UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

Enclosure 1

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BROWNS FERRY NUCLEAR PLANT, UNITS 1, 2, AND 3

DOCKET NOS. 50-259, 50-260, AND 50-296

SEISMIC DESIGN CRITERIA FOR HVAC DUCTS AND THEIR SUPPORTS

1.0 BACKGROUND

During the initial plant construction (1967-70), the Heating, Ventilation and Air Conditioning (HVAC) ducts at the Browns Ferry Nuclear Plant (BFN) were fabricated to industry standards without consideration of seismic loads. In late 1970, the licensee (i.e., Tennessee Valley Authority (TVA)) developed a set of seismic design criteria that were used to modify existing HVAC ducts and associated supports. Later on, in 1978, TVA embarked on an extensive testing program to demonstrate that ducts constructed in accordance with the standards of Sheet Metal and Air Conditioning Contractors National Association (SMACNA), if properly supported, possessed adequate capability to withstand the most demanding seismic loads (relevant to TVA's plants), including those postulated for BFN (Reference 1). A number of provisions of the subject design criteria were based on the results from this testing.

In January 1986, a significant condition report (SCR) was written questioning the adequacy of HVAC support installation and TVA's qualification design criteria BFN 50-721. In addition, field investigations performed by TVA identified discrepancies between the installed HVAC system configuration and the design criteria requirements. As a result of the SCR and subsequent investigations, TVA initiated a seismic qualification program to ensure that existing ducts and associated supports were able to withstand postulated seismic loads. At that time, the design criteria of BFN-50-C-7104, Rev. 1, were the controlling criteria for checking the adequacy of HVAC ducts and their supports. However, TVA also developed interim operability criteria (i.e., BFN-50-C-7304) to support restart of BFN, Unit 2. In NRC Inspection Report (IR) 50-260/89-29, the staff accepted TVA's use of either criteria for the purpose of returning BFN, Unit 2 to service.

In addition, TVA performed an impact assessment to confirm that the duct systems qualified using the El Centro earthquake time history could also be qualified by using an artificial time-history that would closely fit the plant's design response spectrum. The results of this assessment were previously reviewed and accepted by the staff (Reference 2).

In Section 2.2.2.4 of the NRC's final safety evaluation report (SER) on restart of BFN, Unit 2 dated January 1991 (Reference 3), the staff identified the following post-restart open items related to the design and installation of HVAC ducts and supports:

"(1) TVA should evaluate and identify the need for long-term modification of the approximate 11,830 feet of ductwork that met the interim criteria (IR 50-260/88-38).

(2) TVA should perform the long-term modification of the 509 existing supports that were qualified to the interim criteria (IR 50-260/88-38).

(3) TVA should develop long-term criteria for HVAC evaluation and perform long-term buckling evaluation of all ductwork qualified to the interim criteria (IR 50-260/89-42)."

TVA subsequently submitted Section 1 of BFN-50-C-7104, Revision 6 entitled, "Class I Seismic HVAC Duct and Duct Support Design," as Enclosure 3 to a letter dated November 15, 1991 (Reference 4). In this letter, TVA addressed the aforementioned post-restart open items. The long-term modifications identified in items (1) and (2) will be performed by TVA after the staff reviews and approves of the proposed design criteria submitted for item (3). Since the November 15, 1991 letter, TVA submitted several supplemental letters dated March 2, May 6, and June 18, 1992 (References 5, 6, and 7), in response to staff requests for additional information and recommended changes. In addition to a detailed evaluation of TVA's original and supplemental submittals, the staff examined applicable supporting documentation (e.g., Reference 1) and conducted an onsite audit of selected HVAC design calculations, including walkdowns of relevant HVAC sections.

2.0 EVALUATION

1. Seismic Analysis Criteria

Seismic input for the analysis of HVAC ducts and their supports will be in accordance with the criteria established by the staff in Reference 2 and in the Final Safety Analysis Report (FSAR). Damping and stiffness criteria to be used in the seismic analysis have been developed by TVA from the testing performed in 1979 (Reference 1). The basic test criteria and the relevant test results are discussed in the following paragraphs:

The objective of the tests was to demonstrate that the rectangular HVAC ducts designed and fabricated in accordance with the SMACNA standards could withstand the vibratory motion associated with the largest required response spectrum (RRS) that could be developed by the postulated Safe Shutdown Earthquake (SSE) at any of the TVA's nuclear power plants. The RRS peak acceleration was 6.4g between the frequencies of 8.5 Hz. and 11 Hz. The zero period acceleration at 33 Hz. was 1.5g. The staff has not verified the adequacy of the RRS for other TVA plants. However, the staff finds the RRS acceptable for BFN.

Twelve duct specimens were procured which had been constructed in accordance with the SMACNA standards; six of them were fabricated using companion angle (CA) construction, and six of them using pocket lock (PL) construction. Three commonly used sizes and span lengths (i.e., 18"x 48"x 28 ft., 24"x 36"x 24 ft. and 24"x 60"x 32 ft.) were used for each type of construction.

Initially, each specimen was subjected to sinusoidal sweep and decay tests to determine the resonance characteristics and damping of the duct-support systems.

Each specimen was oriented horizontally with either the major or minor axis parallel to the test table. Each specimen was then subjected to random vibration test of 30 sec. duration with a vertical input motion over the frequency range of 1 Hz. and 40 Hz. The amplitude of each one-third octave frequency was independently adjusted until the resulting test response spectrum (TRS) enveloped the RRS. Both types of ducts (CA and PL) withstood the TRS without visible damage. At higher levels of seismic input (i.e., TRS having peak acceleration of 10.2g), the ducts with pocket lock construction started showing signs of appreciable damage but were observed to be delivering air without excessive leakages.

As a result of the seismic testing, TVA determined that actual duct-span frequencies were lower than the ones calculated using the ideal beam equation, and that they differ for CA and PL ducts. To account for this behavior, TVA developed frequency correction factors as 0.59 for PL ducts and 0.87 for CA ducts. The effective bending moment of inertia to be used for stiffness calculations were obtained by multiplying the appropriate HVAC section moment of inertia with the square of the correction factors. The staff finds this provision of the design criteria acceptable.

A second parameter that TVA developed from the test results was damping. The staff review of the test data indicated that the damping coefficient for the CA ducts varied from 0.043 to 0.079, and that for the PL ducts, it varied from 0.072 to 0.108. Based on this data, TVA proposed to use 7 percent damping for seismic analysis of all rectangular ducts. Initially, the staff was reluctant to accept the proposed damping for CA ducts. However, further review by the staff indicated that the acceleration level (in sinusoidal decay tests) accompanying the lower damping in CA ducts was 0.1g, and that accompanying higher damping was 0.25g. Thus, considering the SSE acceleration levels to be more in line with 0.25g, the staff finds the proposed damping value of 7 percent for all HVAC rectangular ducts to be acceptable. The damping value proposed for welded rectangular ducts and round ducts was 2 percent, and that for schedule pipe ducts was 1 percent. These values are higher than 1/2 percent damping approved for piping (Reference 3), and lower than those in Regulatory Guide 1.61 for large diameter piping. However, considering the thin-walled sections of the HVAC ducts and the results of the tests for rectangular ducts, the staff believes that the proposed damping values are reasonable, and finds them acceptable.

The proposed criteria also states that when the modal analysis method is used for an HVAC system, the contribution of rigid modes (frequency>20 Hz.) will be incorporated by using the zero period acceleration value for the pertinent floor. During an audit of the calculations, the staff verified that TVA's computer code used for the analysis of HVAC systems accounted for the "missing mass" by attributing it to the high frequency (i.e., >20 Hz.) responses. These modal responses were then combined by using the square root of the sum

of the square method. The staff found this approach acceptable. For a non-rigid duct system analyzed using the equivalent static load method, TVA proposed to use a multimode factor of 1.5 for the pertinent response spectra accelerations. The staff considers this approach acceptable.

TVA proposed to evaluate the HVAC ducts and their supports for the postulated Design Basis Earthquake (DBE=SSE), but not for the postulated Operating Basis Earthquake (OBE). In response to the staff's question on this issue, TVA stated that the allowable stresses used for HVAC ducts and their supports for the DBE loading were approximately 1.4 to 1.6 times those allowed for OBE loading and the DBE responses were close to twice the OBE responses; therefore, the OBE load will not control the design of the ducts. Thus, an evaluation against OBE was not needed. For the purposes of reevaluation, the staff considers TVA's proposal acceptable.

To account for the three components of the postulated earthquake (i.e., SSE), TVA proposed to use the following approach: Two sets of resultant seismic responses are generated; namely, xy set and zy set, where x and z represent the responses in the two horizontal directions, and y represents the response in the vertical direction. A set is formed by the "absolute sum" combination of the directional component responses. The controlling seismic responses are determined by taking the greater of the two sets of responses. This approach is more conservative than the Square Root of the Sum of the Squares (SRSS) method of combining the two directional responses (as committed to in the FSAR), and is acceptable.

2. <u>Design Evaluation Criteria for Existing and New HVAC Ducts</u>

The Design Criteria describes the duct material properties and method of computing effective moment of inertia for rectangular and round duct sections. These methods were in accordance with standard industry practice and are acceptable.

Initially, TVA did not provide for checking the ducts under normal operating conditions, including any negative pressure. However, as a result of discussions with the staff, TVA committed to evaluate the ducts for normal operating conditions using allowable bending stresses of 8,000 psi, and 10,000 psi, for rectangular and round ducts, respectively.

The Design Criteria specifies that duct stress shall not exceed 90 percent of the critical buckling stress in compression under the dead load and DBE load. The 90 percent value was substantiated by TVA's empirical tests for both types of ducts (CA & PL). These tests demonstrated that the ducts had considerable capability of sustaining high dynamic loads without adverse local buckling effects. In addition, TVA demonstrated the buckling capacity analytically by performing a buckling evaluation of 22 representative rectangular duct sections for the effects of vacuum pressure, axial compression, bi-axial bending, and torsion. The evaluation criterion was based on the AISI Specification for the Design of Cold Formed Steel Structural Members and was documented in TVA design calculation B22 891107 194. The staff reviewed sample calculations of the 22 enveloping cases. Based on the staff's review, TVA's proposed approach for performing buckling evaluation is acceptable.

In Section 1.6 of the design criteria, TVA made an ambiguous statement regarding the consideration of loads due to wind and tornado when the ductwork is located outside Seismic Category I structures. In response to the staff's question on this issue, TVA stated that all the existing ductwork at BFN was located inside Seismic Category 1 buildings. However, TVA did acknowledge that in the future, if ductwork was to be located outside Seismic Category I structures it may be necessary to consider wind and tornado loadings. The staff asserts that for Class I HVAC ductwork outside of Seismic Category I structures, consideration of wind and tornado loadings would be necessary and recommends that TVA revise its HVAC design criteria accordingly.

In order to assess the ability of HVAC ducts to resist shear force induced by DBE loading, TVA proposed to make use of a formula based on prior testing (Reference 1). The basic premise of this formula was that the maximum shearing force is induced by the peak acceleration of the RRS between the frequencies of 8.5 Hz. and 11 Hz. (i.e., 6.4 g). However, the frequency used in the derivation of the formula was 33 hz. The use of a higher frequency (though inconsistent) did result in a lower value for the allowable shear. Also, upon the staff's request, TVA demonstrated that tested ducts resisted about 10.2g when tested to levels higher than the RRS level. The minimum safety factor against duct failure, when the proposed formula is used, was estimated by the staff to be 2.8. Thus, TVA's formula to calculate allowable shear force is acceptable.

Other calculational procedures described in the design criteria were in accordance with standard engineering practice and are acceptable.

3. Design Evaluation Criteria for HVAC Duct Supports

For the evaluation of the existing duct supports and for designing the new supports, TVA proposed to use the following acceptance criteria:

Support Members

Tension & Bending	- 1.5xAISC (ASD)
Compression	- 1.5xAISC (ASD)
Shear	- 0.9 $Fy/\sqrt{3}$
Bolt stresses in tension	- 1.5xAISC (ASD)
Bolt stresses in shear	- 1.4xAISC (ASD)
Weld stresses	- 1.5xAISC (ASD)

ASD - Allowable Stress Design

These allowables are in accordance with (or more conservative than) standard industry practice and are acceptable.

4. Design Evaluation of Anchorages

TVA committed to examine anchorages of HVAC duct supports in accordance with the guidelines of Appendix C to the Generic Implementation Procedure (GIP) developed by the Seismic Qualification Utility Group (SQUG). The staff's

supplemental safety evaluation report (SSER) of Revision 2 of the SQUG GIP was enclosed in Supplement 1 to Generic Letter 87-02 issued May 22, 1992. TVA's use of Appendix C, in concert with the staff's SSER, is acceptable for the evaluation of HVAC duct support anchorages.

5. Other Considerations

TVA's HVAC seismic design criteria addresses conditions that require special consideration such as, effects of cut-outs for grill openings, differential seismic movement for duct systems passing through different buildings, welded heavy gauge ductwork, et cetera. The staff finds these conditions to be adequately described, and the proposed special considerations for these conditions are acceptable.

6. NRC Audit and Walkdowns

Since some of the existing duct systems had already been evaluated by TVA using their proposed seismic design criteria, the staff conducted an onsite audit of selected HVAC design calculations from February 4-6, 1992. These calculations were substantiated by system walkdowns of the accessible areas of relevant ductwork segments and supports. The staff verified for a few selected HVAC sections that the as-built configurations matched the computer model configurations used in the analysis and in the controlled drawings.

3.0 CONCLUSION

Based upon a detailed evaluation of TVA's submittals and supporting documentation, and the staff's on-site audit of selected HVAC design calculations (including walkdowns of applicable HVAC sections installed in the plant), the staff concludes that TVA's proposed HVAC seismic design criteria are acceptable.

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References:

1. "Test Report on Seismic Qualification/Verification of HVAC Ducts," TVA CEB-79-7, June 1979.

2. NUREG-1232, Vol. 3, Supp. 1, "Safety Evaluation Report on Tennessee Valley Authority: Browns Ferry Nuclear Performance Plan," October 1989.

3. NUREG-1232, Vol. 3, Supp. 2, "Safety Evaluation Report on Tennessee Valley Authority: Browns Ferry Nuclear Performance Plan," January 1991.

4. Section 1.0, TVA's General Design Criteria BFN-50-C-7104, "Class I Seismic HVAC Ducts and Ducts Support Design," Revision 6, July 1, 1987, as submitted by letter from TVA to NRC dated November 15, 1991.

5. Letter from TVA to NRC, "Response To NRC Questions," dated March 2, 1992.

6. Letter from TVA to NRC, "Response To Request For Additional Information," dated May 6, 1992.

7. Letter from TVA to NRC, "Response To Request For Additional Information," dated June 18, 1992.