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In the Matter of:	Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3)
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PSEG
P.O. Box 236, Hancocks Bridge, NJ 08038-0236

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10 CFR 50
10 CFR 51
10 CFR 54

LR-N11-0057

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: Close-out of the NRC Audit associated with use of WESTEMS™ related to the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application

Reference: Letter from Mr. Robert C. Braun (PSEG Nuclear, LLC) to the NRC, "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," dated January 31, 2011

On January 18 and 19, 2011, the NRC Staff audited various activities related to the use of WESTEMS™ associated with the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application. In the referenced letter, PSEG Nuclear provided the Staff with information responding to five specific questions raised during the Audit.

Audit activities were resumed on February 8, 2011, at which time PSEG Nuclear, Westinghouse, and NRC staff reviewed the results of calculation updates that documented the basis for stress analyst activities related to the license renewal environmentally-assisted fatigue (EAF) calculations. After this review, the NRC determined that follow-up actions would be needed from PSEG Nuclear in order to satisfactorily complete the Audit.

Enclosure A of this letter is an update to the information provided in Enclosure A of the January 31, 2011 Reference letter, and replaces that response package in its entirety, with changes indicated. Similarly, Enclosure B of this letter updates and replaces the License Renewal Commitment List changes that had been provided as Enclosure B in the January 31, 2011 Reference letter. Although unchanged, Enclosure C from the January 31, 2011 referenced submittal is again provided as Enclosure C to this letter, for completeness. Together, these Enclosures provide the information needed to close out NRC Staff questions associated with the WESTEMS™ Audit.

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There are no other new or revised regulatory commitments associated with this submittal.

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 2/24/11

Sincerely,



Paul J. Davison
Vice President, Operations Support
PSEG Nuclear LLC

Enclosures:

- A. Updated Responses to NRC Questions associated with Use of WESTEMS™ 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

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Enclosure A

**Updated Responses to NRC Questions associated with Use of WESTEMS™
associated with the Salem Nuclear Generating Station, Units 1 and 2 License
Renewal Application**

In January and February, 2011, the NRC conducted an audit of PSEG Nuclear's use of WESTEMS™ associated with the Salem Nuclear Generating Station, Units 1 and 2 License Renewal Application (LRA). During the audit, the NRC requested additional information. PSEG Nuclear provided responses to these requests in its letter LR-N11-0042 dated January 31, 2011. As a result of follow-up audit discussions held on February 8, 2011, these responses are being updated (and new items added) to clarify or supplement the earlier responses. Changes to the earlier responses and affected LRA Sections are shown with **bold, italics** font for additions and ~~striketrough~~ text for deletions. As in the January 31, 2011 letter, 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 **Stress** 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~~ **were** made available for NRC review during the next **February 8, 2011** phase of the WESTEMS™ audit.

During the February 8, 2011 review of the BIT Nozzle Coupling to Cold Leg Weld location calculation update, the basis for analyst removal of two of the peak and valley times from the data was unclear and not sufficiently documented in the calculation. The following discussion provides the detailed basis for the analyst removal of two of the peak and valley times from the data.

Specifically, for Transient 2 (Primary Side Leak Test), WESTEMS™ selected five (5) peaks. The analyst selected two (2) peaks for use in the fatigue evaluation. The first of three (3) peaks was removed because it represented the same Total Stress as a peak approximately seventy-two minutes prior to this peak, and since the Primary plus Secondary stress in this evaluation does not result in any K_e (simplified elastic plastic penalty factor applied to alternating stress when the Primary plus Secondary Stress Intensity Range limit is exceeded), values greater than 1.0, it is redundant with the previous peak, and not required. The last (2) peaks in the transient are redundant peaks of the initial state captured by the first peak time, since the transient returns to the same stress state as it started. This stress state is redundant because it is the same stress state as the initial stress state of another Primary Side Leak Test transient cycle, or any other transient that begins at a similar plant no-load condition (e.g., Unit Load, etc.). For Transient 11 (High Head Safety Injection Boron Injection [Inadvertent Safety Injection] transient), WESTEMS™ selected nine (9) peaks. The analyst selected six (6) peaks for use in the fatigue evaluation. There were five (5) peaks selected by WESTEMS™ early in the transient. The analyst removed two of the five peaks because they were selected based on peaks in the Primary plus Secondary Stress. Since the Primary plus Secondary Stress Intensity Range is less than the allowable of $3S_m$, a K_e penalty factor on alternating stress is not required, and therefore, two peaks were considered redundant and able to be removed. Later in this transient, two peaks were selected by WESTEMS™ within several seconds of each other. WESTEMS™ selected the first of these two peaks because of a stress

intensity inflection point created by a stress component sign reversal and an accompanying change in the controlling principal stress. A revision to the fatigue evaluation re-established the basis for removal of one of these two peaks by reviewing a plot of total stress component history. Only one true peak had occurred and was selected by the analyst for use in the fatigue evaluation. The stress intensity inflection point of the other peak does not represent the final extreme stress range caused by the transient excursion, and was considered unnecessary for inclusion in the fatigue evaluation. Towards the end of the transient, there were two (2) peaks within 65 seconds of each other. Since the stress states were the same, the analyst selected one of these two peaks for use in the fatigue evaluation. The analyst added one (1) peak that was not selected by WESTEMS™ at the initial time of the transient for additional conservatism in the fatigue evaluation.

The associated calculation has now been updated to properly capture the basis for this user intervention activity.

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.~~

PSEG Nuclear has reviewed the justification for the stress peak and valley editing provided in revisions to 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 EAF calculations. Discussions with Westinghouse concluded that stress peak and valley editing during the fatigue calculation process for the remaining locations monitored by WESTEMS™ at Salem Units 1 and 2 is consistent with the two locations that were the subject of the WESTEMS™ benchmarking audit, and that the two calculations that were revised are considered to be the most limiting with respect to cumulative usage. Therefore, PSEG Nuclear has deemed it unnecessary to revise the existing EAF calculations performed for the remaining WESTEMS™ monitored locations to include a written explanation and justification of any user intervention applied for any WESTEMS™ "Design CUF" (NB-3200 module) analyses, including the user intervention applied to the stress peak and valley selection.

Therefore, PSEG Nuclear is retracting what had been proposed as commitment #53 as described in PSEG letter LR-N11-0042, "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", dated January 31, 2011. The License Renewal Commitment List is revised accordingly, as shown in Enclosure B. 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" (**NB-3200** module).

As a result of this response, commitment #54 **53** is added to LRA Table A.5, License Renewal Commitment List, as shown in Enclosure B of this letter. **The seventh paragraph of LRA Section A.4.3.7 is also revised, as shown following the response to Audit Question No. 4, below.**

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 **54** is added to LRA Table A.5, License Renewal Commitment List, as shown in Enclosure B of this letter. **The seventh paragraph of LRA Section A.4.3.7 is also revised, as shown below.**

A.4.3.7 Environmentally-Assisted Fatigue Analyses

The evaluations showed that no cumulative usage factors with environmental penalties exceeded 1.0 for 60 years of service for the identified plant-specific locations. **Future fatigue evaluations using WESTEMS™ "Design CUF" (NB-3200 module) will include written explanation and justification of any user intervention. Future fatigue design calculations will not use or implement the NB-3600 option (module) of the WESTEMS™ program.** The Metal Fatigue of Reactor Coolant Pressure Boundary aging management program (B.3.1.1) will be

used to manage the aging effects of environmentally assisted fatigue for the components in Salem LRA Tables 4.3.7-1 and 4.3.7-2.

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~~ **was** made available for NRC review during the next **February 8, 2011** 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.

Audit Question No. 6:

The response to "Bullet # 5" on Page 14 of Enclosure A of December 21, 2010 PSEG Letter LR-N10-0445 stated that the stress models used in the governing EAF analyses are the same as the stress models employed in the WESTEMS™ online monitoring tool. Based on the discussions during the February 8, 2011 audit activities, it is understood that for the Salem Pressurizer Surge Nozzle Safe End to Pipe Weld location, a different version of the WESTEMS™ stress model was used for the fatigue analysis than what will be used for online fatigue monitoring. Please explain.

PSEG Response:

As a result of performing the benchmark calculation for the Unit 2 Pressurizer Surge Nozzle Safe End to Pipe Weld, it was discovered that the WESTEMS™ online model was different than that used for calculating the 60 Year cumulative usage fatigue (CUF) value for this location, which is listed in LRA Table 4.3.7-2, "Salem Unit 2 60-Year Environmentally-Assisted Fatigue Results". Therefore, we are revising our RAI response to Bullet # 5 on page 14 in Enclosure A of PSEG Letter LR-N10-0445, dated December 21, 2010, as follows, starting with the last sentence on page 14:

The stress models used in these EAF analyses are the same as the stress models employed in the WESTEMS™ online monitoring tool, **with the exception of the Salem Pressurizer Surge Nozzle Safe End to Pipe Weld location and the Surge Line Hot Leg Nozzle to Pipe Weld location.** The stress models used in the EAF analyses for these two locations are specific to each Salem Unit due to slight physical differences that were explained under Bullet # 1 [in PSEG Letter LR-N10-0445]. However, for online fatigue monitoring, Salem used a stress model common to both Units that was determined to be conservative and bounding for each of these two locations.

It was verified that the original statement made in PSEG Letter LR-N10-0445 relative to the stress models being the same is correct for all other monitored locations at Salem.

**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 and 54 as shown below. Note that the item that had been designated as commitment 53 in PSEG letter LR-N11-0042 has been deleted and the other two commitments have been renumbered. Deletions from text in letter LR-N11-0042 are shown with ~~strikethrough~~ format and additions are shown in ***bolded italics***. 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
5453	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" (<i>NB-3200</i> module).	N/A <i>A.4.3.7</i>	Within 60 days of issuance of the renewed operating license.	Salem Letter LR-N11-0042 <i>Salem Letter LR-N11-0057</i>
5554	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 <i>A.4.3.7</i>	Within 60 days of issuance of the renewed operating license.	Salem Letter LR-N11-0042 <i>Salem Letter LR-N11-0057</i>

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)

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 $3S_m$ criteria set by NB-3222.2, then the S_a used with the design fatigue curve must be increased by a penalty factor, K_e , 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 K_e

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 K_e 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 K_e 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 WESTEMSTM 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.

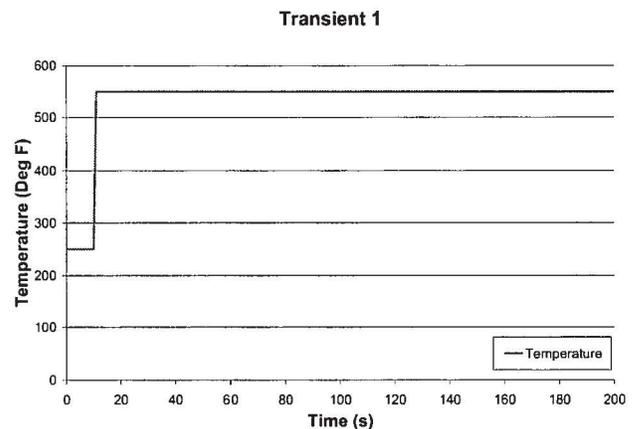


Figure 1 Loading Conditions for Transient 1

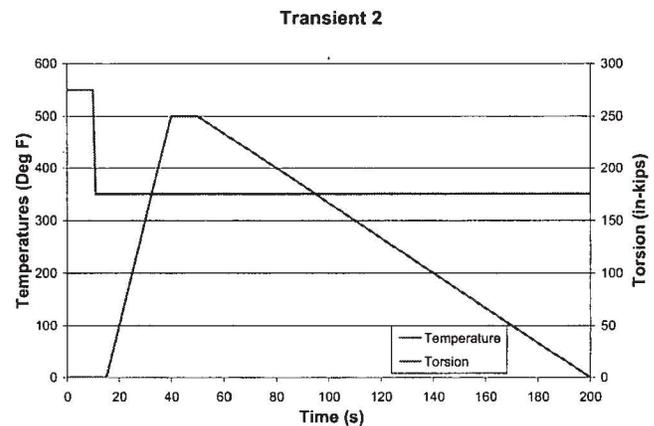


Figure 2 Loading Conditions for Transient 2

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.

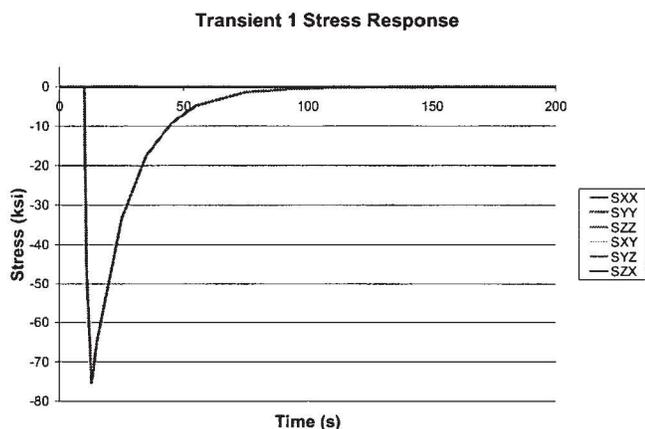


Figure 3 Total Stress Component Time History - Transient 1

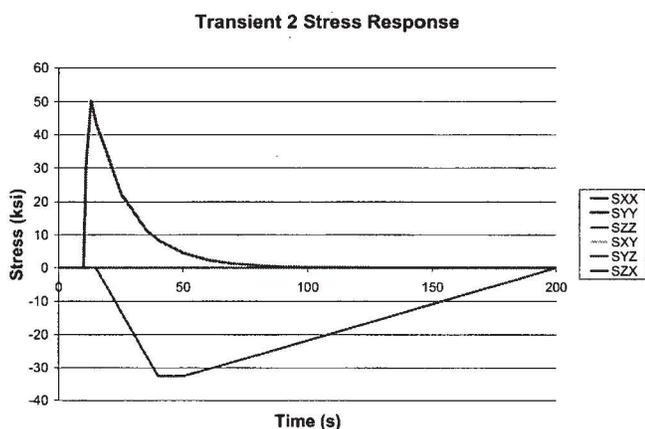


Figure 4 Total Stress Component Time History - Transient 2

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

Trans. 1- 2 Stress Difference Relative to Trans. 1 at 13 sec.							
Time	SXX	SYY	SZZ	SXY	SYZ	SZX	SI
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.

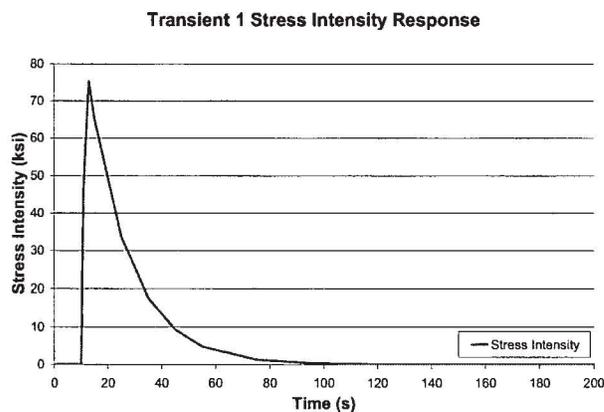


Figure 5 Total Stress Intensity Time History for Transient 1

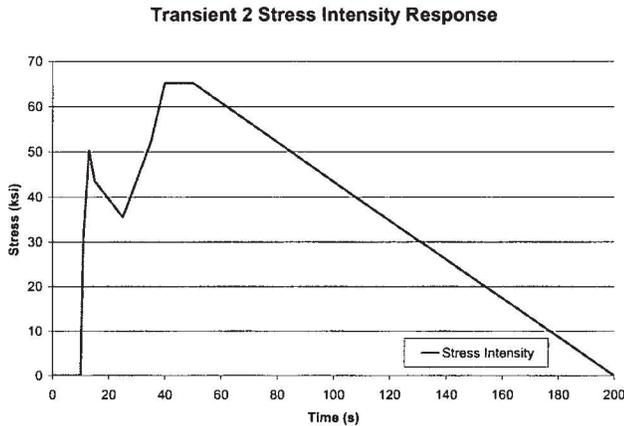


Figure 6 Total Stress Intensity Time History for Transient 2

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 than 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 K_e 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.

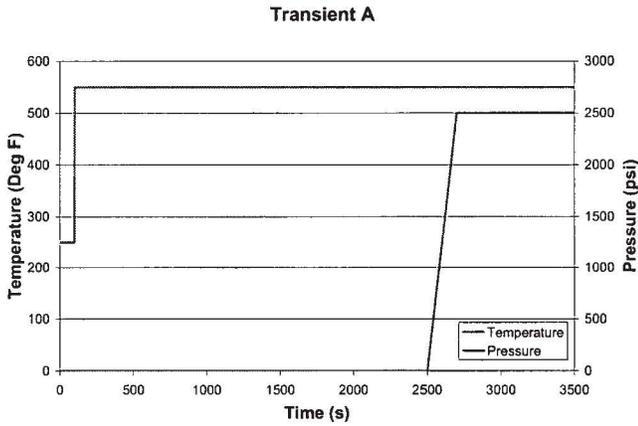


Figure 7 Loading Conditions for Transient A

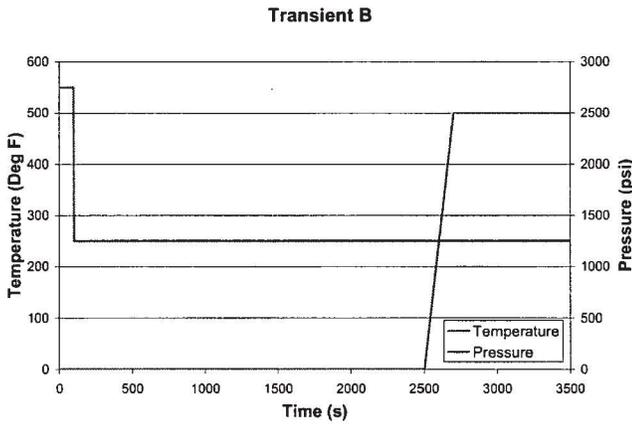


Figure 8 Loading Conditions for Transient B

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.

Transient A Sp and Sn Component Stress Histories

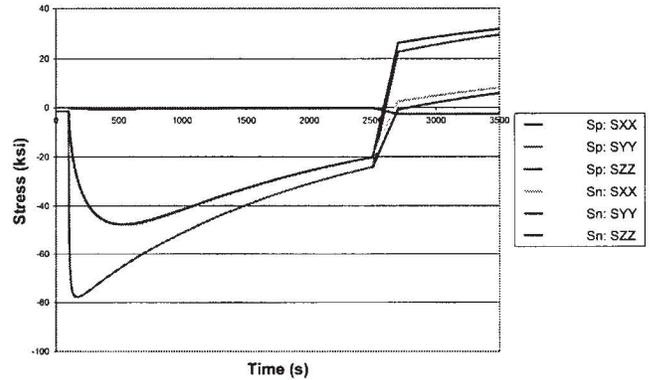


Figure 9 Transient A Sp and Sn Component Stress Histories

Transient B Sp and Sn Component Stress Histories

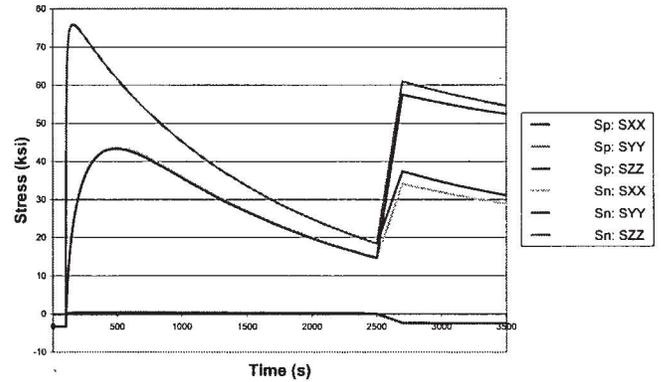


Figure 10 Transient B Sp and Sn Component Stress Histories

Table 4 Fatigue Significant Peaks and Valleys*

Trans. A Peak Time (s)	Sp (ksi)	Sn (ksi)	Trans. B Peak Time (s)	Sp (ksi)	Sn (ksi)
0	1	1	0	3	3
167	78	28	158	76	24
531	65	48	496	62	43
3500	32	34	2500	18	15
			2700	63	60
			3500	57	55

* See Figure 11 and Figure 12

Transient A Total Stress vs. Primary Plus Secondary Stress

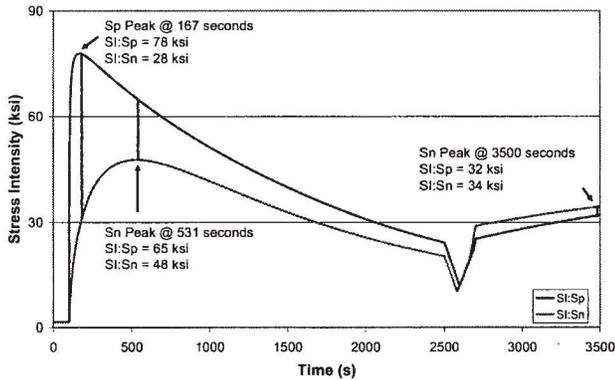


Figure 11 Sp and Sn Stress Intensity Responses for Transient A

Transient B Total Stress vs. Primary Plus Secondary Stress

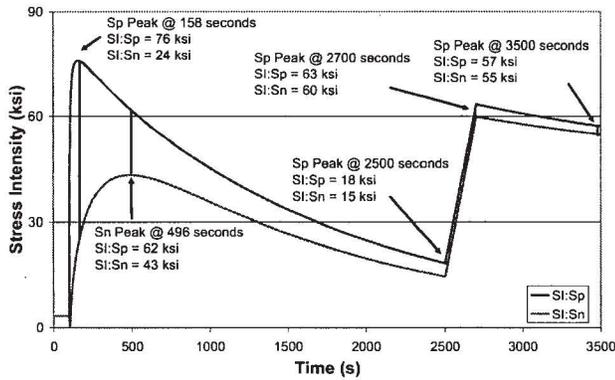


Figure 12 Sp and Sn Stress Intensity Responses for Transient B

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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- [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.