

NRC STAFF AUDIT
OF THE STEAM DRYER DESIGN METHODOLOGY
SUPPORTING CHAPTER 3 OF THE
ECONOMIC SIMPLIFIED BOILING WATER REACTOR
DESIGN CERTIFICATION DOCUMENT, REVISION #1

I. PURPOSE

The purpose of this on-site audit is to review documentation presented by the GE Hitachi (GEH) staff that addresses key errors and additional concerns in four Economic Simplified Boiling-Water Reactor (ESBWR) licensing technical reports (LTRs) for determining fluctuating pressure loading on the steam dryer and determine what additional information needs to be submitted by GEH on the docket to support approval of the LTRs and the ESBWR Design Certification.

II. BACKGROUND AND AUDIT BASES

On November 15, 2011, the U.S. Nuclear Regulatory Commission (NRC) informed GEH that the staff was preparing the final ESBWR Design Certification (DC) rule package for submission to the NRC, and we provided a schedule for completing the ESBWR rulemaking. We estimated delivery of the rule to the Commission in January 2012, and provided the Commission affirmed the final certification, publication in May 2012.

Through the NRC's review of the Grand Gulf Extended Power Uprate (EPU), issues have been identified that are relevant to the conclusions in the staff's March 9, 2011, Final Safety Evaluation Report (FSER) issued in support of the ESBWR DC rulemaking. Specifically, errors have been identified in the benchmarking GEH used as a basis for determining fluctuating pressure loading and stresses/strains on the steam dryer, and errors have been identified in a number of GEH's modeling parameters. The staff has concluded these errors may affect the conclusions in the Safety Evaluation Reports prepared for the four LTRs, which were the basis of the safety conclusions in the staff's FSER and need to be addressed before we complete the ESBWR DC Rulemaking.

The staff's FSER for ESBWR relied on GEH licensing topical reports (LTRs) NEDE-33312P-A, "ESBWR Steam Dryer Acoustic Load Definition," Revision 1, NEDE-33313P-A, "ESBWR Steam Dryer Structural Evaluation," Revision 2, NEDC-33408P-A, "ESBWR Steam Dryer – Plant Based Load Evaluation Methodology," Revision 1, and NEDC-33408 Supplement 1P "ESBWR Steam Dryer – Plant Based Load Evaluation Methodology," Revision 1. The issues identified may affect the basis for the staff's approval of these LTRs and, accordingly, the basis for the staff's ESBWR safety evaluation. These issues are described in the enclosure to NRC's letter to GEH dated January 19, 2012 (ML120170273).

The four LTRs describe the analytical methods for computing oscillating pressure loads acting on the steam dryers in the ESBWR design. The methods include a state-of-the-art acoustic load definition model, as well as a demonstration of that model through benchmarking to data from the Quad Cities (QC2) and Susquehanna nuclear power plants.

The NRC's conclusions in its safety evaluation of these four LTRs, referenced in Section 3.9.5 of the ESBWR FSER, are based on the review of both the model and the benchmarking to show that the method is acceptable. The FSER was completed in March 2011.

The five key errors were discussed with GEH during a public meeting held at the NRC offices on January 31, 2012. GEH indicated there is additional documentation that has not been included or submitted on the docket, which demonstrates that the steam dryer design methodology approved in the topical reports is acceptable.

In addition to the five key errors identified in the letter, new information has prompted the NRC to identify three additional concerns with Susquehanna Steam Electric Station (SSES) structural finite element model and conservatism. The staff has identified information that it would like to review directly related to these three additional concerns during the audit.

III. OBJECTIVES

The objectives of the staff's on-site audit are to:

- Review information related to NRC identified key errors and additional concerns.
- Identify what additional information needs to be submitted by GEH on the docket.
- Identify what areas have not been addressed through the review of the additional information.

IV. REQUIRED GEH ATTENDEES AND REFERENCE MATERIAL (FROM APPLICANT)

During the audit, GEH should have technical staffs that are familiar with the subject matter and documents described in the audit plan.

The following documents are requested to be made available:

1. A comprehensive list of all corrective action documentation related to the five key errors identified by the NRC letter dated January 19, 2012.
2. A listing of all corrective action reports related to the steam dryer from 2005 to date. (Note: If the staff requests a detailed review of any of these corrective actions, GEH should provide supportive information.)
3. All LMS presentations from 2005 related to the steam dryer.
4. All CTQ reports from 2005 related to the steam dryer.
5. All LPI reports from 2005 related to the GGNS dryer and/or ESBWR Plant-Based Load Estimation (PBLE) methodology.
6. Susquehanna Instrument Report (all revisions)

7. Quad Cities Instrument Report (all revisions)
8. Susquehanna Hammer Test Results Report (all revisions)
9. All Root Cause Analysis Reports related to the steam dryer.
10. MSL_Nozzle_Areas_FE-vs-DIR_GGNS-SSES-QC2-CNC_Unverified_v0.xls
11. PBLE Design Release; Design Review DRF Number: Section 0000-0075-4893 under DRF 0000-0009-5266, Date: September 12, 2007
12. QC2 Vessel Mesh Verification Presentation by LMS, 2005
 - a. DIR_QC2_plant_R03_20070726_tdb.doc
 - b. ge124453.tiff
 - c. ge083e0b.tiff
 - d. ge083e0c.tiff
 - e. ge083e0e.tiff
 - f. ge1301ef.tiff
 - g. 2005 – V. Ramani – QC2 Steam Dryer Instrumentation Startup Test Report-Final.pdf
13. Strain Gage Correction Test Report (March 2009), GHNE-0000-0094-0291-RO
14. QC2 and SSES benchmark acoustic meshes and nozzle areas, GGNS final acoustic mesh and nozzle area
 - a. Have available any internal or external Q/A documents for the QC2, SSES, and GGNS acoustic pressure vessel and MSL models.
 - b. Have available any resolutions for all issues raised concerning the QC2, SSES, and GGNS acoustic models
15. Acoustic load mapping
 - a. Have available any internal or external audits/evaluations of the acoustic load mapping procedure, along with any corrective actions requested.
 - b. Have available documentation, if any, indicating how you resolved these issues. If the issues have not been resolved, have the documentation available (CAR numbers, internal documents, other).
 - c. Have documentation available indicating whether CAR 49314 has been resolved. If it has not been resolved, have the documentation available.
16. PBLE and FE bias errors and uncertainties
 - a. Have available any internal or external audits/evaluations of the PBLE bias error and uncertainty calculations, along with any corrective actions requested.

- b. Identify any documentation indicating how the issues were resolved. If the issues have not been resolved, provide the documentation (CAR numbers, internal documents, other).
 - c. Have available the FE bias errors and uncertainties based on SSES-only benchmarks.
 - d. Have available the end-to-end bias errors and uncertainties for the QC2 and SSES benchmarks and any documentation as to why these are not used in place of [].
 - e. Have documentation available indicating whether the QC2-based PBLE bias errors and uncertainties, [],
 - f. [], lead to bounded SSES dryer load estimates. If they do not lead to bounding estimates, have documentation available indicating the underprediction bias errors, and why they are not applied to the GGNS dryer.
17. Time series bias errors and uncertainties, signal filtering, assembly of final stress and margin tables
- a. Have available any internal or external audits/evaluations of the bias error and uncertainty calculation process and final stress and margin calculations, along with any corrective actions requested.
 - b. Identify any documentation indicating how the issues were resolved. If the issues have not been resolved, provide the documentation (CAR numbers, internal documents, other).
18. Stress concentration modeling, shell/solid transition, weld factors
- a. Have available any internal or external audits/evaluations of the QC2, SSES, or GGNS dryer FE models and/or stress calculations, along with any corrective actions requested.
 - b. Identify any documentation indicating how the issues were resolved. If the issues have not been resolved, provide the documentation (CAR numbers, internal documents, other).

V. SCOPE

This audit will consist of two activities which are described in the pre-audit activities and audit activities sections.

V(a). PRE-AUDIT ACTIVITIES

The NRC staff will travel to Wilmington, NC on March 9, 2012, for a 1 day review of the required reference material listed in this audit report. The required reference material should be referenced in the presentations to the staff during the audit and should be available for review during the audit.

V(b). AUDIT ACTIVITIES

Agenda

March 21, 2012

1:00 PM	Audit Entrance Briefing
1:30 PM	NRC Concern #1 (SSES structural model)
3:00 PM	NRC Staff Caucus / Review of Information
3:30 PM	NRC Concern #3 (SSES structural model)
5:00 PM	NRC Staff Caucus / Review of Information
5:30 PM	Status Briefing - Review of open and resolved items identified in Day 1
6:00 PM	Conclusion of Day 1

March 22, 2012

7:30 AM	NRC Key Error #1(QC2 coarse acoustic mesh)
9:30 AM	NRC Staff Caucus / Review of Information
10:00 AM	NRC Key Error #5 (Strain gage errors)
12:00 Noon	Lunch
1:00 PM	NRC Staff Caucus / Review of Information
1:30 PM	NRC Key Error #4 (SSES end-to-end benchmarks)
4:00 PM	NRC Staff Caucus / Review of Information
5:00 PM	Status Briefing - Review of open and resolved items identified in Day 2
6:00 PM	Conclusion of Day 2

March 23, 2012

7:30 AM	NRC Concern #2 (Conservatism)
8:30 AM	NRC Staff Caucus / Review of Information
9:00 AM	NRC Key Error #3 (Load transfer)
9:30 AM	NRC Staff Caucus / Review of Information
10:00 AM	NRC Key Error #2 (MSL nozzle areas/locations)
11:00 AM	NRC Staff Caucus / Review of Information
12:00 Noon	Lunch
1:00 PM	Status Briefing - Review of open and resolved items identified in Day 3
1:30 PM	Audit Exit Briefing
2:30 PM	Conclusion of Audit

During the audit, GEH is requested to identify relevant documentation regarding each concern for the audit team per the agenda. This may include presentations, review of calculations and computational data, and other information determined by the staff to be relevant but not currently on the docket. GEH may also identify docketed information if it believes the staff concerns are addressed. These sessions should be supported by the responsible GEH staff. The NRC staff will note when a piece of information addresses the staff's identified errors or additional concerns. The NRC staff will identify any items that have not been addressed by GEH during the audit (open items). GEH will have the opportunity to provide additional information to the NRC staff for review for any open items identified by the NRC staff. At the end of the audit, the audit team will identify all items, both open and resolved. GEH should

expect the staff to follow-up with a request for additional information for open and resolved items.

Summary of NRC Key Errors and Additional Concerns

To assist GEH in preparing for the NRC audit, below is a detailed discussion of the five key errors identified in NRC's letter to GEH dated January 19, 2012, and the discussion during the public meeting on January 31, 2012. In addition, the staff has identified two additional concerns related to the approved topical reports, which are described below. The NRC staff currently believes that supplemental information needs to be provided on the docket for each error or concern.

NRC Error #1 [] Assumption

- During the public meeting on January 31, 2012, GEH indicated mesh is the subject of RAI 3.9-225, in which a 2nd response (S01) corrected the statement regarding []. Based on the 2nd RAI response, NEDC-33408P was revised to be consistent in the specification that the acoustic model mesh must satisfy the [] requirement. However, the original response suggested certain regions can have this requirement relaxed. Therefore, the NRC requested in S01 to substantiate the adequacy of the recommended minimum number of elements. Based on this inconsistency between the responses and the knowledge that Quad Cities benchmarks and GEH slide 17 indicate that the use of [], GEH should have available any specific information regarding the locations and their significance in acoustic model where the assumption of [] was not satisfied.
- During the public meeting on January 31, 2012, GEH indicated the Quad Cities Unit 2 acoustic model was not revised. However, in Appendix G to NEDC-33408P-A Supplement 1, GEH discusses a sensitivity with a finer mesh model. Please have available the specific modeling differences between this finer mesh model and analysis performed as compared to the Quad Cities Unit 2 model. GEH is requested to have documentation available as to whether the finer mesh QC2 acoustic model meets []. Have available a comparison table for critical sections (as listed in MFN 09-509 (ML092300515)).
- During the public meeting on January 31, 2012, GEH indicated that Appendix G to NEDC-33408P-A Supplement 1 summarizes the sensitivity assessment performed with the finer mesh. The summary, on page 253, is extremely short, and is not sufficient for the staff to determine the impact of the baseline model underresolution. GEH should have available specific information regarding the sensitivity assessment and its results for the acoustic model. This includes any sensitivity results for the finer mesh at high frequency narrow bands to []. A summary description of the results as well as updated tables and figures should be presented at the audit
- GEH should also have available any sensitivity analysis that addresses the impact of the mesh differences between the acoustic model and finite element model, particularly

those differences highlighted in the 2005 LMS QC2 Vessel Mesh Verification powerpoint package, which shows fairly [[

]].

NRC Error #2 [[Area and Nozzle Location

- During the public meeting on January 31, 2012, GEH indicated the corrections for the estimation of the [[]. GEH should have available any specific information regarding the incorporation of the area estimation in the ESBWR steam dryer analysis and the bias and uncertainties from this estimation. GEH should also have available any information related to the [[] estimation for the ESBWR prototype steam dryer that will rely on pressure measurements on the steam dryer rather than [[] measurements.
- During the public meeting on January 31, 2012, GEH indicated the deviation of the MSL nozzle location is less than [[]. GEH should have available any specific information regarding the location of the MSL nozzles. Additionally, LMS reported [[]. As of today, these errors appear to be unresolved in the QC model. Have available any basis for not correcting these errors and any sensitivity analysis that addresses the impact of all these errors on the bias and uncertainty calculations.

NRC Error #3 Potential QC2 Acoustic Modeling Errors

- During the public meeting on January 31, 2012, GEH indicated the [[] has been addressed. GEH should have available any specific information that addresses the [[] and where these values are incorporated into the analysis.

NRC Error #4 Alternative Benchmark Approach

- During the public meeting on January 31, 2012, GEH indicated benchmark evaluations of Susquehanna Unit 1 were performed, but GEH did not have rights to share the data at the time of the ESBWR topical report submittal. Additionally, GEH concluded that [[]. GEH should have available any specific information on the Susquehanna benchmark with comparison to the Quad Cities benchmark using [[] and steam dryer data.
- Based on information reviewed by the NRC staff during interviews during the Fall 2011, the NRC requests that GEH have available any documentation regarding the performance of end-to-end benchmarking to address overall bias and uncertainties in the ESBWR steam dryer analysis, including end-to-end (strain gage) benchmarks of the QC2 and SSES instrumented dryers at OLTP and EPU conditions. This would include documentation clearly explaining any differences between modeling approaches/implementations for QC2, SSES, and future ESBWR conditions. It would also include any documentation that would link all [[

]] measurement locations. If feasible before the audit date, GEH should have available any documentation that computes and provides [[]]. It would include any documentation using worst case assessments based on OLTP and EPU results. Finally, GEH should have available any documentation summarizing its [[]] and including them in its overall end-to-end benchmarking assessment.

NRC Error #5 QC2 MSL Strain Gage Inaccuracies

- During the public meeting on January 31, 2012, GEH indicated the benchmarks account for the identified bias and uncertainties in the MSL strain gage accuracy. Extensive discussions of strain gage calibration and uncertainty were provided in NEDC-33408P-A, Supplement 1, Appendix I. Upon review of this Appendix, the staff's concerns are not addressed. Specifically, the applicant should have available any documentation explaining the ramifications of the [[]]. GEH should have available both the LMS [[]] issued in early 2009, as well as any GEH internal reports describing [[]], and any documentation to reconcile any discrepancies between [[]]. Additionally, GEH should have available any detailed description of the bias errors and uncertainties (including actual values) of the [[]] and how they are accounted for in the PBLE benchmarking and in the SSES dryer stress analysis as documented in MFN09-509 and NEDC-33408P-A, Supplement 1.

The following concerns have been identified since issuance of the NRC letter to GEH dated January 19, 2012.

NRC Additional Concern #1 SSES Structural Finite Model

- Subsequent to the issuance of the ESBWR LTRs and FSER, the staff became aware that the SSES steam dryer was fully instrumented in the Fall 2008, GEH acquired data including strain measurements, and conducted a flow induced vibration FIV analysis using plant based load evaluation methodology (PBLE) predicted loads with an SSES structural model. The staff has learned that the [[]]. In early 2009, the NRC submitted an RAI requesting existing benchmarks. GEH responded with MFN 09-509, which provided an SSES stress analysis and selected bias and uncertainty calculations. Several sections within this RAI response were included in NEDC-33408P, Sup 1 (Revision 1). Based on this information, the staff requests that GEH have available any quantitative description of the reason for the underpredictions of strain and also have available any and all previous strain calculations, explaining differences between the MFN 09-509 and previous calculations, along with any modeling and/or data changes.

- GEH should have available any description of the overlay elements in the SSES finite element model and validation of whether these overlay elements are in the as-built dryer design drawings.
- GEH should have available any description of the modeling of the [[]], and its validation.
- In Section 4.1 of NEDE-33313P-A, Rev. 2, states, [[]] and discusses weld factors for these two types of welds. Figure 4.1 of NEDE-33313P-A only refers to these two types of welds. The lack of discussion on [[]] the impression that the fatigue assessment of these welds is not important for the structural integrity of the steam dryer. GEH should have available any description of whether there will be any [[]] in the ESBWR steam dryer design. If so, the staff anticipates that GEH will need to modify the discussion on weld categories as appropriate including the fatigue factor for partial penetration welds and address them accordingly in Section 4.1 and Figure 4-1 of the LTR NEDE-33313P. Additionally, GEH may need to describe and quantify the weld map for the SSES since MFN 09-509 provides the benchmark bias and uncertainty and stress analysis calculations for the SSES, whereas partial penetration welds were not discussed.
- The NRC notes that hammer test data are available for the instrumented SSES dryer prior to its installation in the SSES plant. The applicant should have available any bias errors and uncertainties for finite element (FE) modeling of the [[]] that is constructed using procedures and standards consistent with those to be used for future ESBWR analyses. These data may be augmented, if available, by similar results for the QC2 dryer or future ESBWR dryers.

NRC Additional Concern #2 Conservatism

GEH states there are conservatisms in its dryer stress assessment. GEH should have available a list of conservatisms and quantification in the GEH SSES and QC2 steam dryer stress evaluations.

NRC Additional Concern #3 SSES Structural Model

- In the February 2012, RAI responses regarding the GGNS dryer, GEH concludes that the Overlay and MPC approach provide conservative results. This conclusion is not acceptable to the staff because the submodeling approach may not necessarily provide a stress ratio less than 1.0 when the effects of the local features are included. Since the GGNS prototype dryer is the SSES, GEH should have the following documentation available for the SSES dryer structural model :
 1. The minimum alternating stress ratio, based on the maximum stress intensity calculated using the MPC option.

2. Confirmation that the submodeling approach provide conservative results at the outer hood location, as discussed in the RAI response.
 3. Confirmation that the use of submodeling shows that the stresses at all the shell-to-solid interfaces calculated using the overlay and MPC approaches are conservative.
- Based on the February 2012, GGNS RAI responses with SSES as the prototype steam dryer for the GGNS, GEH should have available the SSES FE models (global model, sub-models, and shell-to-solid transition areas) used in the steam dryer analysis for the SSES, to verify and confirm:
 1. (a) all nodes are appropriately connected; (b) nodes that are supposed to be connected are not left free inadvertently, and the load path is not shifted away from the critical areas, and (c) if there are any unconnected nodes, GEH is requested to provide a description of such locations and the impact on the SSES steam dryer stresses at EPU conditions.
 2. The quality of the FE mesh (shape or aspect ratios) is acceptable to ensure that there are no regions with poor mesh quality in the global model, in the submodels, and in shell to solid transition areas of the SSES steam dryer FE model.
 - To validate proper stress convergence, GEH should have available a summary of the results from the FE model mesh density convergence studies used in the steam dryer analysis for the SSES.
 - If the SSES has unconnected nodes, GEH should have available the reanalyzed global model using the FIV nominal loads, and should confirm and verify: (a) the minimum alternating stress ratio based on the reanalysis results, (2) the maximum nonconservative error introduced by the disconnected nodes, (3) the effect on the FIV loads resulting from the consideration of the (+/- 10%) frequency shifts, and (4) if the FE model mesh automatically generates using mesh generators or is manually generated.

VII. SCHEDULE AND DELIVERABLES

The audit is currently scheduled to take place on March 21 through 23, 2012. A one day pre-audit trip is scheduled on March 9, 2012. The audit will be conducted over a period of 3 days. The staff will summarize the preliminary findings from the audit at a meeting with GEH on the final day of the audit. The staff expects to issue RAIs within 2 weeks of the conclusion of the audit and an audit report within 45 days after the issuance of the RAIs.

VIII. AUDIT TEAM

The audit team is made up of the following individuals:

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|---------------------|-----|---|
| • David Misenhimer | NRC | (Project Manager) |
| • Mohammed Shuaibi* | NRC | (Deputy Division Director, Division of Engineering) |
| • Joseph Colaccino | NRC | (Chief, Engineering Mechanics Branch) |

4. NEDC-33408, Supplement 1P, Revision 1, "ESBWR Steam Dryer – Plant Based Load Evaluation Methodology," August 2009. (ADAMS Accession No. ML092460350.)
5. NRC's letter to GEH dated January 19, 2012 (ML120170273).