TVA

Tennessee Valley Authority, Post Office Box 2000, Decatur, Alabama 35609-2000

April 3, 2009

TVA-BFN-TS-431 10 CFR 50.90

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
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Washington, D. C. 20555-0001

In the Matter of) Docket Nos. 50-259
Tennessee Valley Authority)

BROWNS FERRY NUCLEAR PLANT (BFN) – UNIT 1 – TECHNICAL SPECIFICATIONS (TS) CHANGE TS-431 – EXTENDED POWER UPRATE (EPU) – RESPONSE TO ROUND 23 REQUEST FOR ADDITIONAL INFORMATION (RAI) EMCB.205 AND EMCB.206 (TAC NO. MD5262)

By letter dated June 28, 2004 (ADAMS Accession No. ML041840109), TVA submitted a license amendment application to NRC for the EPU of BFN Unit 1. The proposed amendment would change the operating license to increase the maximum authorized core thermal power level by approximately 14 percent to 3952 megawatts.

Enclosure 1 provides the responses for draft Round 23 RAIs EMCB.205 and EMCB.206 which were received by e-mail dated March 23, 2009. These RAIs are associated with the steam dryer stress analyses performed for EPU. As described in the response to EMCB.205, the Unit 1 limit curves have been revised and are provided in Enclosure 2, CDI Technical Note No. 07-30P, "Limit Curve Analysis with ACM Rev. 4 for Power Ascension at Browns Ferry Nuclear Unit 1."

Enclosure 3 provides a revision to CDI Report No. 08-04P, "Acoustic and Low Frequency Hydrodynamic Loads at CLTP Power Level on Browns Ferry Nuclear Unit 1 Steam Dryer to 250 Hz." This revision updates Reference 5 from the 1/5 Scale Model Test (SMT) report to the 1/8 SMT report. The 1/5 SMT was a preliminary test to determine if safety relief valve resonance onset is possible within the EPU operating range. Based on the results of the 1/5 SMT, the 1/8 SMT was performed to help predict increases in dryer stress that will be seen during power ascension to EPU. The 1/8 SMT report (CDI Report No. 08-14P, "Flow-Induced Vibration in the Main Steam Lines at Browns Ferry Nuclear Units 1 and 2, With and Without Acoustic Side Branches, and Resulting Steam Dryer Loads") was previously submitted as Enclosure 5 of the letter dated October 31, 2008,

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NRR

"Supplemental Response to Round 19 RAI and Response to Round 22 RAIs Regarding Steam Dryers," (ML083120307).

Note that Enclosures 1, 2 and 3 contain information that Continuum Dynamics, Inc. (CDI) considers to be proprietary in nature and subsequently, pursuant to 10 CFR 2.390(a)(4), CDI requests that such information be withheld from public disclosure. Enclosure 7 provides an affidavit from CDI supporting this request. Enclosures 4, 5 and 6 contain the redacted versions of the proprietary enclosures with the CDI proprietary material removed, which is suitable for public disclosure.

TVA has determined that the additional information provided by this letter does not affect the no significant hazards considerations associated with the proposed TS change. The proposed TS change still qualifies for a categorical exclusion from environmental review pursuant to the provisions of 10 CFR 51.22(c)(9).

No new regulatory commitments are made in this submittal. If you have any questions regarding this letter, please contact J. D. Wolcott at (256) 729-2495.

I declare under penalty of perjury that the foregoing is true and correct. Executed on this 3rd day of April, 2009.

Sincerely,

James J Randich for

R. G. West
Site Vice President

Enclosures:

1. Response to Round 23 Request for Additional Information (RAI) EMCB.205 and EMCB.206 (Proprietary Version)

2. CDI Technical Note No. 07-30P, "Limit Curve Analysis with ACM Rev. 4 for Power Ascension at Browns Ferry Nuclear Unit 1," Revision 3 (Proprietary Version)

3. CDI Report No. 08-04P, "Acoustic and Low Frequency Hydrodynamic Loads at CLTP Power Level on Browns Ferry Nuclear Unit 1 Steam Dryer to 250 Hz," Revision 4 (Proprietary Version)

4. Response to Round 23 Request for Additional Information (RAI) EMCB.205 and EMCB.206 (Non-proprietary Version)

5. CDI Technical Note No. 07-30NP, "Limit Curve Analysis with ACM Rev. 4 for Power Ascension at Browns Ferry Nuclear Unit 1," Revision 3 (Non-proprietary Version)

6. CDI Report No. 08-04NP, "Acoustic and Low Frequency Hydrodynamic Loads at CLTP Power Level on Browns Ferry Nuclear Unit 1 Steam Dryer to 250 Hz," Revision 4 (Non-proprietary Version)

7. CDI Affidavit

Enclosures
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ENCLOSURE 4

TENNESSEE VALLEY AUTHORITY
BROWNS FERRY NUCLEAR PLANT (BFN)
UNIT 1

TECHNICAL SPECIFICATIONS (TS) CHANGE TS-431
EXTENDED POWER UPRATE (EPU)

RESPONSE TO ROUND 23 REQUEST FOR ADDITIONAL INFORMATION (RAI) EMCB.205 AND EMCB.206

(NON-PROPRIETARY VERSION)

Attached is the non-proprietary version of the Response to Round 23 RAI EMCB.205 and EMCB.206.

NRC RAI EMCB.205 (Unit 1)

CDI Technical Note No. 07-30P, Rev. 2, March 2009, states:

> Limit curves were generated from the in-plant CLTP strain gage data collected on Unit 1 and reported in CDI Report No. 08-04 [1]. These data were filtered across the frequency ranges shown in Table 5 to remove noise and extraneous signal content, as suggested in SIA Letter Report No. KKF-07-012 [16]. The resulting PSD curves for each of the eight strain gage locations were used to develop the limit curves, shown in Figures 1 to 4. Level 1 limit curves are found by multiplying the main steam line pressure PSD base traces by the square of the corrected limiting stress ratio ($2.80^2 = 7.84$).

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TVA Response to EMCB.205 (Unit 1)

For Unit 1, the steam dryer stress analysis determines a limiting stress ratio (SR) factor based on MSL strain gage signals where the non-acoustical noise (determined at LF conditions) has been removed. As identified in the NRC RAI, the limit curves (LC) should be determined based on applying the limiting stress ratio only to the portion of the signal with the noise removed. The Unit 1 limit curves have been revised as requested and are included as Enclosure 2, CDI Technical Note No. 07-30P, "Limit Curve Analysis with ACM Rev. 4 for Power Ascension at Browns Ferry Nuclear Unit 1," Revision 3. The limit curves were generated as described below.

1. EIC is spectrally removed from the CLTP and LF signals for each of the eight MSL strain gage locations as follows:

$$\mathrm{CLTP}'(\omega) = \mathrm{CLTP}(\omega) * \left[1 - \frac{|\mathrm{EIC}_{\mathrm{CLTP}}(\omega)|}{|\mathrm{CLTP}(\omega)|}\right]$$

$$\mathrm{LF}'(\omega) = \mathrm{LF}(\omega) * \left[1 - \frac{|\mathrm{EIC}_{\mathrm{LF}}(\omega)|}{|\mathrm{LF}(\omega)|}\right]$$

   where the factors $\frac{|\mathrm{EIC}_{\mathrm{CLTP}}(\omega)|}{|\mathrm{CLTP}(\omega)|}$ and $\frac{|\mathrm{EIC}_{\mathrm{LF}}(\omega)|}{|\mathrm{LF}(\omega)|}$ can each be no larger than 1.0.

2. Notch filters are then applied at identified noise frequencies listed in the steam dryer load reports, such as alternating current (AC) line noise, variable frequency drive AC line noise, and recirculation system pump vane passing frequencies.

3. Non-acoustic noise (LF) is removed from the CLTP signal for each of the eight MSL strain gage locations as follows:

$$\text{CLTP}''(\omega) = \text{CLTP}'(\omega) * \left[1 - \frac{|\text{LF}'(\omega)|}{|\text{CLTP}'(\omega)|}\right]$$

where the factor $\frac{|\text{LF}'(\omega)|}{|\text{CLTP}'(\omega)|}$ can be no larger than 0.5.

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As indicated above, the limit curves provided in Enclosure 2 reflect MSL signals that have EIC removed and notch filters applied. During EPU power ascension, MSL signals will have EIC removed and notch filters applied when comparing to the limit curves.

NRC RAI EMCB.206 (Unit 1)

In a letter dated March 11, 2009, TVA presented the Unit 1 steam dryer support beam analysis in Enclosure 1. The submittal indicates the support beams are the secondary structural members because they play no role in providing structural integrity to steam dryer. As such the main concern related to partially unattached support beams is the generation of loose parts. TVA claims that the generation of loose parts is not a concern because the stresses in the remaining attached welds on the support beams are acceptable. Therefore, the NRC staff requests TVA to show that galloping of the unattached portion due to cross flow of the support beams is not a problem. Additionally, the licensee should address whether these welds are/will be included in the BFN inspection program.

TVA Response to EMCB.206 (Unit 1)

The support beams were illustrated in Figures 1 through 3 of the March 11, 2009, submittal, "Steam Dryer Analyses Additional Information." Figure 1 is reproduced below with additional notations depicting direct steam flow paths (cover plates which were inadvertently left off the previous version have also been added). The portion of the support beam which would become a free end if no credit were taken for the welds is not in the flow path of the steam entering the steam dryer vane banks. This portion of the support beam is located adjacent to and under the steel plate beneath the vane bank and inner plenum (see Figure 3 of the March 11, 2009 submittal for details of this weld area). Accordingly, it is not exposed to significant cross flow and flow induced excitation is not expected.

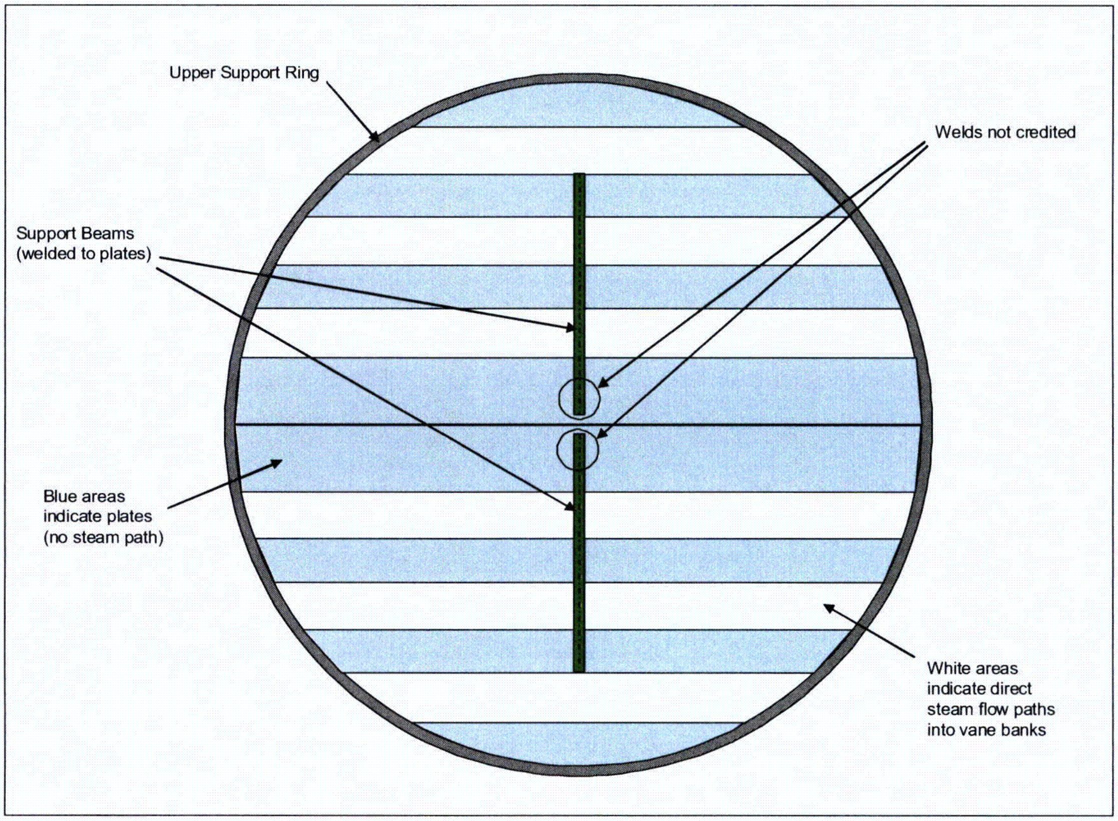

Figure 1: Steam Dryer Bottom Plan View of Support Beams

In order to bound the possibility of galloping of the free end of the support beam, additional analyses were performed. For these analyses, the steam flow rate directed into the vane banks was conservatively applied across the bottom of the vane banks directed at the 14.5 inch (in) free end. This analysis follows.

Summary

The part of the support beam located in the BFN Unit 1 steam dryer under the inner base plates is considered here. For a conservative analysis, this part (14.5 inches in length and extending from the center of the support beam length to the first vane bank) is assumed to be detached from the inner base plates as shown in Figure 1. The beam is subjected to steam flow, and the possibility of flutter vibrations or galloping of this part is investigated. A horizontal onset velocity of 15 feet/second (ft/sec) is assumed to act on this part. This velocity corresponds to the average vertical flow velocity through the inlet plenum at EPU conditions. In actuality, no vertical flow is possible in the vicinity of the support beam part, due to the bounding inner base plates immediately above the support beam. Also, the steady state horizontal flow component should be virtually zero, due to the location of the support beam in a plane of symmetry. Despite this over-estimate in cross flow velocity, it will be demonstrated that no galloping can occur. Using the most conservative analysis, where the drag coefficient (which increases damping) of the member is neglected, the energy supplied by the flow is only 1.2% of the level needed for galloping to be possible. Therefore, galloping of this member will not occur.

Analysis

Acoustic loading due to unsteady pressure fluctuations is fully accounted for in the present steam dryer calculations, and it is shown that the associated structural vibrations do not result in excessive stresses. A remaining concern is whether steady steam flow can cause oscillations of the cantilevered support beam, similar to the vibrations of power lines in a cross wind. The cause of such galloping vibrations is negative aerodynamic damping arising under specific flow conditions. However, such adverse aerodynamic damping, when it is present, has to be sufficiently large to overcome the structural damping, which is conservatively set at 1%. In what follows, the quantitative values of the support beam geometrical configuration and steam flow are used, and it is shown that adverse aerodynamic damping is significantly smaller than structural damping and, thus, no galloping vibration of the support beam is possible.

The following notation is introduced:

Steam density	ρ_s = 2.24 pounds/ft^3 (lbs/ft^3)
Beam height	H = 4 inches = 0.33 ft
Flow speed	U = 15 ft/sec
Steel density	ρ = 0.284 lbs/in^3 = 491 lbs/ft^3
Cross sectional area	S = 3.5 in^2 = 0.024 ft^2
Damping ratio	ζ = 0.01
Frequency	$\omega = 2\pi f$, where f = 285 Hertz (Hz) (mode 1) and 650 Hz (mode 2)
Beam length	x = 14.5 inches
Young's modulus of steel	E = 25.55×10^6 pounds per square inch (psi)

The support beam has a height of 4 inches (vertical part only) and a base width of 3 inches. The thickness of both parts is 0.5 inch and the length of the beam is 14.5 inches. The flow speed U corresponds to the average speed through the vane bank inlet plenum. This speed is conservative, since no vertical velocity can occur at the end of the support beam (the flow is bounded by the base plates) and horizontal cross-velocities are expected to be small in the plane of symmetry containing the support beam.

Cross flow can cause galloping vibrations in the mode shown in Figure 2. The first natural frequency occurs at approximately 285 Hz and corresponds to the mode shown in Figure 3. Since this frequency does not correspond to the galloping motion, the second natural frequency (which occurs at approximately 650 Hz) is used in the analysis. Both frequencies are computed from the cross section geometry and cantilever support condition.

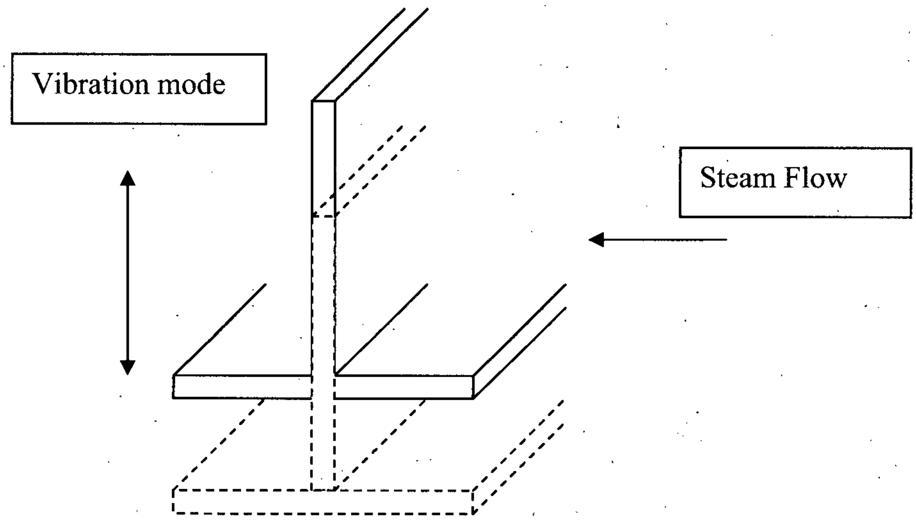

Figure 2: Galloping in the cross flow. Estimated frequency = 650 Hz.

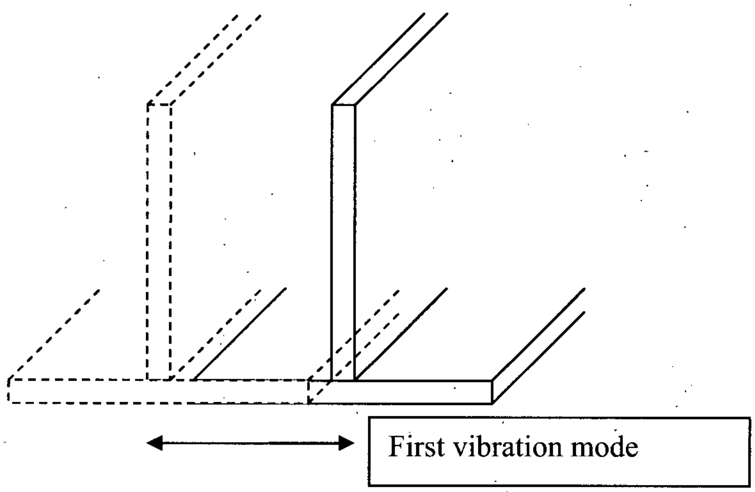

Figure 3: First vibration mode of the cantilevered support beam. Estimated frequency = 285 Hz.

It can be shown [1, 2] that the equation of motion for a body in cross flow can be written as:

$$\rho S\left[\ddot{y} + 2\zeta\omega\dot{y} + \omega^2 y\right] = -\frac{1}{2}\rho_s U^2 H\left[\frac{dC_L}{d\alpha} + C_D\right]\frac{\dot{y}}{U}$$

Here y is the displacement of the support beam in a given cross section; C_L and C_D are lift and drag coefficients, respectively, for the support beam cross-section; and α is the angle of attack. Collecting terms in the equation results in the combined damping term ($\dot{y}$ term) of:

$$D = 2\rho S\zeta\omega + \frac{1}{2}\rho_s UH\left[\frac{dC_L}{d\alpha} + C_D\right]$$

A negative value of D corresponds to negative damping and thus an unstable system. Clearly, there is always a positive part coming from structural damping (ζ term) and drag C_D. However, the derivative $\partial C_L/\partial\alpha$ can, for some cross-sections and incidence angles, be negative, corresponding to a sharp drop in lift at certain angles of attack (stall). For the T shape cross section the lift curve indeed has a negative slope even for small angles of attack, as reported in [3]. Thus, even at small vibrations the aerodynamic forces will add energy to the system rather than dissipate it. The question then reduces to whether this energy $E_{supplied}$ is less than the energy dissipated through the structural damping $E_{dissipated}$.

Following [3], the cross sectional vibration may be assumed in the form:

$$y = \frac{AU}{\omega}\sin\omega t; \quad \dot{y} = AU\cos\omega t; \quad \int_0^{2\pi}\dot{y}^2 dy = \pi A^2U^2$$

where A is a non-dimensional vibration amplitude. Using the expression for D, the net energy over a cycle can be calculated:

$$E_{dissipated} - E_{supplied} = \frac{1}{2\pi}\int_0^{2\pi} D\,\dot{y}^2\,dt = \frac{\rho S\zeta\omega}{\pi}\int_0^{2\pi}\dot{y}^2 dt + \frac{\rho_s UH}{4\pi}\frac{dC_L}{d\alpha}\int_0^{2\pi}\dot{y}^2 dt$$
$$= A^2U^2\left[\rho S\zeta\omega + \frac{\rho_s UH}{4}\frac{dC_L}{d\alpha}\right]$$

Here, for conservatism, C_D is set to zero. The first term on the right hand side of the equation represents energy losses through structural damping, while the second term represents losses or gains of energy from aerodynamic forces. If the right hand side becomes negative, then the energy supplied to the system is not fully dissipated and vibrations will grow.

Using the provided numerical values:

$$E_{dissipated} - E_{supplied} = A^2U^2\left[491\cdot 0.024\cdot 0.01\cdot 2\pi\cdot 650 + \frac{2.24\cdot 15\cdot 0.33}{4}\frac{dC_L}{d\alpha}\right]$$
$$= A^2U^2\left[481 + 2.8\cdot\frac{dC_L}{d\alpha}\right]$$

Galloping can occur if $\partial C_L/\partial\alpha < -172$. The lift curve slope for a support beam in cross flow is provided in [3] and has a value of only -2. Therefore, galloping will not occur and the ratio of the supplied energy is only 1.2% of that required for galloping to become possible.

Reference [3] provides a more rigorous expression for the energy supplied to a support beam in one cycle, with the lift curve slope integrated and the drag coefficient included. As before, the energy dissipated by the structure per cycle is:

$$E_{dissipated} = \frac{1}{2\pi}\int_0^{2\pi} 2\rho S\zeta\omega \dot{y}^2 dt = \frac{\rho S\zeta\omega}{\pi} A^2U^2 \int_0^{2\pi} \sin^2 \omega t dt = \rho S\zeta\omega A^2U^2$$

According to [3], the energy supplied to the structure by aerodynamic forces depends on vibration amplitude. The maximum supplied energy occurs approximately at the non-dimensional amplitude A = 0.15, and is equal to:

$$E_{supplied} = \frac{1}{2}\rho_s HU^3 \cdot 0.007$$

The ratio of supplied and dissipated energies is then:

$$\frac{E_{supplied}}{E_{dissipated}} = \frac{1}{2}\frac{\rho_s HU}{\rho S\zeta\omega A^2} \cdot (0.007)$$

which, using the values corresponding to the current support beam configuration and A=0.15, results in:

$$\frac{E_{supplied}}{E_{dissipated}} = 0.0036$$

Thus, the energy supplied to the system per cycle by aerodynamic forces is less than 1% of the energy dissipated, which implies that no galloping vibrations are possible. This result is in agreement with observations above. The reason why the supplied energy is lower in the second estimate is that drag is accounted for, whereas the first estimate conservatively set the drag to zero.

References

1. Dowell, E. H., Curtiss, Jr., H. C., Scanlan, R. H., Sisto, F., A Modern Course in Aeroelasticity, 3rd Edition, Kluwer Publishers, Dordrecht, 1995.
2. Den Hartog, J. P., Mechanical Vibrations, Dover, New York, 1985.
3. Carpena, A., Diana, G., Behavior to Wind Action of Angle and T bars on H.V. Lattice Structures, *IEEE Transactions on Power Apparatus and Systems*, Volume PAS-91, Issue 2, 1972, p. 536-544.

TVA plans to perform inspections of the steam dryers as described by BWRVIP-139, "BWR Vessel and Internals Project Steam Dryer Inspection and Flaw Evaluation Guidelines," which does not specify inspections of the support beams. The support beams are difficult to access for inspection as they are located on the bottom of the vane banks inside the lower support skirt. The credited welds on the support beams have SR-a > 2.0 at EPU conditions which provides margin to the stress limits.