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

May 7, 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.207 (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.

On April 22, 2009, NRC staff issued a Round 23 RAI (ML091000283) regarding the EPU license amendment request. The enclosure to this letter provides the response for Round 23 RAI EMCB.207. This RAI is associated with the steam dryer stress analyses performed for EPU.

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).

D030
NRR

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 7th day of May, 2009.

Sincerely,

James J Randich
FOR

R. G. West
Site Vice President

Enclosure:

Response to Round 23 Request for Additional Information (RAI) EMCB.207

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ENCLOSURE

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.207

NRC RAI EMCB.207 (Unit 1)

In Enclosure 1 to the letter dated April 3, 2009, TVA responded to EMCB 206. The response considers the possibility of galloping of the unattached portion of the beam to demonstrate that galloping is not a problem. Although the analysis approach used by TVA appears reasonable, the questions regarding the initial assumptions remain. It was expected that the response would address the worst case scenario, especially if the stitch weld of the beam is not to be included in the inspection program. This worst case scenario should consider that the stitch weld is inactive along the whole base plate of the innermost dryer vane bank and, therefore, the beam would be cantilevered on the base plate of the adjacent vane bank.

In this case, the length of the free end of the beam appears to be substantially longer than the 14.5 inches assumed in the galloping analysis and the frequency would be substantially lower. The relevant vibration mode and the relevant flow direction appear to be different from those assumed in the galloping analysis.

Provide an assessment of the worst case loose section length for galloping/flutter with more appropriate assumptions of the length of the unattached portion of the beam, the relevant vibration mode, and the relevant direction of the cross flow.

TVA Response to EMCB.207 (Unit 1)

Evaluations of the Unit 1 steam dryer support beams were discussed in Enclosure 1 of the submittal dated March 11, 2009, "Steam Dryer Analyses Additional Information," (ML090760630) and in the response to RAI EMCB.206 of the submittal dated April 3, 2009, "Response to Round 23 RAI EMCB.205 and EMCB.206," (ML091000291). Of concem is the portion of each support beam (T-beam) that is connected to the base plate of the inner plenum/vane bank. Approximately 24 inches of the end of each support beam is stitch welded on both sides to the inner base plate which is not in the direct steam flow path into the vane banks. Although only the nodes associated with the innermost weld sections exhibit an alternating stress ratio less than 2.0 at EPU conditions, the stress evaluation was conservatively performed by not taking credit for any welds for 14.5 inches from the end of the support beams. The stress evaluation for this case determined that the EPU alternating stress ratios for this portion of the support beam were well above 2.0. On this basis, the galloping evaluation was performed for the conservative case of a 14.5 inch free end. Since this portion of the support beam is located adjacent to and under the steel plate beneath the vane bank and inner plenum, it is not located in the flow stream. Thus the galloping evaluation assumed steam flow directed horizontally onto the 14.5 inch free end. The analysis showed galloping will not occur.

As requested, the galloping analysis was repeated assuming a free end long enough to span the actual flow stream and with the flow directed in the upward direction. This analysis also shows that galloping will not occur. This analysis follows.

Analysis

While 14.5 inches constitutes the worst case length, the galloping analysis is repeated here for a hypothetical configuration where a T-beam is completely disconnected from the inner base plate. Under this configuration the total length of detached beam is 39.75 inches, which is the sum of: (i) the inner base plate width (24 inches), or the total length of the T-beam / inner base plate stitch weld; plus, (ii) the width of the inner vane bank plenum (15.75 inches) for which no weld exists. The T-beam remains connected to the middle and outer base plates.

Aerodynamic loading is dominated by vertical flow of 15 feet per second (ft/sec) through the plenum. If the distance x is measured from the cantilever root towards the tip, where x = L = 39.75 inches, then the aerodynamic loading occurs over the range x = 0 to x = 15.75 inches. The equation governing beam vibrations is given by:

$$\rho S\frac{\partial^2 w}{\partial t^2}+D\frac{\partial w}{\partial t}+EI\frac{\partial^4 w}{\partial x^4}=f \qquad (1)$$

where w(x,t) is the lateral displacement, ρ is the density of steel (0.284 pounds per cubic inch (lbs/in^3)), S is the beam cross-sectional area (3.5 in^2), D represents 1% structural damping, E is the Young's modulus for 304SS steel at 550° Fahrenheit ($E = 25.55 \times 10^6$ pounds per square inch), I is the second moment of inertia of the beam about the vertical axis ($I = 1.17\ in^4$), and t and x are time and distance along the beam, respectively. Note that because the beam is now forced by flow in the vertical direction, the structural response will be in the horizontal plane, so that the second moment of inertia about the vertical axis is appropriate (the moment of inertia about the horizontal axis is higher and would be relevant to vertical vibrations). The flow-induced force per unit length is:

$$f=-\frac{1}{2}\rho_S U^2 W\left[\frac{dC_L}{d\alpha}+C_D\right]\frac{\dot{w}}{U}\lambda \qquad (2)$$

where ρ_s is the density of steam (2.24 lbs/ft^3), U is the vertical flow velocity (15 ft/sec), W is the width of the T-beam (3 inches), C_D is the drag coefficient (which is always positive and is here conservatively taken to be zero), and $dC_L/d\alpha$ is the lift curve slope, which must be negative in order for galloping to occur. The parameter λ(x) is equal to 1 over the part of the beam exposed to the flow (x = 0 to x = 15.75 inches) and zero elsewhere.

The cantilever is assumed to respond in the first mode. Denoting the associated mode shape by Φ(x) so that w(x,t) = y(t)Φ(x) where y(t) is the modal amplitude, then substituting for w(x,t), multiplying by Φ(x), and integrating over the length L gives:

$$\int_0^L\left(\ddot{y}\Phi^2+\frac{D}{\rho S}\dot{y}\Phi^2+\frac{EI}{\rho S}y\frac{\partial^4\Phi}{\partial x^4}\Phi\right)\ dx=\int_0^L\frac{f}{\rho S}\Phi\ dx \qquad (3)$$

Since the mode shape satisfies $d^4\Phi/dx^4 = \beta^4\Phi$, where $\beta^4 = \rho S\omega^2/EI$ and ω is the angular modal frequency, the preceding result reduces to:

$$\ddot{y} + 2\zeta\omega\dot{y} + \omega^2 y = -\frac{\rho_S UW}{2\rho S}\left(\frac{dC_L}{d\alpha} + C_D\right)\dot{y}\Lambda \tag{4}$$

where:

$$\Lambda = \left(\int_0^L \Phi^2 \lambda dx\right) \Big/ \left(\int_0^L \Phi^2 dx\right) \quad \text{and} \quad 2\zeta\omega = \frac{D}{\rho S} \tag{5}$$

Here ζ is the structural damping ratio (1%). This expression for y(t) is exactly the same as that given in the response to RAI EMCB.206 except for the appearance of the parameter Λ. In the response to RAI EMCB.206, $\Lambda = 1$ since the flow force acts along the entire beam. Here, the aerodynamic force only acts over the first 15.75 inches of the L = 39.75 inch beam, measured from the root. Using the analytical expression for the first mode shape of a cantilevered beam, $\Lambda = 0.0174$.

From Equation (4), it follows that galloping occurs if the net damping associated with the rate term $\dot{y}$ due to structural damping and flow-induced damping, $d = d_{sd} + d_{flow} < 0$ where:

$$d_{sd} = 2\zeta\omega \quad \text{and} \quad d_{flow} = \frac{\rho_S UW}{2\rho S}\left[\frac{dC_L}{d\alpha} + C_D\right]\Lambda \tag{6a, b}$$

The fundamental cantilever frequency is given by $\beta^4 = \rho S\omega^2/EI$ with $\beta L = 1.875$ or $f = \omega/2\pi = 38$ Hertz (Hz), so that:

$$\frac{d_{flow}}{d_{sd}} = \frac{\rho_s UW}{4\rho S\omega\zeta}\left[\frac{dC_L}{d\alpha} + C_D\right]\lambda = 0.0737\left[\frac{dC_L}{d\alpha} + C_D\right]\Lambda \tag{7}$$

Galloping can only occur if this ratio $d_{flow}/d_{sd} < -1$. To evaluate the last expression, conservatively set $C_D = 0$. Next, from Figure 3 of Reference 1, the most negative lift curve slope $dC_L/d\alpha$, where α is the angle of attack (nominally $\alpha = 0$), is conservatively estimated as:

$$\frac{dC_L}{d\alpha} = \frac{dC_L}{d(\tan\alpha)}\frac{d(\tan\alpha)}{d\alpha} \cong \left(\frac{-0.3}{0.2}\right)\left(\frac{1}{\cos^2\alpha}\right)_{\alpha=0} = -1.5 \tag{8}$$

For added conservatism a working value of -3.0 (twice the estimate) is used to produce:

$$\frac{d_{flow}}{d_{sd}} = -0.221\Lambda \tag{9}$$

which implies that even for $\Lambda = 1$, which would occur if the entire 39.75 inch beam were exposed to the vertical flow, $d_{flow}/d_{sd} > -1$ and the flow would provide only 22.1% of the forcing needed to overcome structural damping and induce galloping. Using the more appropriate value of $\Lambda = 0.0174$ derived above when only a part of the beam is subjected to flow forcing, it may be seen that the flow provides less than 0.4% of the forcing needed to overcome structural damping. As a result, galloping is not a concern for this configuration and typical flow speeds $U \approx 15$ ft/sec.

Vortex Shedding

The galloping phenomenon described above is caused by the negative damping introduced by hydrodynamics, specifically by the negative lift coefficient slope $dC_L/d\alpha$. Another phenomenon known as vortex shedding can also produce instabilities. In this case the formation of a vortex street downstream of a bluff body structure induces fluctuating loads back onto the structure. These shedding frequencies are given by $f = 0.2(U/W)$, where U is the velocity and W is the characteristic cross-section dimension. Using U = 15 ft/sec and W = 3 inches, one deduces a shedding frequency of 12 Hz, which is well below the fundamental frequency (38 Hz) of the cantilever beam. Given this disparity in frequencies, no vortex shedding induced oscillations will occur.

Conclusions

The assumed T-beam disconnection length of 14.5 inches is shown to be conservative, since stress analysis using this disconnection length produces stresses that are significantly lower than the allowable levels. Moreover, any propagation of putative cracks near the T-beam tip is prevented because a stitch weld rather than continuous weld joins the T-beam to the base plates.

In response to the RAI, analysis of the T-beam for galloping is performed under the hypothetical scenario where it is completely disconnected from the inner base plate. Again, with conservative assumptions regarding the hydrodynamic behavior, the beam is determined to be immune to galloping; the flow provides only 0.4% of the forcing needed to overcome structural damping. Even if the entire length of the disconnected T-beam were subjected to the vertical flow ($\Lambda = 1$), the aerodynamic forcing would be insufficient to produce galloping.

In summary, even for extremely conservative hypothetical scenarios, no galloping of the T-beam occurs.

References

1. Carpena, A. & Diana, G., (1972) *IEEE Transactions on Power Apparatus and Systems* PAS-91, 536-544.