PROFESSIONAL LOSS CONTROL, INC.

ENGINEERING JUSTIFICATION
FOR
PLACEMENT OF AUTOMATIC SPRINKLERS
COMANCHE PEAK STEAM ELECTRIC PLANT
TEXAS UTILITIES GENERATING COMPANY

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Revision 3

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ENGINEERING JUSTIFICATION

FOR

PLACEMENT OF AUTOMATIC SPRINKLERS

AT

COMANCHE PEAK STEAM ELECTRIC PLANT

TEXAS UTILITIES GENERATING COMPANY

1.0 INTRODUCTION

This report examines the installation of the automatic sprinkler/water spray systems provided in safety-related areas of Comanche Peak Steam Electric Plant, Unit 1. Specifically, this report evaluates the placement of sprinkler heads.

The governing document for the engineering/design and installation of automatic sprinkler systems for fire protection is the National Fire Protection Association Standard 13, entitled "Standard for the Installation of Sprinkler Systems." This standard gives detailed guidance in the Chapter 4 for the spacing, location, and positioning of sprinklers. This chapter addresses:

- maximum protection area per sprinkler
- minimum interference to water discharge patterns from beams, girders bracing, pipe, ducts and light fixtures, and
- the location of sprinklers with respect to the ceiling configuration.

In recognition of the problems associated with the placement sprinkler heads in accordance with Section 4-1.1.3 of NFPA 13 and still meet specific protection objectives, the NFPA 13 committee ammended the standard with the addition of Section 4-1.1.5 to allow alternate placement of sprinkler heads, provided comparable sensitivity and performance could be demonstrated by analysis or test. This report provides engineering justification for head placement to ensure performance equal to or better than ceiling level sprinkler heads in accordance with NFPA 13, Section 4-1.1.3.

2.0 SPRINKLER SYSTEM DESIGN OBJECTIVE

The purpose of the automatic sprinkler/water spray systems addressed in this evaluation is to protect safe shutdown equipment, components, and systems such that the plant can be safely shutdown in the event of a fire. The NRC establishes the rules for fire protection of safe shutdown capability in 10 CFR 50, Appendix R, Section III G. Fire protection features for safe shutdown must be capable of limiting fire damage so that:

a. One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage; and

b. Systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) can be repaired within 72 hours.

To achieve these goals, one of the following means must be used to protect redundant trains free of fire damage per Section III G:

a. Separation of cables and equipment and associated non-safety circuits of redundant trains by a fire barrier having a 3-hour rating. Structural steel forming a part of or supporting such fire barriers shall be protected to provide fire resistance equivalent to that required of the barrier.

b. Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance of more than 20 feet with no intervening combustible or fire hazards. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area; or

c. Enclosure of cable and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1 hour rating. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area:

Two of these methods require automatic suppression systems; b above, with redundant trains separated by horizontal distance of more than 20 feet with no intervening combustibles or fire hazard; and c above, with redundant trains separated by at least a 1 hour fire barrier.

The design objective of the safe shutdown area sprinkler protection provided at the Comanche Peak plant is to suppress a floor level exposure fire prior to the ignition of overhead cables. This is based on the critical assumption that electrically initiated propagating cable fires in IEEE 383 qualified cables are not a credible event. Furthermore, in areas with cable trays stacked four or more high directional closed head nozzles or multiple levels of sprinklers are provided above the trays. In order to determine "equivalent performance" as referred to in NFPA 13, the sprinklers below cables must be capable of meeting this design objective, or nozzles must be installed above cable trays to extinguish a cable fire.

3.0 SYSTEM DESCRIPTION - EXISTING AUTOMATIC SPRINKLER/SPRAY SYSTEMS

The automatic suppression systems which are installed in areas of the plant containing safe shutdown systems, are designed and installed to comply with Appendix A to BTP APCSB 9.5-1. The systems installed are combination wet pipe sprinkler systems and closed nozzle water spray systems. Area coverage is provided by sprinklers and specific cable tray protection is provided by the closed water spray nozzles. The equipment in the suppression system is UL listed or FM approved.

Each system is hydraulically designed such that a uniform water density is provided over a specific area. The water flow/pressure demands of these fire suppression systems are less than the available water supply.

The sprinklers used in the systems are UL listed with a temperature rating of 212°F. Both pendent and upright sprinkler heads providing area coverage are Grinnell "duraspeed" heads. The size of the sprinkler orifice varies from 3/8 inch to 1/2 inch. The sprinkler head other than 1/2" orifice have a pintle attached to the deflector. The water spray nozzles are the quartzoid bulb directional type which have a 175°F temperature rating. The directional nozzles are positioned immediately adjacent to cable trays to prevent fire propagation from spreading along the exposed cables. These are provided where more than four trays are installed.

Sprinklers are provided below cable trays in the rooms and corridors as identified in Table 1. Sprinklers are installed at only ceiling level in areas where obstruction are minimal.

TABLE 1

CPSES UNIT 1 BELOW TRAY SPRINKLER PROTECTION

FIRE AREA/ ZONE	ROOM - NAME NUMBER	ELEVA- TION	SPRINKLER PROTECTION DESCRIPTION
AA 21a	175 CCW HX	790	Above and Below Trays
	179 Boric Acid Pumps & Corridor	790	Corridor at Ceiling Pumps Below Ceiling
	180 Corridor	790	Above and Below Trays
AA 21b	207 Corridor	810	Above and Below Trays
AA 21d	226 Corridor	831	Above and Below Trays
AA 21f	241 Corridor	851	Above and Below Trays
SB 4	71 Corridor	790	Above and Below Trays
	70 Corridor	790	Above and Below Trays
SB 8	79 Corridor	810	Above and Below Trays
	82 Corridor	810	Above and Below Trays
SB 15	94 Corridor	831	Above and Below Trays
	95 Personnel Airlock Corridor	831	Ceiling Only
SB 15	88 Non-Rad Pipe Penetration	831	Ceiling Only
EA 57	125 Corridor		Below Cables Only

4.0 SPRINKLER PLACEMENT

NFPA 13 gives specific guidance with respect to the clearance between sprinklers and the ceiling construction. The ceiling construction in the majority area of the plant is considered "Smooth Ceiling Construction" per NFPA 13. Section 4-1.3.1 defines smooth ceiling construction as "continuous smooth bays formed by wood, concrete, or steel beams spaced more than 7-1/2 ft. on centers - beams supported by columns, girders, or trusses." Another type of construction used in the plant is "Beam and Girder Construction." Section 4-1.2.3 defines this as "the term beam and girder construction as used in this standard includes noncombustible and combustible roof or floor decks supported by wood beams on 4-inch or greater nominal thickness or concrete or steel beams spaced 3 to 7-1/2 ft. on centers and either supported or framed into girders."

Relative to these two definitions, Section 4-3.1 defines the positioning of sprinklers for smooth ceiling construction.

> "Deflectors of sprinklers shall be located 1-inch to 10-inches below combustible ceilings or 1-inch to 12-inches below noncombustible ceilings."

Section 4.3.2.1 defines the positioning of sprinklers in beam and girder construction.

> "Deflectors of sprinklers in bays shall be located 1-inch to 16-inches below combustible or noncombustible roof or floor decks."

Sprinklers provided below cable trays do not meet the ceiling clearance limitation of Section 4-3 of NFPA 13. To meet NFPA 13 equivalent performance must be established in accordance with Section 4-1.1.5.

5.0 TECHNICAL JUSTIFICATION

This technical justification addresses the location of sprinkler relative to the ceiling. Section 4-1.1.5 of NFPA 13 states:

> "Clearances between sprinkler and ceiling may exceed the maximum specified in Section 4-3 provided that, for the conditions of occupancy protected, tests or calculations show comparable sensitivity and performance of the sprinklers to be installed in conformance with Section 4-3."

Paragraph A-4-1.1.5 further states:

> "In determining equivalent performance through analytical or experimental methods, the sprinkler's sensitivity, spray distribution, fire size ana droplet size penetration should be considered. Condition of occupancy, such as height of storage, building or equipment configuration, obstructions, etc.,which may effect sprinkler sensitivity should also be considered in evaluating both tests and calculation."

The purpose of this evaluation is to establish if the existing automatic sprinkler/water spray system will achieve its design objective, as outlined in section 2 of this report, as well as or better than a sprinkler system meeting Section 4.3 placement criteria. Specific areas evaluated include:

- Fire properties of cabling insulation and jacketing materials
- Fire scenarios for cable ignition (Fire size)
- Sprinkler Actuation
- Obstructions
- Cable tray water spray protection

5.1 Fire Properties of Cable Insulation and Jacketing Materials

The cables installed at Comanche Peak are IEEE 383 qualified cables. Power cables have EPR insulation and hypalon jackets. Control Cables have cross linked polyethylene (XLPE) insulation and

hypalon jacket. Instrumentation cables have cross linked polyethylene (XLPE) insulation and chlorinated polyethylene jacket. Although these cables are combustible, tests conducted at Factory Mutual Research Corporation (FMRC) sponsored by the Electric Power Research Institute (EPRI) verified the ignition resistance of these cables.

Tests indicated that pyrolysis of the jacketing material occurs at about 850°F. Auto ignition of these types of cables did not occur until about 1100°F. Based on these temperature criteria, fire sizes, necessary to ignite cables in ladder type cable trays can be assessed using plume calculation.

5.2 Fire Scenarios for Cable Ignition - Fire Size

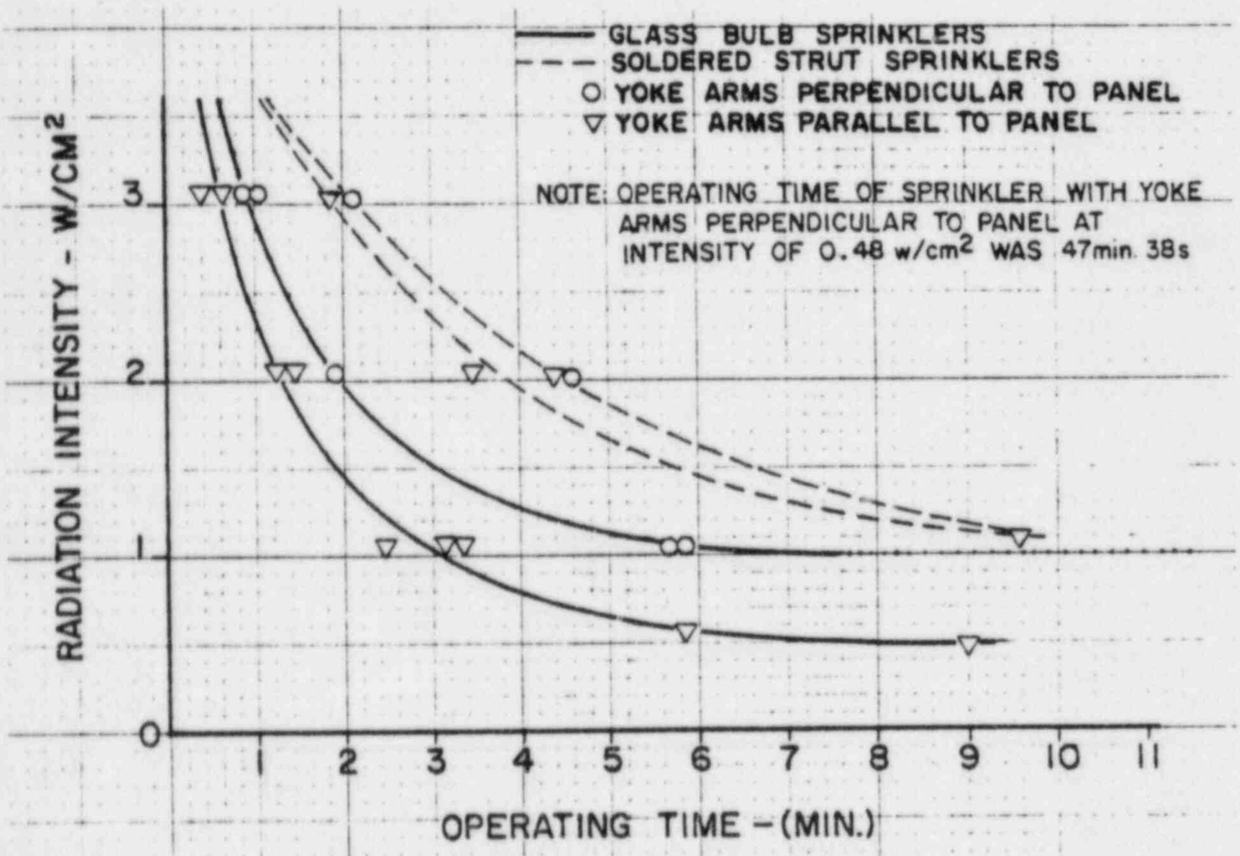
Emperical plume correlation can be applied to determine the size of floor level exposure fires causing pyrolysis and/or ignition of cables installed various distances above the floor. Likewise, these plume correlations can be used to estimate the reaction of sprinklers within the plume. Figure 2 shows the relationship of height above the fire and fire size for two temperatures criteria; increase of 200°F and increase of 800°F (See Appendix A).

5.3 Sprinkler Actuation

It is obvious that a sprinkler rated at 212°F, within the plume of a growing fire will fuse well before cables in the same plume reach their autoignition temperature.

For sprinklers not directly in the fire plume, thermal radiation will be the dominant mode of heat transfer. For these sprinklers, radiation heating from luminous flames will raise the surface temperature of the fusible element until melting occurs. Mathematical relationships have been developed to quantify the intensity of such radiant heat in terms of a heat flux. This flux information has been used to determine if materials will ignite or if structural steel will be damaged. Few specific tests

have been conducted to determine the critical radiant flux necessary to actuate a sprinkler or to establish a relationship between operating time and radiant flux. Tests conducted by Nash and Young in the UK exposed sprinklers to radiant panel tests to develop a comparison of operating times for various radiant fluxes (See Figure 1). These limited data can be compared with calculated radiant fluxes for potential exposure fires to verify the actuation of sprinklers. These calculations are shown in Appendix A.



OPERATING TIMES OF SPRINKLERS AT VARIOUS RADIANT INTENSITIES (NASH & YOUNG)

FIGURE 1

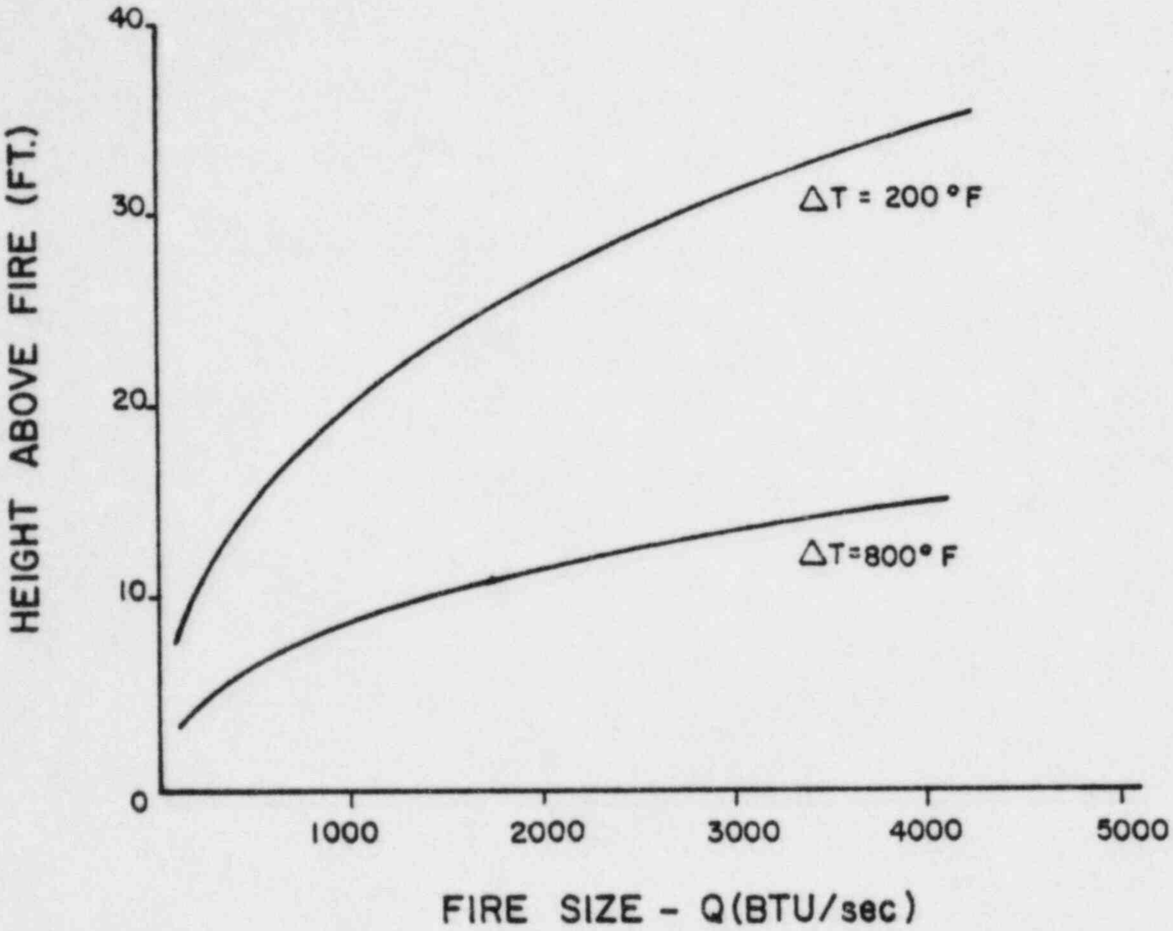

HEIGHT ABOVE FIRE (FT.)
40
30
20
10
0
ΔT = 200 °F
ΔT=800° F
1000
2000
3000
4000
5000
FIRE SIZE - Q(BTU/sec)

FIGURE 2

Based on a comparison of response time index (RTI) of the duraspeed head as compared to the type of sprinklers tested by Nash and Young, it can be concluded that the duraspeed head would operate faster. Although the RTI is a measure of convective heat transfer, it is also a measure of surface area to mass ratio of the fusible element. This ratio will determine the heat transferred to the element regardless of whether convected or radiated.

The worst case configuration for the actuation of the sprinkler systems would be the case when the cable tray is exposed to convective heating from direct plume impingement while the sprinkler heads are exposed only to the radiant heating from the fire. Two questions address the adequacy of response of the sprinkler. First and most important, is the fire size required to yield the radiant heat flux necessary to actuate the sprinkler head less than or equal to the fire size necessary to heat cables to their autoignition temperature? Second, is the fire size required to yield the radiant heat flux necessary to actuate the sprinkler head less than or equal to the fire size necessary to actuate ceiling level sprinklers? To develop quantitative answers to these questions, design (geometry) variables such as height of cable trays above floor exposure fire, ceiling height, sprinkler head spacing (below trays), and sprinkler head heights above floor, were evaluated. Worst case configurations were selected in each area based on these variables. These are shown in Table 2. Additionally, specific relationships between radiant heat flux and time to head actuation for the types and rating of heads installed and specific relationship between heat input and time to ignition for the cables installed should be known. Although the specific relationship for the actual sprinkler heads and actual cables referenced above are not available, the test data from Nash and Young (8) regarding sprinkler heads and EPRI/FMRC (4) regarding cable ignition can be used as conservative representation of the plant installation. Based on these data, radiant heat flux calculations were conducted to determine fire sizes

necessary to actuate sprinklers below cables, outside the fire plume. These calculations are shown in Appendix A and are shown graphically in Figure 3. For these calculations a minimum flux of 1 w/cm^2 (10 kw/m^2) was used.

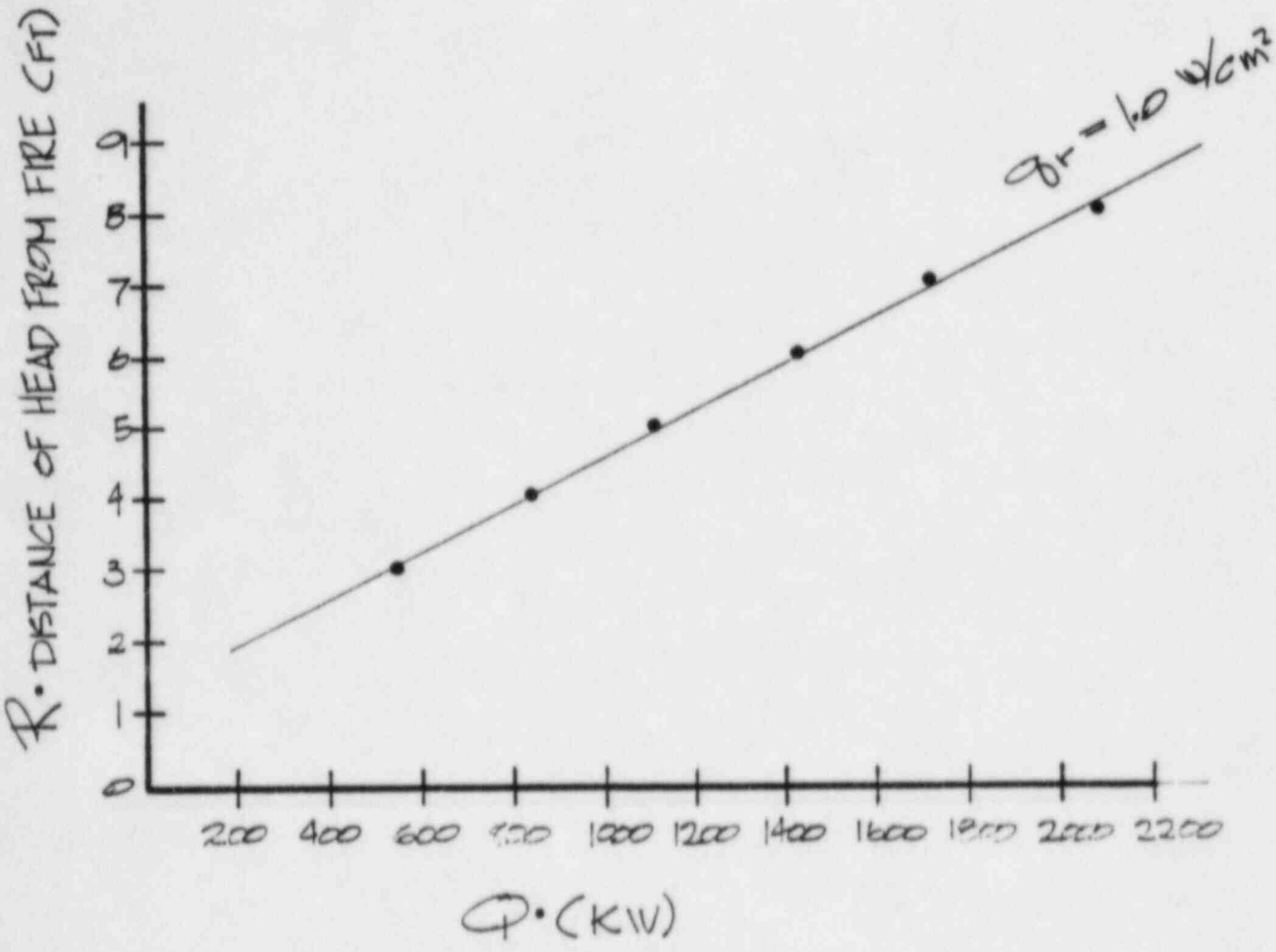
In response to the second question, for the ceiling heights at the plant, a comparison of the plume calculations shown in Figure 2 and the radiant heat flux calculations shown in Figure 3 indicates similar sensitivity of the lower heads to ceiling level heads. The effects of the numerous obstruction to the rising plume would tend to favor the response of the lower heads.

The comparisons described above are shown in Table 2. This table shows the various size fires necessary to actuate suppression systems as designed, and at ceiling and also the size fire necessary to ignite cables. Cases where nozzles were above the trays but not at the ceiling, were not included.

5.4 Obstructions

One of the primary principles for providing proper protection with automatic sprinklers system is minimizing interference to the water discharge pattern. Sprinklers are designed to provide a uniform water density over the protected floor area. Developing a uniform water distribution from actuated sprinklers is not obtainable if the space below the sprinklers is congested with plant equipment. These obstructions are quite noticeable at the ceiling levels in the most areas of the plant. Water spray patterns from sprinkler located at the ceiling would be disrupted by piping, conduit, cable trays, HVAC ducts, light fixtures, seismic hangers, etc. In lieu of positioning the sprinkler at the ceiling level in the corridor, the existing installation has the sprinklers located below these obstruction. Upon actuation of these sprinklers, a uniform water discharge pattern will be obtained. This is a significant advantage over obstructed ceiling sprinklers since a higher percentage of water discharged from the sprinklers will actually reach the seat of the floor level exposure fire.

FIGURE 3


R • DISTANCE OF HEAD FROM FIRE (FT)
0
1
2
3
4
5
6
7
8
9
$q_r = 1.0$ W/cm²
200
400
600
1000
1200
1400
1600
2200
Q • (KW)

FIRE AREA	ROOM		CONFIGURATION				Q Btu/sec		
	#	NAME	CEIL-ING HEIGHT	CABLE TRAY HEIGHT	SPRINK-LER HEIGHT	SPRINK-LER SPACING	T_c=200 CEILING HEAD ACTUATION	T_c=1000 CABLE TRAY IGNITION	qr = 1.0 w/cm^2 LOWER HEAD ACTUATION
EA57	125	Corridor	12.5	8	7.5	6.5	300	1100	900
SB 8	79	Corridor	20	7.75	7.0	8.5	1000	1050	1045
	79	Corridor	20	11.5	11.25	8.5	1000	2750	1640
AA21a	175	CCW HX	20	14.0	8.5	7.0	1000	4450	1045
	179	Boric Acid Pump	17	----	9	9	700	----	1330

TABLE 2

WORST CASE HEAD PLACEMENT COMPARISON

5.5 Protected Area per Sprinkler

The specific occupancy classification for a facility where the primary fire hazard is combustible cable insulation would be considered ordinary hazard. Ordinary hazard being defined as having a moderate amount of combustible and having a moderate rate of heat release. Based upon this type of occupancy, the standard permits a maximum protected area of coverage per sprinkler head to be 130 ft^2. Even for a hazardous occupancy, the standard allows 90 ft^2 coverage per sprinkler. (Refer to Sections 4-2.2.2 and 4-2.2.3 in NFPA 13.) As shown in Table 2 head spacing below the cable trays is closer to these limits.

5.6 Cable Tray Water Spray Protection

For arrays of four or more cable trays, water spray nozzles are installed above the cable trays in addition to the sprinklers below. For these cases, actuation of the lower heads was not evaluated for comparison with tray ignition, since the trays are covered by the overhead sprays.

6.0 CONCLUSION

Based upon the above justification, the installed automatic wet pipe/ water spray nozzle systems with sprinkler placement, described in section 3.0 of this report can achieve its intended objective as well as or better than ceiling level sprinklers.

This conclusion is based upon:

- The postulated fire scenarios in the areas of the sprinkler protection - the sprinklers and water spray nozzles will actuate prior to the ignition of the IEEE 383 qualified cables in trays.

- The sprinklers are installed below physical obstructions - the sprinklers will deliver a uniform water density on the fire area with minimal interference with the discharge pattern.

- The decreased protected area per sprinkler reduces sprinkler operation time - the decreased protected area per sprinkler will enhance the sprinkler performance.

- Cable tray water spray protection - in addition to sprinkler area protection water spray protection is provided for accumulation of grouped electrical cable trays.

File Ref: CP-01-001-29

REFERENCES

1. NFPA #13, "Standard for the Installation of Sprinkler Systems", National Fire Protection Association, Quincy, Massachusetts.

2. 10 CFR 50.98, Appendix R "Fire Protection Program for Operating Nuclear Power Plants, November 19, 1980, USNRC.

3. NUREG 0800, "Standard Review Plan 9.5.1 Fire Protection Program", Rev. 3, July 1981, USNRC.

4. EPRI NP-1881, "Categorization of Cable Flammability - Intermediate - Scale Fire Tests of Cable Tray Installing", August 1982, Electric Power Research Institute, Palo Alto, California.

5. David D. Evans and Daniel Madrgykowski, "Characterizing the Thermal Response of Fusible Link Sprinklers", NBSIR 81-2329, US Department of Commerce, National Bureau of Standards, August 1981.

6. Gunner Heskestad, "Engineering Relations for Fire Plumes", SFPE Technology Report 83-8, Society of Fire Protection Engineers, Boston, Massachusetts.

7. Ronald L. Alpert and E.J. Ward, "Evaluating Unsprinklered Fire Hazards, SFPE Technology Report 83-2, Society of Fire Protection Engineers, Boston, Mass.

8. P. Nash and R.A. Young, "The Performance of the Sprinkler in Detecting Fire," Building Research Establishment, Fire Research Station, Borehamwood, Hetfordshire, United Kingdom.

File Ref: CP-01-001-29

APPENDIX A

Appendix A
Fire Exposure Calculations

Plumes

Correlations for predicting plume temperature above a fire area well established and have provided the input for design of detection systems. These correlations can be used to quantify the size of exposure fire necessary to ignite cables. They, likewise, can be used to evaluate sprinkler system response.

The correlation commonly used relates fire size, Q, height above the fire, H, and plume temperature above ambient, T, as follows (in British units). And a constant K which has the following values:

$$\Delta T = \frac{300\ (k\ Q)^{2/3}}{H^{5/3}}$$

K=1 open area
K=2 against wall
K=4 in corner

This equation was used to develop Figure 2, a plot of height above the fire (in feet) vs. fire size (in BTU/sec) for temperature increases of 200°F, 800°F. Table A.1 shows the points plotted in Figure 2, and 1000°F increase for autoignition of the cables.

Fire Exposure Calculations

Radiant Heat Flux

Class A (Wood)

The radiant heat flux from a fire involving stacked wood was calculated using Equations 4 and 5 from Alpert and Ward's report entitled "Evaluating Unsprinklered Fire Hazards."[7]

$$qr = \frac{2}{\pi} \tan^{-1}\left(\frac{A_p}{2R^2}\right)\frac{YQ}{A_f}$$

$$Ap = \frac{Df\ H_t}{2}$$

$$Af = \frac{\pi\, Df^2}{4}\left(1 + \sqrt{1 + 4\left(\frac{H_t}{D_f}\right)^2}\right)$$

$$H_f = .011\ (KQ)^{.4}$$

$$H_t = H_f + H_p$$

where:

qr = radiant flux received at sprinkler (kW/m^2)

R = minimum straight line distance from flame zone to sprinkler head (m)

Fire Exposure Calculations

Radiant Heat Flux

Class A (Wood)

Df = equivalent diameter of fire obtained from floor area of stacked wood (m)

Ap = Flame area projected onto a flat surface (m^2)

Y = Fraction of total heat release that appears as radiation 0.4 per Alpert and Ward

Q = heat release rate of stacked wood: $3387 \frac{kW}{m^2 m}$ of stacked wood height obtained by multiplying 3387 x Hp x floor area of wood stack

Af = Total surface area of flame outer envelope (m^2)

Hf = Flame height above wood (m)

Hp = Height of wood stack (m)

Ht = Total height of flame above floor (m)

These calculations were performed varying the wood stack height and the distance from the fire to the sprinkler.

Fire Exposure Calculations

Radiant Heat Flux

Class B (Pool Fire - Combustible Liquid)

The radiant heat flux from a pool fire was calculated using Equation 6 from Alpert and Ward's report entitled "Evaluating Unsprinklered Fire Hazards."[7]

$$qr = \tan^{-1}\left(\frac{D_f^2}{2R^2}\right)\frac{Y\,\dot{Q}}{2\;D_f}$$

where:

qr = radiant flux received at sprinkler (kW/m^2)

Df = diameter of pool fire (m)

R = minimum straight-line distance from flame zone to sprinkler head (m)

Y = fraction of total heat release that appears as radiation is 0.4 per Alpert and Ward

Q = total heat release rate of burning fuel (kW) obtained by multiplying area of pool fire by heat release rate of fuel: 3291 kW/m^2 for kerosene

Calculations were performed varying the pool diameter and distance from the fire to the sprinkler.

Appendix A Cont'd

Fire Exposure Calculations

To determine the pool fire size necessary to actuate a sprinkler head it is necessary to establish the minimum distance of the head from the fire. The methodology described by Alpert and Ward assumes the flame is cone shaped with the height of the flame equal to twice the pool diameter (H_f=2d). The distance of the head from the flame, R, is shown graphically in figure A-1. To calculate R, the square root is taken of the sum of the squares of the horizontal and vertical separation.

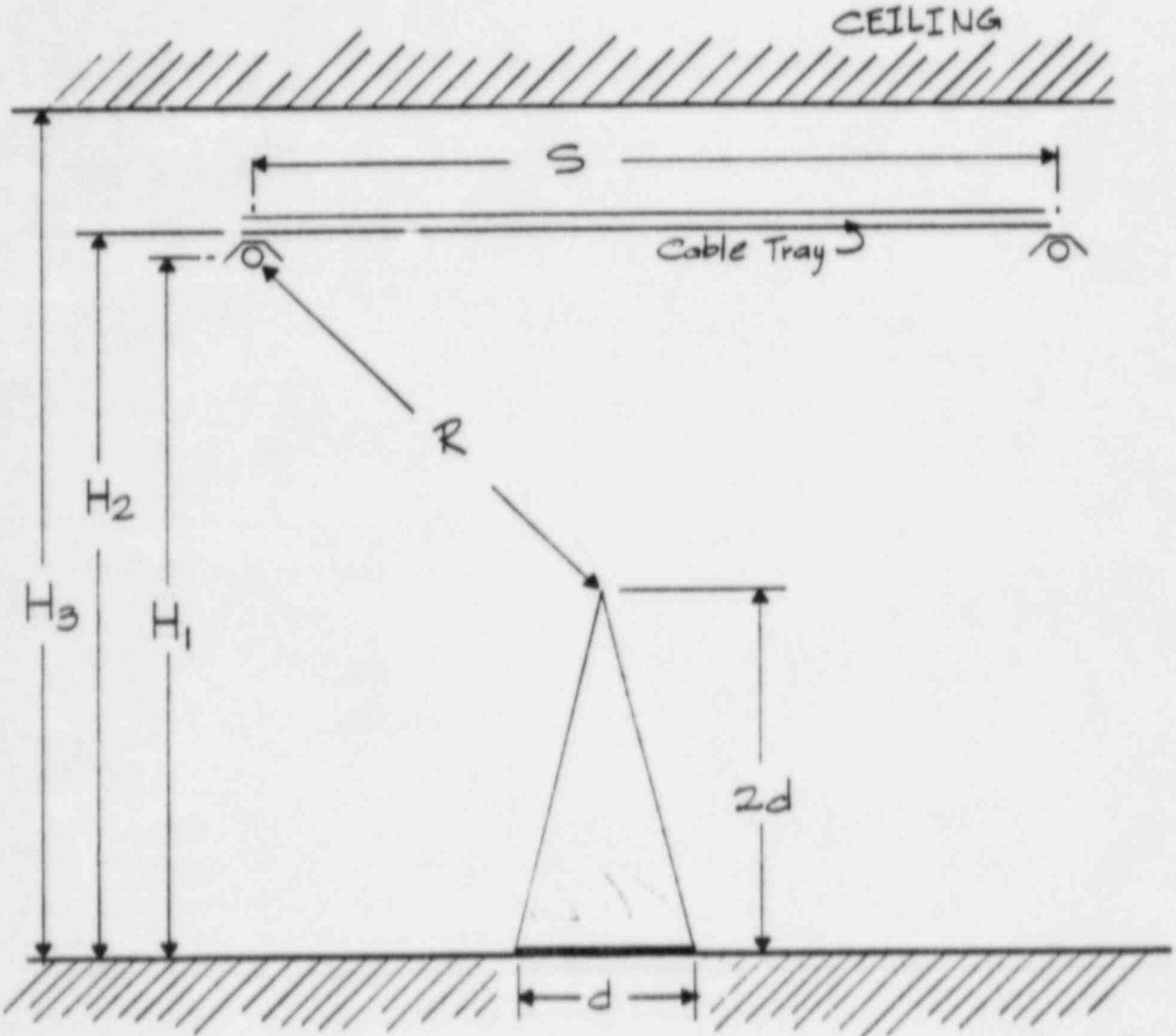


FIGURE A-1

H_1 – Height of Sprinkler Above Floor
H_2 – Height of Tray Above Floor
H_3 – Ceiling Height
S – Spacing between Heads
d – Pool Fire Diameter

$$R = \left[\left(\frac{S}{2}\right)^2 + (H_1 - 2d)^2 \right]^{1/2}$$

Appendix A Cont'd

Fire Exposure Calculations

AA 21a Room 175 CCW HX

Case 1

H_1	H_2	H_3	S
8.5	14	20'	7.0

Assume $R \approx 5$

$R = ((3.5)^2 + (4^2))^{1/2} = 5.3$

$R \approx 5 \quad Q \sim 1102$ KW = 1045 BTU/sec

Assume $R \approx 6$

$R = ((3.5)^2 + (3.5)^2)^{1/2} = 4.9$

AA 21 Room 179 Boric Acid Pumps

H_1	H_3	S
9	17	9

Assume $R \approx 6$

$R = ((4.5)^2 + (4^2))^{1/2} = 6 \quad Q \approx 1413$ KW = 1330 BTU/sec

Appendix A Cont'd

Fire Exposure Calculations

SB8 Room 79 Corridor

Case 1

H_1	H_2	H_3	S
7'	7.75	20'	8.5

Assume $R \approx 5$

$R = ((4.25)^2 + (2.5^2))^{1/2} = (18.06 + 6.25)^{1/2} = 4.9$ ok

$Q \sim 1102$ KW = 1095 BTU/sec

Case 2

11.25	11.5	20	8.5

Assume $R \approx 6$

$R = ((4.25)^2 + (6.25)^2)^{1/2} = 7.0$

Assume $R \approx 7$

$R = ((4.25)^2 + (1.25 - 5.4)^2)^{1/2} = 7.2$ ok

$Q \sim 1730$ KW = 1640 BTU/sec

Appendix A Cont'd

Fire Exposure Calculations

EA57 Room 125 Corridor

H_1	H_2	H_3	S
7.5	8	12.5	6.5

Assume $R \approx 5$

$R = ((3.25)^2 + 3^2) = 4.4$

Assume $R \approx 4$ $R \approx 4.5$ $Q \sim 950$ KW = 900 BTU/sec

$R = ((3.25)^2 + (3.4)^2)^{1/2} = 4.7$

NOTE: 1.055 KW = 1 BTU/sec

TABLE A-1

T (of)	H (feet)	Q (BTU/sec)
200	8.05479988912	100
200	12.5025523464	300
200	15.3384880094	500
200	17.5494290202	700
200	19.4062940525	900
200	21.029072003	1100
200	22.483032332	1300
200	23.8081953476	1500
200	25.0311275804	1700
200	26.1704955658	1900
200	27.239980329	2100
200	28.2499859	2300
200	29.208573476	2500
200	30.1221893244	2700
200	30.9960558096	2900
200	31.8344759704	3100
200	32.6410434942	3300
200	33.4187950398	3500
200	34.1703231054	3700
200	34.8978612148	3900
200	35.6033492806	4100
200	36.288484501	4300
200	36.9547614734	4500
200	37.603504224	4700
200	38.2358920372	4900
800	3.50605529032	100
800	5.442051994	300
800	6.6764646884	500
800	7.63883265972	700
800	8.44708010944	900
800	9.15343523872	1100
800	9.78630823048	1300
800	10.3631189357	1500
800	10.8954311076	1700
800	11.3913698283	1900
800	11.8563935922	2100
800	12.2965205699	2300
800	12.713770046	2500
800	13.1114444418	2700
800	13.4918169224	2900
800	13.8567604934	3100
800	14.2078394003	3300
800	14.5463754235	3500
800	14.8734970137	3700
800	15.1901763687	3900
800	15.4972570859	4100
800	15.7954803119	4300
800	16.0854942085	4500
800	16.3678758915	4700
800	16.6431386754	4900

```
10   T=200
20   Q=100
30   H=(300*Q^.667/T)^.6
40   PRINT T,H,Q
50   PRINTER IS 7,1
60   Q=Q+200
70   IF Q<5000 THEN 30
80   IF T=800 THEN 100
90   T=800
91   GOTO 20
100  STOP
```

1000	4.76010660368	300
1000	5.83983462248	500
1000	6.68160793512	700
1000	7.3885736216	900
1000	8.00641514904	1100
1000	8.55998261072	1300
1000	9.0645129696	1500
1000	9.53012092144	1700
1000	9.96391339248	1900
1000	10.3711022146	2100
1000	10.7556393853	2300
1000	11.1206031885	2500
1000	11.4684448703	2700
1000	11.8011527457	2900
1000	12.120365113	3100
1000	12.4274502021	3300
1000	12.7235641617	3500
1000	13.0096940333	3700
1000	13.2866901907	3900
1000	13.5552912183	4100
1000	13.8161432905	4300
1000	14.0698154467	4500
1000	14.316811785	4700
1000	14.5575812949	4900

```
10    T=1000
20    Q=100
30    H=(300*Q^.667/T)^.6
40    PRINT T,H,Q
50    PRINTER IS 7,1
60    Q=Q+200
70    IF Q<5000 THEN 30
80    STOP
```

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
12	2	1	2303	233.62
12	2	2	2303	114.83
12	2	3	2303	56.49
12	2	4	2303	32.41
12	2	5	2303	20.86
12	2	6	2303	14.52
12	2	7	2303	10.68
12	2	8	2303	8.18

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
12	3	1	3454	319.55
12	3	2	3454	185.98
12	3	3	3454	98.10
12	3	4	3454	57.31
12	3	5	3454	37.08
12	3	6	3454	25.86
12	3	7	3454	19.03
12	3	8	3454	14.58

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
12	4	1	4605	382.22
12	4	2	4605	248.14
12	4	3	4605	159.93
12	4	4	4605	83.47
12	4	5	4605	54.38
12	4	6	4605	38.01
12	4	7	4605	28.01
12	4	8	4605	21.47

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR (kW/m2)
12	5	1	5757	429.57
12	5	2	5757	300.57
12	5	3	5757	179.95
12	5	4	5757	109.83
12	5	5	5757	72.11
12	5	6	5757	50.56
12	5	7	5757	37.30
12	5	8	5757	28.62

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR (kW/m2)
15	2	1	2878	250.31
15	2	2	2878	131.74
15	2	3	2878	66.55
15	2	4	2878	38.42
15	2	5	2878	24.77
15	2	6	2878	17.25
15	2	7	2878	12.69
15	2	8	2878	9.72

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR (kW/m2)
15	3	1	4317	344.17
15	3	2	4317	212.17
15	3	3	4317	115.82
15	3	4	4317	68.36
15	3	5	4317	44.30
15	3	6	4317	30.98
15	3	7	4317	22.31
15	3	8	4317	17.48

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
15	4	1	5757	411.98
15	4	2	5757	281.46
15	4	3	5757	165.08
15	4	4	5757	99.92
15	4	5	5757	65.41
15	4	6	5757	45.81
15	4	7	5757	33.78
15	4	8	5757	25.91

STACKED WOOD FIRE RADIANT HEAT FLUX CALCULATIONS

FLOOR AREA OF PALLETS (ft2)	HEIGHT OF PALLETS (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF PALLETS (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
15	5	1	7196	464.56
15	5	2	7196	339.43
15	5	3	7196	211.77
15	5	4	7196	131.55
15	5	5	7196	87.03
15	5	6	7196	61.19
15	5	7	7196	45.20
15	5	8	7196	34.70

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	1	60	3.12
1.0	1	240	23.25
1.5	1	540	63.51
2.0	1	961	111.06
2.5	1	1501	158.12
3.0	1	2161	203.45
3.5	1	2942	247.33
4.0	1	3842	290.18
4.5	1	4863	332.30
5.0	1	6003	373.90

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	2	60	.78
1.0	2	240	[illegible]
1.5	2	540	20.63
2.0	2	961	[illegible]
2.5	2	1501	83.16
3.0	2	2161	127.02
3.5	2	2942	174.19
4.0	2	3842	222.12
4.5	2	4863	269.61
5.0	2	6003	[illegible]

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	3	60	.35
1.0	3	240	2.78
1.5	3	540	9.36
2.0	3	961	21.73
2.5	3	1501	41.90
3.0	3	2161	69.76
3.5	3	2942	104.90
4.0	3	3842	145.78
4.5	3	4863	190.52
5.0	3		

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	4	60	.20
1.0	4	240	1.57
1.5	4	540	5.28
2.0	4	961	12.47
2.5	4	1501	24.19
3.0	4	2161	41.25
3.5	4	2942	64.18
4.0	4	3842	93.02
4.5	4	4863	127.34
5.0	4	6003	166.31

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	5	60	.13
1.0	5	240	1.08
1.5	5	[illegible]	3.38
2.0	5	961	8.61
2.5	5	1501	15.59
3.0	5	2161	26.58
3.5	5	2942	42.18
4.0	5	3842	62.13
4.5	5	4863	85.05
5.0	5	6003	116.27

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	6	60	.09
1.0	6	[illegible]	.70
1.5	6	[illegible]	2.35
2.0	6	961	5.87
2.5	6	1501	10.06
3.0	6	2161	18.71
3.5	6	2942	27.58
4.0	6	3842	[illegible]
4.5	6	4863	61.08
5.0	6	[illegible]	[illegible]

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	7	60	.06
1.0	7	240	.31
1.5	7	540	1.73
2.0	7	961	4.09
2.5	7	1501	7.99
3.0	7	2161	13.78
3.5	7	2942	21.83
4.0	7	3842	32.47
4.5	7	4863	45.99
5.0	7	6003	62.64

POOL FIRE RADIANT HEAT FLUX CALCULATIONS

POOL DIA. (ft)	DISTANCE FROM FIRE TO SPKLR. (ft)	HEAT OUTPUT OF POOL FIRE (kW)	RADIANT HEAT FLUX AT SPKLR. (kW/m2)
.5	8	60	.05
1.0	8	[illegible]	.37
1.5	8	[illegible]	[illegible]
2.0	8	[illegible]	3.[illegible]
2.5	8	[illegible]	6.[illegible]
3.0	8	2161	10.[illegible]
3.5	8	2942	16.75
4.0	8	3842	[illegible]
4.5	8	4863	[illegible]
5.0	8	[illegible]	[illegible]