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U.S. Nuclear Regulatory Commission
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Washington, DC 20555-0001

Salem Nuclear Generating Station, Unit No. 1 and Unit No. 2
Facility Operating License Nos. DPR-70 and DPR-75
NRC Docket Nos. 50-272 and 50-311

Subject: Follow-Up Responses to Questions Raised during January 18-19, 2011 NRC Audit of WESTEMS™ Program Benchmarking Activities, Related to the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application

References: 1. Letter from Ms. Bennett Brady (USNRC) to Mr. Thomas Joyce (PSEG Nuclear, LLC) "REQUEST FOR ADDITIONAL INFORMATION FOR SALEM NUCLEAR GENERATING STATION, UNITS 1 AND 2, LICENSE RENEWAL APPLICATION FOR USE OF WESTEMS PROGRAM IN METAL FATIGUE ANALYSIS (TAC NO. ME1834 AND ME1836)", dated November 22, 2010

2. Letter from Mr. Paul J. Davison (PSEG Nuclear, LLC) to the NRC, "Response to NRC Request for Additional Information, dated November 22, 2010, related to 1) The use of the WESTEMS™ Program in Metal Fatigue Analysis, and 2) Confirmation of Environmental Fatigue Locations, associated with the Salem Nuclear Generating Station Units 1 and 2 License Renewal Application", dated December 21, 2010

3. Letter from Mr. Paul J. Davison (PSEG Nuclear, LLC) to the NRC, "Results of WESTEMS™ Program Benchmarking Activities Associated with the Response to NRC Request for Additional Information, dated November 22, 2010, Related to the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application", dated January 7, 2011

4. E-Mail from Ms. Bennett Brady (USNRC) to Mr. John Hufnagel (Exelon Corporation) "Requests from the Salem WESTEMS Audit", dated January 19, 2011

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In response to Reference 1, PSEG Nuclear, LLC provided information (in References 2 and 3) related to the use of the WESTEMS™ metal fatigue analysis program related to the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application

After reviewing that information, the NRC staff performed an audit of the WESTEMS™ program methodology and associated benchmarking evaluation at the Westinghouse Rockville, Maryland office on January 18 and 19, 2011. During this Audit, the NRC staff developed some additional information requests (Reference 4).

Enclosure A to this letter provides responses to the follow-up requests resulting from this NRC audit.

Enclosure B provides an update to the License Renewal Commitment List (LRA Appendix A, Section A.5) adding commitments #53, #54, and #55 as a result of this audit follow-up response.

Enclosure C contains an industry publication providing supporting documentation to respond to a specific follow-up request.

If you have any questions, please contact Mr. Ali Fakhar, PSEG Manager - License Renewal, at 856-339-1646.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on 1/31/11

Sincerely,

Robert C. Braun
Senior Vice President, Operations
PSEG Nuclear LLC

Enclosures:

A Response to Questions Raised during January 18-19, 2011 NRC Audit of Westinghouse WESTEMS™ Benchmarking and Methodology associated with the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application

B Update to License Renewal Commitment List

C "Method for Selecting Stress States for Use in an NB-3200 Fatigue Analysis," Proceedings of the ASME 2010 Pressure Vessels & Piping Division / K-PVP Conference, July 18-22, 2010, Bellevue, Washington, USA

cc: William M. Dean, Regional Administrator – USNRC Region I
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NRC Senior Resident Inspector – Salem
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L. Marabella, Corporate Commitment Tracking Coordinator
Howard Berrick, Salem Commitment Tracking Coordinator

Enclosure A

Response to Questions raised during January 18-19, 2011 NRC Audit of Westinghouse WESTEMS™ Benchmarking and Methodology associated with the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application

The NRC conducted an audit of PSEG Nuclear response to the NRC Request for Additional Information (Reference 3), and supporting documentation from January 18-19, 2011 in the Westinghouse Rockville, MD offices. During the audit, the NRC requested additional information. PSEG Nuclear is providing the responses to requests for additional information raised during the audit (Reference 4). For clarity, the specific request for additional information is stated below, followed by the PSEG Nuclear response.

Audit Question No. 1:

In order to close-out the Salem WESTEMS audit, for the WESTEMS "Design CUF" module analysis of the BIT and surge nozzles, provide written explanation and justification of any user intervention in the process including the user intervention applied to the peak and valley selection process.

PSEG Response:

Westinghouse has revised their environmentally-assisted fatigue (EAF) calculations that supported the Salem License Renewal Application (LRA) for the Unit 2 Pressurizer Surge Nozzle Safe End to Pipe Weld and the Unit 2 Safety Injection Boron Injection Tank (BIT) Nozzle Coupling to Cold Leg Weld. The revision specifically added a new section to an existing Appendix to document the following:

1. Description of the WESTEMS™ stress peak and valley selection algorithm.

2. A new WESTEMS™ program run with no analyst intervention (i.e. no manual removal by the analyst).

3. Numerical comparison of the number of stress peaks and valleys selected by the analyst in the original revision of the calculation to the number of stress peaks and valleys selected during the new WESTEMS™ program run.

4. Justification for analyst manual removal of the stress peaks and valleys on a transient-by-transient basis only when WESTEMS™ selected more stress peaks and valleys than the analyst. In the cases where the analyst selected more stress peaks and valleys than WESTEMS™, justification is not required since this method is more conservative for the fatigue evaluation.

   The justification is illustrated in the new section of the Appendix by use of plots generated by a spreadsheet containing downloaded data of the Total Stress Intensity and Primary plus Secondary Intensity values for each transient. The plots depict the stress peaks selected by WESTEMS™ and by the analyst. Documentation is provided in the new section of the Appendix justifying removal of redundant stress peaks and valleys for each transient.

5. For the Unit 2 Safety Injection BIT Nozzle Coupling to Cold Leg Weld location, two new tables are added to list the fatigue pairs and corresponding fatigue usage for the original revision of the calculation (analyst intervention) and where no analyst intervention was involved for comparison of the total

cumulative usage factor (CUF). For the Unit 2 Pressurizer Surge Nozzle Safe End to Pipe Weld location, the fatigue usage values were compared and were the same value in both the original revision of the calculation, and the revised calculation where no analyst intervention was involved.

Although the 60-Year Design CUF value for the Unit 2 Safety Injection BIT Nozzle Coupling to Cold Leg Weld location was higher in the case of no analyst intervention during the stress peak and valley process, justification is provided for removal of redundant stress peaks and valleys. The 60-Year Design CUF listed in LRA Table 4.3.7-2, "Salem Unit 2 60-Year Environmentally-Assisted Fatigue Results," reflects justified analyst intervention during the stress peak and valley process.

The revised proprietary calculations have been approved by Salem, and will be made available for NRC review during the next phase of the WESTEMS™ audit.

Audit Question No. 2:

For any WESTEMS "Design CUF" module analyses performed for the remaining monitored locations at Salem (i.e., other than the BIT and surge nozzles), provide written explanation and justification of any user intervention applied in the process including the user intervention applied to the peak and valley selection process prior to two years before entering the period of extended operation.

PSEG Response:

Salem will revise the fatigue calculations for all locations monitored at Salem Units 1 and 2 to include a written explanation and justification of any user intervention applied for any WESTEMS™ "Design CUF" module analyses, including the user intervention applied to the stress peak and valley selection, at least two years prior to entering the period of extended operation.

As a result of this response, commitment #53 is added to LRA Table A.5, License Renewal Commitment List, as shown in Enclosure B of this letter.

Audit Question No. 3:

For any use of the WESTEMS "Design CUF" module in the future at Salem, include written explanation and justification of any user intervention in the process.

PSEG Response:

Salem will include written explanation and justification of any user intervention in future evaluations using the WESTEMS "Design CUF" module.

As a result of this response, commitment #54 is added to LRA Table A.5, License Renewal Commitment List, as shown in Enclosure B of this letter.

Audit Question No. 4:

Provide a commitment that the NB-3600 option of the WESTEMS "Design CUF" module will not be implemented or used in the future at Salem.

PSEG Response:

Salem will commit to not use or implement the NB-3600 option (module) of the WESTEMS™ program in future online fatigue monitoring and design CUF calculations.

As a result of this response, commitment #55 is added to LRA Table A.5, License Renewal Commitment List, as shown in Enclosure B of this letter.

Audit Question No. 5:

Provide a description of the peak and valley selection process used by WESTEMS and how that process aligns with ASME Code NB-3216 methodology.

PSEG Response:

WESTEMS™ is a software program developed by Westinghouse Electric Company LLC (Westinghouse). It is used to perform fatigue evaluations for components using NB-3200 stress models, referred to as Analysis Section Number (ASN) models by Westinghouse, according to the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB-3222.4, 1986 edition. As part of the ASME Code fatigue evaluation, the person performing the fatigue evaluation (analyst) is required to select the extremes of the stress cycles (stress peaks and valleys) imposed by the component's transient loads (thermal, mechanical, etc.). WESTEMS™ uses an automated approach to assist the analyst in selecting the stress peak and valley times in each transient. The approach is described in general, with respect to the associated ASME Code fatigue evaluation requirements, in Westinghouse's publication, "Method for Selecting Stress States for Use in an NB-3200 Fatigue Analysis," PVP2010-25891, Proceedings of the ASME 2010 Pressure Vessels & Piping Division / K-PVP Conference, July 18-22, 2010, Bellevue, Washington, USA . This paper is attached to this letter as Enclosure C.

The WESTEMS™ stress peak and valley algorithm and associated analyst options for its use are described in the WESTEMS™ User's Manual, Volume 2. The alignment between the WESTEMS™ automated approach and ASME Code NB-3216 methodology (NB-3216) is illustrated below with the aid of excerpts from the previously referenced Westinghouse publication and sections of the WESTEMS™ User's Manual .

The following paragraphs are based on, or taken directly from, Westinghouse publication PVP2010-25891:

Performing a fatigue evaluation per ASME Code Section III, Subsection NB-3222.4 (NB-3222.4) requires calculating the stress differences for each type of stress cycle in accordance with NB-3216. In determining the number of cycles for each type of stress cycle, consideration is given to the superposition of cycles from various stress cycles that produce a total stress range greater than that of each individual stress cycle alone. This procedure is outlined in NB-3222.4(e) (5), Step 1. The resulting cycles and alternating stress intensities from this procedure are then applied in a cumulative manner using the appropriate design fatigue curve, in NB-3222.4(e) (5), Steps 3-6, to calculate fatigue usage factors. In traditional ASME Section III Code fatigue evaluations, the extremes of the stress cycle have been selected by the analyst based on experience and review of the stress component and/or stress intensity histories produced by the various transients.

The stress state selection method incorporated in WESTEMS™ fatigue evaluations employs a stress intensity based approach that is a practical method used to interpret and apply NB-3216.2. It can capture Primary plus Secondary stress and Total stress ranges for complex transients, allowing for the proper application of NB-3222.4. The approach emulates considerations employed by analysts for decades in applying various calculation methods to NB-3200 requirements.

The method used by WESTEMS™ to select the stress peak and valley times utilizes a straightforward mathematical process to select times where the stress states are at a relative minimum or maximum. Additionally, the method employs controlled options that provide the ability to control the treatment of initial condition stress states in the selection process.

The basic algorithm used by WESTEMS™ is as follows. For each transient cycle in the component fatigue evaluation, the six stress components of Primary plus Secondary stress and of Total stress are calculated for the entire transient time history. Then the stress intensities for the Primary plus Secondary stress and the Total stress time histories are calculated. Relative maxima and minima within the Primary plus Secondary stress and Total stress time histories for each transient are identified using the second derivative test (comparing the slopes of the stress history around a time point).

It is important to note that in following an NB-3216.2 procedure, the analyst is to pick a time point where stress conditions are known to be extreme and then find the maximum stress component range relative to this extreme. Using the stress intensity based approach, the time points where stress conditions are extreme are picked at the relative stress peaks and valleys, or maximum and minimum stress states along the stress intensity time history. Effectively, NB-3216.2 calculates stress component ranges from chosen extreme stress component states, where the stress intensity based approach picks extreme stress states based on stress intensity, which is a good indicator of stress component and related principal stress difference extremities. The stress intensity based approach identifies the time points of these extremes, then calculates stress component ranges, the principal stress ranges, and finally the resulting stress intensity range between two selected stress states using the corresponding component stresses at those time points (not the values of stress intensity used to select those points in time as extremes). This is consistent with the procedure used in NB-3216.2. In summary, the stress intensity time histories for each transient are used to select relative extremes, and the component stresses at those extremes are used in calculating stress ranges with other stress states that were selected in the same manner. This procedure is performed for both the Primary plus Secondary and Total stress time histories for all transients considered in the evaluation. Specific examples illustrating the approach are provided in Westinghouse publication PVP2010-25891.

The following discussion is based on and provides specific references to sections of the WESTEMS™ User's Manual. The proprietary WESTEMS™ User's Manual will be made available for NRC review during the next phase of the WESTEMS™ audit.

The WESTEMS™ stress peak and valley selection algorithm that follows the approach described in the Westinghouse publication PVP2010-25891 is described in section 14.0 of the WESTEMS™ User's Manual, Volume 2. The process used by WESTEMS™ is designed to find all of the inflection points (also known as maxima and minima) in the controlling stress intensity histories. It considers the ASME Section III Code Total stress and Primary plus Secondary stress time histories, since both may influence the fatigue usage calculation. It should be noted that, while the WESTEMS™ algorithm uses the stress intensity history to find the times of the stress peaks and valleys, the individual components of stress available for the stress model are retained at the time points selected, so that the stress range pairs in the fatigue evaluation may be calculated based on the ASME Code Section III methodology. In the WESTEMS™ User's Manual, Volume 2, the general term "peaks" is used to refer to the set of inflection points that include the stress peak and valley stress states in a transient.

The WESTEMS™ algorithm is generally designed to ensure that no valid stress peaks are missed, and so it may, in many cases, conservatively select the number of stress peaks. Therefore, as discussed in section 8.1.3 of the WESTEMS™ User's Manual, Volume 2, the software program permits the analyst to provide inputs, such as stress filter and time constant merge parameters, to attempt to eliminate redundant or unnecessary stress peaks. In the WESTEMS™ design analysis mode, the results are dependent on the analyst time-history input. Therefore, the analyst has ultimate control over the stress peaks used in the fatigue evaluation, to the extent of final editing of the stress peaks selected by the program using the WESTEMS™ stress peak editing tool, which is described in section 8.11 of the User's Manual. The fatigue evaluation is independently verified by another analyst and approved by a manager.

Since the WESTEMS™ algorithm selects stress peaks and valleys consistent with the criteria in ASME Code Section III, Subsections NB-3216 and NB-3222.4, as described above, and the user controls are used to reduce WESTEMS™ program conservatism and do not change the overall basis for the stress peak selection, the final WESTEMS™ fatigue evaluations are performed consistent with the criteria in ASME Code Section III, Subsections NB-3216 and NB-3222.4.

Enclosure B
Update to License Renewal Commitment List

As a result of this response, the commitments discussed above are added to LRA Table A.5, License Renewal Commitment List as commitment numbers 53, 54, and 55, as shown below. Any other actions described in this letter are not regulatory commitments and are described for the NRC staff's information:

A.5 License Renewal Commitment List

No.	Program or Topic	Commitment	UFSAR Supplement Location (LRA App. A)	Enhancement or Implementation Schedule	Source
53	*Salem Fatigue Calculations for WESTEMS™ Monitored Locations*	*Salem will revise the fatigue calculations for all locations monitored at Salem Units 1 and 2 to provide written explanation and justification of any user intervention applied for any WESTEMS™ "Design CUF" module analyses including the user intervention applied to the stress peak and valley selection.*	*N/A*	*At least 2 years prior to the period of extended operation.*	*Salem Letter LR-N11-0042*
54	*Salem Fatigue Calculations using WESTEMS™ program*	*Salem will include written explanation and justification of any user intervention in future evaluations using the WESTEMS "Design CUF" module.*	*N/A*	*Within 60 days of issuance of the renewed operating license.*	*Salem Letter LR-N11-0042*
55	*Salem Fatigue Calculations using WESTEMS™ program*	*Salem will not use or implement the NB-3600 option (module) of the WESTEMS™ program in future online fatigue monitoring and design calculations.*	*N/A*	*Within 60 days of issuance of the renewed operating license.*	*Salem Letter LR-N11-0042*

Enclosure C

"Method for Selecting Stress States for Use in an NB-3200 Fatigue Analysis,"
Proceedings of the ASME 2010 Pressure Vessels & Piping Division / K-PVP Conference,
July 18-22, 2010, Bellevue, Washington, USA (7 pages)

Proceedings of the ASME 2010 Pressure Vessels & Piping Division / K-PVP Conference
PVP 2010
July 18-22, 2010, Bellevue, Washington, USA

PVP2010-25891

METHOD FOR SELECTING STRESS STATES FOR USE IN AN NB-3200 FATIGUE ANALYSIS

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ABSTRACT

In ASME Code Section III NB-3222.4 fatigue evaluations, selecting stress states to determine the stress cycles according to Section NB-3216.2, Varying Principal Stress Direction, can become a challenging and complex task if the transient stress conditions are the result of multiple independent time varying stressors. This paper will describe an automated method that identifies the relative minimum and maximum stress states in a component's transient stress time history and fulfills the criteria of NB-3216.2 and NB-3222.4. Utilization of the method described ensures that all meaningful stress states are identified in each transient's stress time history. The method is very effective in identifying the maximum total stress range that can occur between any real or postulated transient stress time histories. In addition, the method ensures that the maximum primary plus secondary stress range is also identified, even if it is out of phase with the total stress maxima and minima. The method includes a process to determine if a primary plus secondary stress relative minimum or maximum should be considered in addition to those stress states identified in the total stress time history. The method is suitable for use in design analysis applications as well as in on-line stress and fatigue monitoring

INTRODUCTION/BACKGROUND

Traditionally, the task of selecting stress states for consideration in fatigue analysis was considered a relatively simple and straightforward process. This was true in large part because of:

a) the simplicity of the design transients, and

b) simplifying assumptions that were introduced during the qualification process.

Now, as analytical capabilities have improved, we are able to more precisely model postulated design transient conditions. In the past, when analytical capabilities were more expensive, simplifications were employed to reduce costs and shorten design times. These simplifications would use methods like lumping external loads into minimum and maximum states and creating groups of enveloped transient conditions to achieve the desired effects. In general, this approach is acceptable for situations with a small number of loading conditions and little or no differences in the response characteristics to the loads. However, when the loading conditions are defined in a very complex manner, as is the case with some components in a PWR, this approach is not necessarily easy to apply to satisfy the analytical requirements in NB-3216.2 and NB-3222.4. Some reasons why these simplifications can fail are as follows:

a) Complex transient time histories typically have many more significant stress states per global transient cycle than the simplified transients.
b) Complex transients may have significantly varying local thermal conditions within one global cycle of the transient.
c) Complex transients produce primary plus secondary stresses that are at times out of phase with the total stress.

Subsection NB-3216.2 explains the method for calculating alternating stress intensity for cases where the directions of the principal stresses can change during the stress cycle at the location being considered. This method for computing stress differences is described as permitting the principal stresses to change direction while still maintaining their identity as they rotate.

Performing a fatigue evaluation per NB-3222.4 requires calculating the stress differences for each type of stress cycle in accordance to NB-3216. In determining the number of cycles for each type of stress cycle, consideration is given to the superposition of cycles from various stress cycles that produce a total stress range greater than that of each individual stress cycle alone. This procedure is outlined in NB-3222.4(e) (5), Step 1. The resulting cycles and alternating stress intensities from this procedure are then applied in a cumulative manner using the appropriate design fatigue curve, in NB-3222.4(e) (5), Steps 3-6, to calculate fatigue usage factors.

To meet the requirements of subsection NB-3216.2, one would first compute the total stress component time histories for the complete transient cycle, considering all loading conditions and structural discontinuities. Then, a point in time during the transient cycle must be chosen when stress conditions are known to be extreme (either maximum or minimum). The stress components associated with this time point are then subtracted from the corresponding stress components for every time in the transient cycle. The result is a stress component range history relative to one extreme of the transient cycle. From these component stress ranges, principal stresses and the resulting stress differences are calculated for each point in time for the transient cycle. The alternating stress intensity is half of the largest absolute magnitude of the stress intensity range time history. This procedure must be repeated for each transient cycle to be considered for the component.

To calculate the correct alternating stress intensity to use with the design fatigue curve from a computed total stress range, an additional factor that must be considered is the satisfaction of NB-3222.2 for that specific total stress range. If the primary plus secondary stress range corresponding to the total stress range fails to meet the 3Sm criteria set by NB-3222.2, then the Sa used with the design fatigue curve must be increased by a penalty factor, Ke, as part of the simplified elastic-plastic analysis requirements of NB-3228.5. This mandates that primary plus secondary stress range history and total stress range history must be computed for each transient cycle using the procedure described in NB-3216.2.

Also, because primary plus secondary stress is influenced by different properties of the component location, the time when its magnitude is at an extreme may not be the same time point as the extreme for the total stress history of the single point where fatigue usage is being calculated for the component. The magnitude of the primary plus secondary stress at this maximum, and the associated total stress at the same time, may produce a more conservative alternating stress in the forthcoming fatigue analysis. In this case, at least two separate total stress ranges resulting from the same event must be considered in computing the applicable alternating stress. These include at least one based on the primary plus secondary extreme time points and one based on the total stress extreme time points. After it is established which combination of total stress range and primary plus secondary stress range will produce the highest alternating stress, considering the Ke effect, the lesser alternating stress range can be neglected, since both stress ranges originated from the same event.

NOMENCLATURE

Transient Cycle: Any stress cycle experienced by a component due to a plant loading event, regardless of whether it was caused by thermal or mechanical load conditions.
Sp: Total Stress
Sn: Primary plus Secondary Stress
Salt: Alternating Stress Intensity
Sm: Material Allowable Stress
Emod: Elastic Modulus Correction Factor
Ke: NB-3228.5 Elastic-plastic Penalty Factor

TRANSIENTS VS. STRESS STATES

Depending on the location of the component analyzed, the component geometry, the location of the component within the system, and loading conditions, the stress responses from various transient cycles can be simple or complex. The superposition of various loadings, whether thermal or mechanical in origin, can make selecting an extreme time point during the transient cycle per NB-3216.2 a challenge. It is also possible that there are multiple relative maximum and minimum stress ranges that should be considered within the component fatigue evaluation. Finally, each loading condition must be evaluated per NB-3200 rules to determine if the NB-3222.2 Primary plus Secondary stress range limit is met, and the possible Ke penalty that may result. Two relatively simple transients are shown in Figure 1 and Figure 2. These two transients were arbitrarily defined to reinforce the premise of the stress intensity based method to relative maxima and minima selection, as described in the next section.

STRESS INTENSITY BASED APPROACH

Although with today's current computational power it might be possible to program an algorithm that would be a literal interpretation of NB-3216.2, there would still be some issues that would have to be resolved in selecting the correct stress ranges. Those issues include capturing the effect of the possible Ke penalty induced from a failure of NB-3222.2, and applying NB-3216.2 to a complex transient with multiple stress ranges. Westinghouse engineers have developed a repeatable method to identify all significant stress states in a given stress time history. This method does not rely on the engineer's experience but rather utilizes a straightforward mathematical process to select times where the stress states are at a relative minimum or maximum. Additionally, the method employs controlled options that provide the ability to control the treatment of initial condition stress states in the selection process.

The stress state selection method has been incorporated into Westinghouse's internally developed stress and fatigue analysis program called WESTEMS™ and is described below. The method employs a stress intensity based approach that is a practical method used to interpret and apply NB-3216.2. It can capture primary plus secondary stress and total stress ranges for complex transients, allowing for the proper application of NB-3222.4. The approach emulates considerations employed by engineers for decades in applying various calculation methods to NB-3200 requirements.

The basic algorithm is as follows. For each transient cycle in the component fatigue evaluation, the six stress components of primary plus secondary stress and of total stress are calculated for the entire transient time history. Then the stress intensities for the primary plus secondary stress and the total stress time histories are calculated. Relative maxima and minima within the primary plus secondary stress and total stress time histories for each transient are identified using the second derivative test. Special considerations are used to address relative flat spots that are plateaus in the stress intensity time histories.

It is important to note here that in following an NB-3216.2 procedure, the analyst is to pick a time point where stress conditions are known to be extreme and then find the maximum stress component range relative to this extreme. Using the stress intensity based approach, the points where stress conditions are extreme are picked at the relative peaks and valleys, or maximum and minimum stress states along the stress intensity time history. Effectively, NB-3216.2 calculates stress component ranges from chosen extreme total stress component states, where the stress intensity based approach picks extreme stress states based on stress intensity, which is a good indicator of stress component and related principal stress difference extremities. The stress intensity based approach identifies the times of these extremes, then calculates stress component ranges, the principal stress ranges, and finally the resulting stress intensity range between two selected stress states using the corresponding component stresses at those times (not the values of stress intensity used to select those points in time as extremes). This is consistent with the procedure used in NB-3216.2. In summary, the stress intensity time histories for each transient are used to select relative extremes, and the component stresses at those extremes are used in calculating stress ranges with other stress states that were selected in the same manner. This procedure is performed for both the primary plus secondary and total stress time histories for all transients considered in the evaluation.

Several tests were performed to prove that the stress intensity approach satisfies NB-3216.2, One example problem is provided here that uses both the literal interpretation of NB-3216.2 and the stress intensity based approach to show that the resulting maximum stress range calculated between two transients would be the same. First, two arbitrary transients are defined that include a simple thermal transient (Transient 1) and a second thermal transient that also includes a varying torsion load (Transient 2). The torsion load was included in the second transient to introduce a varying principal stress direction response. Figure 1 and Figure 2 illustrate Transient 1 and Transient 2 loading conditions, respectively.

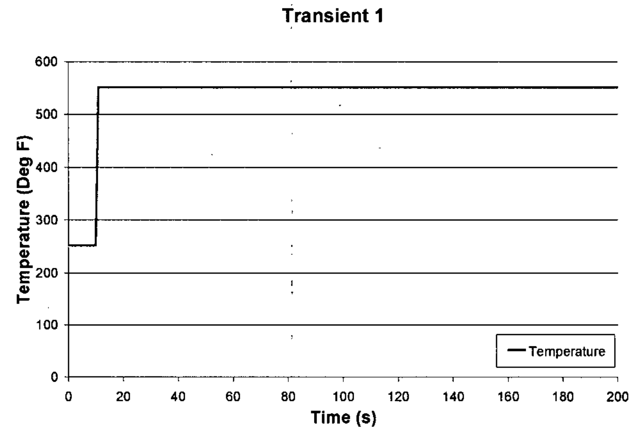

Figure 1 Loading Conditions for Transient 1

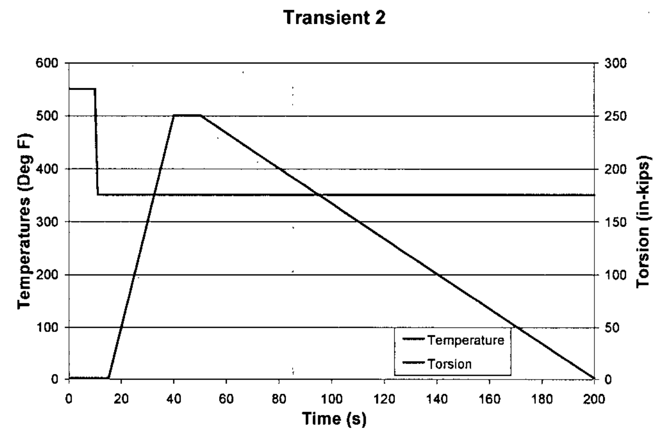

Figure 2 Loading Conditions for Transient 2

After the total stress component histories for each transient are calculated, the process of selecting the largest total stress range was conducted using both methodologies. A rigorous analysis using the procedure described in NB-3216.2 was performed to calculate the maximum local component stress ranges relative to each time step within the transient and between the two transients. For Transient 1, the maximum stress intensity range occurred at 13 seconds. For Transient 2, the maximum stress intensity ranges occurred at 13 seconds and 40 seconds. Refer to Figure 3 and Figure 4 for total stress component time histories of Transient 1 and Transient 2, respectively.

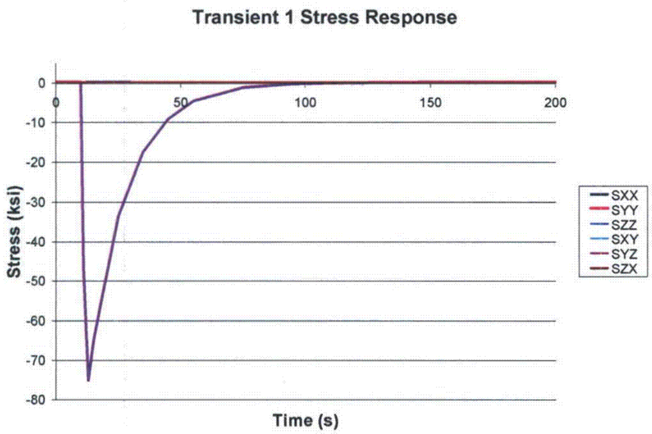

Figure 3 Total Stress Component Time History - Transient 1

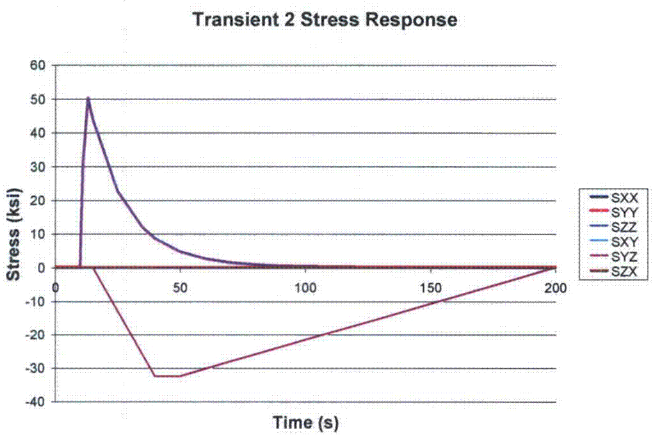

Figure 4 Total Stress Component Time History -Transient 2

When the relative stress component ranges, principal stress ranges, and the resulting stress intensity ranges were computed between transients, the two relative maximum stress intensity ranges occurred between Transient 1 at 13 seconds and Transient 2 at 13 seconds, and also between Transient 1 at 13 seconds and Transient 2 at 40 seconds.

Table 1 NB-3216.2 - Relative Stress Intensity Range Results

Trans. 1- 2 Stress Difference Relative to Trans. 1 at 13 sec.							
Time	**SXX**	**SYY**	**SZZ**	**SXY**	**SYZ**	**SZX**	**SI**
0	0.08	-75.21	-75.30	0.00	0.00	-0.02	75.38
10	0.08	-75.21	-75.30	0.00	0.00	-0.02	75.38
11	0.08	-106.29	-106.39	0.00	0.00	-0.03	106.47
13	0.13	-125.35	-125.51	0.00	0.00	-0.04	125.64
15	0.14	-118.74	-118.90	0.00	0.00	-0.03	119.04
25	0.11	-97.62	-97.75	0.00	13.04	-0.03	110.84
35	0.10	-86.92	-87.05	0.00	26.09	-0.02	113.16
40	0.09	-83.61	-83.74	0.00	32.61	-0.02	116.38
50	0.09	-79.63	-79.75	0.00	32.61	-0.02	112.39
60	0.08	-77.57	-77.69	0.00	30.44	-0.02	108.15
70	0.08	-76.48	-76.59	0.00	28.26	-0.02	104.87
80	0.08	-75.89	-76.00	0.00	26.09	-0.02	102.11
90	0.08	-75.52	-75.62	0.00	23.91	-0.02	99.56
110	0.08	-75.30	-75.40	0.00	19.57	-0.02	94.99
130	0.08	-75.25	-75.35	0.00	15.22	-0.02	90.60
150	0.08	-75.20	-75.30	0.00	10.87	-0.02	86.20
190	0.08	-75.21	-75.30	0.00	2.17	-0.02	77.51
200	0.08	-75.21	-75.30	0.00	0.00	-0.02	75.38

The process of locating the local relative maximum stress ranges was then conducted using the stress intensity based approach. After the total stress intensity histories were calculated, the program algorithm was run to select the local stress intensity peaks and valleys. Relative maxima and minima within the total stress intensity time histories for each transient were identified using the second derivative test. Figure 5 and Figure 6 illustrate the stress intensity time histories for Transient 1 and Transient 2. The peak and valley times selected using the stress intensity based approach are summarized in Table 2.

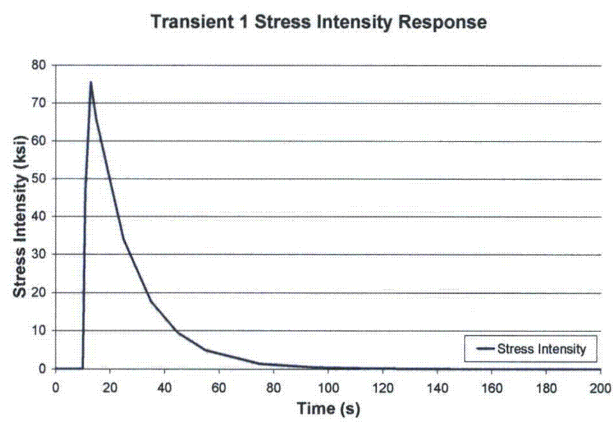

Figure 5 Total Stress Intensity Time History for Transient 1

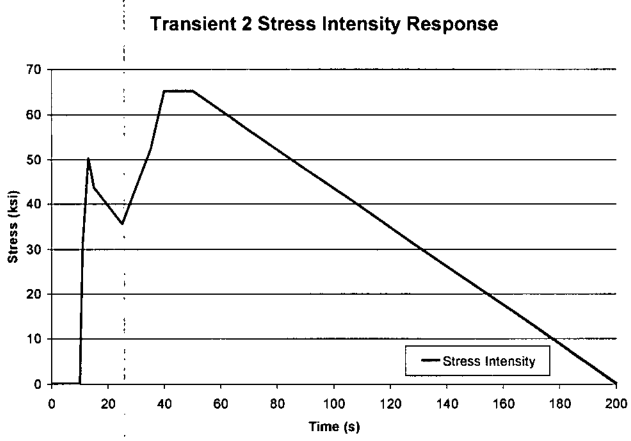

Figure 6 Total Stress Intensity Time History for Transient 2

Table 2 Selected Maxima and Minima - Stress Intensity Method

Time	Transient	SI
13	1	75.38700
15	1	65.48500
195	1	0.00100
0	2	0.00500
13	2	50.25200
25	2	35.49900
40	2	65.22001
50	2	65.22000
200	2	0.00600

Once the peaks were selected using the stress intensity based approach, all possible pairings of maxima and minima were calculated to reveal those that would yield the highest total stress intensity range. This was done by calculating the component stress ranges between the selected stress state times, computing the principal stress ranges, and the resulting stress intensity ranges. The two highest stress intensity ranges are shown in Table 3.

Table 3 Maximum Stress Intensity Range Results - Stress Intensity Based Approach

Trans_B	Time_B	Trans_A	Time_A	SI
2	13	1	13	125.64
2	40	1	13	116.38

A simple comparison between Table 1 and Table 3 reveals that the stress intensity based approach yields the same results as the approach used in NB-3216.2. In the ensuing fatigue evaluation, the cycles for each stress intensity range would be assigned based on the approach described in NB-3222.4.

PRIMARY PLUS SECONDARY STRESS CONSIDERATION

As described in the introduction, a circumstance that can arise is the possibility of the primary plus secondary stress time history lagging the total stress time history. This is because primary plus secondary stress is influenced more by properties like section thickness and geometric and material discontinuities, and can have a slower stress response that the total stress at a point. The WESTEMS™ program implementing the method stores the primary plus secondary stress components and the total stress components for each stress state time selected, regardless of whether it was selected based on primary plus secondary or total stress. This is because when two stress states pair in NB-3222.4, the primary plus secondary stress range of that pair must be measured against NB-3222.2 limits, and any resulting Ke penalty must be applied to the total stress intensity range of that pair to calculate the alternating stress. The example problem below illustrates how WESTEMS™ incorporates primary plus secondary stress into its algorithm to calculate alternating stress.

If two stress states were selected because the primary plus secondary was out of phase but was caused by the same event, then one of the stress states can be disregarded. This can only be done once it is determined which stress state is contributing to the pair resulting in the higher alternating stress. Then, the stress state associated with the lesser alternating stress is disregarded.

If, for a specific component, it is known that the total stress state is always controlling, the program also has the option to automatically disregard the primary plus secondary peak/valley based on a time constant. If there is a primary plus secondary peak/valley within a specified time relative to the total stress peak/valley, then the primary plus secondary stress peak/valley will be disregarded. The time constant for a location can be approximated by evaluating a transient composed of only thermal stress and reviewing the primary plus secondary stress and total stress responses. The period between these two peaks/valleys would be a good initial estimate of the time constant.

Example Problem

This example problem illustrates a simple example of when a peak/valley time chosen from primary plus secondary stress can actually be the controlling stress state over the total stress peak/valley for an event. Figure 7 and Figure 8 below illustrate the loading conditions within two arbitrary transients.

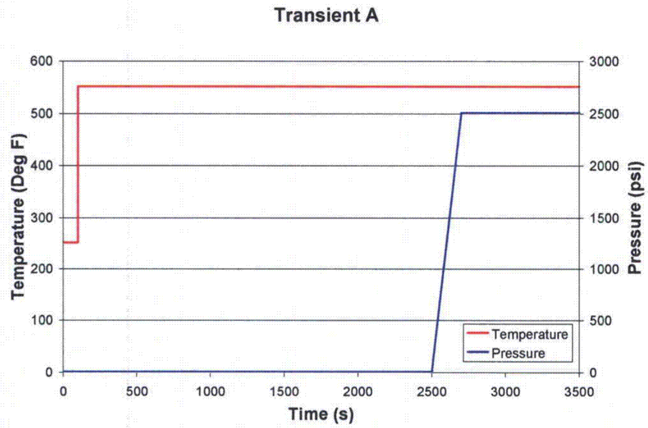

Figure 7 Loading Conditions for Transient A

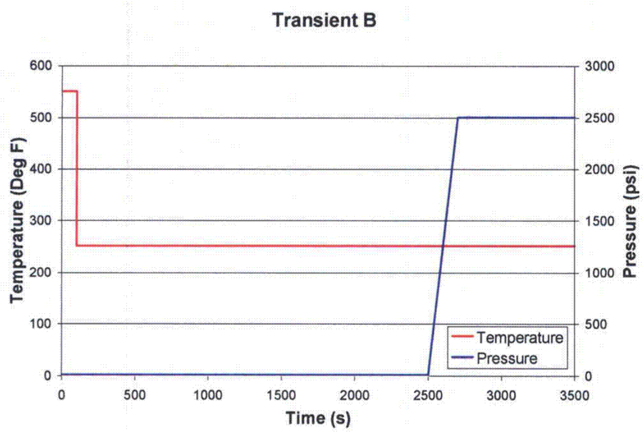

Figure 8 Loading Conditions for Transient B

A stress model of a thick-walled component was used to evaluate these transients. A thick-walled component was chosen because it will increase the primary plus secondary stress lag behind total stress for a thermal excursion. The primary plus secondary and total stress component histories are shown in Figure 9 and Figure 10 for transient A and transient B, respectively. The stress intensity responses for these two transients are shown in Figure 11 and Figure 12. The peak/valley times were selected using the stress intensity based approach for primary plus secondary stress and total stress histories. A summary of the peaks/valleys selected can be seen in Table 4.

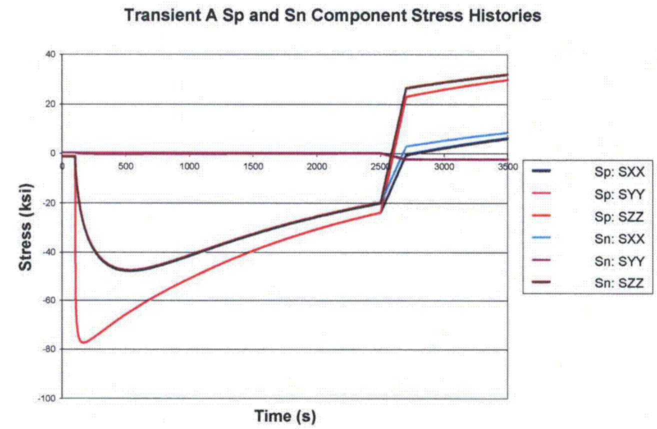

Figure 9 Transient A Sp and Sn Component Stress Histories

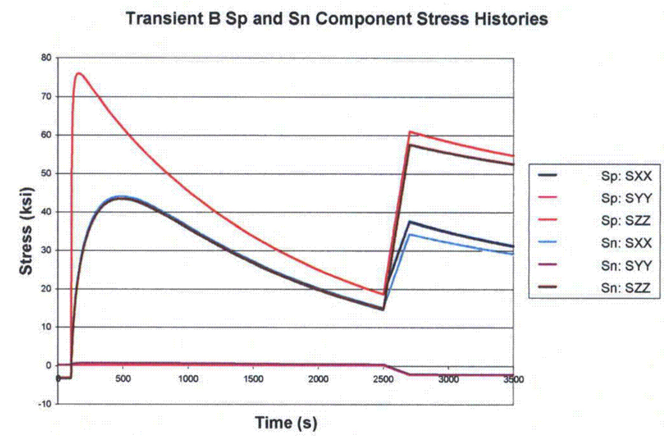

Figure 10 Transient B Sp and Sn Component Stress Histories

Table 4 Fatigue Significant Peaks and Valleys*

Trans. A Peak Time (s)	Sp (ksi)	Sn (ksi)
0	1	1
167	78	28
531	65	48
3500	32	34

Trans. B Peak Time (s)	Sp (ksi)	Sn (ksi)
0	3	3
158	76	24
496	62	43
2500	18	15
2700	63	60
3500	57	55

* See Figure 11 and Figure 12

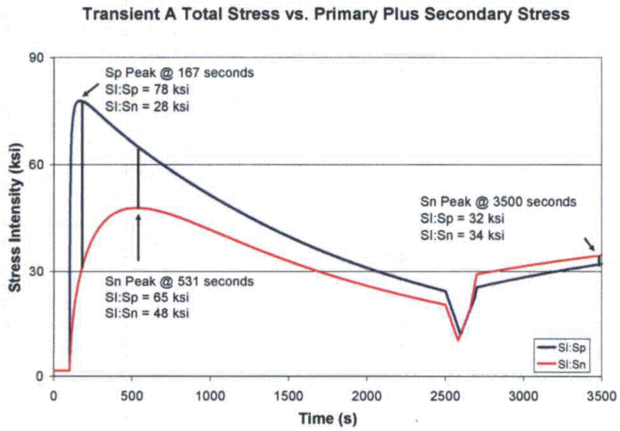

Figure 11 Sp and Sn Stress Intensity Responses for Transient A

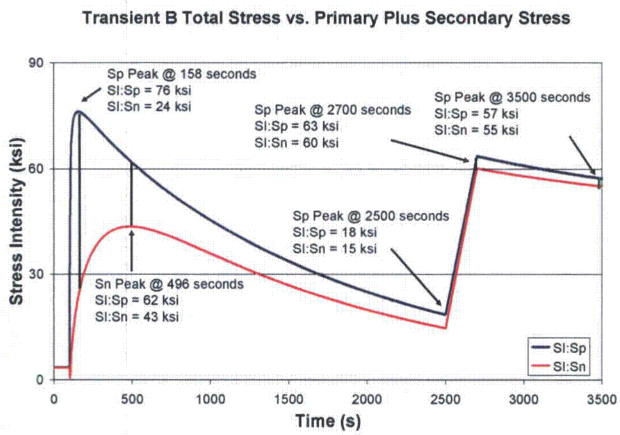

Figure 12 Sp and Sn Stress Intensity Responses for Transient B

From Figure 11 and Figure 12, it is not clear which stress state pairs would result in the highest alternating stress range. The algorithm employed by WESTEMS™ automatically calculates the actual primary plus secondary stress and total stress ranges, based on the stress components, for each possible pair to reveal which stress state pairs would result in the highest alternating stress intensity. Table 5 summarizes the stress state pairs that result in the highest alternating stress intensity, Sa.

Table 5 Alternating Stress Intensity

Trans.	Time	Trans	Time	3Sm	Sn	Ke	Sp	Emod	Salt
A	531	B	2700	60	107	3.3	129	1.05	226
A	167	B	3500	60	83	2.3	135	1.04	160
B	0	B	158	53	27	1	79	1.1	55
B	496	A	0	58	45	1	63	1.06	37
A	3500	B	2500	57	24	1	24	1.07	14

Note: All recorded time is in seconds and stress is in ksi

From Table 5, it can be seen that a pair including a peak selected from a primary plus secondary stress intensity peak resulted in the highest alternating stress intensity. This is because of the primary plus secondary stress range and the resulting Ke penalty, which significantly increased the total alternating stress intensity calculated for that pair. This illustrates the importance of considering both stress quantifies in the selection of peak/valley times to consider in the fatigue analysis.

CONCLUSIONS

The stress state selection method described here is notable because it is a repeatable process that can be taught and applied using automated methods. The method improves the overall quality of the work performed because the method ensures that all significant states are identified in the stress time histories. While it is possible to apply the method manually using graphing techniques, the method is best implemented using an automated process. Because the method is easily automated, it is ideal for use in both design calculations as well as in an online monitoring role.

ACKNOWLEDGMENTS

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REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, 2007, "Rules for Construction of Nuclear Facility Components, Class 1 Components," American Society of Mechanical Engineers, New York.