Attachment
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TEMPERATURE RESPONSE OF STRUCTURAL STEEL RELATED TO RATED FIRE BARRIERS AT THE DUANE ARNOLD ENERGY CENTER

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1.0 INTRODUCTION

Iowa Electric met with NRC (Chemical Engineering Branch) reviewers in Bethesda on September 5, 1984, to discuss several exemptions to 10 CFR 50, Appendix R. In that meeting, Iowa Electric proposed exemptions from the requirement to protect structural steel forming part of or supporting required fire barriers. The basis for these proposed exemptions was that the peak temperature of the structural steel would not exceed the critical temperature of 1,100° Farenheit (F) when exposed to fires postulated in the DAEC Fire Hazards Analysis (Reference 1). The basis for the critical temperature of 1,100F is explained in NRC Generic Letter 83-33. Structural steel associated with required fire barriers and found to exceed 1,100F without considering local effects has already been protected.

However, the peak temperature calculations performed by Iowa Electric did not explicitly model local temperature effects due to the spatial relationship of combustible material to structural steel, flame plume effects, or fire zone ventilation. At the meeting, the NRC reviewers indicated that these local effects would need to be considered and that the approach used by Philadelphia Electric's Limerick plant had been reviewed and found to be acceptable.

Iowa Electric has performed the peak steel temperature calculations using the Limerick methodology. The results are that the majority of the structural steel analyzed will not exceed the 1,100F critical temperature. The calculations indicate that certain exposed structural steel forming part of or supporting required fire barriers will experience peak temperatures above 1,100F; that portion of the structural steel which exceeds 1,100F and is required to maintain fire barrier integrity will be protected to assure that the steel temperature will not exceed 1,100F. Similarly, structural steel columns were analyzed with a 1,000F critical temperature limit in the manner of the Limerick analysis; columns necessary to support required fire barriers that exceed this temperature limit will be protected to assure that the column temperature will not exceed 1,000F.

This document provides the methodology and the results of calculations performed by Bechtel Power Corporation to determine the temperature response of structural steel to further support the exemption requests transmitted to the NRC in Reference 2. Section 2.0 describes the methodology for the room and structural steel temperature calculations, including the models used for localized heating. Section 3.0 contains a summary of the results of the analysis and gives additional pertinent details for each of the fire zones analyzed.

2.0 METHODOLOGY

Temperature response of structural steel at the DAEC is calculated based on the method used by the Limerick Generating Station, Units 1 and 2, as documented in two submittals to the NRC (References 3 and 4). The procedure for analyzing the structural steel response is described in this section, and key mathematical relationships and assumptions are identified.

2.1 ROOM AIR TEMPERATURE CALCULATIONS

Room air temperature calculations are first performed for each zone where exposed structural steel supports a rated fire barrier required for safe shutdown. If the zone air temperature does not reach 1,100F, then structural steel cannot exceed 1,100F due to heatup from ambient air; however, localized heating may still be a problem and is analyzed as described in Section 2.1.3. If the peak room air temperature is calculated to exceed 1,100F, the response of structural steel is calculated to determine if the room heatup alone can cause overheating of the steel.

2.1.1 Heat Release Rate

The room air temperature calculations are based on the zone combustible loading as defined in the DAEC Fire Hazards Analysis (Reference 1). As in References 3 and 4, the DAEC analysis considers limitations on combustion caused by insufficient ventilation for zones that are enclosed, i.e, ventilation-limited fires. The heat release rate for ventilation-limited fires is the same as the Limerick analysis and is approximated as follows:

$$Q = 1{,}580\ A\ \sqrt{H}$$

where

Q = heat output (kW)
A = area of opening (m^2)
H = height of opening (m)

The opening is typically assumed to be a single, open door in each zone utilizing the ventilation-controlled fire model.

For open zones in the plant where excess air is available for combustion, the heat release rate above cannot be used and a fuel-controlled fire is assumed. The method for determining the heat release rate for a fuel controlled fire is that used in References 3 and 4. A fire is assumed to start at the most pessimistic location in the zone, considering all types of combustibles. Where cable trays contribute, the total area of cable tray that has become involved when the point of origin burns out defines the steady state fire size and heat release rate.

2.1.2 Room Heat Balance

The assumptions used to develop the room heat balance are those used in References 3 and 4, specifically:

- Heat losses through openings in the room are neglected.
- Heat loss through the walls is dominated by the thermal capacity of the walls, which are modeled as semi-infinite slabs.
- The floor is conservatively neglected as a heat sink.

The room gas temperature is related to the total fire heat release by the following expression, which considers heat conduction and radiation:

$$T_g = \left\{ \frac{Q}{\sigma A \eta} + \left(T_o + \frac{Q\sqrt{t}}{A K} \right)^4 \right\}^{1/4}$$

where

Q = heat release rate (kW) of fire

K = $1/2\ (\pi k \rho C_p)^{1/2}$

η = function of emissivity of fire gasses and boundary walls

A = total heat loss surface area of boundary

σ = Stefan Boltzmann constant

T_g = temperature of air in room (absolute)

T_o = initial temperature of walls and ceiling (absolute)

ρ = density of wall material

C_p = specific heat of wall material

t = time after initiation of fire

2.1.3 Local Heating Effects

A specific model for lubricating oil pool fires is not required for the DAEC analysis, mainly because the structural steel in zones containing large quantities of lube oil has already been protected. Zones containing small quantities of lube oil incorporate the lube oil into the portion of the heat rate that is assumed to ignite instantaneously . Ceiling height in these areas is sufficient to preclude localized heating for small quantities of lubricating oil at the floor elevation.

The fire plume model assumed for cable tray fires is the same as that used in References 3 and 4, which can be summarized by the table below:

Number of Stacked Cable Trays	Distance from Top Tray in Stack to Structural Steel (ft)		
	Plume Temperature = 1,500F	Plume Temperature = 1,300F	No Localized Heating
1	0-1	1-2	>2
2	0-1	1-3	>3
3-5	0-1	1-4	>4
>5	0-1	1-5	>5

For cable trays that meet the criterion for no localized heating, the room air temperature is used for structural steel response. For cable tray stacks closer to structural steel where structural steel localized heating can occur, the steel is assumed to experience either a 1,300F or a 1,500F flame temperature in calculating the steel temperature response.

Trays were assumed to subject a beam to a constant temperature defined above for the period of time it takes for the tray to burn to completion. This duration depends on the cable burn rate and tray fill. The trays were assumed to be maximum fill, regardless of actual fill, and consumed at the rate of 0.1 (lbs/min)/ft^2 of cable tray (References 3 and 4) top area.

2.2 STRUCTURAL STEEL TEMPERATURE RESPONSE

For cases where peak room air temperature exceeds 1,100F or where a localized heating interaction is identified, the structural steel is analyzed for temperature response. As in the Limerick submittal (References 3 and 4), the temperature of the structural steel member is determined using the following empirical transient heat transfer relationship.

$$\Delta T = 231 \frac{U}{G} (T_a - T_i) \Delta t$$

where

ΔT = temperature rise in steel member during interval Δt (°C)

U = surface of steel member exposed to fire (m^2/m)

G = weight of steel member (Kg/m)

T_a = average fire or air temperature during interval (°C)

T_i = temperature of steel member at beginning of interval (°C)

Δt = time interval in hours

The cumulative steel temperature transient is derived by successively adding the steel temperature rise to the previous steel temperature for the next time increment. In all cases, the peak fire or air temperatures have been used as an input to the steel temperature calculations, out to the time when the combustibles are totally consumed.

If the calculated structural steel temperature is less than 1,100F, the structural steel is acceptable without protection. A limit of 1,000F is used for columns. If the calculated temperature exceeds these values, the structural steel will be protected, or in the case of transient combustible loadings near columns, measures are taken to assure an acceptable amount of combustibles.

The temperatures used for T_a depend on whether the structural steel is being evaluated for air temperature response or response to a 1,300F or 1,500F flame. A flame temperature of 1,500F is used for all columns regardless of the combustible hazard makeup.

3.0 SUMMARY OF RESULTS

Table 1 is reproduced from Iowa Electric's structural steel exemption request (Reference 2) and indicates the fire zone boundaries where structural steel has been reanalyzed using the Limerick plant methodology for peak room air temperature and localized heating.

Table 2 shows the results of the room air and structural steel peak temperatures for the boundaries listed in Table 1 and provides the principal justification for the exemption to protect structural steel. For each boundary, a case description is shown that describes whether the fire is ventilation controlled or fuel controlled. The fire durations listed correspond to the combustion rates used in the room temperature calculation. The maximum area temperatures are calculated based on the model described in Section 2.1.2. If there are no potential local heatup problems, "NO" is entered in the localized heating problem column. Where applicable, localized heating interactions are specifically designated, e.g., cable tray, and the peak steel temperature is shown with the time of the peak value. In those cases where the steel temperature exceeds 1,100F, the time that the steel reached 1,100F is shown. The times and temperatures are calculated for each size structural member; however, only values characteristic of the limiting member are shown in the table.

For those cases where steel temperature exceeds 1,100F, the comment indicates that affected steel will be protected. Not all of the steel member sizes are specifically designated; in some cases, only certain steel members will be protected and, in others, only the portions adjacent to localized heating sources need be protected if room temperatures alone do not cause the steel to overheat. Steel that does not require protection is also identified.

4.0 REFERENCES

1. Letter IE-79-856, L. Liu to H. Denton, dated June 7, 1979, transmitting DAEC Fire Hazards Analysis (Chron 8808)

2. Letter, NG-84-4135, R.W. McGaughy (IELP) to H. Denton (NRC) dated September 28, 1984, 10 CFR 50, Appendix R Exemption Requests.

3. Letter, J.S. Kemper (Philadelphia Electric Co.) to A. Schwencer (USNRC), dated February 29, 1984, Limerick Generating Station Units 1 and 2, Structural Steel Survivability Evaluation.

4. Letter, J.S. Kemper (Philadelphia Electric Co.) to A. Schwencer (USNRC), dated May 31, 1984, Limerick Generating Station Units 1 and 2, Structural Steel Survivability Evaluation.

TABLE 1

STRUCTURAL STEEL EXEMPTION SUMMARY

Zone From	Zone To	Description
1C	2A/2B	Partial first floor ceiling structure (northeast corner)
1D	2A/2B	Partial first floor ceiling structure (southeast corner)
2A/2B	3A/3B, 3C, 3D	Second floor ceiling structure
2D	3A/3B	Partial second floor ceiling structure
3A/3B	4A/4B	Third floor ceiling structure
7E	8F, 8G, 8H, 8J	Ceiling structure below diesel generators
8F, 8H	8H, 8F	Diesel generator room ceilings above common rated boundary (Note 1)
10B, 10C, 10D, 10E, 10F	11A	Essential switchgear and battery rooms Ceiling structure
11A	12A	Cable spreading room ceiling structure
16A, B	16B, A	Pumphouse adjoining rooms, el 746'-6"
16F	16A, B	Pumphouse sump ceiling
17A, B	17B, A	Intake structure ceiling steel penetrating rated wall (Note 1)
17C, D	17D, C	Intake structure ceiling steel penetrating rated wall (Note 1)

Note 1: Wall in question is 3-hour rated and the structural steel (if any) is protected. The concern is that the ceiling above could fail, thereby causing the required fire barrier to fail. Exemption is being requested from protecting that structural steel supporting the ceiling above the wall that will not exceed 1,100F during the appropriate postulated fire.

(From Reference 2)

TABLE 2

SUMMARY OF STRUCTURAL STEEL TEMPERATURE ANALYSIS

Boundary From	Boundary To	Description	Case Description	Fire Duration (min)	Max Area Temp (F)	Localized Heating Problem*	Comments
1C	2A/2B	NE corner room ceiling (RB)	Ventilation controlled, one door open	36	972	No	Steel does not require fireproofing.
1D	2A/2B	SE corner room ceiling (RB)	Ventilation controlled, one door open	30	950	No	Steel does not require fireproofing.
2A	3A, 3C, 3D	RB second floor ceiling - north end	Fuel controlled	180	884	Cable tray T(S) = 1,100F at 7.5 min.	Affected steel will be protected.
2B	3B, 3D	RB second floor ceiling - south end	Fuel controlled	180	624	Cable tray T(S) = 1,100F at 7.5 min.	Affected steel will be protected.
2D	3A/3B	RHR valve room ceiling (RB)	Ventilation controlled, one door open	4	930	Cable tray T(S) = 312F at 4 min.	Steel does not require fireproofing.
3A	4A	RB third floor ceiling - north end	Fuel controlled	180	1,092	Cable tray T(S) = 1,100F at 50.0 min.	Affected steel will be protected.
3B	4B	RB third floor ceiling - south end	Fuel controlled	180	927	Cable tray T(S) = 1,100F at 15.0 min.	Affected steel will be protected.
7B	7C	TB lower switchgear room wall	Ventilation controlled, one door open	140	>1,500	NA	Affected steel will be protected. Room temperature exceeds limit without local effects.

Summary of Structural Steel Temperature Analysis (Continued)

Boundary From	Boundary To	Description	Case Description	Fire Duration (min)	Max Area Temp (F)	Localized Heating Problem*	Comments
7E	8F, 8G, 8H, 8J	TB condensate pump area ceiling	Fuel controlled	180	452	Cable tray T(S) = 1,100F at 15.0 min.	Affected steel will be protected.
8F 8H	8H 8F	Diesel generator room ceilings above rated boundary (TB)					Field verification confirms structural steel already protected.
10A	11A	Control building corridor ceiling	Ventilation controlled, one door open	4.5	1,005	Cable tray T(S) = 727F at 4.5 min.	Steel does not require fireproofing.
10B	11A	Div 2 battery room ceiling	Ventilation controlled, 100% HVAC air flow	180	955	NA	Steel does not require fireproofing.
10C	10E, 10F, 11A	Nondivisional battery room ceiling and walls	Ventilation controlled, 100% HVAC air flow	180	1,380	NA	Affected steel will be protected. Room temperature exceeds limit without local effects.
10D	11A	Div 1 battery room ceiling	Ventilation controlled, 100% HVAC air flow	180	995	NA	Steel does not require fireproofing.
10E	10F, 11A	Div 2 essential switchgear room	Ventilation controlled Fuel controlled	100 160	>1,500 1,232	NA NA	Affected steel will be protected. Room temperature exceeds limit without local effects.
10F	10E, 11A	Div 1 essential switchgear room	Ventilation controlled Fuel controlled	125 180	>1,500 1,344	NA NA	Affected steel will be protected. Room temperature exceeds limit without local effects.

Summary of Structural Steel Temperature Analysis (Continued)

Boundary From	Boundary To	Description	Case Description	Fire Duration (min)	Max Area Temp (F)	Localized Heating Problem*	Comments
11A	12A	Div 2 cable spreading room ceiling	Ventilation controlled, one door open	180	990	Cable tray T(S) = 1,100F at 14 min.	Steel does not require fireproofing. Automatic detection and suppression throughout the zone will extinguish fire prior to structural steel heatup.
16A	16B	Div 2 pump area (pumphouse) wall	Ventilation controlled, one door open	24	1,062	No	Steel does not require fireproofing.
16B	16A	Div 1 pump area wall (pumphouse)	Ventilation controlled, one door open	20	1,052	No	Steel does not require fireproofing.
16F	16A, 16B	Pumphouse sump ceiling	Ventilation controlled, one door open	9	928	Cable tray T(S) = 1,070F at 9 min.	Steel does not require fireproofing.
17A	17B	Div 1 pump room (intake structure)	Ventilation controlled, one door open	5	1,358	Hypothetical 1,500F pool fire T(S) = 775F at 5 min.	Steel does not require fireproofing.
17B	17A	Div 2 pump room (intake structure)	Ventilation controlled, one door open	5	1,358	Hypothetical 1,500F pool fire T(S) = 775F at 5 min.	Steel does not require fireproofing.
17C	17D	Div 1 screen area (intake structure)	Ventilation controlled, one door open	6	1,172	Hypothetical 1,500F flame exposure T(S) = 847F at 6 min.	Steel does not require fireproofing.

Summary of Structural Steel Temperature Analysis (Continued)

Boundary From	Boundary To	Description	Case Description	Fire Duration (min)	Max Area Temp (F)	Localized Heating Problem*	Comments
17D	17C	Div 2 screen area (intake structure)	Ventilation controlled, one door open	5	1,160	Hypothetical 1,500F flame exposure T(S) = 758F at 5 min.	Steel does not require fireproofing.

*T(S) is bulk steel temperature.