UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

OF RESPONSES BY THE DETROIT EDISON COMPANY TO NRC CONCERNS

REGARDING THE STRUCTURAL QUALIFICATION

OF THE CONTROL CENTER HEATING,

VENTILATION AND AIR CONDITIONING SYSTEM AT FERMI 2

1.0 BACKGROUND

By memorandum dated May 29, 1991 (Ref. 1), Region III requested NRR's technical assistance with the resolution of certain issues regarding the structural integrity of the Control Center Heating, Ventilation, and Air Conditioning (CCHVAC) at Fermi 2. Concerns regarding inadequate ductwork design were initially identified by the senior resident inspector at Fermi 2 in April 1989, which resulted in a Notice of Violation (50-341/89-011-02B(DRP)). The Detroit Edison Company (DECo) responded to these concerns in a response to the Notice of Violation, dated November 29, 1989 (Ref. 1a), and supported this response with design calculations (Refs. 8, 18a, and 22). A detailed review of these calculations identified additional concerns, which were summarized in the enclosure to the memorandum (Ref. 2).

Reference 2 stated that the ductwork at Fermi 2 was initially designed to plus or minus 6 inches water gage (WG) internal pressure. The licensing basis design/construction specification of the ductwork at Fermi 2 was based on the national HVAC construction standard published by the Sheet Metal and Air Conditioning National Contractors Association (SMACNA, Ref. 3).

The habitability of the control room is governed by the provisions of Regulatory Guide (RG) 1.52 (Ref. 4) for engineered safety features. This RG also specifies ANSI/ASME N509-1976 (Ref. 5) as the standard for the design, construction, and testing of HVAC ducting systems. DECo stated in the Final Safety Analysis Report (FSAR) that the control center filtration system ductwork component design criteria are not in conformance with Position C.3.n of RG 1.52, which states in part that the design of HVAC ductwork should conform with Section 5.10 of ANSI/ASME N509-1976. In a letter dated January 8, 1985 (Ref. 6), DECo submitted additional information clarifying its position on RG 1.52, and stated that the applicable criteria for control center filtration system design at Fermi 2 are those of Section 2.8 of standard ORNL-NSIC-65 (Ref. 7) and not those of Section 5.10 of ANSI/ASME N-509-1976. This exception to RG 1.52 was accepted by the staff in Supplement 5 (March 1985) to the Fermi 2 Safety Evaluation Report (SER, NUREG-0798).

Toward the end of the construction process, a recirculation train, including recirculation fans, was added to the CCHVAC system. The addition of these fans increased the maximum internal negative pressure on the additional ductwork and some of the existing ductwork from -6 inches WG to -22 inches WG.

Based on SMACNA requirements, the existing ductwork was fabricated from 18-inch gage sheet metal (0.0478-inch bare metal thickness). This is valid for ductwork with internal pressure in the range plus or minus 6 inches WG. For the additional ductwork, Section 2.8.1 of ORNL-NSIC-65 specifies 16-inch gage sheet metal (0.0598-inch bare thickness) as appropriate for rectangular ductwork experiencing a negative internal pressure of -22 inches WG. However, the DECo design/construction specification was not changed to reflect this pressure change, so that the additional ductwork was fabricated with the same gage wall thickness as the existing ductwork. Section 2.8.1 of ORNL-NSIC-65 also specifies that ductwork must be proof tested under negative pressure to at least 1.5 times the maximum fan static pressure for a period of at least 12 hours. The ductwork at Fermi 2 was tested only to plus or minus 8 inches WG, and not to -33 inches WG. Therefore, in this respect, Fermi 2 did not conform to its commitment in the FSAR.

The CCHVAC is classified in the FSAR as Seismic Category I. No information was provided in the FSAR regarding the methodology used for seismically qualifying the CCHVAC ductwork. There are no requirements or criteria for seismic qualification of ductwork in ORNL-NSIC-65. In addition, the seismic qualification did not consider the combined effect of the newly determined high negative internal pressure.

In its response to Section 89-011-02B of the Notice of Violation, DECo submitted calculation report DC-5089 (Ref. 8), in support of the seismic qualification of the CCHVAC under the worst load combination which included dead weight (DW), the safe-shutdown earthquake (SSE), and the maximum expected negative pressure (-22 inches WG). The qualification was based on the criteria stated in Section 5.10 of ANSI/ASME N509-1980 (Ref. 9). The acceptable standard under RG 1.52 is ANSI/ASME N509-1976. However, in Enclosure B to the letter dated January 8, 1985, titled "Clarification of FSAR Commitment" (Ref. 6), DECo stated that Appendix A of the FSAR took exception to the requirement in RG 1.52 that ductwork be designed, constructed, and tested in accordance with provisions of Section 5.10 of ANSI/ASME N509-1976, and instead committed to Section 2.8 of ORNL-NSIC-65. Subsequently, DECo submitted Revision 3 of March 1990 to Appendix A of the Updated FSAR (UFSAR), in which it changed this commitment, and stated that the ductwork conforms to the intent of ANSI/ASME N509-1980 for all areas of duct construction and testing. DECo interpreted this intent as permitting local yielding at the rectangular duct corners under the worst loading combination. The staff disagrees with this interpretation. DECo also interpreted the intent of ANSI/ASME N509-1980 as permitting brazing of the longitudinal mechanical lock type seams, combined with internal sealant. The staff also disagrees with this interpretation. Furthermore, the mechanical lock seams in Fermi 2 ductwork were not brazed but braze welded. ANSI/ASME N509-1980 does not reference brazing or braze welding as a means of ensuring the leak tightness of mechanical lock seams.

In Reference 10, the NRC provided a safety evaluation of the Calculation Report DC 5089. The calculations in DC 5089 were performed by DECo consultants, Hopper and Associates (H&A), and consisted of two attachments to the report: Calculation Document HA-09/89-686 (Ref. 18a) and Calculation Document HA-09/89-696 (Ref. 22). Calculation Document HA-09/89-686 provided the reevaluation of ductwork systems 2848-3, 4316-1, 4316-6 and 4316-7, which were considered as flexible. This required a reanalysis of these systems. Calculation Document HA-09/89-696 provided the reevaluation of 55 ductwork systems considered as rigid, based on results available from existing calculations. Calculation Report DC 5089 as well as the two attachments were provided as enclosures to Reference 2. In the Safety Evaluation, the staff concluded that DECo had not adequately demonstrated the structural integrity or the leak tightness of the CCHVAC under maximum negative pressure combined with SSE conditions. In Reference 11, DECo responded to the issues stated in the safety evaluation by identifying 19 "NRC Concerns." DECo addressed each concern separately in Attachment 1, and attached extensive supporting calculations performed by H&A.

2.0 EVALUATION

The staff has reviewed the responses by DECo and the attachments by H&A to the identified NRC concerns (Ref. 11) and has performed a separate evaluation of each response and the corresponding attachment, as discussed below.

2.1 NRC Concern No. 1:

The analyses were not based on as-built configurations.

Evaluation:

A walk-down was performed by DECo and minor discrepancies were found. The duct systems were reevaluated without impact on the results of the evaluation. The staff finds this acceptable, and considers this concern resolved.

2.2 NRC Concern No. 2:

The seismic analysis of the ducts used full-section properties (cross-sectional moment of inertia and area) rather than section properties based on the "effective" width of the compressive flange. The effect of using full-section properties is to underestimate the stresses and deflections resulting from seismic loading.

Evaluation:

In Attachment 2, H&A responded by calculating the "effective flange width" of a plate of a square duct and assumed that only one plate experiences compression. On this basis, H&A then determined the cross-sectional moment of inertia and recalculated the stresses under seismic loading. Based on these calculations H&A concluded that the resulting changes in stresses and deflections are negligible.

The staff has reviewed H&A's response and has concluded that the H&A response is deficient. This topic has been addressed in the open literature, as shown, for example, in References 12, 13, and 14. The procedure shown in the response is strictly valid for beam bending under static loading only, provided the capacity of the webs is adequate to support their share of the bending loads. Under general biaxial bending loads the concept of "effective width" is considered applicable to all panels comprising the duct cross-section (e.g., Refs. 13 and 14). An additional consideration is that duct panels as fabricated and installed are slightly buckled, but the corners are fabricated straight. Thus, the loading is taken mostly by the corners (Refs. 15 and 16) even at loads causing stresses below the critical stresses. H&A has performed a reevaluation with a cross-section based on one effective flange and showed that there is a minimal change in the internal moments and stresses. On this basis, H&A concluded that analyses with full sections was adequate. The staff concludes that the internal moments and stresses calculated on this basis may be substantially underestimated, and that the original concern has not been properly addressed. This concern is therefore considered unresolved.

2.3 NRC Concern No. 3:

The section properties and the stresses were calculated based on the thickness of the galvanized sheet metal. These should be based on the thickness of the bare metal.

Evaluation:

DECo stated that the use of the bare metal thickness is considered a significant analytical conservatism. The bare metal is 8% thinner than the galvanized metal. However, the requirement to use the base metal thickness is specifically stated in standards such as Reference 18, which is based on the fact that the coatings have no strength capability. It is therefore not an analytical conservatism, as stated by DECo.

In Attachment 3, H&A provided an extensive response to this concern, including the results of the reevaluation of systems 4316-1, 4316-6 and 4316-7, under combined DW, -22 inches WG negative internal pressure (P), and SSE (7% damping), using the bare sheet metal thickness. These systems had previously been evaluated in H&A calculation package HA-05/89-686 (Ref. 18a), using galvanized sheet metal thickness and the same load combination, except that the seismic analysis was based on 2% damping SSE. No basis was given for adopting 7% damping. The intent was to show that using the bare sheet metal thickness introduces no significant differences in the stress results. However, a direct comparison can be made only for system 4316-1, which was reevaluated with 2% damping.

The staff has reviewed the response to this concern and has identified the following deficiencies:

- The response to this concern includes detailed calculations and computer input and output of the seismic analysis of system 4316-1. The input shows a 7% vertical velocity response spectrum input. The output labeled "calculated load case = 3 inches" shows motion only in the horizontal plane, and only internal bending moments about vertical axes, indicating that this load case apparently calculated only the response to the horizontal spectra input. However, the maximum internal moment from this load case was used to calculate the maximum stress due to 7% damping SSE loading for this system. The table of forces and moments at the critical location of duct system 4316-1 also shows no horizontal or torsional moments. The exclusion of the vertical response underestimates the maximum moments in the system, and the maximum stress is also underestimated. No justification for this has been presented.

- The response of system 4316-1 (frequencies, internal beam bending moments and forces) under SSE loading was calculated using the nominal cross-sectional properties of the ducts based on the bare metal thickness. The nominal compressive stress in a panel was found to exceed the corresponding critical stresses. This requires that the response of the duct system be determined using cross-sectional properties based on the concept of effective width, where appropriate, thus increasing the flexibility of the system. This step was not performed, and the internal moments may thus be underestimated.

- The stresses in the ducts due to negative internal pressure were evaluated using elastic large deflection plate theory. Two sets of calculations were performed, depending on whether the boundary conditions for the duct panels were assumed as fixed or simply supported. For fixed conditions, the stresses were determined from the theory in Reference 23. For simply supported conditions, the stresses were determined based on an approach shown in Reference 23a. The staff has not reviewed nor evaluated this reference. The staff considers fixed boundary conditions as the appropriate conditions for determining the elastic stresses in the panels under pressure, as discussed later in this section.

- The equations used by H&A to calculate the effective panel width on page 15 of Attachment 3, and the maximum longitudinal panel stress on page 32 of the same reference, both include the product of the elastic critical stress and the nominal width of the panel. There is no basis for the inclusion of this product.

- In the calculation of the safety margins H&A based the allowable stresses on the yield stress for structural steel ASTM A36. The yield stress for this material is 36 ksi. The duct metal is stated as galvanized sheet metal ASTM A-526/527. The minimum yield stress for this material is 33 ksi (Ref. 19). The allowable stresses are thus overestimated by 9%. The use of the ASTM A36 yield stress for safety calculations of HVAC ducts fabricated with ASTM A-526/527 is not acceptable.

- The maximum stress resulting from DW+P+SSE was determined to exceed the allowable stress from ANSI/ASME N509-1980. However, the exceedance may be greater than stated, since the maximum seismic stress, which depends on the maximum bending moments calculated based on nominal cross-sections, may be underestimated.

- Thin wall panels subjected to axial compression experience transverse stresses associated with finite panel deflections (Ref. 20, page 415). These stresses may not be negligible and will contribute to the combined stresses in the panels. The effect of these stresses has not been considered in the response to this concern, or in the response to Concern No. 13.

- H&A has stated that the effect of the exceedance of the allowable stress for membrane plus bending will result in localized yielding and plastic buckling of the corners, and that this is acceptable as long as the membrane stresses remain below the allowable stress. ANSI/ASME N509-1980 does not classify stresses into membrane and bending, and has no specific criteria for membrane stresses. The stated allowable stresses are applicable only to the maximum stresses, which are based on combined membrane plus bending stresses. ANSI/ASME N509-1980 also has no provision for localized yielding and plastic buckling. The staff position is that it is not the intent of ANSI/ASME N509-1980 to permit localized yielding and plastic buckling.

- H&A has also discussed the boundary conditions of the panels associated with the calculation of the membrane and bending stresses due to pressure loading. H&A has concluded that the actual boundary conditions are somewhere between fixed edge and simply supported edge conditions, and therefore the panel stresses are overestimated. However, the rectangular ducts at Fermi 2 are fabricated with formed and welded mechanica. lock seams and are subjected to simultaneous uniform pressure on all four panels. There is no basis for representing the joints between adjacent panels by other than fixed edge conditions. On this basis, and on experimental and analytical work shown in Reference 21 and other references, the staff concludes that the proper boundary conditions to be invoked are indeed fixed edge conditions, and therefore these boundary conditions form the correct basis for the calculation of the stresses in the duct panels under pressure.

- H&A stated in the conclusion that localized buckling and yielding occur at some locations in systems 4316-1, 4316-6, 4316-7, but the primary stresses meet the allowable stress in ANSI/ASME N509-1980 under DW+P+SSE. Section 5.10.3.3 of ANSI/ASME N509-1980 does not define primary stress. In addition, there exists no statement in ANSI/ASME N509-1980 regarding allowable localized buckling and yielding, which implies exceedance of the yield stress.

A comparison of the 2% SSE results for system 4316-1 with the parallel results in HA-05/89-686 shows that the effect of using the bare sheet metal thickness instead of the galvanized sheet metal thickness is to increase the maximum stress by 13%. No such comparisons are possible for systems 4316-6 and 4316-7, since these were evaluated with 7% damping, instead of 2% damping. It is also not clear that H&A used the bare metal thickness to reevaluate all other duct calculations. This concern is therefore considered unresolved.

2.4 <u>NRC Concern No. 4</u>:

In all analyses, the beam bending stresses were based on one significant moment.

<u>Evaluation</u>:

A review of the computer output attached to the H&A response to Concern No. 3 indicates that the response of the duct system to seismic loading appears to be almost entirely in a horizontal plane, even though this loading is three-dimensional. It does not appear to be reasonable that the vertical response should be close to zero under vertical seismic loading. This concern is therefore considered unresolved.

2.5 NRC Concern No. 5:

There is no discussion of potential stress intensification or local deformation effects at "tee" and "wye" type connections, elbows, other fittings and rectangular-to-round transitions.

Evaluation:

DECo stated that the stresses at "tee" type connections, elbows, "wye" fittings, and rectangular-to-round transitions are secondary and that peak stresses that may cause local yielding, which is permitted for the SSE loading, were not analyzed. DECo has not provided the basis for the classification of the stresses in these components as secondary, or for the statement that local yielding is permitted for SSE loading. ANSI/ASME N509-1980 does not classify stresses into primary, secondary and peak, and has no provision for permitting local yielding. In addition, paragraph 5.10.3.3 of ANSI/ASME N509-1980, states that the allowable stress for combined loads which include the SSE shall be 0.9 of the yield stress. By analogy with piping, HVAC duct fittings may experience additional flexibility and intensification of the stresses, similar to pipe fittings. Section 2.8.1 of ORNL-NSIC-65 also recommends that sheet metal thicknesses of elbows and transitions should be one or two gage numbers thicker than straight runs, in recognition of the potential for higher stresses in these components. This concern is therefore considered unresolved.

2.6 NRC Concern No. 6:

The critical stresses and moments for plates in bending (representing the webs) did not consider the interaction with transverse compressive loading. These critical values may therefore be overestimated.

Evaluation:

H&A stated that "if it was found that if the axial compression of the flanges was large enough to cause buckling, the web panels were conservatively assumed to be ineffective in carrying any load." The staff finds this condition acceptable and considers this concern resolved.

2.7 NRC Concern No. 7:

The calculation of the edge membrane and bending stresses in panels did not include the seismic inertia loads acting on the panels.

Evaluation:

In Attachment 6, H&A demonstrated the procedure for calculating the inertia loads on duct panels, for two different size panels, and concluded that seismic inertia loads do not contribute significantly to the loading on the panels. The staff has reviewed the H&A response and finds that the procedure appears reasonable. This concern is considered resolved.

2.8 NRC Concern No. 8:

No discussion of the seismic qualification of the filter housings, and of the supports or the attachments to the buildings was presented.

Evaluation:

DECo stated that the filter housings and the supports are outside the scope of its evaluation, but that they were designed to the requirements of ORNL-NSIC-65. A seismic analysis was performed to demonstrate that the stresses meet the American Institute of Steel Construction (AISC) specifications. The supports were seismically qualified by DECo, and the resultant stresses were stated as being within the AISC allowables. The staff has not verified these statements, but considers them reasonable and acceptable. This concern is considered resolved.

2.9 NRC Concern No. 9:

The correctness of the vertical spectral value input in the dynamic analysis is uncertain.

Evaluation:

DECo does not appear to have understood the concern. The vertical spectra in Figures 1 and 2 of Attachment 7 are shown approaching a constant value as the frequency approaches zero. Conversely, the curves do not appear to approach a zero period acceleration (ZPA) with increasing frequency. This is contrary to the shapes of the N-S and E-W spectra. The cut-off frequency for modal response spectrum analysis with vertical spectra is therefore considerably greater than the highest frequency shown on the diagram (50 Hz). This concern is therefore unresolved.

2.10 NRC Concern No. 10:

The analysis states that there will be localized yielding under SSE loading, but that the primary membrane stress will not exceed the allowable stress (0.9Sy). In view of the above, this assertion cannot be verified.

Evaluation:

DECo has interpreted the "above" in the concern as referring to the uncertainty in the vertical spectra. The "above" in the SER referred to all concerns listed prior to this one. The subject of this concern was addressed in the evaluation of Concern No. 3. This concern is therefore considered closed.

2.11 NRC Concern No. 11:

The structural integrity and air-tightness of the brazed joints in the longitudinal corners and middle seams was not evaluated.

Evaluation:

DECo evaluated this concern together with Concern No. 13. This concern is therefore considered closed.

2.12 NRC Concern No. 12:

The structural integrity and air tightness of the transverse joints was not evaluated.

Evaluation:

In Attachment 8, H&A submitted extensive calculations which demonstrated the structural integrity and air-tightness of the transverse joints in duct systems 2848-3, 4316-1, 4316-6, 4316-7. These systems were previously evaluated in HA-05/89-686. The staff has reviewed the methodology and has concluded that it appears to be reasonable and in accordance with standard practice. However, the staff has also identified the following deficiencies:

- The flanges and stiffeners are stated as fabricated from A575 M1020 (Merchant Quality) carbon steel. This material is not specified as an acceptable material in Section 5.10.6 of ANSI/ASME N509-1980, and is therefore a deviation from this code.

- In Calculation DECo 5089, DECo stated that the stiffener material is the same as the duct galvanized steel. This appears to contradict the stated material in this response. This identified contradiction should be resolved.

- H&A has based the allowable stresses of A527 and A575 M1020 on the yield stress of A36. The allowable stresses should have been based on the yield strength of A527 (33 ksi) and the yield strength of A575 (M1020) (32 ksi, per ASTM A519). H&A also specified the ultimate strength of A527 as that of A36 (58 ksi). The minimum ultimate strength of A527 is specified as 45 ksi (Ref. 19). The calculations should be based on the proper strengths of these materials.

- H&A did not provide information on the structural integrity and leak tightness re-evaluation of the duct systems evaluated in HA-05/89-696.

This concern is therefore considered unresolved.

2.13 NRC Concern No. 13:

The structural integrity and air-tightness of the brazed joints in the longitudinal corner and middle seams ("Pittsburgh Lock" and "Acme Lock") was not evaluated.

Evaluation:

The staff has reviewed the H&A response to this concern in Attachment 9 and has identified the following deficiencies, in addition to those previously identified in the evaluations of the responses to Concerns 2 and 3:

- Sections 4.12 and 5.10.4 of ANSI/ASME N509-1980 do not specify brazing or braze welding as an acceptable method for providing assurance of structural integrity and leak tightness of mechanical lock seams in ductwork. Section 2.8.2 of ORNL-NSIC-65 also does not specify brazing or braze welding of longitudinal seams. No justification has been provided for braze welding the mechanical lock seams in the Fermi 2 ductwork.

- The mechanical properties of A527 and A575 were assumed the same as those of A36.

- Material properties were taken from the ASME Boiler and Pressure Vessel, 1992 Edition. This edition has not been endorsed in 10 CFR 50.55a.

- The panel membrane stresses are calculated based on data from Reference 24. The magnitude of the panel membrane stresses under pressure for the same edge boundary conditions are different from those calculated in the response to Concern No. 3. No explanation is available for this discrepancy.

- The effects of the localized yielding and buckling in systems 4316-1, 4316-7 and 2850-2 on the strength and leak tightness of the braze welded seams have not been evaluated.

Based on the above this concern is considered unresolved.

2.14 NRC Concern No. 14:

It is unclear how the directional components of horizontal and vertical spectra were applied in calculations of seismic stresses.

Evaluation:

In Attachment 10, H&A provided the methodology for the application of the earthquake components in the static calculations reported in HA-05/89-696. This methodology is based on calculating load factors (LF) in both horizontal and vertical directions. These factors were determined as the product of the ratio S = SSE ZPA/OBE [operating basis earthquake] ZPA and the ratio D = SSE PEAK A/SSE ZPA, i.e., LF = SxD. These values were determined from both OBE and SSE horizontal and vertical spectra, based on 2% damping.

The load factors were calculated at two elevations in the Reactor Building from the corresponding spectra. At each elevation the factors in the three directions were about the same in magnitude, and H&A used a constant value for all three directions. The load factors were applied as multipliers of the stresses from existing seismic analyses of the ductwork for those systems which were considered rigid (fundamental frequency is greater than 33 Hz).

However, H&A stated that "in some cases, where the system was deemed rigid, it was necessary to remove some conservatism" in which case only the factor "S" was used as the multiplier. This needs clarification since the load factors were supposed to be applied to rigid systems, and H&A did not state the basis for determining that its solution was over-conservative.

H&A also provided the spectra which form the basis for the load factors. An examination of the SSE vertical response spectra shown in Figures 2.3.3 and 2.3.9 of Attachment 10 indicates that the ZPA for these spectra was arbitrarily hand-drawn for frequencies greater than 33 Hz. The OBE vertical response spectra shown in Figures 2.3.6 and 2.3.12 indicate that the cut-off frequency may be greater than 50 Hz. and the ZPA lower than shown. The rigidity criterion of 33 Hz may therefore not be applicable under vertical seismic excitation.

The staff concludes that additional clarification is needed for the conditions under which the load factor concept was applied by H&A. This concern is therefore unresolved.

2.15 <u>NRC Concern No. 15</u>:

> Details of the calculations to determine the maximum permissible internal pressure from the stresses under combined loads were not reported. An examination of the stated values for permissible pressure under dead weight, and dead weight and seismic loading, shows that for some ducts the ratio of these pressures are as high as 20. No justification for these ratios has been provided.

<u>Evaluation</u>:

In Calculation Document HA-09/89-696, H&A reported the allowable negative pressure of 55 ducting systems under DW loading, and loading due to combined DW plus SSE. No justification was provided to show the basis for determining these pressures. For many rectangular ducts, the allowable pressure under DW plus SSE appeared to be unreasonably in excess of the allowable pressure for DW only.

In Attachment 11, H&A provided the methodology used for calculating the allowable pressure of rectangular ducts. It is based on previously calculated bending moments resulting from DW and SSE, the bending and stability theory of rectangular plates from References 20 and 23, and allowable stresses and deflections from ANSI/ASME N509-1980.

Two representative cases in Calculation Document HA-09/89-696 were provided, showing the details of the calculation of the allowable pressure. These were a 20x16 duct from duct system 2849-1, and a 7x24 duct from duct system 2848-1-1B. For the 20x16 duct the ratio of allowable pressure for DW+SSE to the allowable pressure for DW is about 1.8. For the 7x24 duct this ratio is about 10. The highest ratio was found for a 16x43 duct in duct system 2848-1-1A, with a ratio of about 21. No calculation was shown for this duct.

The internal moments due to DW and SSE were determined from existing static calculations multiplied by load factors. The nominally largest longitudinal compressive stress in biaxial bending for DW, and DW+SSE, was calculated elastically on the basis of full section moments of inertia and galvanized sheet metal thickness. The stress for each loading condition was compared to the critical stress for the widest panel of the particular duct. The critical stress was determined by using the equation for a uniformly compressed rectangular plate with simply supported edges (Ref. 20). For the case where the critical stress was not exceeded, the allowable pressure was determined by using the maximum shear stress criterion at a duct corner, the allowable stresses from ANSI/ASME N509-1980, and the elastic large deflection equations for a rectangular plate loaded by uniform pressure given in Reference 23.

For the case where the critical stress was exceeded, the maximum longitudinal compressive stress in a panel was determined by using an ad-hoc procedure based on the assumption that the corner nominal compressive bending stress is uniformly distributed over the width of the panel, and von Karman's concept of effective width and ultimate strength theory of perfectly flat plates (Ref. 20). The calculation of the effective width using this concept does not consider initial imperfections, and is thus a deficiency in this approach. (Such imperfections are considered in equations shown in Ref. 18). The longitudinal compressive stress determined on this basis is considerably larger than the nominal longitudinal compressive stress, but lower than the yield stress. This procedure is therefore inconsistent but may nevertheless provide conservative stress values as compared to iterative procedures used in the industry. This has not been verified. The allowable pressure was again determined on the basis of the maximum shear stress criterion, the allowable stresses, and the large deflection equation of rectangular plates under uniform pressure, as shown in Reference 23. When using this procedure, the allowable pressure under DW+SSE was often calculated smaller than the allowable pressure under DW only, even though the allowable stress for DW+SSE is 50% larger than that for DW only. For the case where the critical stress in the DW and DW+SSE analyses was not exceeded, the allowable pressure for DW+SSE was always calculated greater than the allowable pressure for DW only.

H&A modified the procedure described above to calculate a higher allowable pressure for DW+SSE by considering only the membrane stress component of the elastic large deflection equations of plates with built-in edges bent into cylindrical shapes (Ref. 23). The basis for this was stated as "this pressure capability is based on membrane stress alone, since bending stress vanishes with the formation of a hinge by yielding at the boundaries." On this basis, the allowable pressure was calculated considerably larger, giving in many cases a substantially greater allowable pressure for DW+SSE as compared to DW only. However, there is no rational basis for this procedure. In the H&A response, the membrane plus bending stress was shown considerably lower than the allowable stress of 0.9Sy, therefore no hinge could have formed under this loading condition. Furthermore, the bending stress does not vanish with the formation of a hinge by yielding, but interacts with the membrane stress at the yield stress of the material. Therefore, not considering the bending stress is a deficiency of this procedure. The use of this procedure as a basis for calculating the allowable pressure in rectangular ducts is therefore not acceptable.

H&A also calculated the allowable pressure based on the allowable deflection of panels in ANSI/ASME N509-1980. This allowable deflection is 1/8 inch per foot of maximum panel span. H&A calculated the allowable pressure from the difference of the maximum allowable deflection and the deflection of the panel at the critical stress. This is a deficiency of the procedure. The allowable pressure should be calculated from the difference of the allowable deflection and the post-buckled deflection under maximum calculated stress. This requires the calculation of the ratio of the average longitudinal strain to critical strain from the actual stress distribution. The post-buckling deflection can be considerably larger than the panel thickness, and depending on the maximum post-buckling stress, may exceed the allowable code deflection. Other deficiencies noted in this procedure are the deflection of a rectangular panel based on the equation for the deflection of a square plate compressed in two perpendicular directions. The deflection should be based on the equation for a square plate compressed in one direction (Ref. 20), corresponding to the calculation of the critical stress. The use of the square plate approximation for determining the deflection of a rectangular panel, in lieu of a detailed analysis, is acceptable provided the approximation is based on the largest dimension of the panel. H&A chose the width of the panel for the dimensions of the square plate but should have used the length of the panel.

H&A determined the allowable pressure for DW+SSE as the largest pressure calculated using the methods described above. The allowable pressure should be based on the smallest calculated pressure.

The following additional deficiencies were identified:

- The equation for determining the largest longitudinal stress based on the effective width concept contains a term based on the critical stress of the panel. There is no basis for including this term.

- The membrane stress did not include the transverse tensile stress resulting from axial compression of the panel (Ref. 20).

- Torsional stresses due to seismic loading were not considered in the calculation of the pressure capability.

- The yield stress for A-36 was used instead of the yield stress for A527.

- The allowable pressure is based on galvanized sheet metal thickness instead of bare sheet metal thickness.

- Some of the moments appear to be mislabeled.

- The magnitude of the edge bending stresses has not been determined.

Based on the above, the staff concludes that the pressure capability of a number of ducting systems in Calculation Document HA-09/89-696 under DW+SSE has been considerably overestimated, and that the allowable stress criteria in ANSI/ASME N509-1980 have been exceeded. This issue is therefore considered unresolved.

2.16 NRC Concern No. 16:

For circular ducts the maximum allowable negative pressure is apparently total vacuum. The basis for this result was not presented so it isn't clear if it was determined based on the interaction with simultaneous tensile and compressive loads, and if manufacturing imperfections were considered.

Evaluation:

In Attachment 12, H&A provided a description of the procedure for determining the allowable external pressure of circular ducts, and selected a 48-inch duct in system 2849-10 as a bounding case to demonstrate this procedure. This duct is the largest duct evaluated by H&A. The analysis was based on the bare metal thickness (0.0478 inch) and the yield stress of A-36. The allowable design pressure for this system was -6 inches WG. Two load conditions were evaluated: DW+P and DW+P+SSE. Although using the yield stress of A-36 is a deficiency, it did not affect the calculation of the allowable pressure.

H&A determined the critical stress in a cylinder under pure bending from a graph presented in Reference 23a. It is stated to be based on experimental results and includes the effects of imperfections. Although the staff has not reviewed this reference the value obtained by H&A appears to be reasonable and is therefore acceptable.

The allowable pressure under bending for the loading condition DW+P was determined as greater than vacuum. However, based on a safety factor of 7.15 to account for imperfections, H&A determined the allowable pressure for this condition as 3.2 psi or 88 inches WG. The allowable pressure under DW+P+SSE was also determined as greater than vacuum. Using the same safety factor H&A determined the allowable pressure as 1.83 psi or 50 inches WG. H&A also determined the critical pressure under external pressure only, and applying the safety factor above, concluded that the allowable pressure for this loading is 0.246 psi or 6.8 inches WG. This pressure is slightly above the design pressure but is considerably less than the value stated in HA-09/89-696.

The staff has reviewed the H&A analysis and finds it acceptable. However, DECo did not reevaluate the allowable pressure for all circular ducts listed in Calculation Document HA-09/89-696. This concern is therefore considered unresolved.

2.17 NRC Concern No. 17:

The H&A report stated that "some of the rectangular duct panels are loaded beyond their bifurcation point during SSE, and that is structurally inconsequential since the distributed stresses remain low." This statement is acceptable only if it is shown that the maximum redistributed stress remains below the allowable stress (0.9Sy) under the SSE loading condition.

Evaluation:

The response to this concern is related to the response to NRC Concern No. 15. In Attachment 13, H&A stated that "if no buckling occurred, the membrane and bending stresses in the duct were compared directly to the stress requirements of ANSI/ASME N509-1980, paragraph 5.10.3.3. Once the allowable stresses and the operational stresses due to self-weight and seismic loads were established, the maximum permissible internal pressure can be determined. If buckling occurred, the yield will take place locally at the corners of the duct and stress will be redistributed. The load carrying capacity will then be performed by membrane action alone. The resulting primary membrane stresses are less than 0.9Sy." The staff has identified the following deficiencies in this response:

- It is unclear what buckling is being referred to. Post-buckling of rectangular panels is acceptable provided the stress allowables in ANSI/ASME N509-1980 are not exceeded.
- It is unclear how yielding takes place and the stress redistributed, and how this is considered in the analysis. H&A apparently assumes that the bending stresses at the duct corners vanish once yielding is achieved. No justification for this assumption was provided.
- ANSI/ASME N509-1980 has no provision for local yielding and stress redistribution.

DECo should provide a detailed stress analysis of a duct to clarify the meaning of these statements above. This concern is therefore considered unresolved.

2.18 NRC Co cern No. 18:

The analysis of system 2850-2 indicated that this system responded inelastically at one location, and it was thus concluded that a ductility factor of 2 was sufficient to achieve the required pressure load. The meaning of this is unclear since it implies that somewhere in the system the highest stress calculated on an elastic basis was about 2Sy, considerably exceeding the maximum allowable stress.

Evaluation

In Calculation Document HA-09/69-696, H&A stated that a detailed analysis of system 2850-2 indicated that it is a very flexible system, but did not provide any information regarding the analysis, other than stating the fundamental frequency (5.7 Hz). H&A also stated that a ductility factor of 2 was necessary to achieve the required pressure load, implying significant inelastic deformation somewhere in the system.

In its response to this concern, DECo stated that the highest expected stress in Calculation Document HA-09/89-696, calculated on an elastic basis, was 1.3Sy, thus considerably exceeding the allowable stress in ANSI/ASME N509-1980. DECo stated that to quantify the conservatism of the original analysis, this system was reanalyzed for the SSE plus the actual pressure requirement and various damping values. DECo stated that a literature review suggested damping values of 10%-15% for systems responding at or near yield, and that these values would have been appropriate for the analysis of this system. In Reference 17 the staff approved damping in HVAC systems limited to 7% for rectangular ducts and 4% for circular ducts. Damping greater than these values are not acceptable.

In Attachment 14, H&A provided limited information regarding the analysis of system 2850-2. It appears to have been based on modal superposition response spectrum analysis, and a modification of 10% damped horizontal elastic response spectra based on the concept of ductility. The use of 10% damping in response spectrum calculations, and/or the application of ductility factors to modify elastic response spectra for use with modal superposition response spectrum analysis, has not been endorsed or approved by the staff in similar applications.

H&A also reported the analysis of system 2850-2 based on 7% damped elastic response spectra. The following deficiencies were identified:

- H&A provided minimal information and no details regarding this analysis. Since this system is considered a highly flexible system, no justification was provided for not including this system in Calculation Document HA-05/89-686, since this calculation evaluated those ducting systems considered as flexible.

- The revision considered the response to horizontal excitation only. The response to vertical excitation (horizontal moment and vertical shear) was apparently not included. No basis for this is apparent and no justification has been provided.

- The section properties, the stress due to pressure, and the critical stress are based on galvanized sheet metal thickness and the yield stress of A-36.

- The seismic stress at 7% damping was not calculated from an analysis, but determined by interpolation between the 2% stress and the 10% stress. The validity of this procedure is not evident and was not justified.

- The flexibility of the system was attributed to highly flexible supports. No details of the safety qualification of the supports were provided.

- No details of the stresses due to pressure were given. These may be underestimated, since they are based on the galvanized sheet metal thickness.

- The maximum stress under the DW+SSE+P loading combination exceeds the allowable stress in ANSI/ASME N509-1980.

This concern is therefore considered unresolved.

2.19 NRC Concern No. 19:

The analyses in this report address only the ductwork. No safety calculation of the supports or calculated safety margins determined in such calculations have been reported. The design calculation report DC-5089 states that all hangers, stiffeners, and supports meet the stress criteria of ANSI/ASME N509-1980. No documentation has been provided to support this statement.

Evaluation:

In its response, DECo stated that bounding analyses, encompassing all possible duct and stiffener sizes and configurations, show that all stiffeners, welds, brazings, and tie-rods are structurally adequate and that the stiffeners meet the stress criteria of ANSI/ASME N509-1980 based on the maximum anticipated loading. DECo also stated that the hangers and supports were seismically qualified by DECo and that all calculated stresses are within the AISC allowables. These allowables are lower than the allowables specified in ANSI/ASME N509-1980.

In Attachment 15, H&A provided supplementary calculations to demonstrate the safety evaluation of stiffeners. The staff has reviewed these calculations and has identified the following deficiencies:

- H&A stated that the stiffeners are fabricated from A575 carbon steel. This material is not listed in Section 5.10.6 of ANSI/ASME N509-1980 as an acceptable material. In addition, this is inconsistent with DC-5089, which states that the stiffener material is the same as the duct metal. The qualification of the stiffeners is based on the yield strength of A36. It should be based on the yield strength of A527.

- The calculation of the weld capacity is based on the ultimate strength of A36 steel (58 ksi). It should be based on the ultimate strength of A527 steel (45 ksi, Ref. 19).

- DECo stated that the stiffeners meet the stress criteria of ANSI/ASME N509-1980 based on the maximum anticipated loading. In Attachment 15, the adequacy of welds and stiffeners was determined based on the operational internal pressures of the ducts. Clarification is needed that the adequacy of the stiffeners and welds was also determined for the allowable pressures under SSE conditions stated in Calculation Document HA-09/89-696.

- In Attachment 16, DECo provided a representative calculation of the seismic qualification of duct system supports. The loads in this calculation, and in all support calculations, were based on the loads determined from the H&A duct calculations. These loads may therefore be underestimated.

Based on the above, this concern is considered unresolved.

3.0 CONCLUSION

The staff has noted a number of deficiencies in the DECo and H&A responses to the NRC concerns. Most of the concerns are therefore still unresolved.

Based on the safety evaluation of DECo's responses, the staff concludes that DECo has not demonstrated the structural integrity and functionality of the CCHVAC under combined loading due to DW plus SSE plus the maximum expected internal negative pressure, and therefore the requirements and the intent of Sections 4.12 and 5.10 of ANSI/ASME N509-1980 have not been met.

The staff recommends that DECo provide the qualification of the Fermi 2 CCHVAC, including all ductwork and supports evaluated in Calculation Documents HA-09/89-686 and HA-09/89-696, to show structural integrity and functionality under the load combination consisting of DW plus SSE plus maximum expected negative internal pressure load, in accordance with the unresolved concerns stated above and all applicable requirements of ANSI/ASME N509-1980. This qualification should be completed before the end of the next refueling outage currently scheduled to begin September 27, 1996.

Principal Contributor: M. Hartzman

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