ENCLOSURE 2

Attachment 9

GE Report GE-NE-0000-0041-9435, "Quad Cities 1 & 2 Steam Dryer Replacement – 4% Structural Damping for Steam Dryer Skirt FIV Analysis," dated June 16, 2005

GE NUCLEAR ENERGY
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June 16, 2005
dkh0513
Report No. GE-NE-0000-0041-9435

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TO: GE Nuclear Energy DRF No.: eDRF-0000-0039-4747

FROM: D. K. Henrie

SUBJECT: **Quad Cities 1 & 2 Steam Dryer Replacement - 4% Structural Damping for Steam Dryer Skirt FIV Analysis.**

REFERENCES:

(1) GE Nuclear Energy Letter Report GE-NE-0000-0039-4749, from D. K. Henrie to J. Klapproth, "Exelon Steam Dryer Replacement Program – 2% structural Damping for Seismic and Non-Seismic (FIV) Dynamic Analysis", March 18, 2005. (dkh0503)

(2) GE Nuclear Energy Calculation No. eDRF Section 0000-0034-1855, "Damping Value for Steam Dryer Structural Dynamic Analysis", Richard Wu, November 5, 2004.

(3) GE Nuclear Energy Generic Design Specification No. 386HA596, Rev. 0, "Dynamic Load Methods & Criteria – NSSS Equipment, Piping, RPV & Internals", Issued July 2, 1986. **(GE Proprietary)**

(4) US Atomic Energy Commission Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", October 1973.

(5) Quad Cities UFSAR

(6) GE Nuclear Energy Letter Report GE-NE-0000-0039-4768, from D. K. Henrie to DRF No./Section: eDRF-0000-0039-4747/4768, "Quad Cities 1 & 2 Steam Dryer Replacement - 4% structural Damping for Vane Bank FIV Analysis", April 21, 2005. (dkh0507)

(7) GE Nuclear Energy Report GE-NE-0000-0039-5860-01-P, Rev. 1, "Test and Analysis Report - Quad Cities New Design Steam Dryer – Dryer #1 Experimental Modal Analysis and Correlation with Finite Element Results", May 2005.

(8) GE Nuclear Energy Report GE-NE-0000-0041-1656-01-P, "Test and Analysis Report - Quad Cities New Design Steam Dryer – Dryer #2 Experimental Modal Analysis and Correlation with Finite Element Results", May 2005.

1.0 PURPOSE

This letter report provides the recommendation and technical justification for the structural damping to be utilized in the ongoing structural design adequacy evaluation of the Quad Cities 1 & 2 replacement dryer skirt. The recommended damping is to be used for the FIV load case, direct integration, time history analyses conducted by GE Nuclear Energy for Quad Cities 1 & 2.

2.0 CONCLUSIONS

Based on the present evaluation, it is concluded that an equivalent, linear viscous damping value, corresponding to 4.0% of critical damping, can be conservatively used for the FIV structural design adequacy analyses required for the Quad Cities 1 & 2 replacement dryer skirts. The technical basis for this conclusion is provided below.

The details of the present evaluation, as well as evidence of verification, are documented in the GE Nuclear Energy Design Record File, DRF No. 0000-0039-4747, Section 0000-0041-9435.

3.0 DRYER SKIRT DAMPING BASED ON TECHNICAL LITERATURE

The technical justification for the structural damping used in the overall seismic (OBE and SSE) and dynamic (FIV) structural integrity design adequacy evaluation for the Quad Cities 1 and 2 replacement steam dryers is provided in References 1 through 3 and 6. The Quad Cities structural damping, licensing requirement for all primary structure components, except the RPV and internals, is given in Reference 5 and the RPV and internals requirement in Reference 3.

3.1 <u>US NRC Regulatory Guide 1.61 Damping.</u> Table 1 of Regulatory Guide 1.61, Reference 4, tabulates modal damping values acceptable to the US NRC for the analysis and design of nuclear power plant seismic Category I structures, systems and components. The damping values in Table 1 are given in terms of percent of critical damping and are acknowledged to be conservative. Referring to Subsection C.2 of the guide, "*Damping values higher than the ones delineated in Table 1 my be used in a dynamic seismic analysis if documented test data are provided to support higher values.*" Conversely, the following caveat is also given in Subsection C.3 of the guide: "*If the maximum combined stresses due to static, seismic, and other dynamic loading are significantly lower than the yield stress and ½ yield stress for SSE and ½ SSE, respectively, in any structure or component, damping values lower than those specified in Table 1 of this guide should be used for that structure or component to avoid underestimating the amplitude of vibrations or dynamic stresses.*"

In particular, the damping values contained in Table 1 of the guide are highly dependent on: (i) the material and structural characteristics of the structure or component, and (ii) the dynamic excitation level to which the structure or component is subjected (hence, the excitation level to which it responds). With regard to material and structural characteristics, the dryer skirt corresponds to a welded steel structure. With regard to excitation level (hence response level), damping values are provided in Table 1 for OBE and SSE levels of excitation.

Referring to Table 1 of the guide for a welded steel structure, the conservative value of damping for the OBE level of excitation is 2% of critical and that for the SSE level of excitation is 4%. From the current, ongoing FIV analysis for the Quad Cities 2 replacement dryer skirt, the maximum stress at multiple locations in the **skirt** corresponding to 2% damping is 14,590 psi and corresponding to 4% damping is 10,800 psi. At 545°F, the yield stress for SS304L is 15,940 psi. It then fellows that in the dryer skirt the maximum FIV stress, corresponding to 2% structural damping, is equal to 0.92 of yield and for 4% structural damping, the dryer skirt maximum stress is equal to 0.68 of the yield stress, a response that is more representative of SSE excitation.

Based on the foregoing discussion, it then follows from Table 1 of Regulatory Guide 1.61 that the structural damping level for a welded steel structure subjected to the SSE level of excitation (hence, the SSE level of response) is appropriate for the dryer skirt FIV analysis. Therefore, it is concluded that 4% structural damping is appropriate for the FIV design adequacy evaluation of the Quad Cities 1 & 2 replacement steam dryer skirt.

Two finally observations are now made. First, it is noted that the damping values given in Table 1 of the guide all correspond to the vibration of the dynamically excited structures and components in the air. The corresponding damping values if the structures are submerged in water will be significantly higher. Because at least two-thirds of the dryer skirt is submerged at low water level, 4% damping is even more conservative.

Second, it is also noted that per the caveat quoted above, the maximum combined stress to be compared to the yield stress is due to static, seismic, and other dynamic loadings (i.e., FIV loadings). The stresses cited above in terms of the yield stress for 2% and 4% structural damping correspond to only FIV loading which occurs during normal plant operation.

3.2 <u>Quad Cities/Dresden UFSAR Damping.</u> The damping values provided in Tables 3.7-1 of the Quad Cities and Dresden UFSARs correspond to design licensing basis values to be applied to all safety related structures, components and equipment in the plants except the RPV internals and the RPV stabilizer. The footnote in Table 3.7-1 in the Dresden UFSAR reiterates that the design licensing basis damping values for the RPV and internals and the RPV stabilizer are GE Nuclear Energy proprietary and "*are provided in GENE-771-84-1194, Revision 2*", prepared by GE Nuclear Energy for the Dresden shroud repairs.

3.3 <u>GE Nuclear Energy Methods & Criteria Document Damping.</u> The RPV internals damping values provided in the above referenced GENE report are based on the GE Nuclear Energy Methods and Criteria document, Reference 3. The seismic damping values are contained in Table 5.8.1-1 and the nonseismic damping values in Table 5.8.2-1 of Reference 3. Similar to Regulatory Guide 1.61 damping, the design licensing basis damping values contained in Reference 3 are dependent on the material and structural characteristics of the structure or component being excited as well as on the level of the excitation (hence the level of the response). However, differing from Regulatory Guide 1.61, selected damping values contained in Reference 3 are also dependent on the direction, horizontal or vertical, in which the structure or component is excited.

Also, similar to the OBE level of excitation in Regulatory Guide 1.61, the seismic damping values in Table 5.8.1-1, designated as OBE, and the nonseismic damping values in Table5.8.2-1, designated as Normal or Upset, are to be used in the structure or component dynamic analysis in which the resulting maximum stresses are at, or not significantly below, the one-half yield stress. Again, similar to the SSE level of excitation in Regulatory Guide 1.61, the seismic damping values in Table 5.8.1-1, designated as SSE, and the nonseismic damping values in Table5.8.2-1, designated as Emergency or Faulted, are to be used in the structure or component dynamic analysis if the resulting maximum stresses are significantly above the one-half the yield stress and not significantly below the yield stress.

Referring to Table 5.8.2-1 of Reference 3, for a welded steel structure subjected to the Emergency or Faulted level of excitation (hence, level of response), the appropriate structural damping is 4% of critical. Therefore, it is concluded that 4% structural damping can be conservatively applied in the FIV structural design adequacy evaluation of the Quad Cities 1 & 2 and the Dresden 2 and 3 replacement steam dryer skirts. The result is the same as that for Regulatory Guide 1.61

4.0 DRYER SKIRT DAMPING BASED ON HAMMER TEST DATA

The results of the hammer tests, just completed for the Exelon replacement steam dryers 1 and 2, are summarized in References 7 and 8, respectively. The primary purpose of the hammer test is to identify the natural frequencies of the dryer assemblies. The vibration test data generated by the hammer test can also be utilized to determine representative, lower bound values of the structural damping inherent to the steam dryer assemblies. The (i) Logarithmic Decrement, (ii) Half Power Bandwidth (or equivalent), and (iii) Modal Curve Fitting (Individual FRFs), and (iv) Modal Curve Fitting (Whole Component) methods were all applied in References 7 and 8 to the hammer test data to generate approximate, lower bound structural damping values for the steam dryer hoods and skirts.

4.1 Conservatism Inherent to Damping Values Based on Hammer Tests. Typically, the hammer test is performed using a 2 lb to 3 lb soft tipped (load cell) hammer that is used to gently tap (impact) the dryer assembly. There is no metal-to-metal contact. The impact test should not cause local damage to the dryer surfaces, e.g., no dents or scratches. Furthermore, care is taken not to damage the installed sensors and the sensor leads.

From this description, it is clear that during the hammer test the excitation level, deformation, strain, stress, displacement, velocity, strain rate, etc., are all essentially zero. However as discussed in Subsections 3.1 and 3.3 above, the damping magnitude inherent to a structure or component is highly correlated to its excitation (hence response) level. Typically, the greater the excitation level the greater the structural damping magnitude; however, the correlation between the two is nonlinear.

Based on the foregoing discussion, it is concluded that the damping coefficients generated, based on hammer test vibration data, will correspond to very conservative, lower bound values when compared to the actual damping characteristics inherent to the replacement steam dryer assembly during normal plant operation.

4.2 Dryer Skirt FIV Response Characteristic Frequencies. The maximum strain (stress) in the dryer skirt, due to the FIV loading associated with the Quad Cities 2 post startup main steam line data taken at 2885 MWt, occurs at Node 66818 of the steam dryer assembly Finite Element Model (FEM). The frequency content of the corresponding strain (stress) time history, that is calculated at Node 66818 in the associated GE 1% structural damping, direct integration, time history analysis of the dryer FEM, is obtained from the FFT of that time history. The dominant characteristic frequency associated with the dryer skirt maximum strain (stress), defined in the corresponding strain time history FFT plot, is in the range 25Hz to 35Hz.

4.3 Dryer Skirt Damping from Hammer Tests. Referring to Table 1 of Reference 7 for Dryer #1 and Table 1a of Reference 8 for Dryer #2, it is observed that the dryer skirt hammer test calculated damping values vary dramatically depending on: (i) the frequency at which the damping is calculated is calculated, and (ii) which of the four methods mentioned above are applied in the damping calculation.

The damping in terms of percent critical damping in Dryer #1, Reference 7, ranged from 0.2% to 7.7% on the 90° skirt panel, with the higher frequencies generally showing lower damping. The 270° skirt panel showed a similar trend, with a damping range of 0.4% to 13%. In general, the skirt damping values generated based on strain gage hammer test data were slightly higher than the corresponding damping values generated based on accelerometer hammer test data.

For Dryer #2, Reference 8, the damping in terms of percent critical damping for the individual FRFs ranged from 0.2% to 3.7% on the 90° skirt panel, with the higher frequencies generally showing lower damping. The 270° skirt panel showed a similar trend, with a damping range of 0.5% to 5.6%. In general, the skirt damping values generated based on strain gage hammer test data were slightly higher than the corresponding damping values generated based on accelerometer hammer test data.

The procedure consisting of the four steps defined below is applied to the hammer test damping values contained in Table 1 of Reference 7 and Table 1a of Reference 8 to obtain an appropriate damping value which can be conservatively applied in the Quad Cities 1 & 2 FIV structural design adequacy evaluation of the replacement steam dryer skirt.

Step 1: Consistent with the conservatism inherent to damping values that are calculated based on hammer test data (discussed in Subsection 4.1 above), when a range of damping values is calculated at a given frequency by any one of the four methods noted at the beginning of Section 3.0, the maximum damping value in the range is taken as the damping value calculated by that method for that frequency.

Step 2: Whenever more than one of the four methods are applied to calculate dryer skirt damping value at a given frequency, the damping value at that frequency is taken as the average of the damping values calculated by the methods applied.

Step 3: Whenever damping values are calculated at multiple frequencies which fall in the frequency range of the dominant characteristic frequency of the dryer maximum strain (stress), the damping value for the entire frequency range can be taken as the average of the damping values calculated for each individual frequency in the range.

Step 4: The dryer skirt damping can be taken as the damping obtained by applying Step 1 through Step 3 for the frequency range which is equal to the dominant characteristic frequency range of the dryer skirt maximum strain (stress) as discussed in Subsection 4.2 above.

The dryer skirt structural damping, based on hammer test data, is now approximated for Dryer #1 and Dryer # 2 by applying Steps 1 through 4 above to the hammer test data contained in Table 1 of Reference 7 and Table 1a of Reference 8, respectively. The resulting damping values are tabulated in Table 1 below.

TABLE 1

Dryer Skirt Structural Damping (% of Critical)

	Dryer #1	Dryer #2
90° Skirt Panel	4.76%	2.53%
270° Skirt Panel	5.71%	1.50%

4.4 <u>Discussion Dryer Skirt Damping Results from Hammer Tests.</u> Because the vertical plane that contains the dryer assembly horizontal 0° - 180° axis corresponds to a structural plane of symmetry, it is expected that the damping values on the 90° Skirt Panels and the 270° Skirt Panels would be the same. Also, because the structural characteristic of Dryer #1 and Dryer #2 are essentially identical it was also expected that damping values for the two dryers would be the same.

The apparent differences can be partly explained by comparing Table 1 from Reference 7 with Table 1a from Reference 8. In comparing the two tables, it is observed that: (i) the damping values were not generally calculated at the same frequencies for the two dryers, (ii) the damping values were generally not calculated using the same methodology for the two dryers, and (iii) for the same dryer, the damping values were not generally calculated at the same frequencies for the 90° and the 270° skirt panels even though the same methodology was applied. This does not fully explain the differences because there are several cases for which the dissimilar damping values were calculated at the same time point using the same methodology for the two dryers. Probably there are also some differences in the test setup or how the tests were performed between the two dryers or between the two dryer skirt planes for the same dryer.

The Dryer #1, hammer based, damping values given in Table 1 above for the 90° skirt panel and the 180° skirt panel are sufficient to justify 4% structural damping for the Quad Cities 2 dryer skirt structural design adequacy evaluation for the FIV load case. Based on the foregoing discussion, the justification can also be applied to the Quad Cities 1dryer skirt.

5.0 SUMMARY OF EXELON REPLACEMENT DRYER ASSEMBLY DAMPING

From the foregoing discussion it is recommended that 4% structural damping be conservatively applied for the FIV structural integrity evaluation of the dryer assembly skirt.

The FIV structural integrity of: (i) the steam dryer RPV vessel lugs, and (ii) the dryer upper assembly (excluding the vane banks, Reference 6) will still be based on 2% structural damping for the dryer assembly, Reference 1. Also, the FIV structural integrity evaluation of all other steam dryer assembly components will be based on 1% structural damping in the steam dryer assembly, Reference 2.

Based on the present evaluation, it is concluded that an equivalent linear viscous modal damping value of 4.0% of critical damping can be conservatively applied for direct integration time history analyses of the replacement steam dryer skirt for Quad Cities 1 & 2 for the FIV dynamic load case. The technical basis for this recommendation is presented above.

If there are any questions, or if I can be of additional help, please call me at (925) 862-4350 or on my cell phone at (408) 204-6244.

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