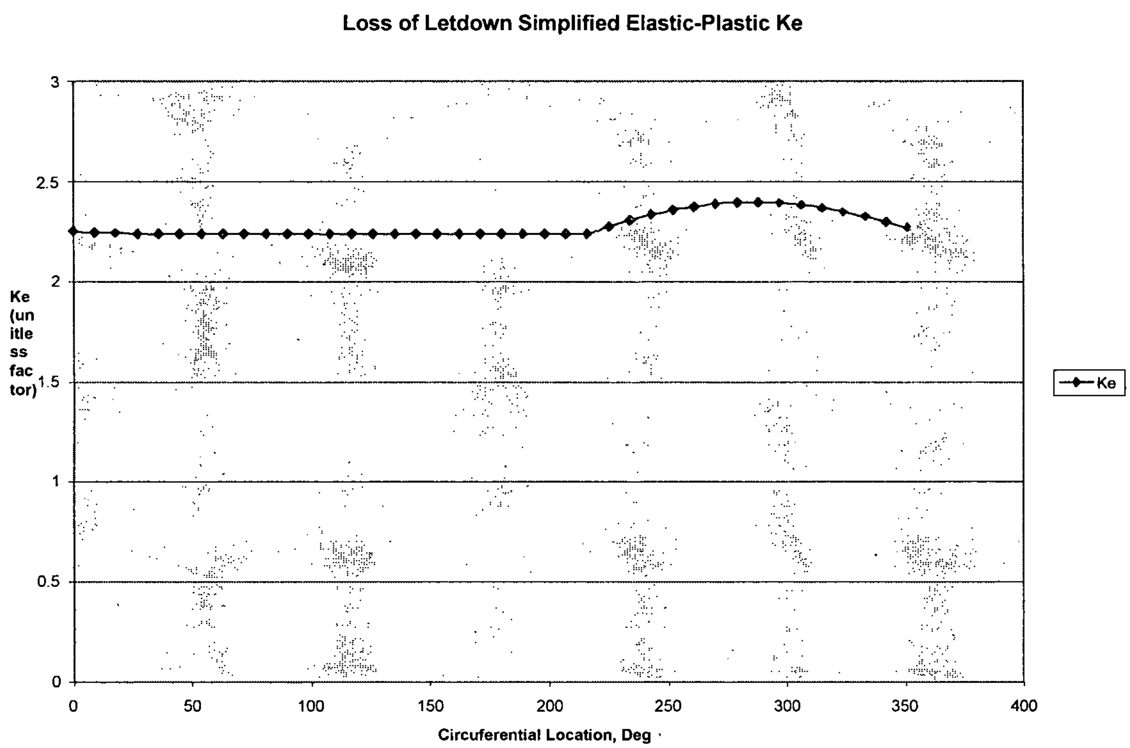

Figure 4: Simplified Elastic-Plastic Factor, Ke

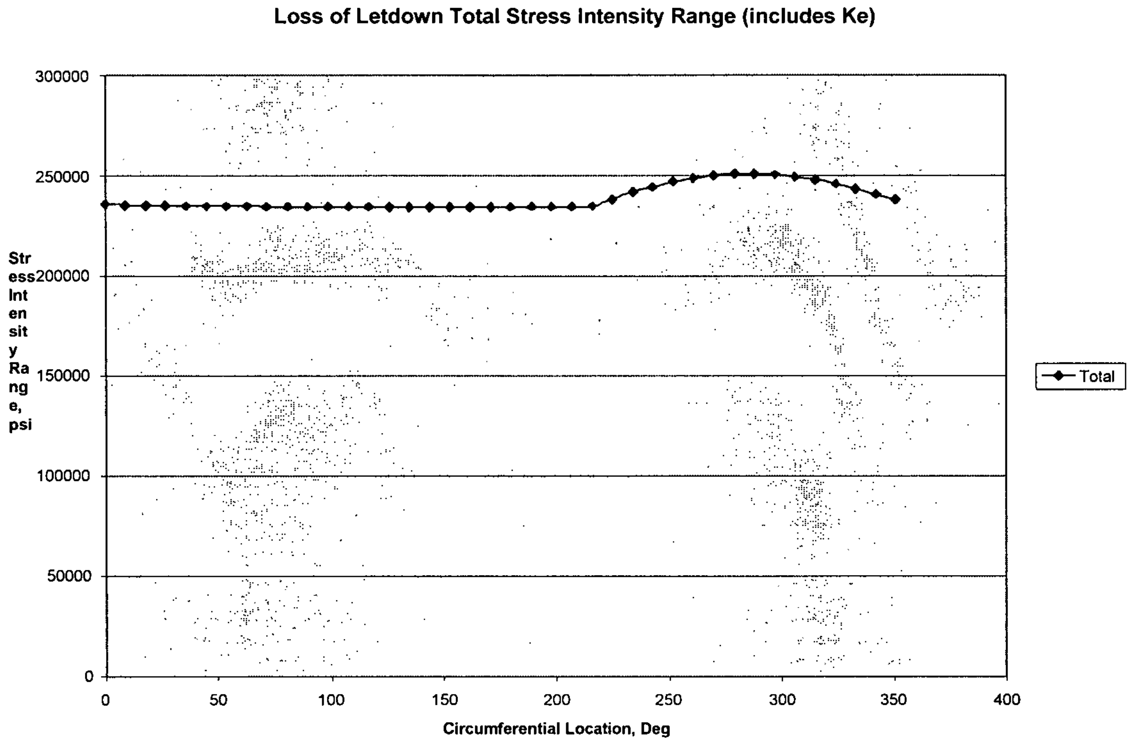

Figure 5: Total (or Peak) Stress Intensity Range including Ke

Slow Transient:

The slow transient (Heatup / Cooldown) was also evaluated. For very slow heatup rates, transient thermal stresses are small. To isolate the effects of the uniaxial stress assumption for the pressure and bending moment stresses in FatiguePro, only pressure and the moment loads were considered, effectively simulating an infinitesimally small rate of temperature change. The stress-intensity range is therefore based on the difference between a zero stress state (70°F) and the stress state induced from the combination of assumed operating pressure and bending moments. As such, no transient thermal analysis was performed, and the stress analysis included only the final pressure and moment load conditions. A set of total stress intensity and linearized stress intensity results were then extracted around the circumference of the nozzle at the location, as indicated in Figure 2.

The resulting stress intensities are thus treated as stress ranges (based on a pairing with zero stress condition). The variation around the circumference is shown in Figures 6 and 7. (Since the membrane-plus-bending stress-intensity range is below the allowable of $3S_m$, no simplified elastic-plastic Ke factor was required.)

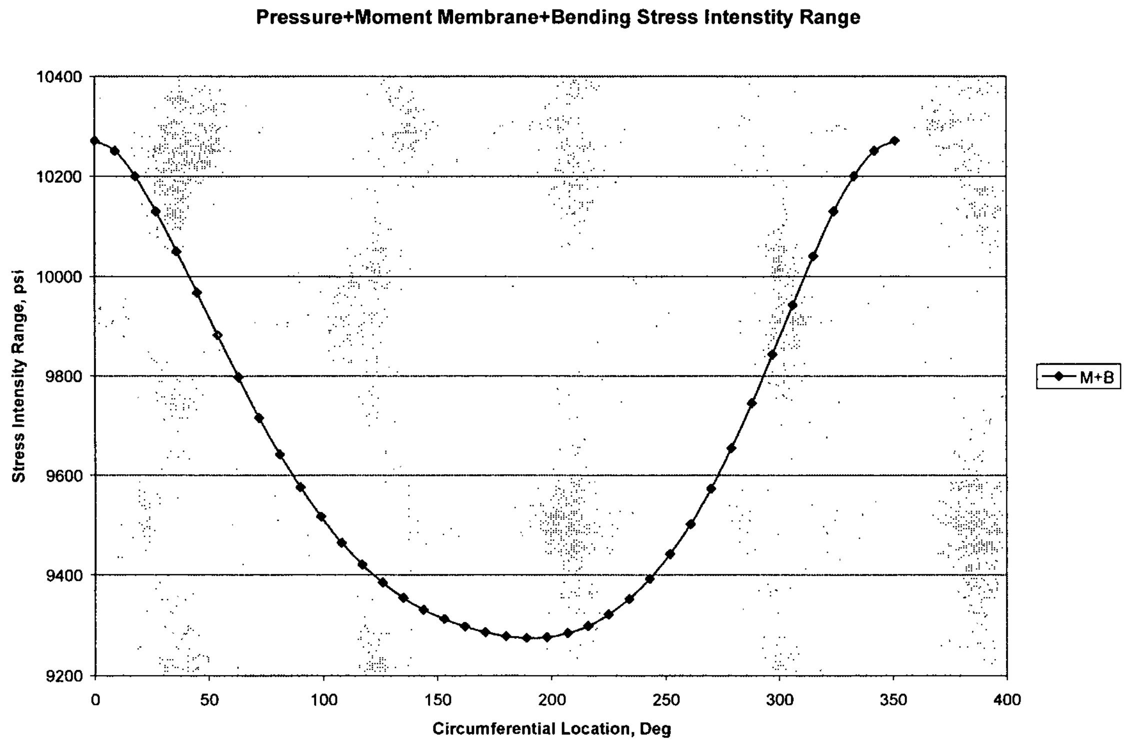

Figure 6: Membrane-plus-Bending Stress Intensity Range

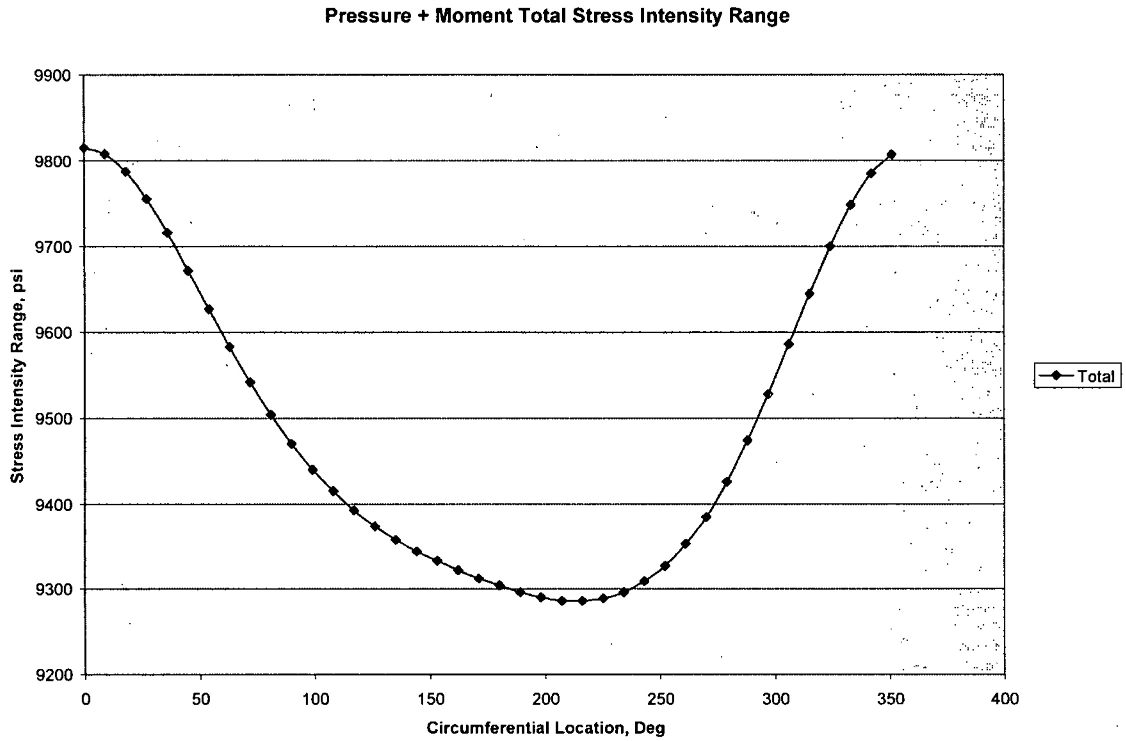

Figure 7: Total (or Peak) Stress Intensity Range

FatiguePro Analysis:

The two transients were simulated in FatiguePro, using the transient definitions in Figure 8 (fast transient) and Figure 9 (slow transient). Note that the simulated input was digitized on a 10-second basis, to conform to the 10-second timestep used in FatiguePro. The simulated data was then exported to 4 CDT (FatiguePro input) files.

The FatiguePro software for Wolf Creek [4, 5] was installed on a computer. A new FatiguePro project was created, using the empty Project Database (PDB) bundled with the software. (This PDB contains the same configuration data as the Wolf Creek monitoring data base used in the License Renewal analysis [6].) The simulated transients were then run, sequentially, using the installed FatiguePro software.

Starting with the unprocessed databases, the days 7/12/2007 – 7/15/2007 were run through a FatiguePro analysis. The analysis was run for the "CHRG_NOZ" with the option to retrieve detailed information on the various stress components (thermal, pressure, piping) tuned on. The following file was saved:

CHRG_NOZ.dbg 2,171,981 bytes 07/18/07 14:29

The data for the fast transient (7/12/07, 0:00 – 0:55) was then imported into the 'Loss of Letdown - Delayed' sheet of the "Wolf Creek Transient Simulation". Data for the Cooldown transient (7/13/07, 0:00 – 4:59) was imported into the 'Cooldown' tab, and for the Heatup transient (7/14/07, 0:00 – 4:59) into the 'Heatup' tab of the workbook.

The parameters 'Pchrg', 'Tchrg' and 'Tcl' were then used as the transient definition for the ANSYS finite element analysis. In addition, terms for the specific directional moments (Ma, Mb, Mc) were derived and tabulated. These parameters were extracted from the worksheet and transferred to the ANSYS input files.

The FatiguePro stress analysis is described in detail in Section 4.0 of Reference [3]. In short, FatiguePro computes the total stress as the integer sum of three stress terms:

$$\sigma_{\text{thermal}} = \int \frac{Green's}{Function} * T_{Loc}\, dt, \quad \text{[ksi]}$$

$$\sigma_{\text{pressure}} = 0.0047 * P_{chg}, \quad \text{[ksi]}$$

$$\sigma_{\text{piping}} = 0.039 * (\text{CL\_TEMP}) - 0.017 * (T_{chg}) - 1.54, \quad \text{[ksi]}$$

The computed values for each of these terms is included in the data. These values were compared to the stress terms from the ANSYS analysis.

The FatiguePro fatigue calculation develops a stress loading spectrum from the local peaks and valleys of the monitored stress history. For the simple simulation performed here, the stress history consists of a single stress pair, derived from the up- and down-shocks of the Loss-of-Letdown Delayed transient. The details are reported in a Fatigue Details Report (see Figure 10).

From that report, you can see that the fatigue usage is determined by a single stress pair, with a (total) stress intensity range of 147.3 ksi. A corresponding Ke factor of 3.067 is applied, giving a usage factor of 0.00787. (Note that the stress intensity range for the simulated cooldown/heatup transient is too small to have a significant effect on the computed fatigue usage.) The local temperature transient is shown in Figure 11. Figure 12 shows the resulting stress history, with the fatigue-significant portion zoomed-in in Figure 13.

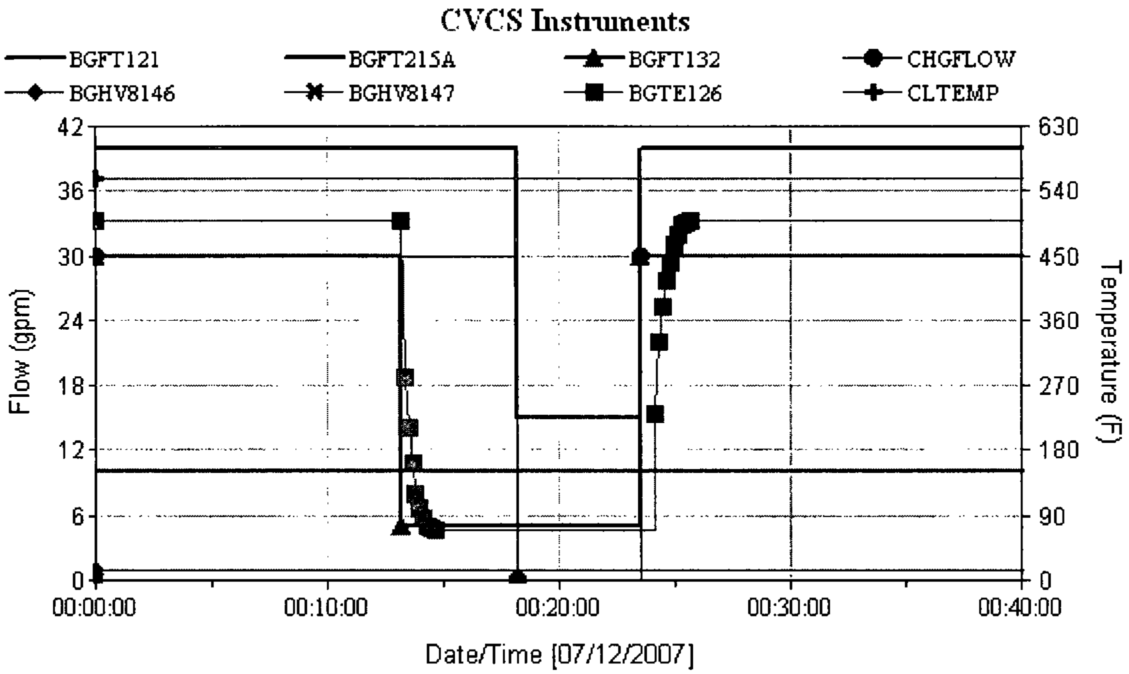

Figure 8: Transient Definition for Fast Transient

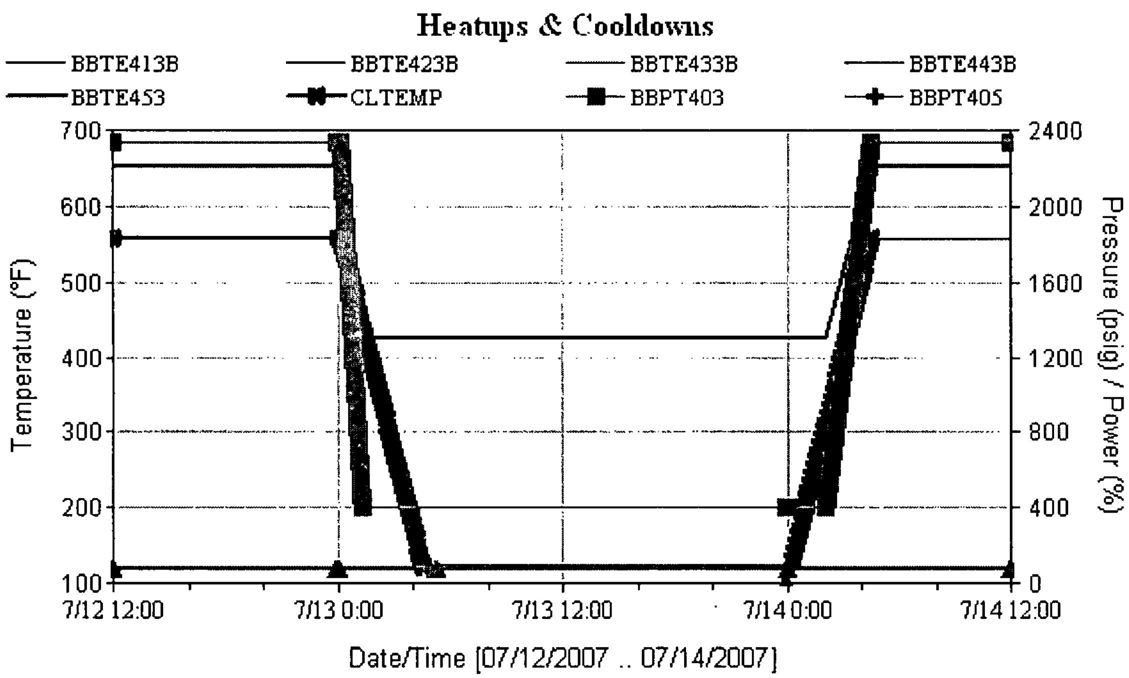

Figure 9: Transient Definition for Slow Transient

Fatigue Details - CHRG_NOZ

Ordered Overall Range Table

Level(%)	Cycles	Usage
99.50	1	0.00787
98.00	0	0.00000
96.00	0	0.00000
93.50	0	0.00000
90.00	0	0.00000
86.00	0	0.00000
81.00	0	0.00000
75.50	0	0.00000
69.00	0	0.00000
61.50	0	0.00000
53.00	0	0.00000
44.00	0	0.00000
34.00	0	0.00000

Usage from Spectrum	0.00786932
Removed Usage	0
Initial Fatigue Usage	0
Total Fatigue Usage	0.00786932
Peak Stress Range	147.273
Maximum Ke	3.06668
Rapid-Cycle Usage	0

Note: fatigue details reported in this dialog reflect the entire analysis -- they are not limited to any report period.

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Figure 10: FatiguePro Fatigue Details Table for Transient 1

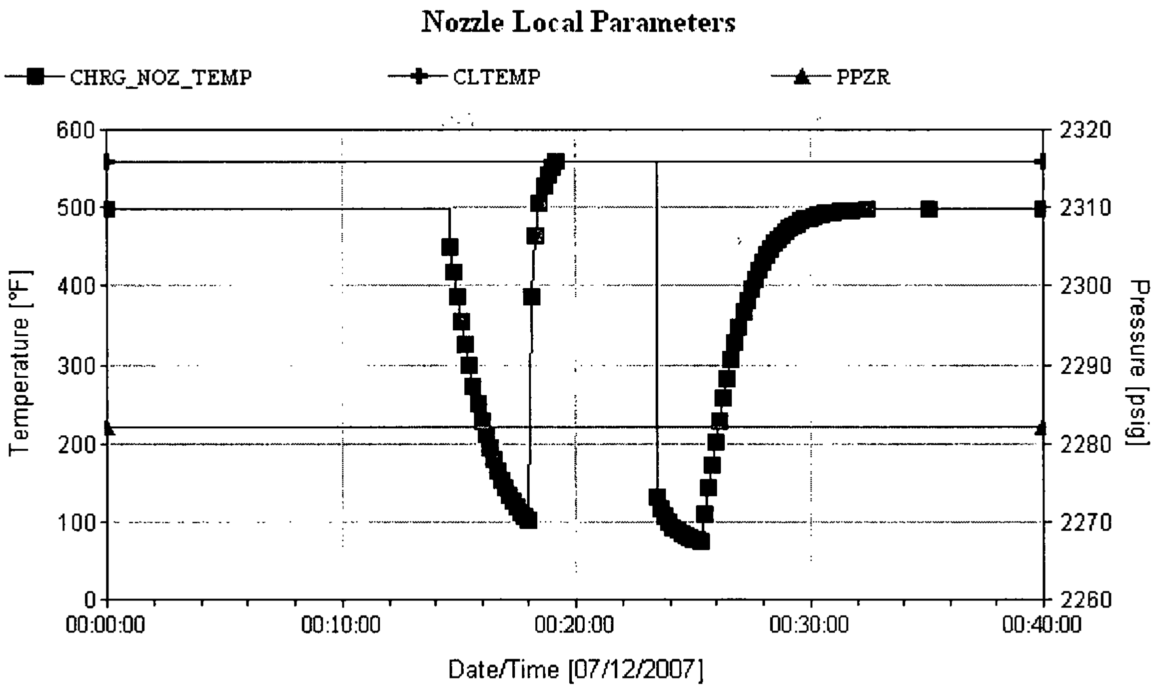

Figure 11: FatiguePro Local Parameters for Transient 1

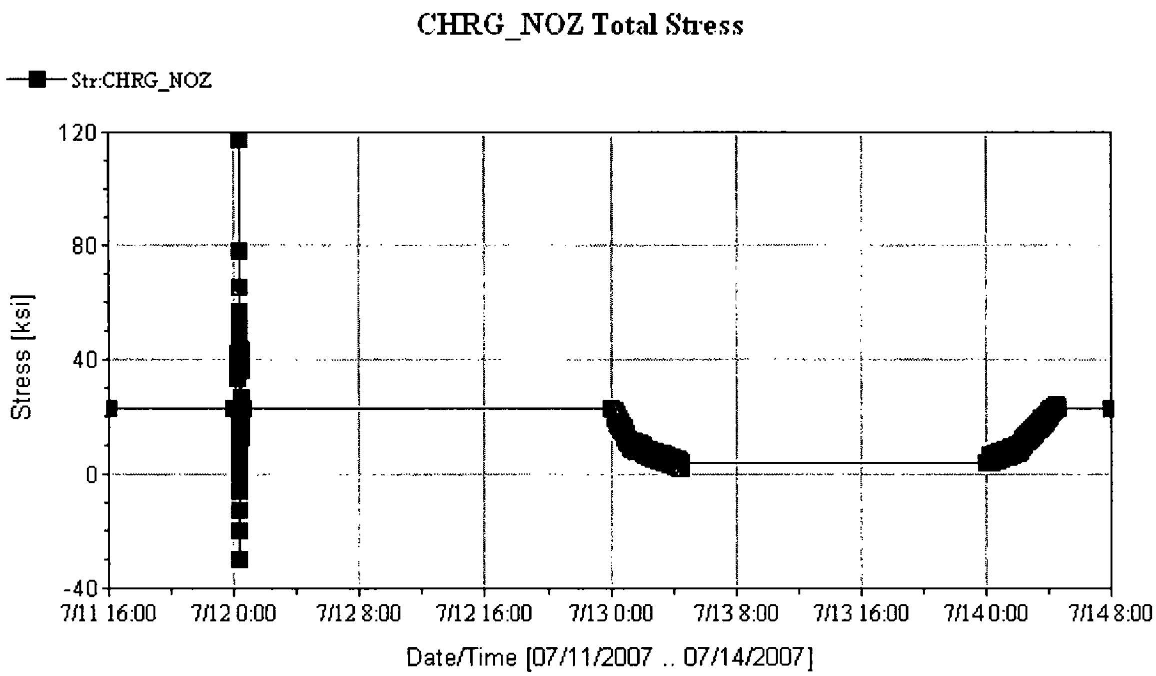

Figure 12: FatiguePro Total Stress

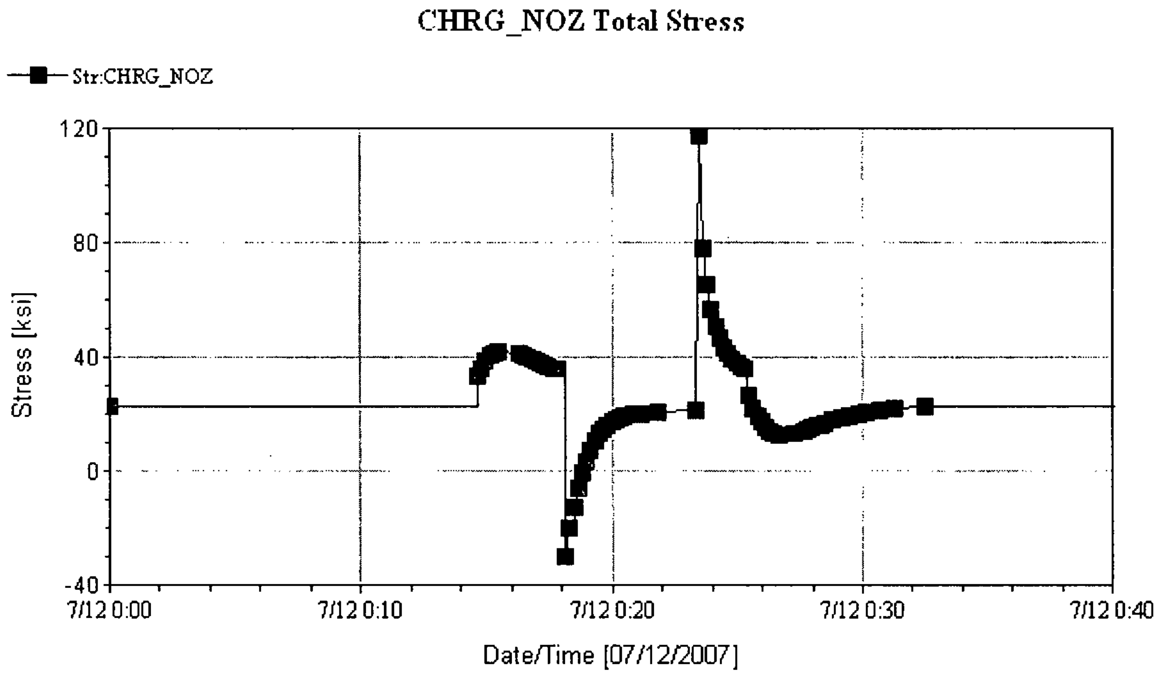

Figure 13: FatiguePro Total Stress for Transient 1

Conclusion:

Fast Transient:

The peak stress intensity range for the fast Loss of Letdown transient computed by FatiguePro was 147.273 ksi with a maximum Ke of 3.07 (see Figure 10). Multiplying the linear elastic stress range by Ke results in a corrected stress range of 452 ksi.

The peak stress intensity range for the same transient computed by a 3D finite element analysis was less than 71.2 ksi per Figure 3, with a maximum Ke of 2.40 (Figure 4) and a corrected stress range of less than 252 ksi (Figure 5).

Slow Transient:

The peak stress intensity range from FatiguePro for the slow transient is arrived at by using the equations for stress taken from the FatiguePro transfer functions:

$$\sigma_{pressure} = 0.0047 * P_{chg}, \quad [ksi]$$
$$\sigma_{piping} = 0.039 * (CL\_TEMP) - 0.017 * (T_{chg}) - 1.54, \quad [ksi]$$

The resulting summation of $\sigma_{pressure} + \sigma_{piping}$ for the full pressure and temperature condition is 22.7 ksi.

The peak stress intensity range for the same condition computed by a three-dimensional finite element analysis was less than 11 ksi per Figures 6 and 7.

Discussion:

In both cases, the results show significant conservatism inherent in the FatiguePro analysis. There are various reasons accounting for the conservatism. Among them:

- FatiguePro uses a conservative ASME Code NB-3600 type of equation to compute the maximum bending stress (including stress concentration factor) on the *outside* surface of the pipe and adds it to the maximum transient thermal and pressure stress on the *inside* of the pipe. The 3D ANSYS model accounts for the more precise application of bending moments in the 3 orthogonal directions and extracts stresses on the inside surface of the pipe.
- FatiguePro assumes step changes in temperature between each time step in the simulated transient. The ANSYS model assumes more realistic ramped changes in temperature between the same time steps.
- FatiguePro computes stress intensity separately for the transient thermal stress, the pressure stress, and the bending stress, and applies them in the worst case summation to maximize stress range. The three-dimensional ANSYS model algebraically sums individual stress components, and then the VESLFAT software computes a more precise stress intensity range difference.

Isolating the effect of the pressure and bending moment stress combinations assumed in FatiguePro, the results of this study show significant conservatism inherent in the FatiguePro-computed stress intensity ranges.

References:

1. SI Calculation, "Charging Nozzle 2D Model", Revision 0, November 1994, SI File No. UE-01Q-305

2. VESLFAT software, Version 1.42, 02/06/07, Structural Integrity Associates.

3. SI Report No. SIR-06-158, Revision 0, "Transfer Function and System Logic Report, Transient and Fatigue Monitoring System for Wolf Creek Generating Station", April 2006, SI File No. FP-WOLF-403.

4. FatiguePro Generic Software, Version 3.01.01-04020, SI File No. EPRI-136Q-403.

5. FatiguePro Plant-specific Software for Wolf Creek, Version (WolfCr) 3.01.04-06116, 5/26/06, SI File No. FP-WOLF-503.

6. (a) SI Calculation, "Baseline Evaluation and 60-Year Projection for Wolf Creek", Revision 0, 5/25/2006, SI File No. FP-WOLF-304.
(b) SI Calculation, "2006 Wolf Creek Baseline and 60-Year Projection Update", Revision 0, 2/1/2007, SI File No. FP-WOLF-305.

7. SI Calculation, "Normal Flow Green's Function for Charging Nozzle", Revision 0, 3/5/2006, SI File No. WOLF-03Q-303.

8. "Callaway/Wolf Creek Piping Loads" date, SI File No. UE-01Q-267.

Wolf Creek Nuclear Operating Corporation (WCNOC) Response to NRC Requests for Additional Information RAI 4.3-2

RAI 4.3-2

In audit question TLAAA025, the staff requested that the applicant explain how to determine the stress transfer function for pressure and moments by using WCAP-14137 Table E.2-1 as an example to demonstrate the following:

S(pr) = 3.71 (psi/psi pressure)
S(momxz) = 9.4 (psi/applied in-kip bending moment)
S(momy) = 0.0 (psi/applied in-kip torsion)

In its response dated June 7, 2007, the applicant stated that this information was derived from a proprietary stress report rather than computed according to some formula. The staff notes that WCAP-14137 Table E.2-1 lists a 14 inch schedule 160 pipe stress transfer function. For a standard 14 inch schedule 160 pipe, stress can be calculated with a well known pressure stress equation, bending stress equation, and torsion shear stress equation as shown below:

For axial stress: $S(pr) = pRi_2 / (Ro_2 - Ri_2)$
For maximum hoop stress: $S(pr) = p(Ro_2 + Ri_2) / (Ro_2 - Ri_2)$
S(bending) = My / I
S(torsion shear) = My / J

Therefore, the staff requests that the applicant demonstrate that 1D virtual stress for pressure, bending, and torsion can be benchmarked with close form solutions and that they are within a reasonable percentage of deviation.

WCNOC Response RAI 4.3- 2:

Basis for Stresses in WCAP-14173 Table E.2-1

The stress intensity values in Table E.2-1 are for the surge line pipe model at the controlling node, 34, as shown in Figure E.2-1. These were developed using stresses from surge line stratification stress and fatigue analyses for the controlling surge line pipe location for Wolf Creek. The stresses used in the fatigue analyses came from finite element analyses, adjusted as needed to account for surge line piping components using NB-3600 stress indices, as discussed in report sections E.1 and E.2. The stress inputs were also developed to fit the FatiguePro requirement for "signed stress intensity" input, and to result in conservative stress intensity ranges from expected loadings. The bases for each stress value requested are provided below:

S(pr) = 3.71 (psi/psi)	This is the stress intensity in psi at node 34 (OD) in the finite element model due to internal pressure loading of 1 psi. (This is also the hoop stress at this location.) The classic thick-wall cylinder pressure stress at the outside diameter is computed as Stress = $p * 2 * r_i^2 / (r_o^2 - r_i^2)$ = 3.53 psi/psi pressure.
S(momxz) = 9.4 (psi/in-kip)	This is the stress intensity in psi at node 34 due to 1 in-kip of moment load in the top-to-bottom bending direction. It was applied in the monitoring model with the moment resultant from top-to-bottom bending (Mx) and torsion (Mz), as described in Section E.2.2. This was done to produce conservative total stresses when added to the thermal stratification stresses at this location. It should also be noted that the stress value given includes a conservative factor of 1.5, which was used in the

	surge line fatigue analysis to envelop both girth butt welds and 5-D bends (bends have a C2 value of 1.5).
S(momy) = 0.0 (psi/in-kip)	This is the stress intensity in psi at node 34 due to 1 in-kip of moment load in the lateral bending direction (My).