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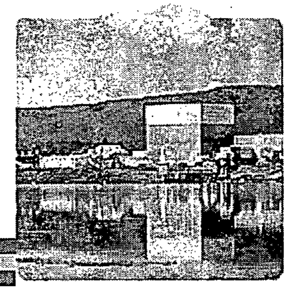

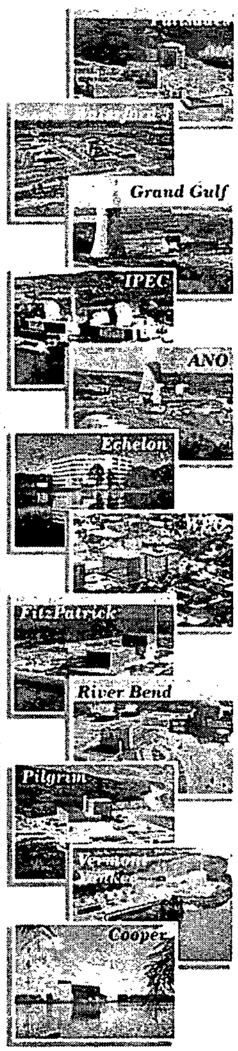

Presentation to NRC Staff Regarding Reactor Pressure Vessel Nozzle Environmental Fatigue Analyses for License Renewal

Vermont Yankee
Nuclear Power Station (VYNPS)

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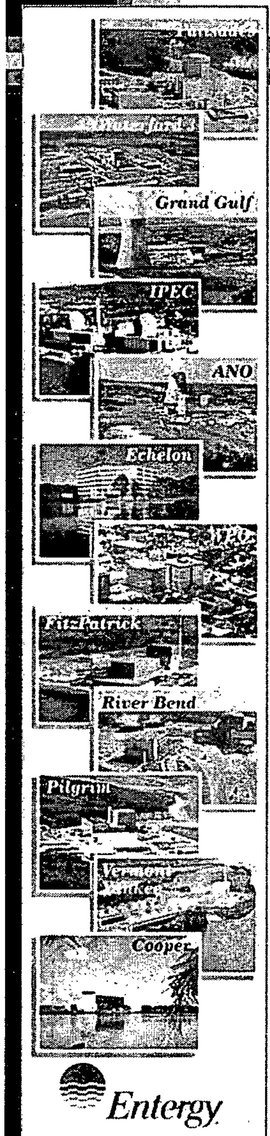
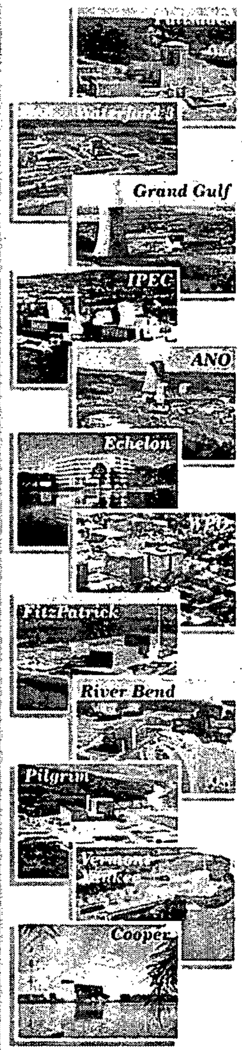


Introduction

Jay Thayer

Vice President Entergy

Agenda



- Overview
- Technical Presentation
- Open Discussion
- Summary/Follow-up Actions
- Closing Remarks

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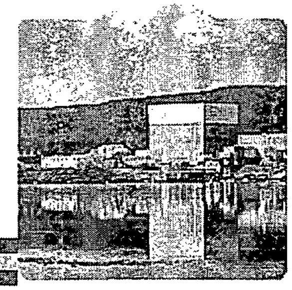
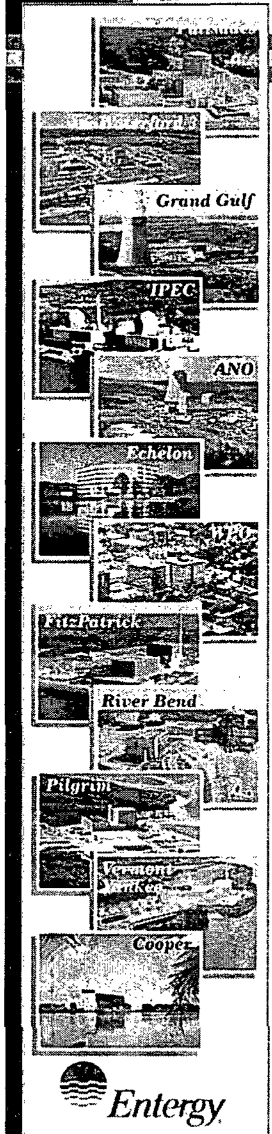
Technical Presentation





- Open Technical Questions
- Nomenclature
- Industry Experience
- VYNPS Fatigue Analysis Methodology
- Conservatisms in VYNPS Analysis Approach
- Basis for Acceptability of VYNPS Approach
- Confirmatory Analyses

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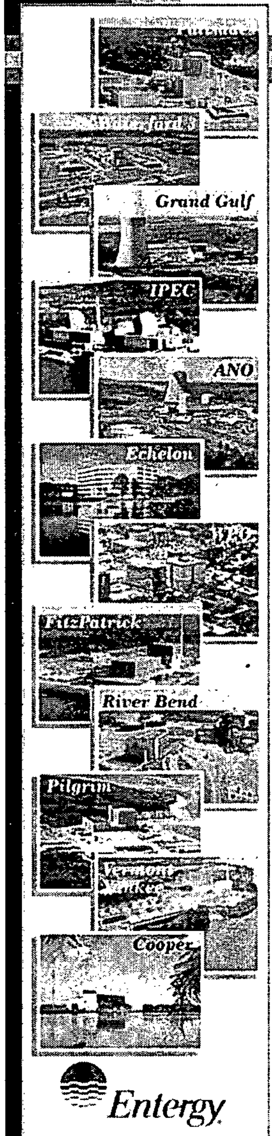
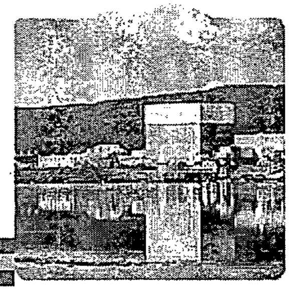
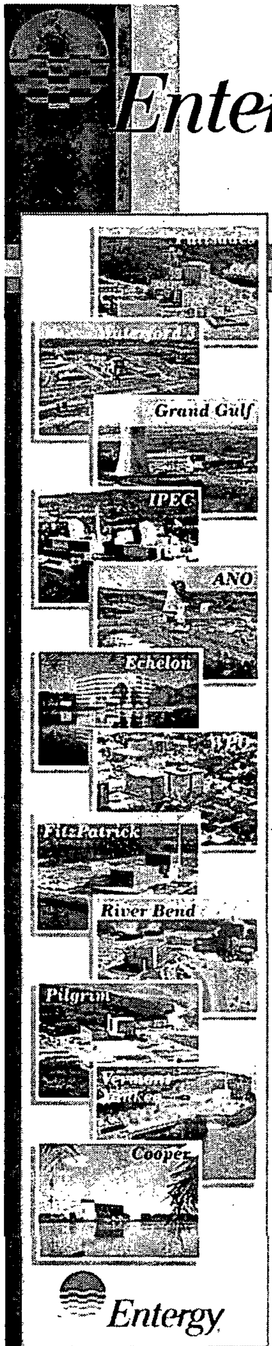
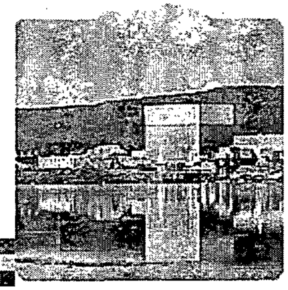




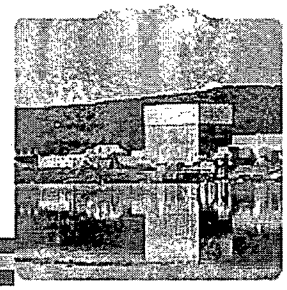
Open Technical Questions

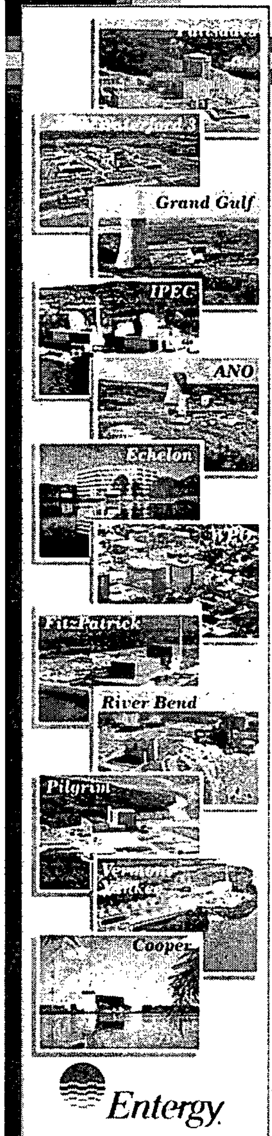


Entergy Open Technical Questions



- RAI 4.3.3-2 Questions
  - Use of axisymmetric model for vessel nozzles.
  - Use of component stresses in lieu of principal stresses.
  - Use of Green's Functions for thermal transients.





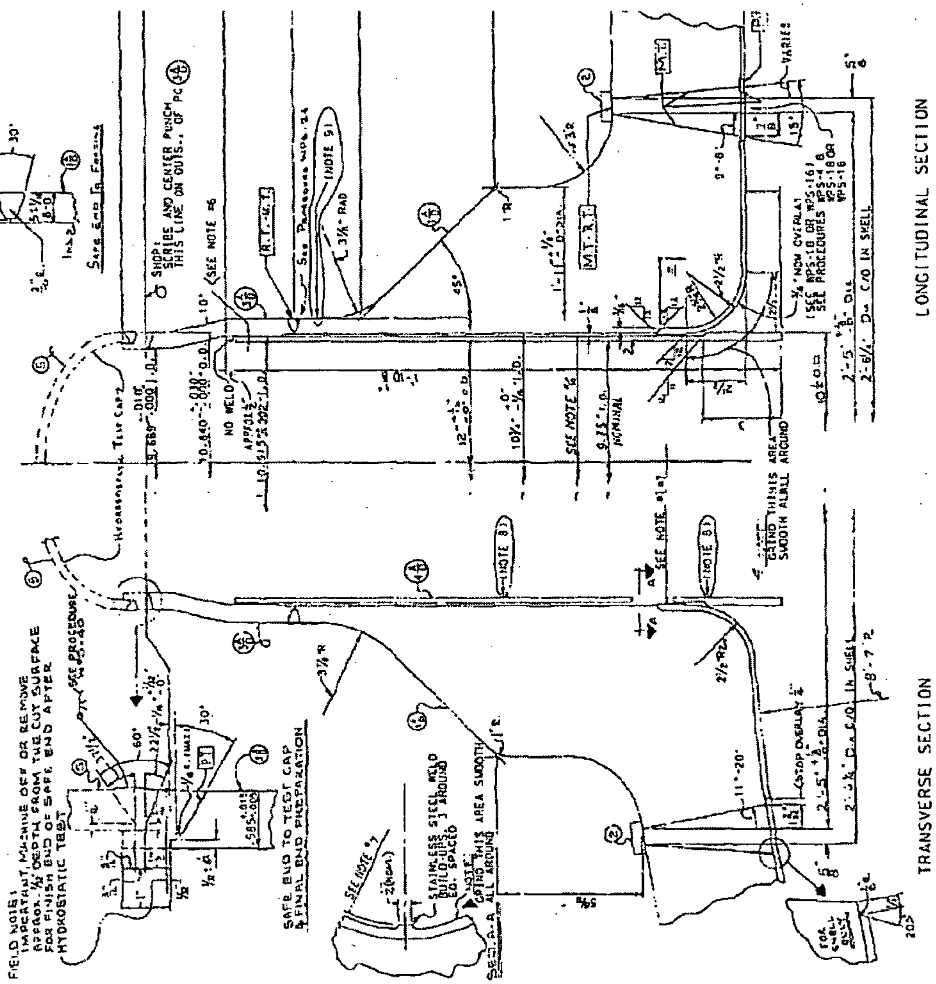
Nomenclature

Nomenclature

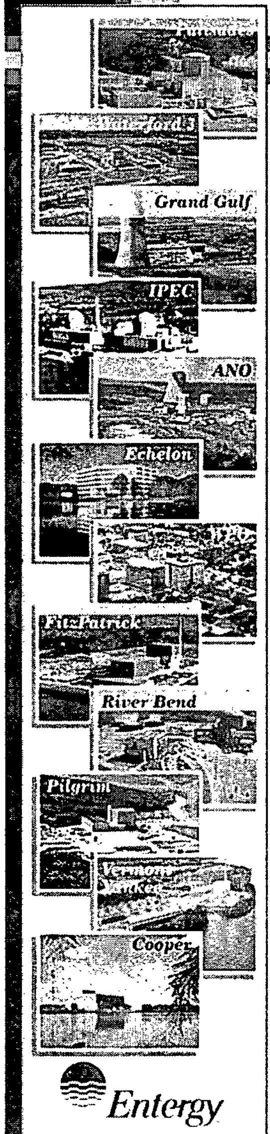
Terminology requiring clarification

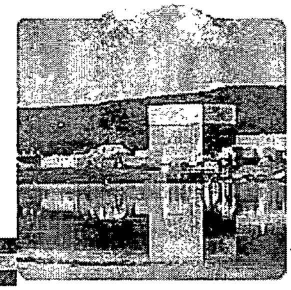
- "2D" vs. 3D
  - Nozzle corner contour effects
- "1D virtual stress"
  - Use of a single stress difference vs. using 6 stress components
- Nozzle corner, blend radius & inner radius are interchangeable terms.

Nomenclature



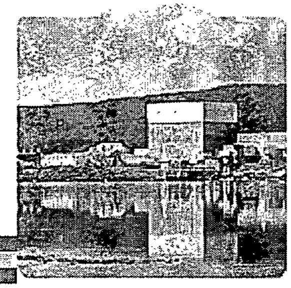
VYNPS Feedwater Nozzle

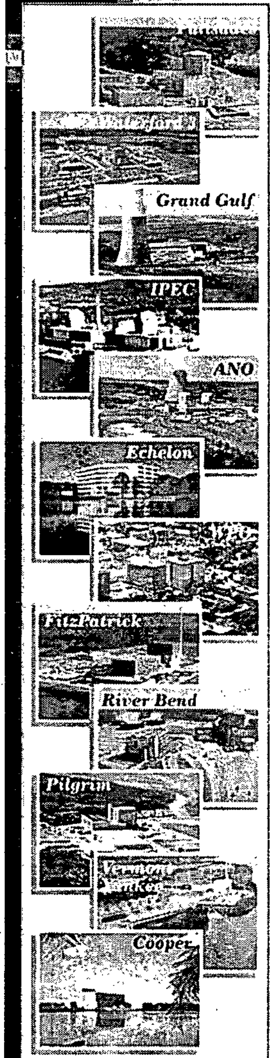




VYNPS Fatigue Analysis Methodology

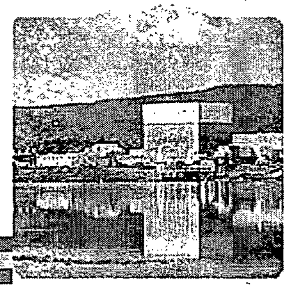
VYNPS Fatigue Analysis Methodology

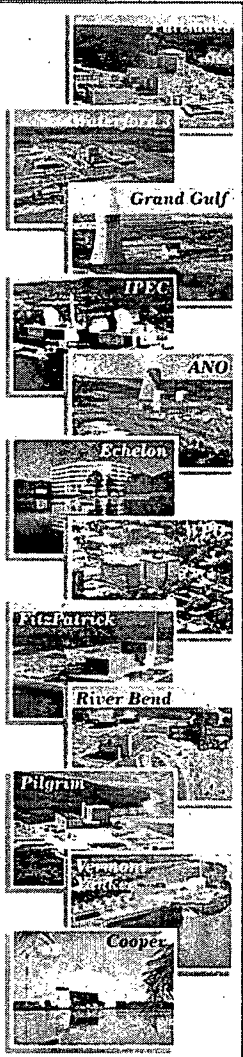




1. An axisymmetric nozzle finite element model (FEM) is developed from plant-specific drawings and material specifications.
2. Heat transfer coefficients and boundary conditions are established for the FEM based on the RPV Certified Design Specification and Stress Report.
3. The thermal stress response (i.e., Green's Function) is developed for a step change in temperature. A scalable pressure stress is separately obtained by applying a unit pressure load to the FEM.

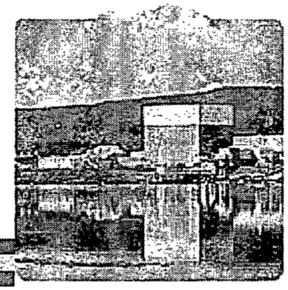
VYNPS Fatigue Analysis Methodology

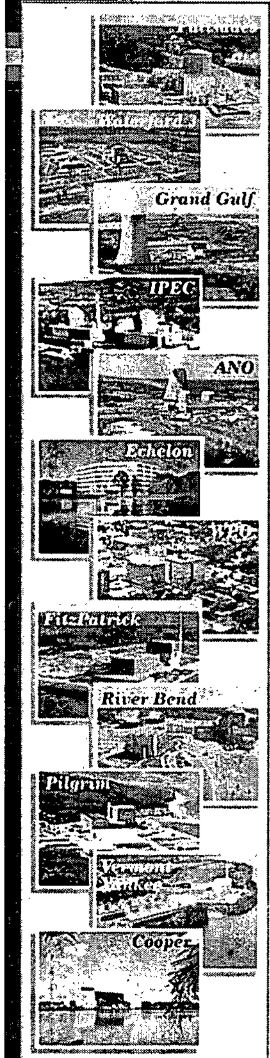




4. Thermal transients are based on appropriate Design Specification and BWR-4 thermal cycle definitions.
5. Thermal stress histories are obtained (using Green's Function integration) for each thermal transient. The Green's Function results are reviewed for appropriateness.
6. The associated pressure for each thermal stress point is determined based on linearly scaling the unit pressure stress response based on the transient pressure time history.

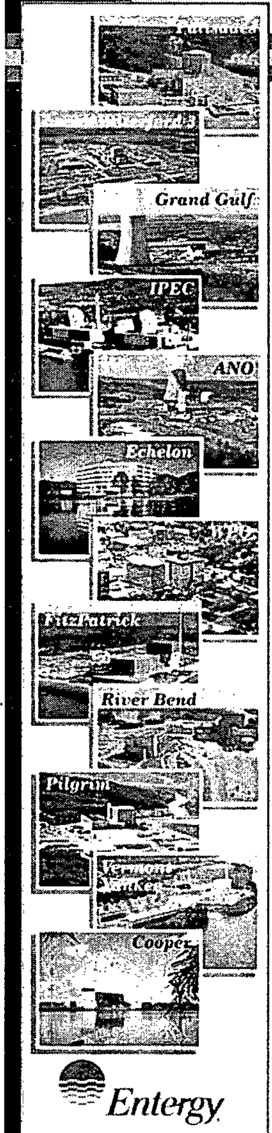
VYNPS Fatigue Analysis Methodology





7. Stresses due to attached piping loads are conservatively calculated and are scaled based on RPV temperature for each transient.
8. NB-3200 fatigue analysis is performed for the collected thermal transients stress histories, conservatively combining the thermal, pressure (with a scaling factor to account for nozzle contour effects), and attached piping stresses, and using conservative cycle projections to determine the 60-year CUF.

The VYNPS methodology is the same as the approach used for most CLB BWR RPV nozzle fatigue analyses.



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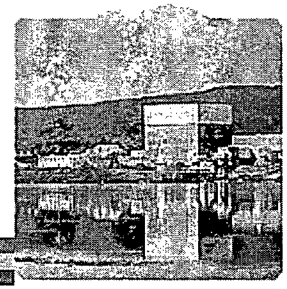
VYNPS Fatigue Analysis Methodology



9. Maximum fatigue life correction factors (F_{en} multipliers) are calculated for water chemistry conditions (including power uprate effects) expected to occur over the 60-year operating period.
10. Environmental fatigue effects are calculated by multiplying the CUF for 60 years by the F_{en}.

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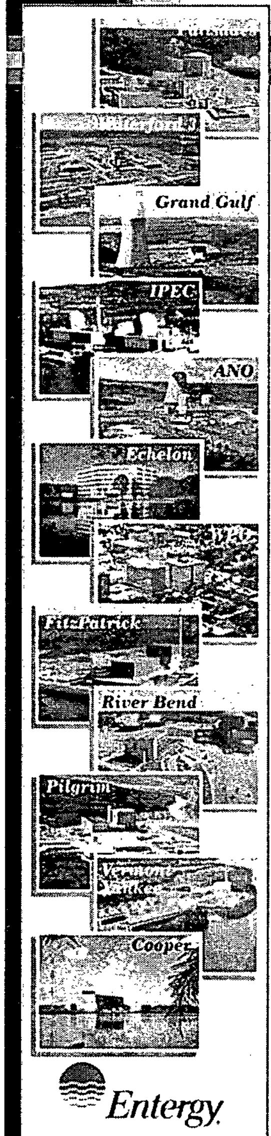
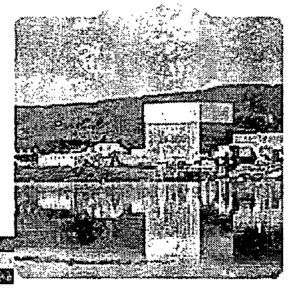
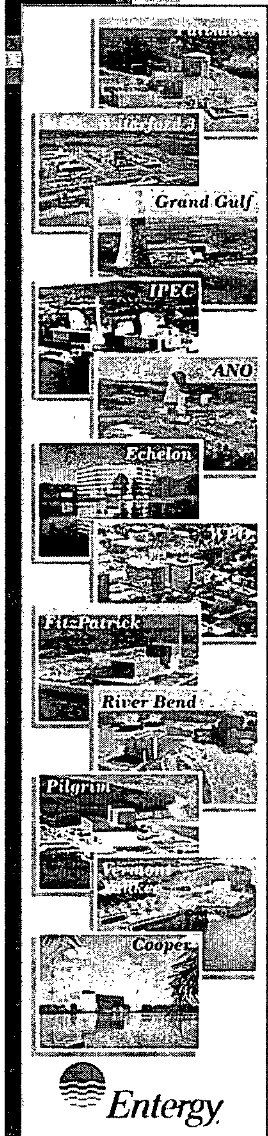
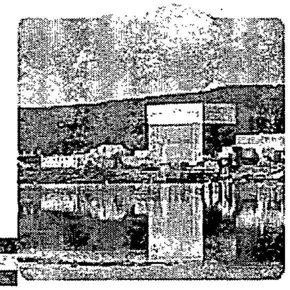




Conservatisms in VYNPS Analysis Approach

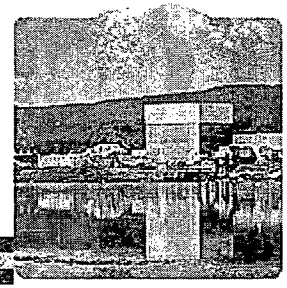
Conservatisms in VYNPS Analysis Approach

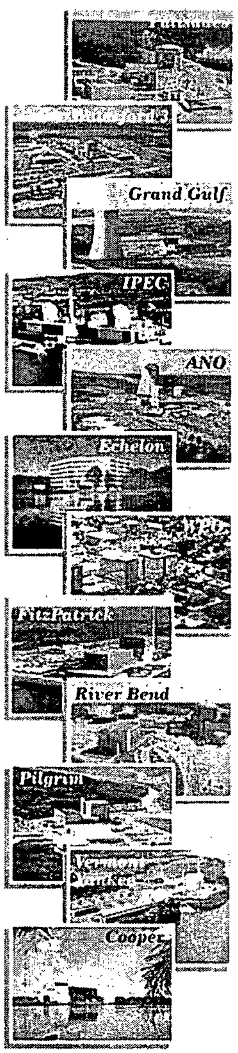




- Constant (bounding) material properties are used. [4, 11, 14]
- The FEM mesh is much finer than that used in the CLB stress analyses for VYNPS, which results in higher peak stresses. [1, 2, 4, 11, 14]
- Thermal stresses are calculated using conservative heat transfer coefficients based on bounding flow rates. [4, 11, 14]
- Attached piping stresses are always combined with thermal stresses with like signs, such that they always maximize alternating stress ranges. [9, 13, 16]

Conservatisms in VYNPS Analysis Approach





- Bounding values for pressure and temperature (at power uprate conditions) are assumed for the entire 60-year period of plant operation. [9, 13, 16]
- The entire stress time history for each transient is generated, compared to selected transient points generated in the CLB stress analysis. This ensures that maximum peak stresses are used.
- K_e is calculated consistent with current ASME Code methodology, which ensures alternating stresses are maximized. K_e was not required for the VYNPS CLB vessel fatigue analysis. [1, 2, 5, 9, 10, 13, 16]

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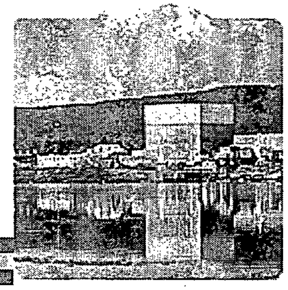
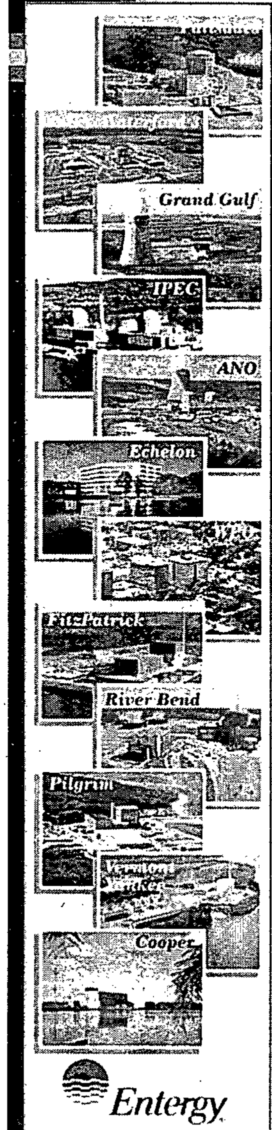
Conservatisms in VYNPS Analysis Approach





- The number of transient cycles for 60 years used in the analysis is conservative relative to the number of transients experienced to-date and expected through 60 years of operation (to be monitored). [19]
- Design basis transient severity definitions were used.
- Bounding F_{en} multipliers were calculated using values for temperature, strain rate and sulfur content that were selected to maximize the F_{en} multiplier. [10]

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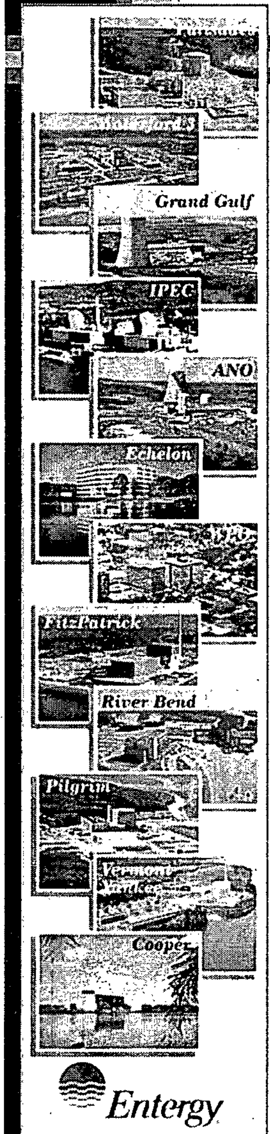
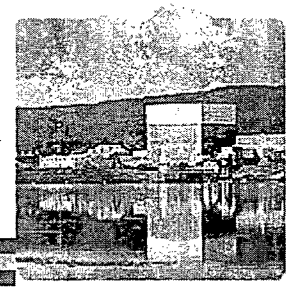
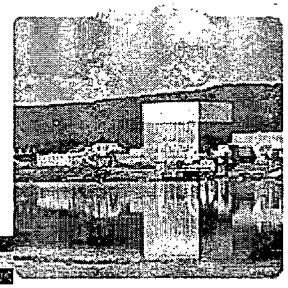
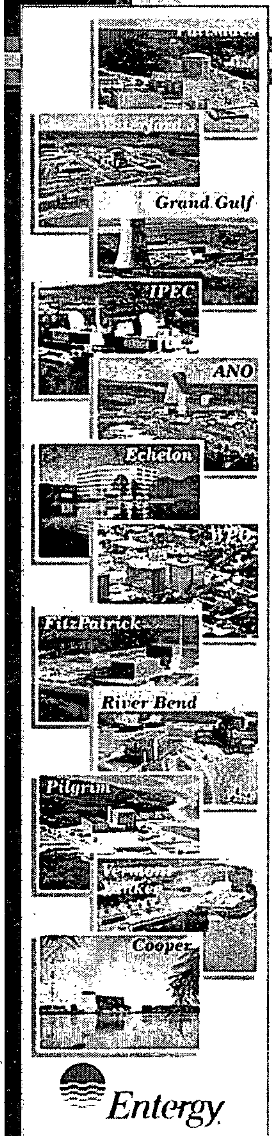




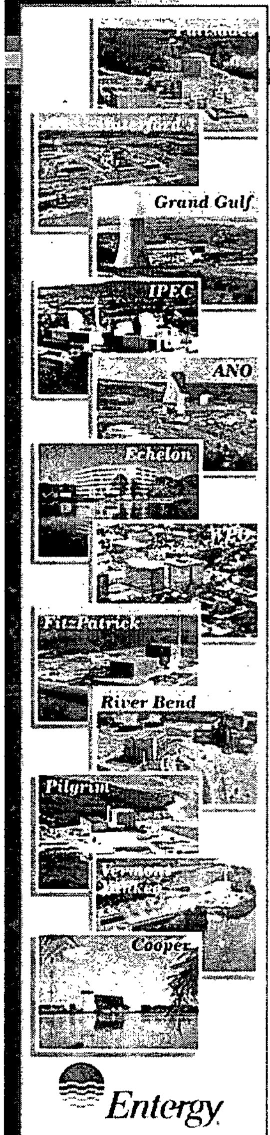
Industry Experience

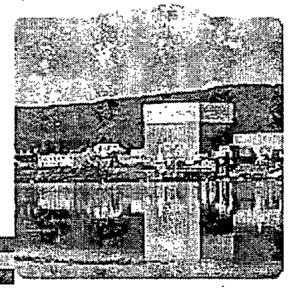
Industry Experience





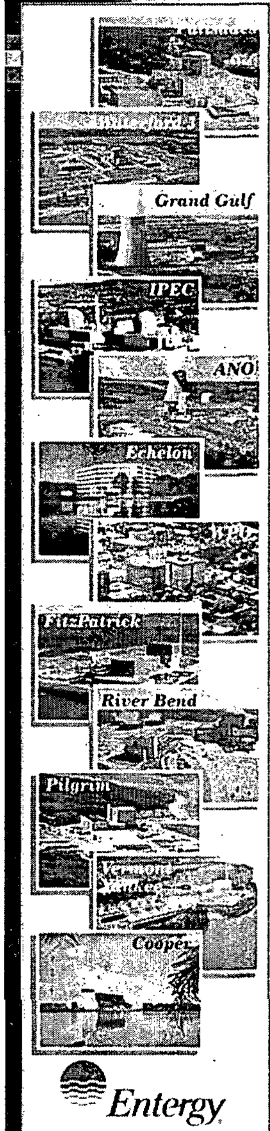
- VYNPS considered methodology used by previous license renewal applicants
- VYNPS selected the methodology used by:
  - Dresden/Quad Cities
  - Nine Mile Point Unit 1
  - Oyster Creek
  - Ginna
  - Point Beach
  - Farley
  - Palisades
  - Millstone 2/3

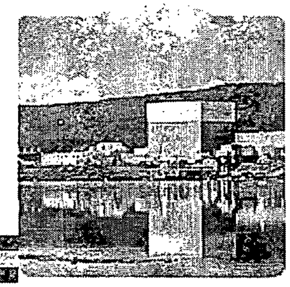




Basis for Acceptability of VYNPS Approach

Basis for Acceptability of VYNPS Approach





- The nozzle FEM techniques and analysis methods used to establish stress histories are consistent with the current design and licensing bases (CLB) for VYNPS.
- The use of Green's Functions for calculating thermal transient stresses is well established throughout the industry (since 1986). [6]
- The multiple conservatisms in the analysis methods.
- The comparisons performed between the VYNPS approach and the classical ASME NB-3200 approach show that the VYNPS approach provides equal or higher alternating stresses and fatigue usage. [18, 20]

Use of Axisymmetric Model

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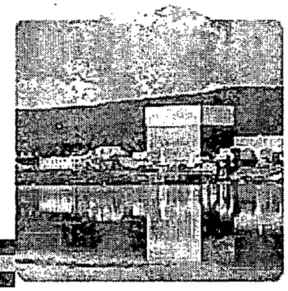
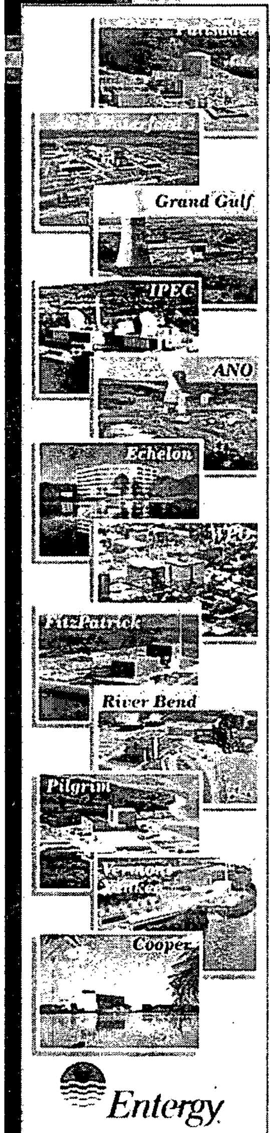
Use of Axisymmetric Model





General

- The CLB RPV nozzle fatigue analyses for VYNPS are based on the use of axisymmetric models. [1, 2] This approach has been an industry standard for many years and is the basis for most existing nozzle fatigue analyses in U.S. operating reactors.

- The approach VYNPS used for environmental fatigue calculations is consistent with the VYNPS CLB.

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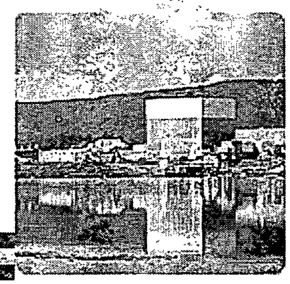
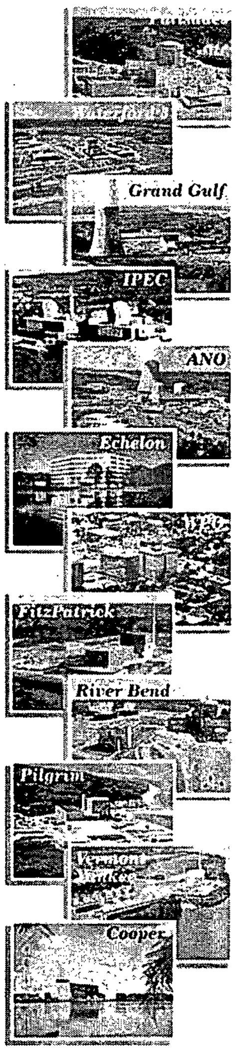
Use of Axisymmetric Model





Technical Considerations

- Nozzle contour effects have been accounted for in the VYNPS axisymmetric models.
  - Thermal transient stresses were shown in BWRVIP-108 to be azimuthally uniform in the nozzle/RPV contour region for a variety of RPV nozzles using full 3D (non-axisymmetric) finite element models
    - For example, refer to the next slide. [3]
    - Therefore, no adjustment for nozzle contour effects is required for thermal stresses.
  - Pressure stresses were accounted for by increasing the radius of the reactor vessel in the axisymmetric model (to be consistent with the CLB analysis) and/or application of an additional multiplier to fully account for nozzle contour pressure stress effects in the nozzle/RPV contour region. [9, 11, 14]

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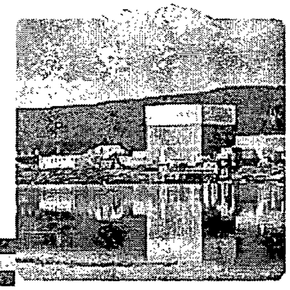
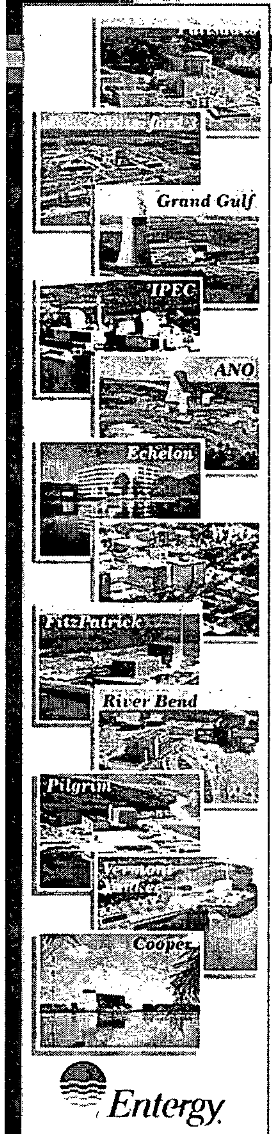
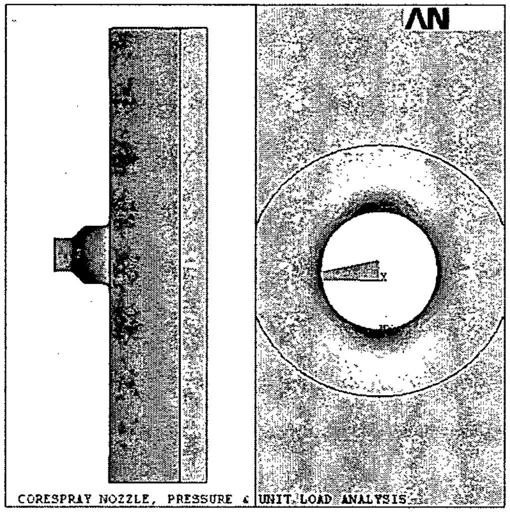
Use of Axisymmetric Model

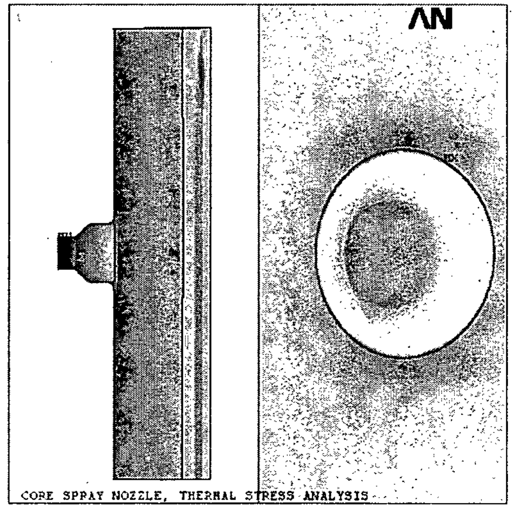




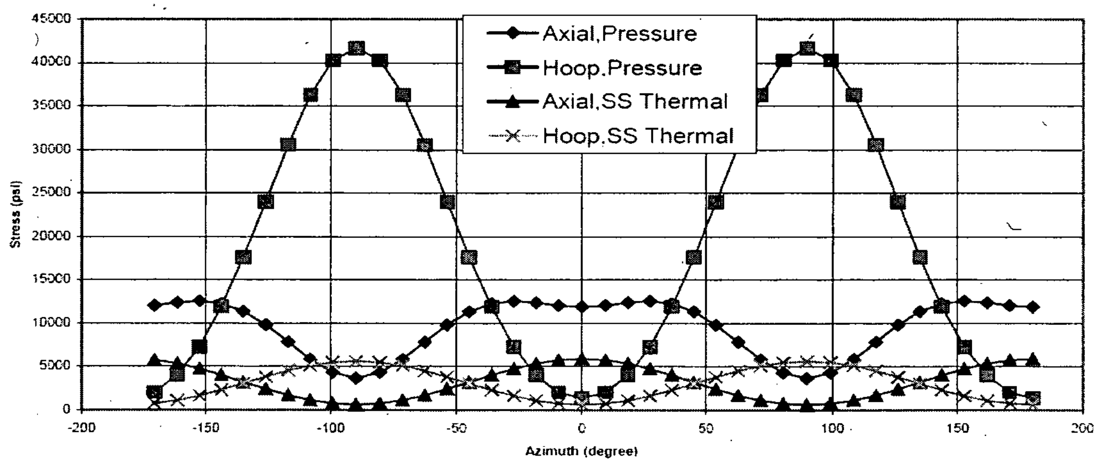
Technical Considerations

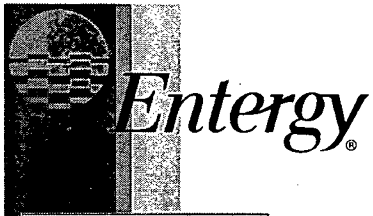
(typical example of results from BWRVIP-108)



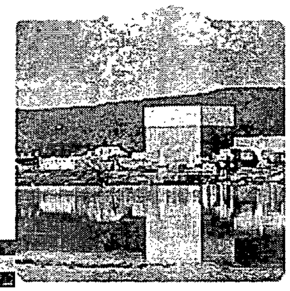


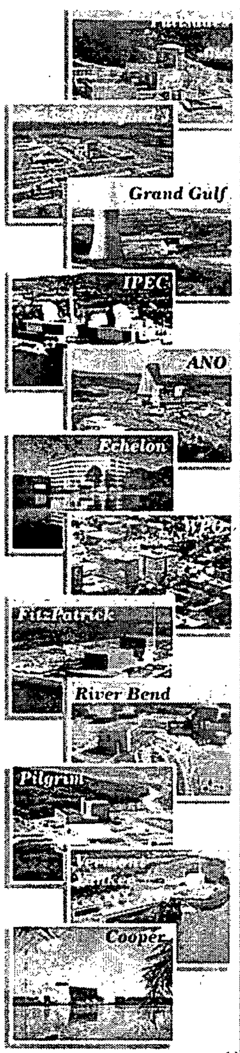
Core Spray Nozzle, Blend Radius, Inside Surface





Use of Axisymmetric Model





Technical Considerations – Pressure Stress

- Multipliers on vessel radius have traditionally been used for CLB analyses to account for nozzle contour effects.
- The multipliers applied to environmental fatigue calculations are consistent with the maximum values used historically in the VYNPS CLB. [2, 4, 5]
- The VYNPS nozzle analyses appropriately considered nozzle contour effects on stress.
  - The finite element model accounts for material and geometric discontinuities of the nozzle corner.
  - A multiplier of 2.0 was used to account for the spherical modeling effect.

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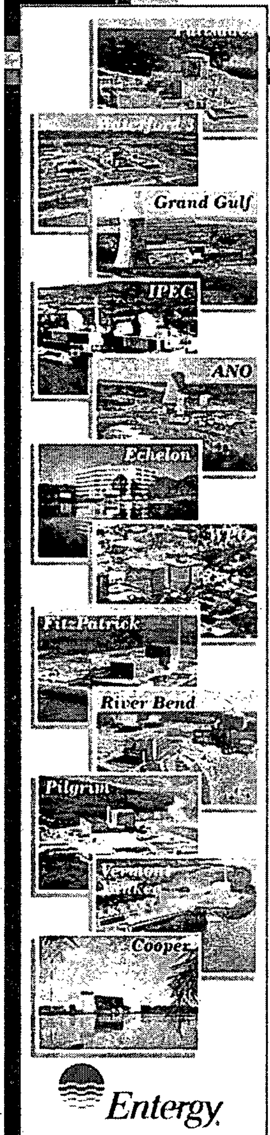
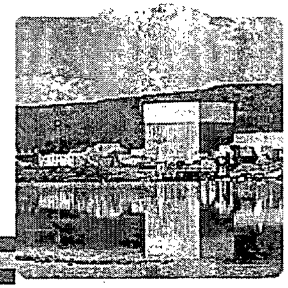
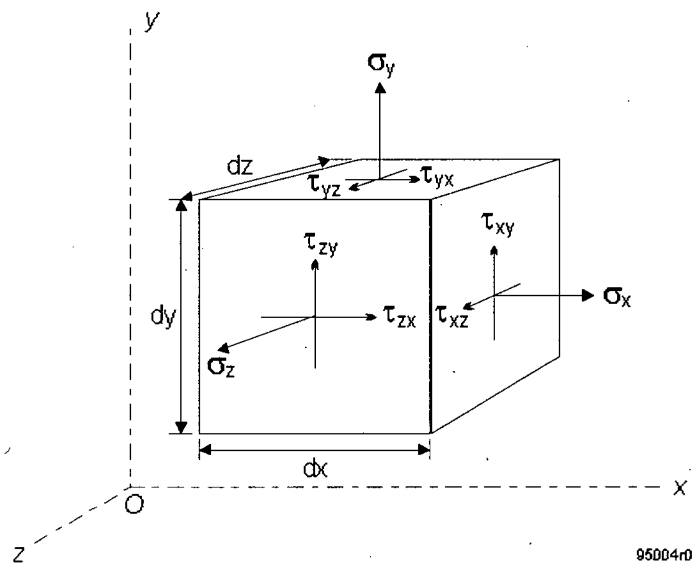




Use of Component Stresses

Use of Component Stresses

General Case (3D stress) [21]



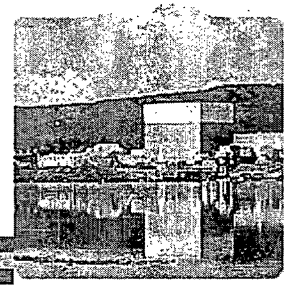
- It can be shown that the complete state of stress can be determined by knowledge of stress vectors on any three perpendicular planes.
- It is conventional to consider the three mutually perpendicular planes as faces of a cube of infinitesimal size, a stress element.
- The state of stress can be conveniently written as a matrix or a tensor:

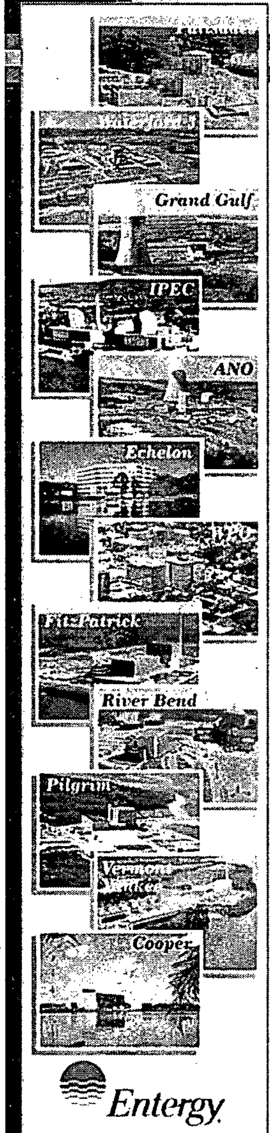
$$S = \begin{bmatrix} \sigma_x \tau_{xy} \ \tau_{xz} \\ \tau_{yx} \ \sigma_y \ \tau_{yz} \\ \tau_{zx} \ \tau_{zy} \ \sigma_z \end{bmatrix}$$

- Only six components are independent:

$$\tau_{xy} = \tau_{yx} \ ; \tau_{xz} = \tau_{zx} \ ; \tau_{yz} = \tau_{zy}$$

Use of Component Stresses





- There exists an orthogonal set of axes 1, 2, 3 called principal axes with respect to which the stress state elements are all zero except for those in the principal diagonal:

$$S' = \begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix}$$

- In other words, there always exists a set of mutually perpendicular planes with zero shear stress.
- The stress intensity, SI is defined as:

$$SI = \text{MAXIMUM}\ (\sigma_1 - \sigma_2,\ \sigma_2 - \sigma_3,\ \sigma_3 - \sigma_1)$$

- Thus, if a stress difference based on component stresses (i.e., $\sigma_z - \sigma_x$) equals SI, then shear stresses are negligible.

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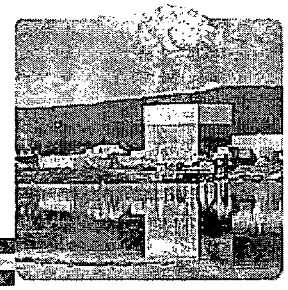
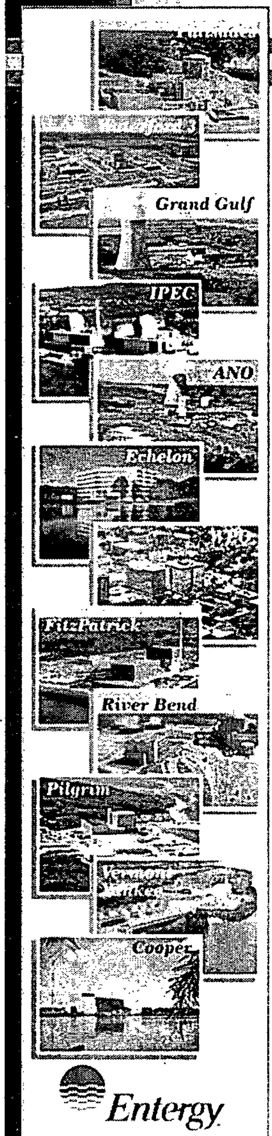
Use of Component Stresses





- The NSSS vendor practice for BWR CLB nozzle analyses has traditionally been to use component (Sx, Sy, Sz) stresses, for two reasons:
  - ASME Code Section III, NB-3215(d) states, "In many pressure component calculations, the t, l, and r directions may be so chosen that the shear stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r."
  - Experience indicated that shear stresses were negligible.
- The VYNPS CLB analyses used component stresses, since shear stresses are negligible. [2, 4, 5]

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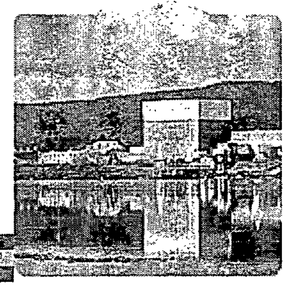
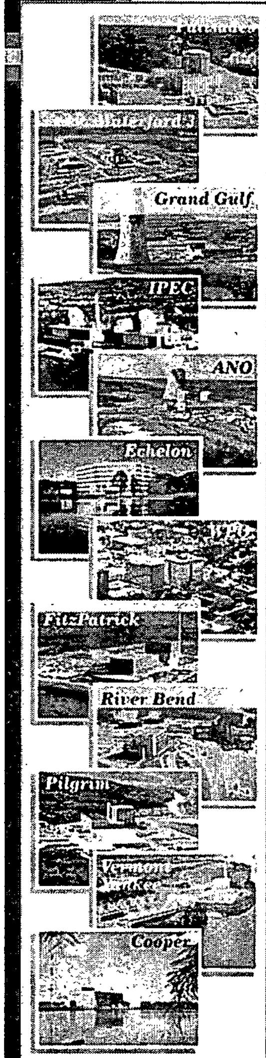
Use of Component Stresses





Technical Considerations – Feedwater Nozzle

- The impact of using component stresses was evaluated for the nozzle corner and safe end locations for all three nozzles analyzed for VYNPS. [7, 17]
- The feedwater nozzle has the highest environmentally adjusted CUF (0.639 at the nozzle corner and 0.256 at the safe end).
- The thermal stress response to a 400°F step change in temperature for the two nozzle locations evaluated is shown on the next 2 slides. [7, 17]
- For both feedwater nozzle locations, excellent agreement exists between SI and the maximum component stress difference for the Green's Function.
- Based on this close agreement, using SI would not change the calculated CUF.

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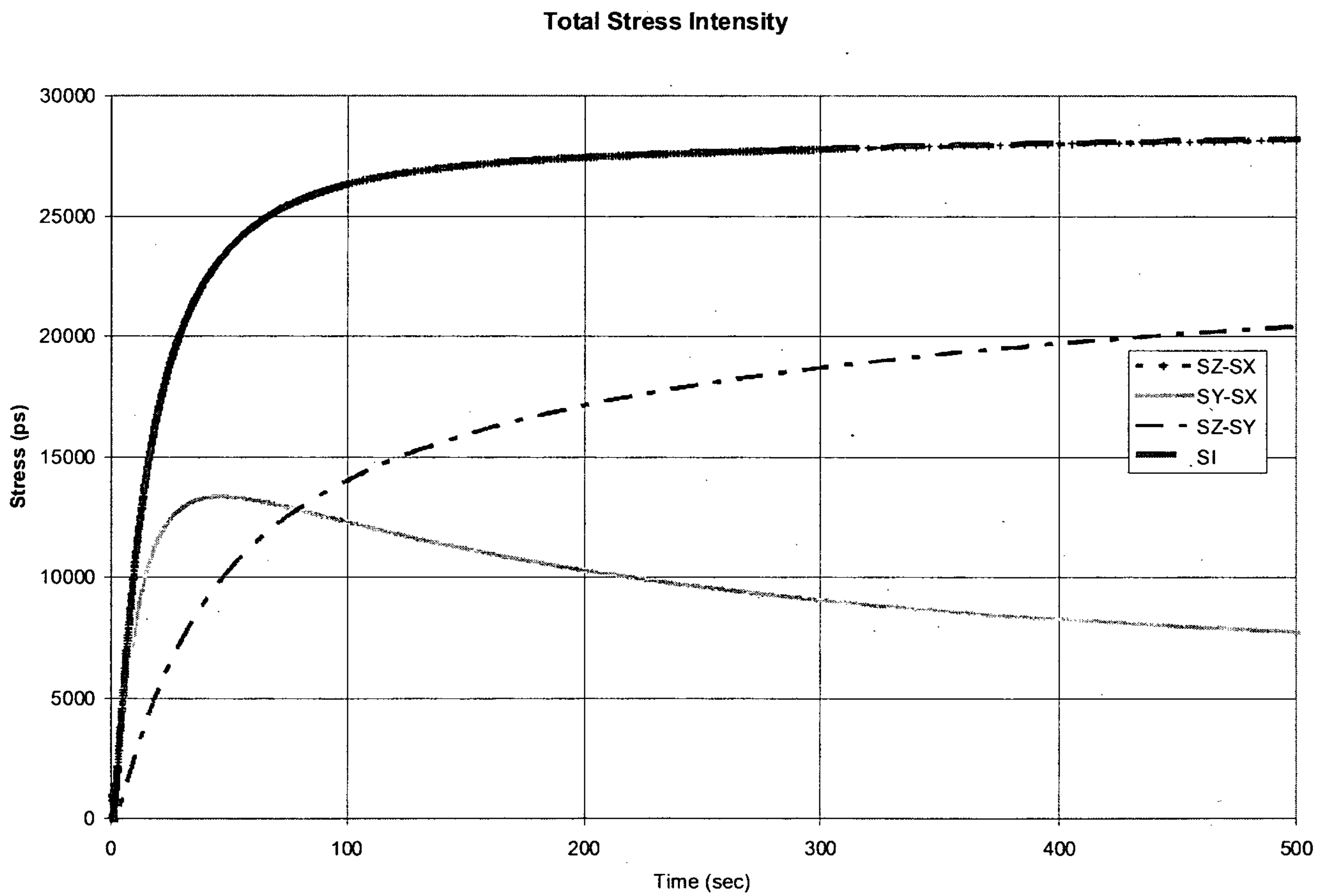
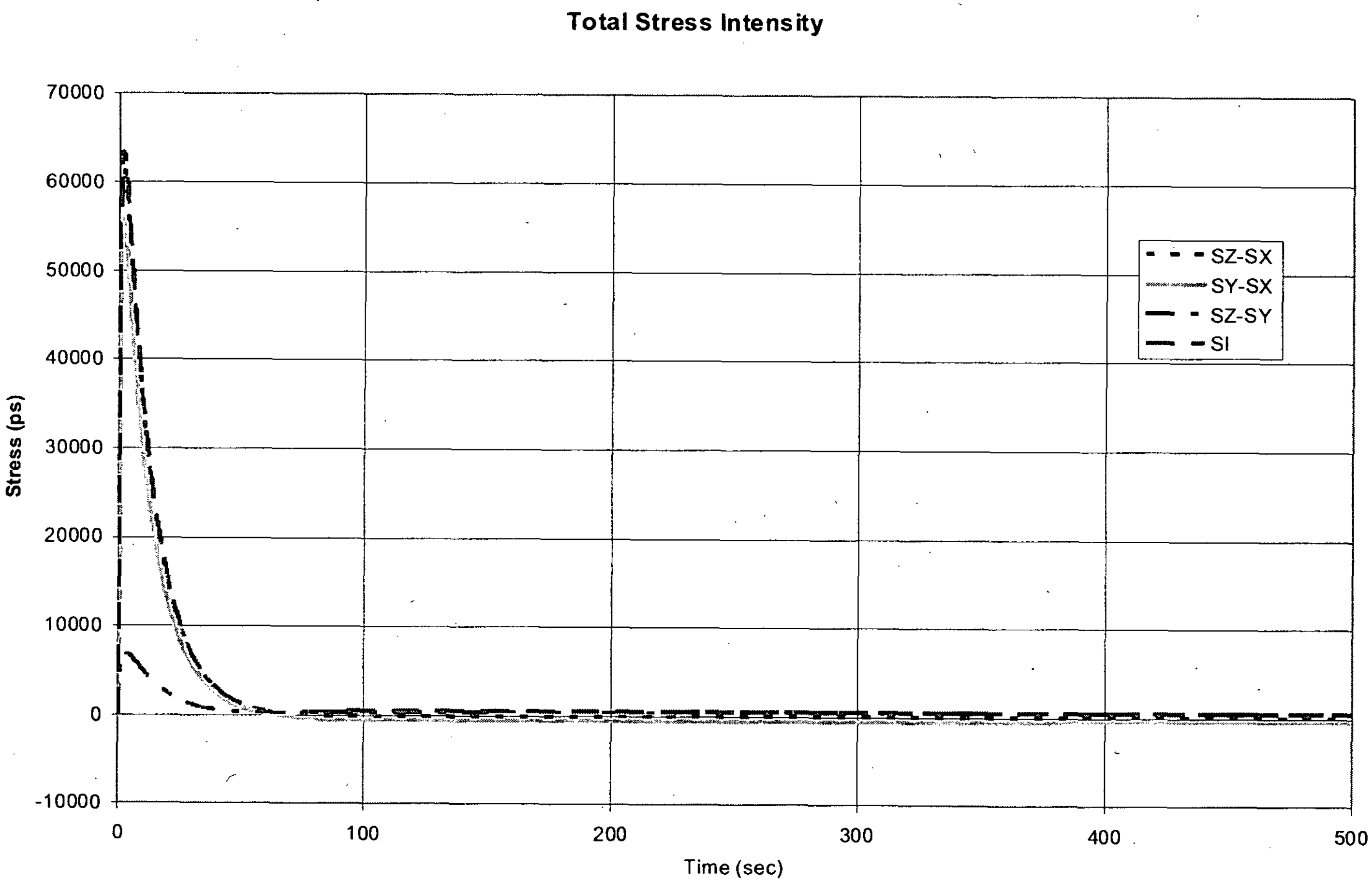
Use of Component Stresses

Feedwater Nozzle Corner Stress Difference Comparison



Use of Component Stresses

Feedwater Nozzle Safe End Stress Difference Comparison



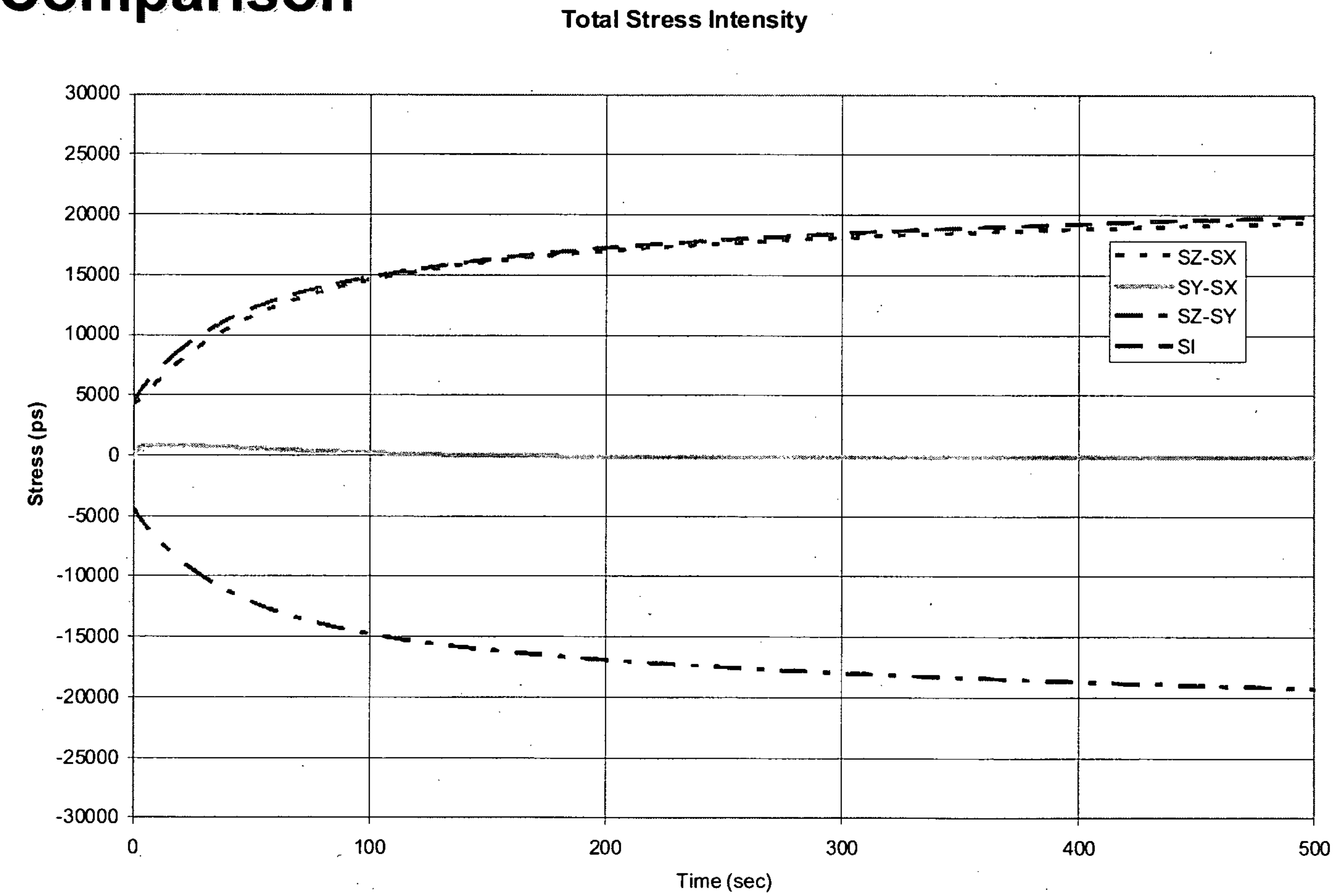
Use of Component Stresses

Technical Considerations – Core Spray Nozzle

- The core spray nozzle has the next highest environmentally adjusted CUF (0.167 for the nozzle corner and 0.059 for the safe end). [16]
- The thermal stress response to a 400°F step change in temperature for the two nozzle locations evaluated is shown on the next 2 slides. [7, 17]
- There is very close agreement between SI and the maximum component stress difference at the nozzle corner.
    - Based on this close agreement for the nozzle corner, using SI would not change the calculated CUF.
- The safe end also has very good agreement at the peak value for the Green's Function. However, there was a difference (up to 50%) at decay stress values.
    - Due to the difference in stresses for the safe end, a confirmatory evaluation was performed using SI. This resulted in a calculated increase in environmentally adjusted CUF of 0.003
    - The total environmentally adjusted CUF increased from 0.059 to 0.062, or 5%. [7]
    - This increase is small, is within the accuracy of the analysis, and is enveloped by conservatisms in the analysis.
    - This small difference is a result of the Green's Function process, where the key comparison is the peak stress value.
- A significant margin of 0.833 exists with respect to the ASME Code limit of 1.0.

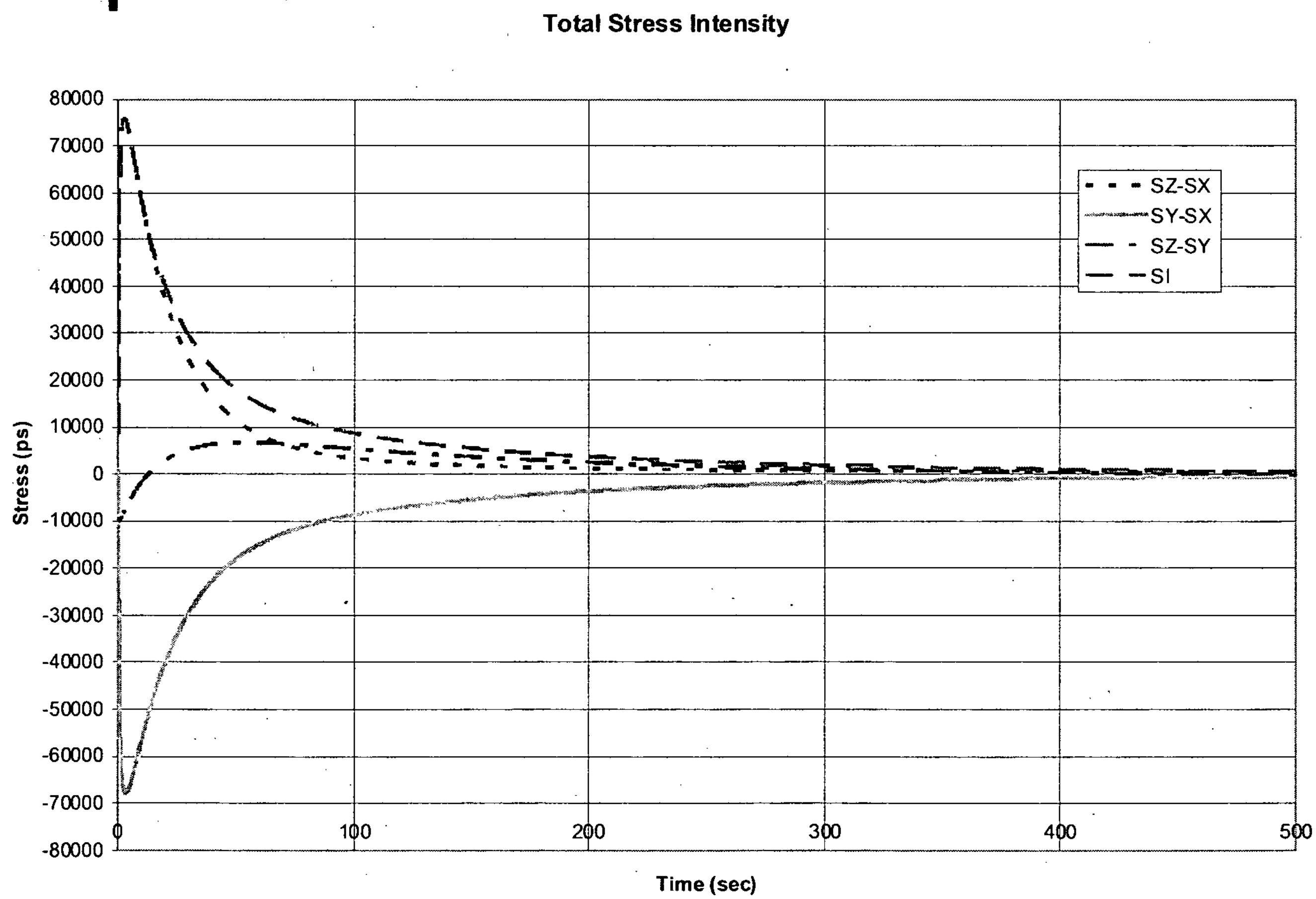
Entergy Use of Component Stresses

Core Spray Nozzle Corner Stress Difference Comparison



Use of Component Stresses

Core Spray Nozzle Safe End Stress Difference Comparison



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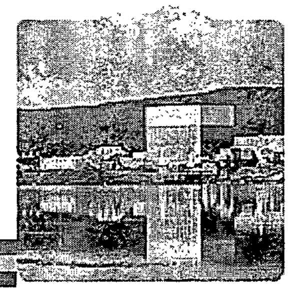
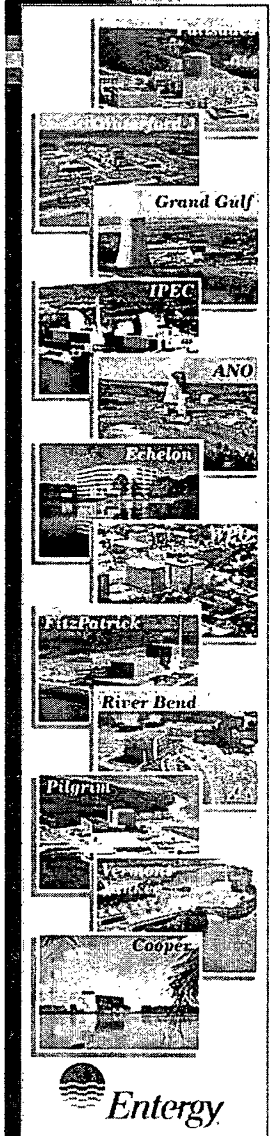
Use of Component Stresses



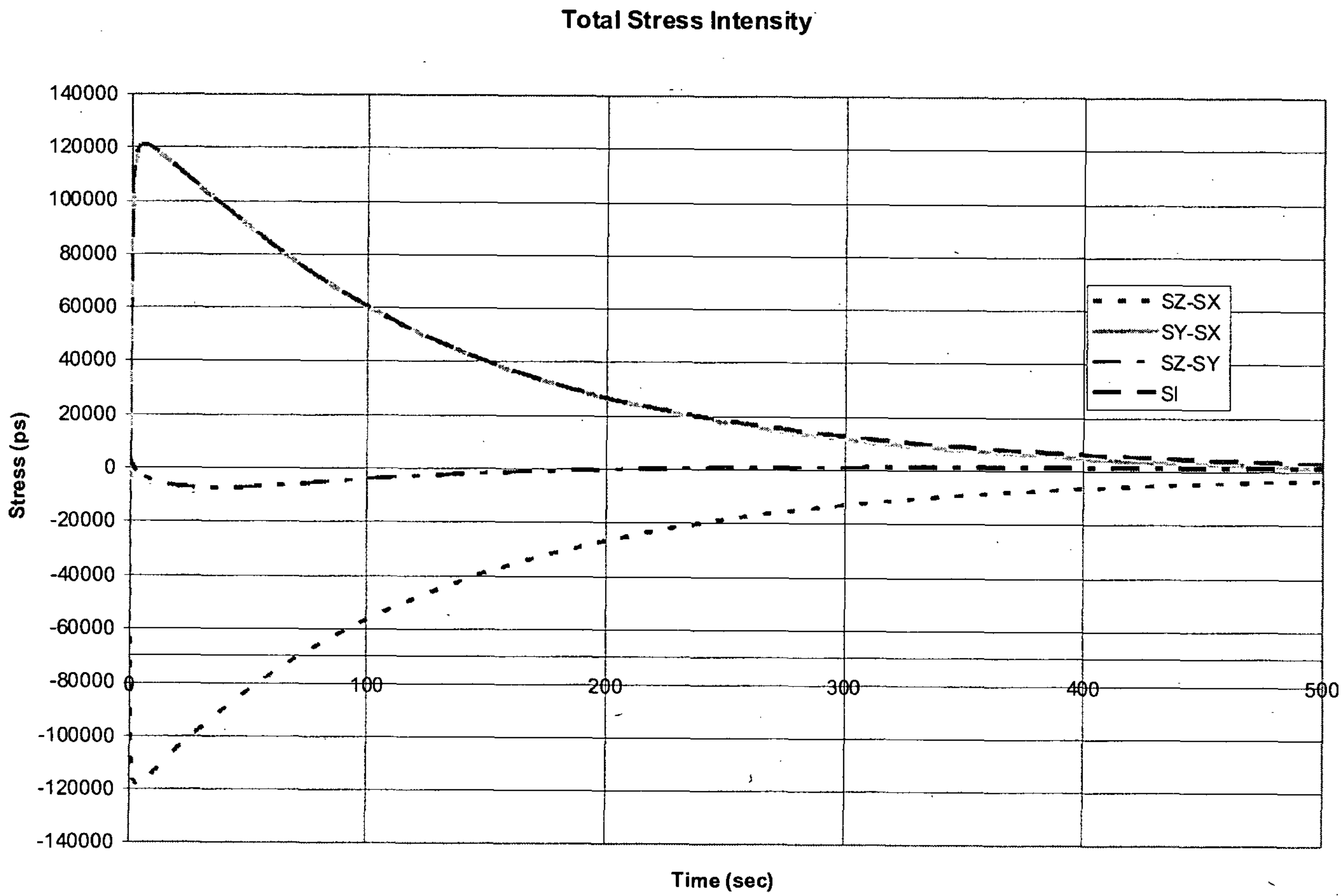


Technical Considerations
– Recirculation Outlet Nozzle

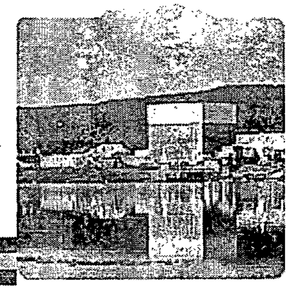
- The recirculation outlet nozzle has a environmentally adjusted CUF of 0.084 for the nozzle corner and 0.018 for the safe end. [13]
- The thermal stress response to a 400°F step change in temperature for the two nozzle locations evaluated is shown on the 2 follow-on slides. [7, 17]
- For the safe end location, there was excellent agreement between SI and the maximum component stress difference for the Green's Function.
  - Based on this close agreement for the safe end, using SI would not change the calculated CUF.

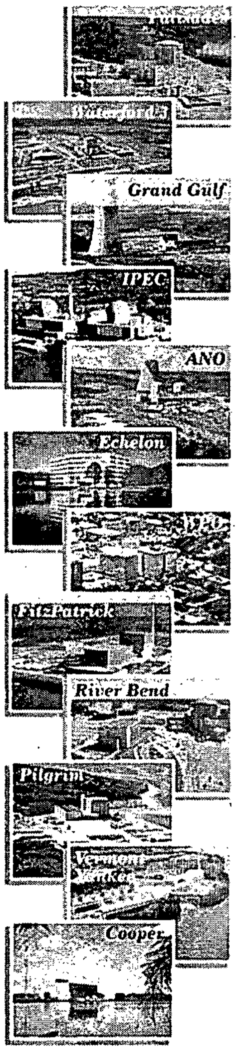
Use of Component Stresses

Recirculation Outlet Nozzle Safe End Stress Difference Comparison



Use of Component Stresses



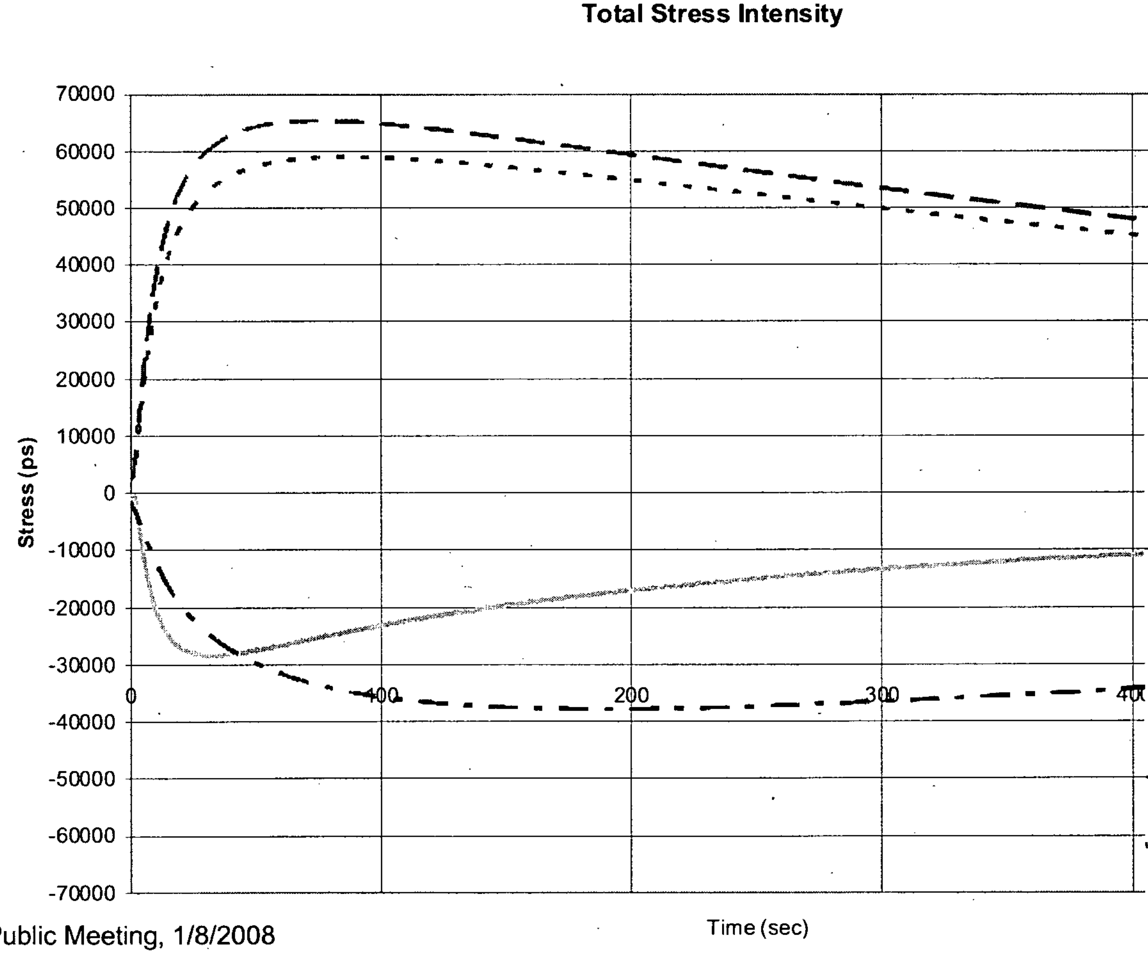


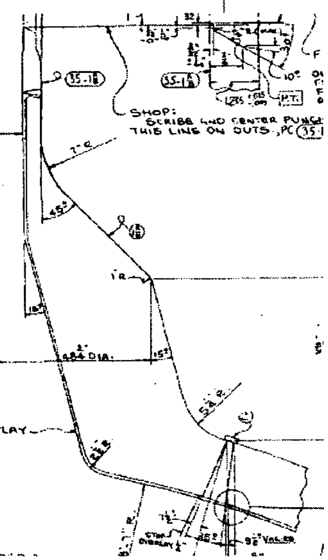
Technical Considerations
– Recirculation Outlet Nozzle

- For the nozzle corner location, there was a difference of 10% between the peak values of SI and the maximum component stress difference for the Green's Function.
  - The difference between SI and the maximum component stress difference has a negligible effect because:
    - The most significant thermal transient (Improper Start causing reverse flow) was modeled directly in the FEM due to its unique characteristics.
    - In the nozzle corner, the thermal stresses are small compared to the pressure stresses. [13]
  - Due to the difference in stresses for the nozzle corner, a confirmatory evaluation was performed using SI. This resulted in a calculated increase in environmentally adjusted CUF of 0.003.
  - The total environmentally adjusted CUF increased from 0.084 to 0.087, or 3.5%. [7]
  - This increase is small, is within the accuracy of the analysis, and is enveloped by conservatisms in the analysis.
- A significant margin of 0.913 exists to the ASME Code limit of 1.0.

Use of Component Stresses

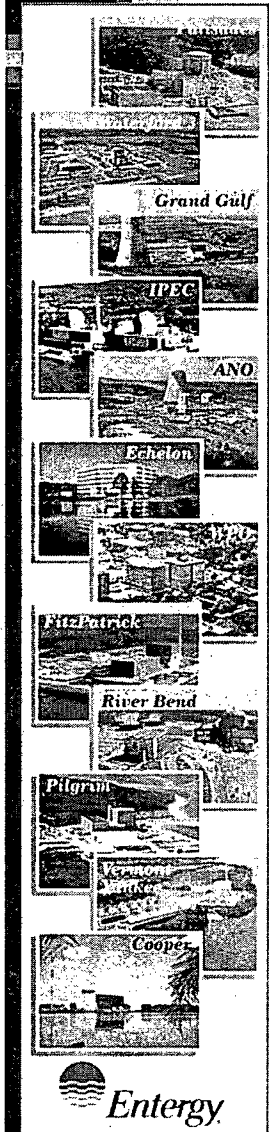
Recirculation Outlet Nozzle Corner Stress Difference Comparison

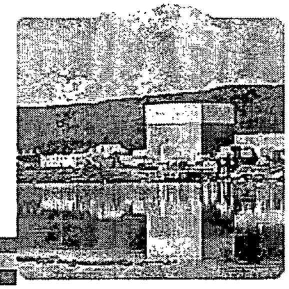




Use of Green's Function Approach

Use of Green's Function Approach

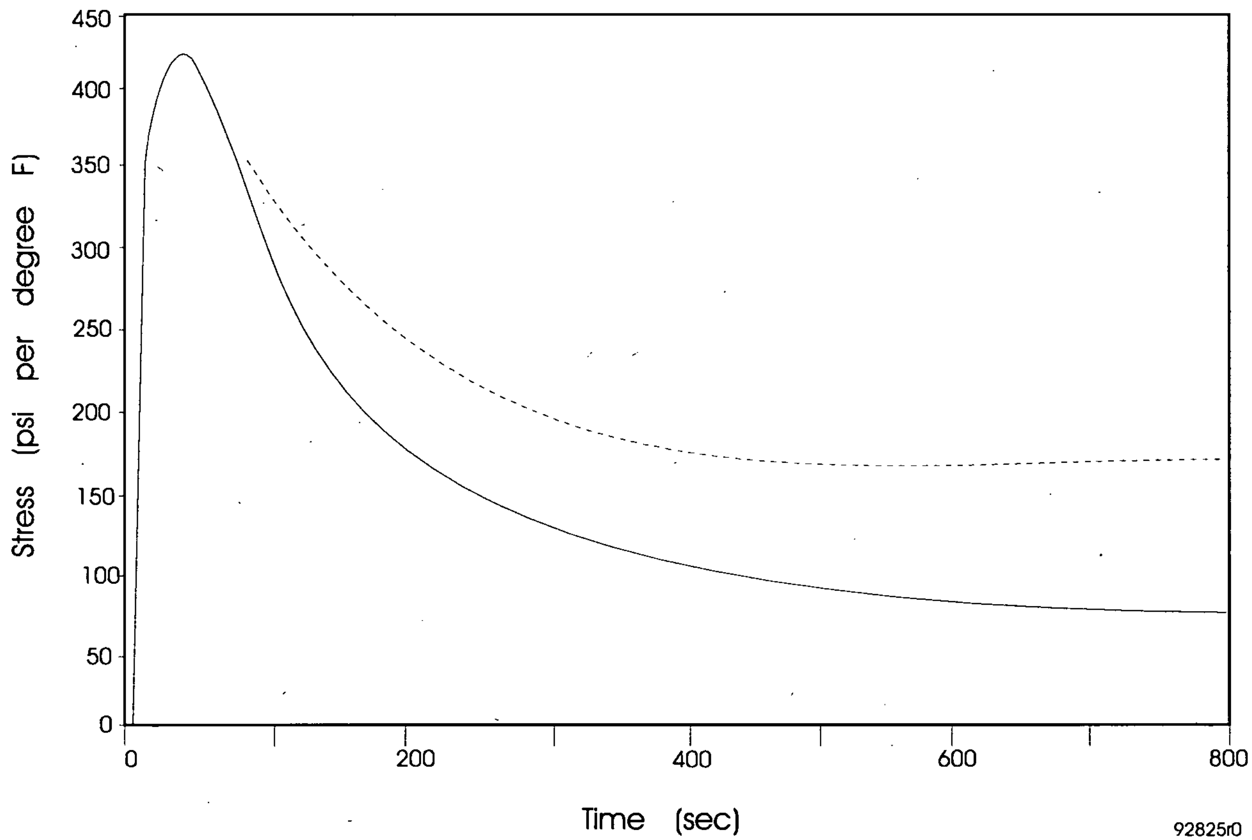




- The use of integration functions, such as Green's Functions, are a well-established mathematical technique. [6]
  - This approach is used to establish the correlation, or stress response, to a unit step change thermal transient.
  - From the stress response to the unit step transient, a stress history can be easily integrated for any thermal transient.
  - The method is accurate and reliable, and has proven mathematics behind it.
    - "Duhamel's Formulas" in most college engineering text books.
    - Similar to integrating the area under a curve, the only limitation is the size of the integration time step.
    - The VYNPS Green's Functions utilize time steps as small as 0.01 second.

Use of Green's Function Approach

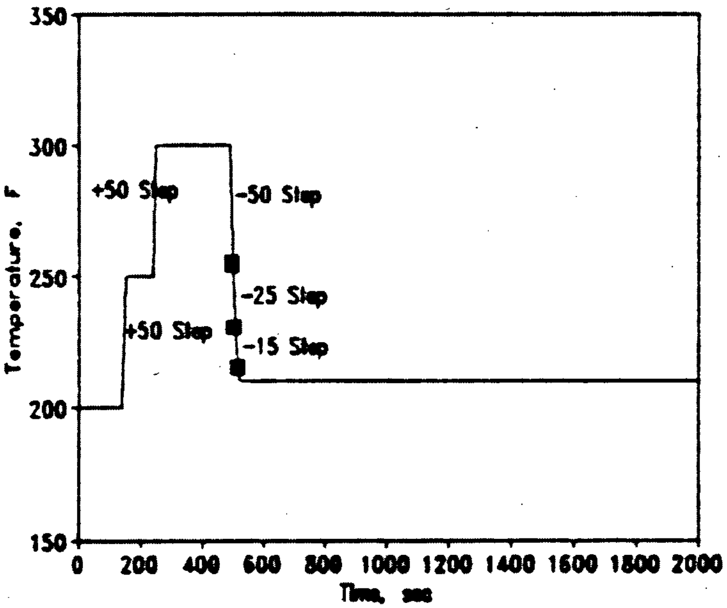
Green's Functions

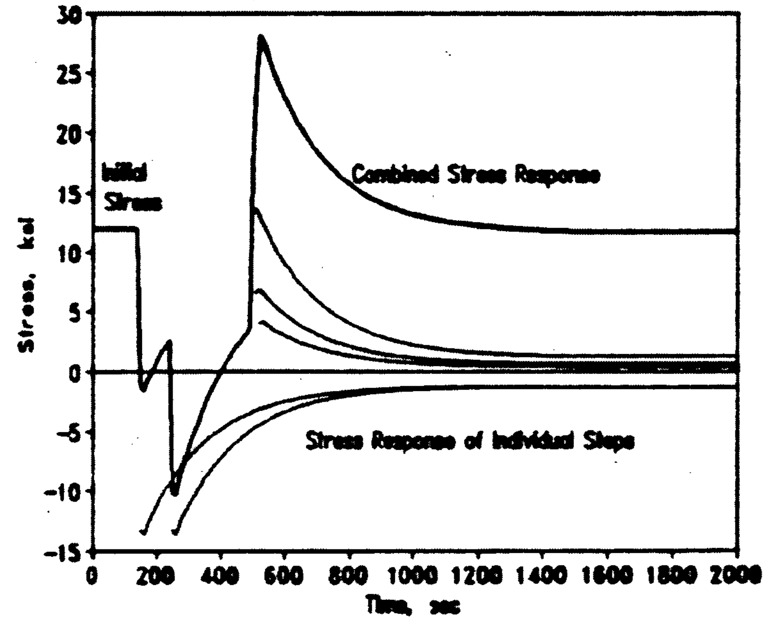


Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

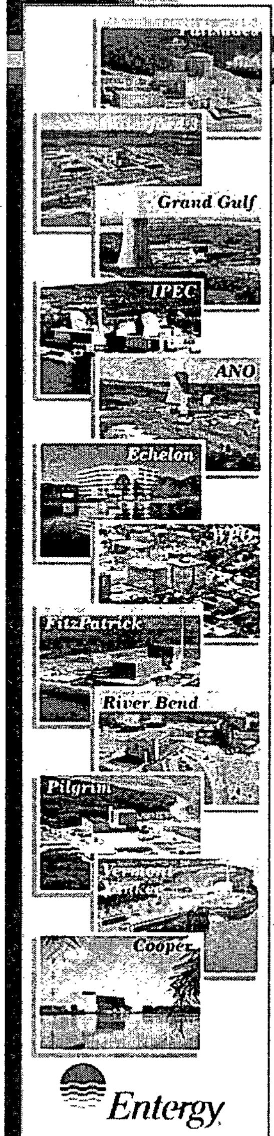
Use of Green's Function Approach

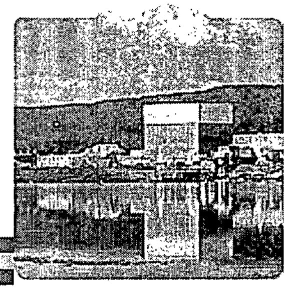
Green's Function Integration Process





- To compute the thermal stress response for an arbitrary transient, the local fluid temperature is deconstructed into a series of step-loadings.
- By using the Green's Function, the response to each step can be quickly determined.
- By the principle of superposition, these can be added (algebraically) to determine the response to the original load history.
  - The result is demonstrated in the figure on the right.
  - The input transient temperature history contains five step-changes of varying size, as shown in the figure on the left.
  - These five step changes produce the five successive stress responses in the figure on the right. By adding all five response curves, the real-time stress response for the input thermal transient is computed.
- The Green's Function methodology produces identical results compared to running the input transient through the finite element model.
- The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model.





Additional Confirmatory Work Planned

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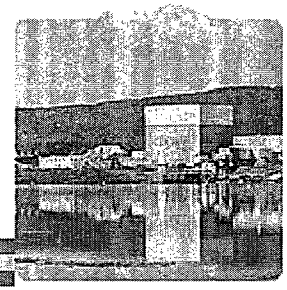
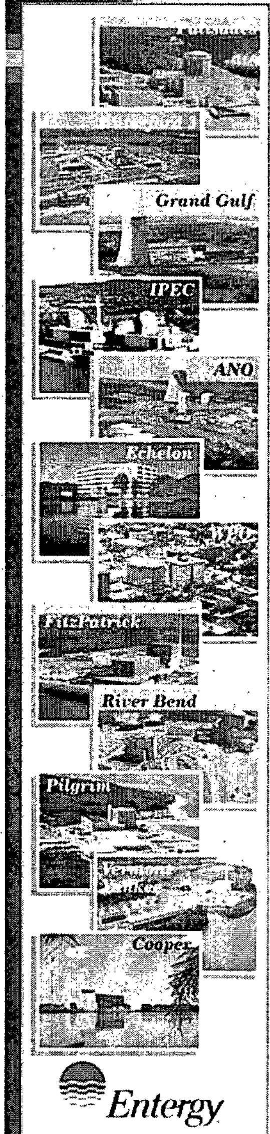
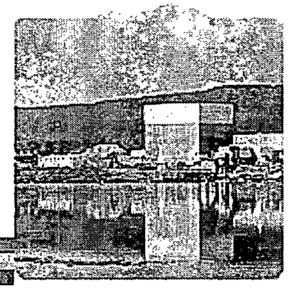
Confirmatory Analysis



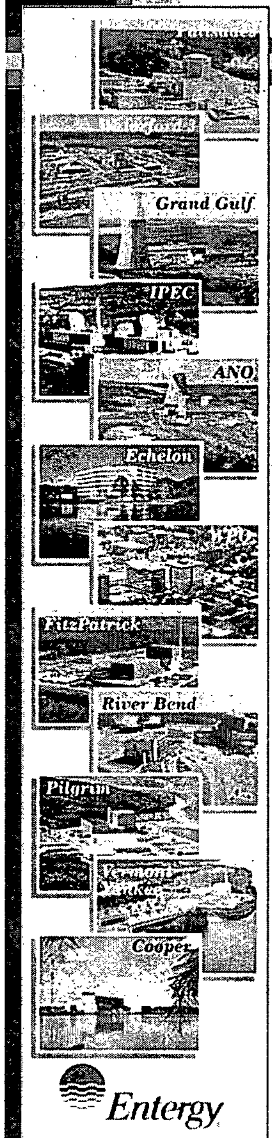


A benchmarking calculation will be performed of the limiting component (feedwater nozzle) as further confirmation of the VYNPS fatigue analysis approach.

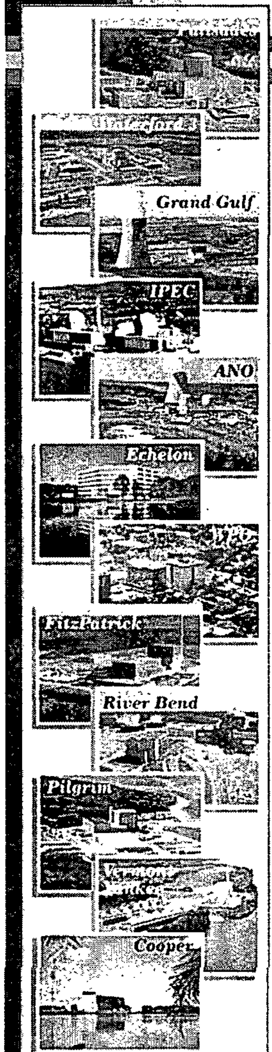
- The feedwater nozzle was chosen because:
  - It has the largest number and the most severe transients.
  - It has the largest fatigue usage.
- Results will be bounding for the core spray and recirculation outlet nozzles.
- The analysis will be performed using the existing axisymmetric model.

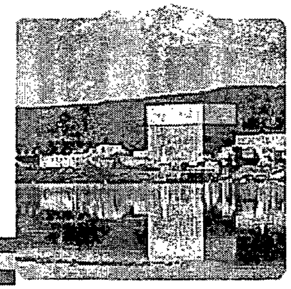


Confirmatory Analysis

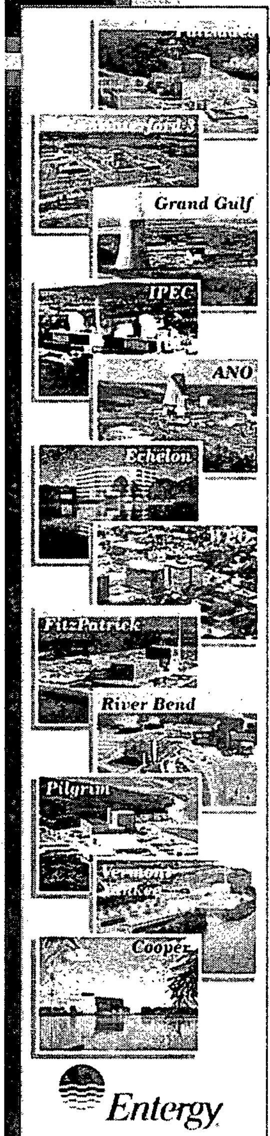


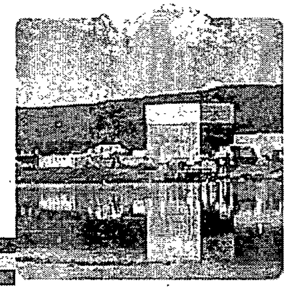
- All defined transients will be evaluated using the finite element model.
- All six stress components will be used to compute fatigue usage via ASME Section III NB-3200 methods.
- The CUF results will be compared to CUF results from the previous environmental fatigue calculations.





Open Discussion


Grand Gulf
IPEC
ANO
Echelon
FitzPatrick
River Bend
Pilgrim
Cooper
Entergy



Conclusion

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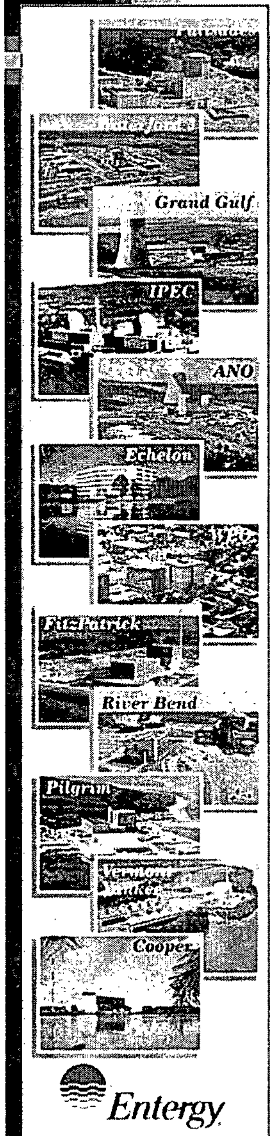
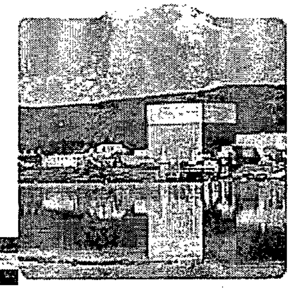
Conclusion





- VYNPS nozzle fatigue analyses were performed using modeling techniques (axisymmetric) and methodologies that are consistent with the CLB.
- The methods used in the VYNPS nozzle fatigue analyses are consistent with classical ASME Code Section III NB-3200 methodology.
- Conservatisms exist in the analysis approach that bound any uncertainties, which are small when compared to the analysis results.
  - Bounding design basis transient definitions
  - Bounding 60-year cycle counts
  - Bounding heat transfer coefficients
- Significant margin (0.36) remains to the ASME Code allowable value of 1.0 (maximum CUF is 0.64).

References

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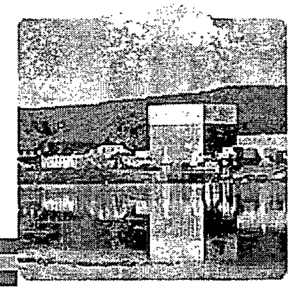
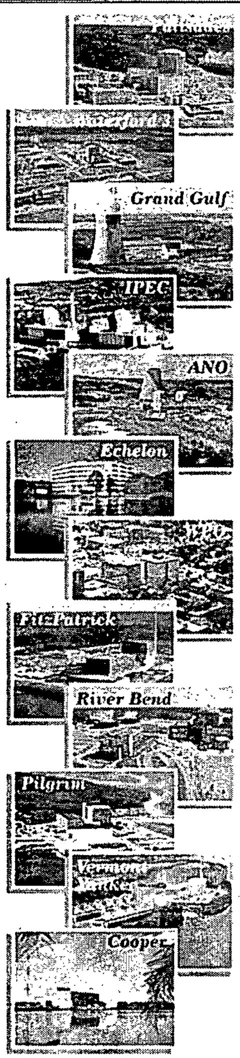
References





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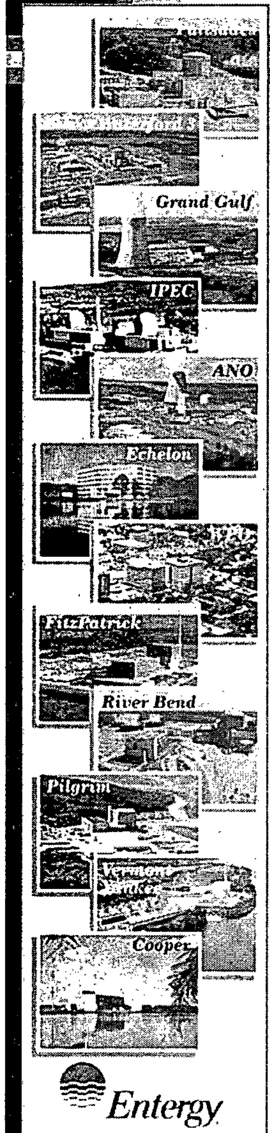

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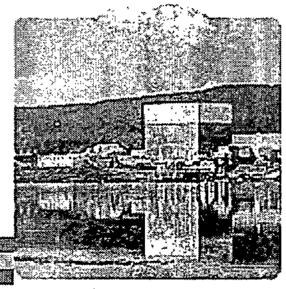

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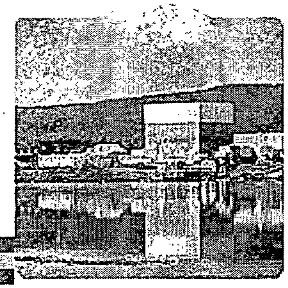

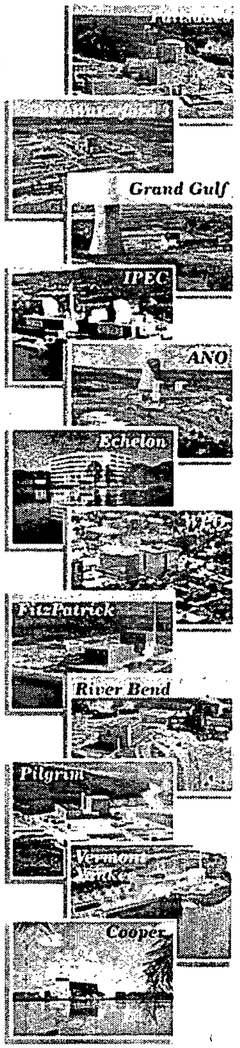

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