Enclosure 2

MFN 12-054, Revision 1

GEH Final Response to RAI 3.9-283

Public Version

Non-Proprietary Version

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NRC RAI 3.9-283

During the audit, the staff discussed with GEH the GGNS summarized [[ ]] approach resulted in higher stress with a difference greater than [[ ]] for the following several dryer components: [[ ]] Entergy justified these high stress areas by performing a [[ ]] However, that location is not the higher stress location in terms of magnitude [[ ]] or the higher percentage difference location [[ ]]. If a similar approach was applied to SSES steam dryer, GEH is requested to provide additional justification for the other significant locations noted above for the applicability of the submodel analysis conclusion, or validate the conclusion based on additional submodels.

GEH Response Summary

The following information explains and justifies why GEH did not perform a similar approach as described in your request on the Susquehanna Steam Electric Station (SSES) dryer. The specific SSES submodel results do not impact the finite element benchmark because the benchmark only accounts for stresses in the global model relative to the stresses measured at strain gage locations. As a convenience, previously submitted GGNS RAI responses concerning this topic (taken from GEH design record files[1]) are attached to this response as an addendum.

GEH Response

The staff's request for information mentions the [[ ]] A series of questions on this topic were asked as part of the Grand Gulf Nuclear Station (GGNS) steam dryer review, where GEH compared [[ ]] which were discussed in the details of the responses provided to the NRC.

[[ ]] was not performed for the Susquehanna Steam Electric Station (SSES) dryer. So a similar approach has not been applied to the SSES steam dryer. [[ ]] Given that GEH did not apply a similar approach to the SSES steam dryer, no further information is needed to respond to this RAI.

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[1] These versions of these responses may differ slightly (e.g., editorial changes) from the versions originally submitted by Entergy to support the review of the GGNS power uprate license amendment application.

In any event, to the extent that this request for additional information is based on the belief that a Susquehanna-based comparison will serve as a benchmark for the ESBWR, that premise is no longer accurate. At one point in time, SSES was proposed as a potential benchmark plant to address NRC concerns related to the original Quad Cities 2 benchmark [1]. However, in late 2012, GEH revised this plan and has since pursued more a contemporary demonstration evaluation for Method 1 based on GGNS [2]. The GGNS-based benchmark is an application of up-to-date models, where staff concerns (e.g., [[ ]]) have been addressed. As a convenience, previously submitted RAI responses concerning this topic (taken from GEH design record files[2]) are attached to this response as an addendum.

In general, bias and uncertainty values are derived from comparisons with benchmark data [[ ]] In the dryer analysis process, submodels are only applied to resolve stresses and are essentially post-processed from the global model results. Specific SSES or GGNS submodel results are not relevant to the ESBWR dryer, other than the fact that they are representative of process steps that may eventually be taken in a future analysis.

In order to explain why [[ ]], it is helpful to remember that this is a very large FE model that consumes significant computational resources in order to produce results. The global model takes advantage of carefully selected simplifications, [[ ]] must maintain consistency with the methodology basis. In other words, the methods that will be applied to the ESBWR dryer will be consistent with the methods applied to establish FE model bias and uncertainty, since these techniques influence accuracy.

References

1. MFN 12-131, David Misenhimer (NRC) to Jerald G. Head (GEH), "Audit Report of the Steam Dryer Design Methodology Supporting Chapter 3 of the Economic Simplified Boiling Water Reactor Design Control Document," June 14, 2012.
2. MFN 12-130, Jerald G. Head (GEH) to the USNRC Document Control Desk, "Economic Simplified Boiling Water Reactor (ESBWR) Steam Dryer Design Methodology Supporting Chapter 3 of the ESBWR Design Control Document," December 12, 2012.

DCD Changes

No change is proposed for the DCD or referenced License Topical Reports.

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[2] These versions of these responses may differ slightly (e.g., editorial changes) from the versions originally submitted by Entergy to support the review of the GGNS power uprate license amendment application.

Addendum to RAI 3.9-283

EMCB-GGNS1-SD-7-RAI-03

The licensee summarized the [[

]] approach resulted in higher stress with a difference greater than [[ ]] for the following dryer components: [[
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The licensee justified by performing a submodel analysis for the cover plate showing that the [[.]] However, that location is not the higher stress location in terms of magnitude [[( ]]or the higher percentage difference location [[ ]]. The licensee is requested to provide additional justification for the other significant locations noted above for the applicability of the submodel analysis conclusion, or validate the conclusion based on additional submodels.

GEH Response

Table 1 in the response to EMCB-GGNS1-SD-4-RAI-04 provided a comparison of the calculated maximum stress intensities for all steam dryer components using the embedded / overlay approach for the shell-to-solid transition versus the Multi-Point Constraint (MPC) algorithm. The most significant differences in the stress results for the two approaches were seen for the [[
]] components. This sensitivity study was performed for a full transient dynamic analysis using the Flow Induced Vibration (FIV) loading for the low frequency nominal load case. The stresses presented in Table 1 of the EMCB-GGNS1-SD-4-RAI-04 response were from the primary results scoping, i.e., there were no adjustment factors (weld factor, bias and uncertainty (B&U), etc.) applied.

In the GGNS replacement dryer fatigue evaluation, in order to address the uncertainties in the steam dryer structural frequency response, [[

]] The latest final stress table was provided in the response to EMCB-GGNS1-SD-6-RAI-06.

For the four components that have the highest percentage differences from the overlay versus MPC comparison, Table 1 of this response provides the raw stresses from ANSYS primary results scoping, the weld factor, the maximum final stresses under EPU conditions, and MASR. For the [[

]] An estimated "B&U Factor" [[

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[[

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There are two basic dryer design configurations where the shell-to-solid transitions were used in the global model. The first configuration is where the [[ ]] Examples of these are the [[ ]] The other configuration is where the [[ ]] Examples of these components are [[ ]]

Components with the first configuration are addressed by the solid element submodel analysis described in the response to EMCB-GGNS1-SD-4-RAI-04. This solid element submodel analysis investigated the [[

]] The submodel results are representative of this configuration and show that the use of the shell overlay method in the global model to transfer the shell node moments into the solid nodes is acceptable.

For the second configuration, the analysis in the response to EMCB-GGNS1-SD-4-RAI-04 showed that [[

]] These results show that the use of the shell overlay method in the global model to transfer the shell node moments into the solid nodes is acceptable for this configuration.

It should be noted that if the global model stress results in these locations did not meet the minimum MASR of 2.0, the region would be analyzed with a refined submodel which replaces the shell-to-solid transitions in the high stress locations, using either overlay or MPC, with solid elements. With this approach, it is only necessary that the shell-to-solid transition methodology used in the global model produce conservative results. It is not necessary to seek out which methodology maximizes the additional conservatism introduced in the global model results. In general, the submodeling technique or approach is a widely accepted method for treating stress risers (i.e., resolving local geometry features where the mesh is too coarse to produce accurate results) without revising and reanalyzing an entire global Finite Element (FE) model. In essence, the method can be thought of as (strictly) local mesh refinement; submodel analysis will produce accurate results as long as the cut boundaries are treated properly, standard FE modeling good practices for producing the refined mesh are followed, and the results by comparing boundary results to the original model are confirmed [1].

Reference:

1. Robert D. Cook, *Finite Element Modeling for Stress Analysis*, John Wiley & Sons, New York, 1995.

Table 1 Raw Stresses and Final Stresses for the Three Components that Have Highest Percentage Difference between [[ ]]

[[

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EMCB-GGNS1-SD-6-RAI-01

The response does not resolve this RAI satisfactorily. For several components, the use of multi-point constraints (MPC) option provided in general purpose finite element (FE) program ANSYS [[

]] The licensee states that [[

]] The licensee further states that according to ANSYS, the use of multi point constraint (MPC) equations option does not guarantee the accuracy of the local stresses near the shell-thickness interface (at least within the shell thickness range). The licensee has performed further evaluation of the high-stresses at the outer-hood location and determines that [[

]] Therefore, the licensee concludes that the Overlay and MPC approach provide conservative results. This conclusion is not acceptable to the staff because, as stated in the response to RAI 6(a), the submodeling approach may not necessarily always provide a stress ratio less than 1.0 when the effects of the local features are included. The licensee is requested to provide the following:

1. *What is the difference between the MPC option provided in ANSYS and the use of constraint equations in modeling the shell-solid interface?*
2. *Please explain how the accuracy of the stresses calculated using the MPC option is determined?*
3. *What is the accuracy of the stresses calculated using the overlay option?*
4. *Based on the maximum stress intensity calculated using the MPC option, what is the minimum alternating stress ratio?*
5. *Explain why the submodeling approach provides conservative results at the outer hood location, as discussed in the response.*
6. *Confirm that the use of submodeling shows that the stresses at all the shell-to-solid interfaces calculated using the overlay and MPC option are conservative.*
7. *Confirm that the results in Table 1 account for the effects of any unconnected nodes.*

GEH Response

In general, the Multi-Point Constraints (MPC) or the overlay technique provides a technically sound means of treating solid-shell transitions. As a point of clarification, the only location in the MPC versus overlay shell study that showed any significant differences is at the interface where these constraints are located, which was not unexpected. A more accurate submodel of the structure was evaluated and was used in the response to EMCB-GGNS1-SD-4-RAI-04. This submodel did show that the overlay shell method provided more accurate results than the MPC approach in this area. The detailed solid model will provide a better stress prediction than will a shell model in intricate corners such as the location where [[

]] The submodel approach is the standard practice for resolving stress details and was applied to GGNS as described in NEDC-33601P. The following responses address the more specific questions:

1. Conceptually, there is no difference between the general approach of Constraint Equations (CEs) and the use of the MPC algorithm, although the mechanics of applying the particular software options will vary. Constraint equations are a general set of

equations that relate the degrees of freedom of one nodal point to another. These can be formulated (constructed) in various ways. The point-to-surface contact method (MPC algorithm) is one method. The CE method requires the user to establish constraints, essentially by hand, but requires the user to know exactly how the constraints are applied. The MPC method is more automatic, with ANSYS picking nodes that will be connected, with the user not knowing exactly which nodes are connected beforehand. The MPC algorithm internally generates a set of CEs to connect the nodes on the contact point to the target surface. These CEs are generated in the first time step and remain as such throughout the entire transient dynamic analysis (whereby direct integration is used). The internal creation of these CEs is dependent on the user’s input and the selection of parameters for the “pin-ball” region and tolerance factor. The “pin-ball” is a sphere which selects all nodes within the sphere. Nodes out of plane and a “pinball” radius away from each other can be selected to be connected by constraint equations when in actuality they should not be connected. However, the ANSYS equations will be set up with these out of plane connections, generating artificial nodal moments which should not be in the equation set, resulting, often in artificially high stress results. Great care must be used with the MPC method, to insure that all constraint equations established automatically are in fact valid. For the Grand Gulf Nuclear Station (GGNS) replacement steam dryer global Finite Element Model (FEM), [[ ]], leading to artificially high stress results. The reason the ANSYS manual states that stress at the interface is not ‘guaranteed (i.e. not accurate and not to be trusted), is that ANSYS cannot guarantee that only correct nodes are selected to be coupled. However, the incorrect nodal moments will offset each other in general, so stress in elements away from the interface are accurate.

2. The accuracy of the calculated stress using the MPC algorithm is not determined by the user, but rather by the ANSYS software developer. The software developer claims that the results at the MPC interface are not accurate. One possible explanation for this limitation associated with MPC algorithm is discussed in item 3 below.

3. The deformations and displacements in the dryer fatigue analysis at normal operating conditions are [[ ]], which would suggest that traditional constraint equations could be used for this application; however, the internal nodal rotations may not be insignificant. The use of CEs to connect the shell rotations to the solid nodes tends to produce artificially high internal moments. These internal moments sum to zero across the MPC boundary thereby producing an accurate set of output loads for a given set of input loads. This is confirmed by the stress prediction similarity between the MPC method and overlay shell method a short distance from the interface. These artificial moments will, however, affect the strain energy and stress at the interface in an adverse manner. The use of overlay shells also adequately transmits the shell rotations into the solid nodes, but the artificial internal moments are not generated. Therefore, the stress predictions in the shell elements are not significantly affected when using the overlay shell method. More importantly, the [[ ]] confirms that both the overlay shell method and MPC algorithm are conservative; the (limited) study results indicate that the overlay shell approach provides a more accurate stress prediction in the dryer interface regions than does the MPC algorithm.

4. The MPC option was not used as the basis for the GGNS replacement dryer analysis. The MPC-based analysis was performed solely as an alternate calculation to support the

validity of the design approach and to address the previous RAI. [[ ]] Regardless, if the minimum alternating stress ratio calculated using either the overlay option or the MPC option were to exceed the acceptance criterion, [[ ]] Given this discussion and the fact that limiting dryer locations are resolved using the more accurate submodels, the MPC study does not impact the limiting margin (MASR) of the dryer.

5. In general, all models are approximations; otherwise they would not be 'models'. Models of the dryer with all shells would be the least accurate approximation, combinations of shells and solids the next best, and a model made fully solid elements, with all fillets and curved geometry, the most accurate. However, a geometrically perfect model would be too large to solve with current technology, so engineering approximations are used to get as close to a fully accurate answer as possible. Submodeling improves the resolution of the model to improve the accuracy of the predicted stress results in a local region, and is a trade-off of accuracy vs. ability to solve the engineering model. The addition of local features in the submodels, such as sharp corners and small fillet radii, removes the need for operator supplied constraint equations, and therefore operator judgement, as well as blind computer generated constraint equations. All the stress equations have direct connectivity. This can sometimes result in an increase in stress as compared to the global model prediction, but in general removes the artificially high stress generated with improper constraint equations, and is therefore a better approximation to the real stress in the dryer. In locations where the global model sufficiently models the geometric details, the global model results are appropriate for use. For locations where the global model does not sufficiently model the geometric details, accurately detailed submodels are used to calculate stress results. With an accurate submodel, whether or not the results are conservative depends on factors other than the FE model (e.g., input load definition). The outer hood model submodel shown in Round 5 RAI-04 used solid elements to accurately model the region where the [[ ]] In that submodel, solid elements are used to model the [[ ]], which was modeled with shell elements in the global model. The use of solid elements for both the [[ ]] eliminates the need to use either the overlay option or the MPC option. The weld details were also modeled with solid elements. The [[ ]] submodel with 3D solid elements accurately reflects the geometry and, therefore, is accurate for its intended purpose.

6. In the response to Round 5 RAI-04, both methods have been shown to predict conservative stress results in a majority of the component element stress intensity results (when compared to highly accurate submodel stress results). In the locations where additional refinement was necessary, it was observed that either a localized stress singularity was present or the global model did not sufficiently model the localized geometric details in enough detail to accurately resolve the strain energy (thus leading to an inaccurate stress solution). Application of the submodel technique (as described in NEDC-33601P) was appropriate in these cases and the dryer stresses were appropriately resolved; the overall application method [[ ]] ensures that the stresses and associated margins are adequately conservative.

7. Table 1 will be updated to include the effects of any disconnected nodes found in the earlier finite element model. These effects are to be calculated in response to Round 6 RAI-02 and tabulated in the response to Round 6-RAI-06.

In conclusion, the use of overlay shells to transmit the shell element nodal rotations into the solid element nodes is an acceptable method to use in the GGNS replacement steam dryer analysis.

EMCB-GGNS1-SD-4-RAI-04

In response to Action Item #5 (GNRO-2011/00088, ML112840176), the applicant explains how it determined the [[ ]] based on a study of [[ ]] The response appears to be acceptable as it shows that for the [[ ]] However, [[ ]] would modify the steam dryer structure and makes it stiffer at the shell-solid interface, and may affect the steam dryer overall structural response. For solid-shell transition interface modeling. ANSYS general purpose finite element program does have an option to use constraint equations with Command CEINTF. In addition, ANSYS has another option for modeling shell-solid assembly as described in Section 9.2, Modeling a Shell-Solid Assembly, of ANSYS Documentation, Release 11. The licensee is requested to confirm whether the use of these options provides the steam dryer stresses that are similar to the ones obtained using the [[ ]]

GEH Response

Care must be taken when joining elements that have different degrees of freedom (DOFs) as with connecting beam and shell elements having nodes with six DOFs to solid elements with nodes having three DOFs. The ANSYS software recognizes this issue stating that "To be consistent, two elements must have the same DOFs; for example, they must both have the same number and type of displacement DOFs and the same number and type of rotational DOFs. Furthermore, the DOFs must overlay (be tied to) each other; that is, they must be continuous across the element boundaries at the interface." In practice, several methods are used to connect such elements together. Among the methods to tie the shell element rotations to the surrounding solid element nodes are the use of [[ ]], the use of constraint equations (CEs), and the use of multi-point constraints (MPCs). [[ ]] for modeling the connection in the global finite element model (FEM) was chosen where the GGNS dryer [[ ]] The primary reason for this choice is that [[ ]] in determining some of the components minimum alternating stress ratio (MASR). [[ ]] of transferring the shell element moments into the solid element nodes is the least invasive to these results.

The ANSYS CEINTF command generates general CEs between element interfaces. It is used to tie together two regions with dissimilar meshes. However, a restriction is placed on the algorithm that the elements at the interface must have the same nodal DOFs in number and type. As described above, shell elements and solid elements differ in the number of DOFs. Therefore, the CEINTF method cannot be used to tie the shell element moments to the solid element nodes.

The use of MPCS is another method recognized by the ANSYS program. To connect a shell to solid interface together, the ANSYS contact technology provides the "bonded always" option. This option enforces compatibility at the solid-to-shell interface by generating internal MPCs during the solution phase. Reference [1] provides a more detailed explanation of how the bonded always contact pairs should be used.

Advantages of the MPC approach include:

- Degrees of freedom of the contact nodes are eliminated.
- No additional normal or tangential stiffness is generated.
- No iteration is needed for small deformation problems, (*i.e.,* it represents "true linear contact" behavior.)
- The method can be used to bond shell-to-solid.

The disadvantages of the MPC approach are:

- The solid mesh density should be sufficiently refined to have a minimum of two elements through the shell thickness.
- "The accuracy of local stresses near the shell-solid interface (at least within the shell thickness range) is not guaranteed." (Reference [1])

In industry, [[ ]] Some of the key advantages and disadvantages are as follows:

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Evaluations were performed to assess the differences in the structural response between the [[ ]] and the MPC methods. The first evaluation is a modal analysis to determine if the [[ ]] significantly alter the fundamental dryer modes. The ANSYS modal analysis results indicate that [[ ]] (Figure 1 top) [[ ]] (Figure 1 bottom). [[ ]] Based on the mode shape similarity, it is expected that the steam dryer stress predictions from the [[ ]] approach and MPC approach will not vary significantly.

Calculations were performed utilizing the results from the full transient dynamic analysis due to the flow induced vibration (FIV) loading for the [[ ]] The calculations are used to assess the impact of the added membrane stiffness to the overall state of stress of the steam dryer. The FIV analysis was performed on the steam dryer FEM using the MPC method (bonded always contact technology) for comparison to the [[ ]] The maximum stress comparison for each component is provided as Table 1. For most components, the stress difference is [[ ]] However, as shown in Table 1, the stress differences are [[ ]], thus warranting further examination. The contour plots comparing the maximum stress locations between the [[

]] and MPC methods for the components exhibiting the [[ ]] between the methods. The comparative contour plots for the [[ ]] components are provided as Figures 2 thru 8, respectively. The plots show that the maximum stress is located at the [[ ]

Several stress time histories were obtained [[ ]] (see Figures 9 and 10). The power spectrum (PS) curves, plotting the square root of the power spectral density (PSD) using both methods (i.e., [[ ]] and MPC) were compared for several of the components. Figures 11 thru 14 present these curves for the [[ ]] components, respectively. The PS plots show that the stress responses a short distance away from the shell-to solid interface are [[ ]] and MPC methods.

A detailed solid submodel analysis was also performed in the area of the [[ ]] Figure 15 illustrates this submodel. The model is comprised entirely of [[ ]] in and around the location of interest (*i.e.,* [[ ]]. A stress contour plot showing the location of the maximum stress intensity predicted in the submodel analysis is provided in Figure 16. [[ ]] The submodel stress prediction is lower than that for both [[ ]] and MPC global model methods. These results also show that the global model result for the [[ ]] method provides a conservative stress prediction.

In conclusion, the CEINTF method of connection at the shell to solid interface is dismissed based on the limitations of the algorithm with respect to this application. The [[ ]] and MPC methods provide comparable global stress responses. A comparison of the modal analysis results showed that the mode shapes are comparable between the two methods. This is also evident in the maximum predicted stress comparisons of the components a located away from the interface. Power spectrum comparisons of the stresses at locations a short distance from the interfaces show that the local stress response of the two methods is comparable. In addition, a submodel analysis shows that both the [[ ]] and MPC methods provide conservative stress predictions at the interface. Therefore, the use of the [[ ]] is acceptable.

Reference(s)

[1] ANSYS Release 11.0 Documentation, “Contact Technology Guide”

Table 1: Comparison of Maximum Stress Intensities for all Steam Dryer Components using MPC Algorithm and Embedded/Overlay Approach

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Figure 1: [[ ]]

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Figure 2: [[ ]]

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Figure 3: [[ ]]

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Figure 4: [[

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Figure 5: [[ ]]

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Figure 6: [[

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Figure 7: [[ ]]

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Figure 8: [[ ]]

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Figure 9: [[ ]]

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Figure 10: [[ ]]

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Figure 11: [[ ]]

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Figure 12: [[ ]]

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Figure 13: [[ ]]

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Figure 14: [[ ]]

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Figure 15: [[ ]]

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Figure 16: [[ ]]