PROFESSIONAL LOSS CONTROL, INC.

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

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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 "non-standard" aspect of the installation of sprinkler placement. 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.

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 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. In order to determine "equivalent performance" as referred to in NFPA 13, the existing system must be capable of meeting this design objective.

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 a combination wet pipe system and closed nozzle water spray system. Generally, 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 non-standard sprinklers 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.

The position of sprinklers relative to the ceilings varies with the specific plant areas. Generally, sprinklers which are provided in rooms, are located just below the ceiling. However, sprinklers in hallways and corridors are generally positioned below obstruction, such as from piping, conduit, and HVAC ducts. These corridor sprinklers are located 6 to 8 feet above the floor.

The sprinklers which are located some distance from the ceiling are, in most cases, spaced less than 10 feet between branch lines and less than 10 feet between sprinklers. Many sprinklers which are not adjacent to the ceiling are provided with heat collector pans above the sprinklers.

4.0 NON-STANDARD 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."

In general, the sprinklers located in the corridors areas of the plant do not comply with these section of NFPA 13.

One reason for the non-standard sprinkler placement is obstructions in the upper portion of the corridor. These obstructions include conduit, cable trays, light fixture, piping, seismic hangers, etc. If sprinklers are located at the ceiling level and obstruction are located between the sprinklers and the floor, then the adequacy of water distribution patterns may be jeopardized.

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 and 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. Specific areas evaluated include:

- Fire properties of cabling insulation and jacketing materials
- Fire scenarios for cable ignition (Fire size)
- Obstructions
- Protected area per sprinkler
- 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 polyethylne 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.

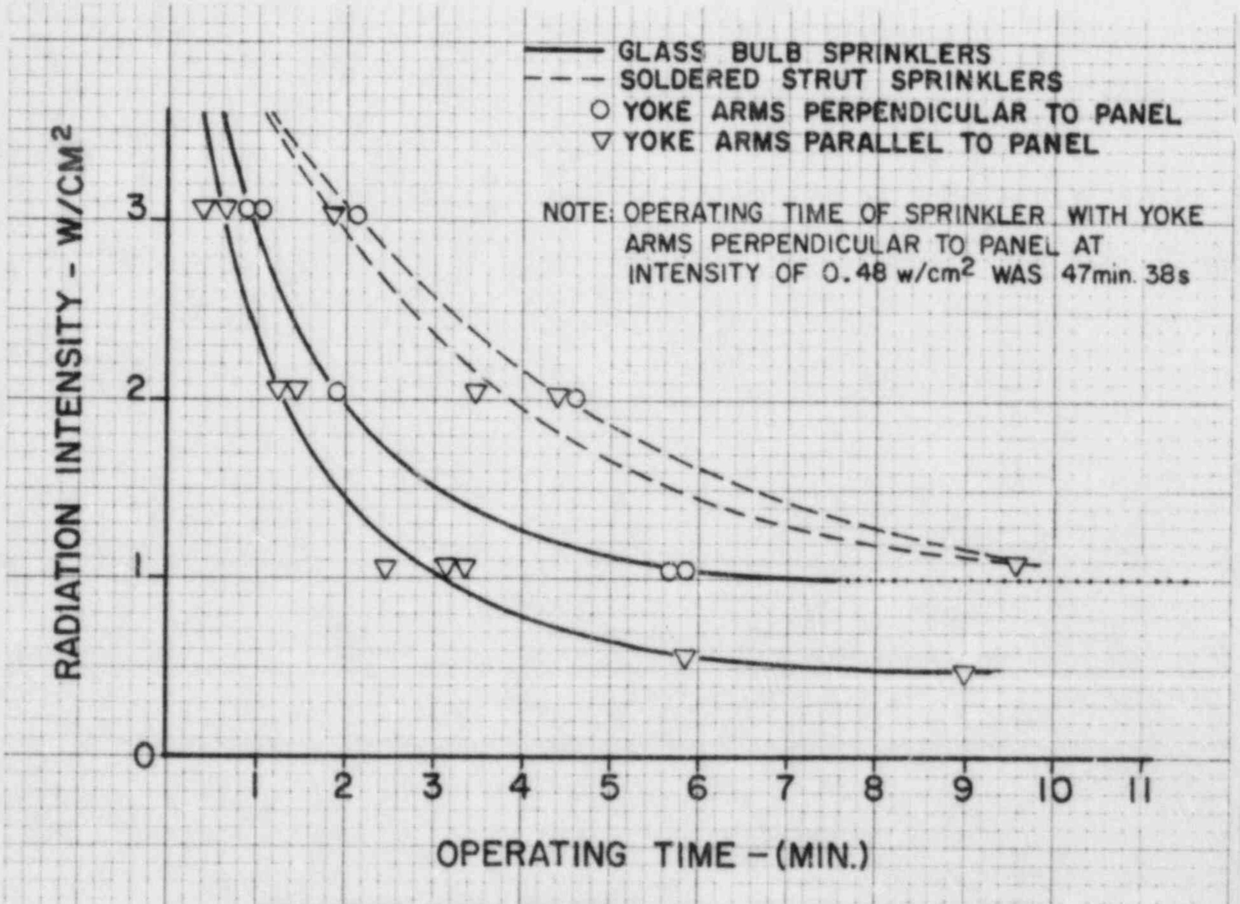
Tests indicated that pyrolysis of the jacketing material occurs at about 850°F. Auto ignition of these types of cables did not occur until about 1100°F. Based on these temperature criteria, fire sizes, necessary to ignite cables in ladder type cable trays can be assessed using plume calculation.

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). 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 ralationships 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 plumes 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

It would be expected that the "durospeed" type sprinklers used at Comanche Peak would operate faster than the soldered strut sprinklers used in the above tests by Nash and Young.

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, must be known. 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 must 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 and using the calculation in the Appendix, it can be concluded that the sprinkler system as designed will actuate prior to cable ignition.

Additional limited tests conducted by Union Carbide Corporation in Oak Ridge, Tennessee, in July, 1973, demonstrated that sprinklers on a 6 ft by 8 ft spacing, 5 ft. to 7 ft. above the floor, actuated outside the plume from the radiant heat of a kerosene pan fire (see Appendix B). These tests support the conclusions above.

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 the appendix 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.

5.3 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 noticable 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.

5.4 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.)

The coverage provided by sprinklers in corridors with the placement of the sprinklers 6 to 8 ft. above the floor will enhance the sprinklers performance. In general, the spacing of sprinklers on branch lines ranges from 6 ft. on center to 9 ft. on center. Distance between branch lines also range from 6 ft. on centers to 9 ft. on center. With the closer spacing of the sprinklers, the response time for sprinklers in a given fire situation will be improved, since sprinklers will be close to the fire source (flame and plume).

5.5 Cable Tray Water Spray Protection

The purpose of the water spray nozzles is to provide fire suppression capability for groups of cable trays. The water spray nozzles are connected to the automatic wet pipe sprinkler systems. The directional nozzles are UL listed for the protection of special hazards. These nozzles are the closed type with a 175°F quartzoid bulb actuating mechanism. The nozzles are installed to impinge water spray on the upper surfaces of group cable trays. Actuation of these nozzles will mitigate fire propagation along vertical and horizontal cable trays. The corridors that contain the non-standard sprinkler placement have water spray nozzles protecting the cable trays above the sprinklers for cable tray arrays of greater than four (4) trays.

6.0 CONCLUSION

Based upon the above justification, the installed automatic wet pipe/ water spray nozzle systems with non-standard 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.

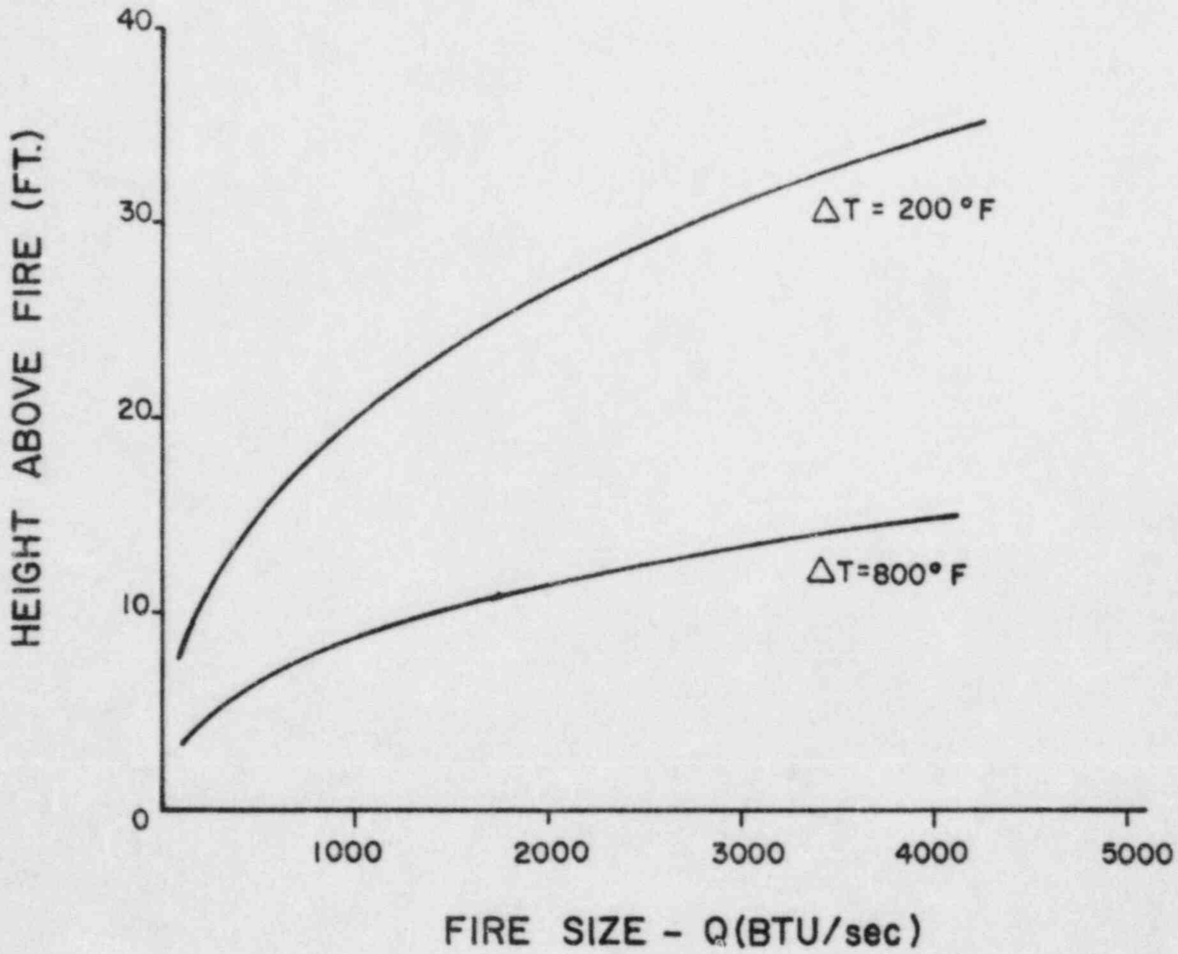

HEIGHT ABOVE FIRE (FT.)
40
30
20
10
0
1000
2000
3000
4000
5000
ΔT = 200 °F
ΔT=800° F
FIRE SIZE - Q(BTU/sec)

FIGURE 2

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.

9. J.R. DeMonbrun and J.W. McCormick, "Experiments with Sprinkler Head Canopies for Fire Protection", Y-JA-96, USAEC July 2, 1973.

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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, ΔT, as follows (in British units).

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

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 and 800°F. Table A.1 shows the points plotted in Figure 2.

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]

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

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

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

$$H_f = .011\ (K\dot{Q})^{.4}$$

$$H_t = H_f + H_p$$

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]

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

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.

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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	27.239988329	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	11.8568935922	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	15.4972578859	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
```

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	139.93
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	131.94
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	343.17
15	3	2	4317	212.17
15	3	3	4317	115.82
15	3	4	4317	68.36
15	3	5	4317	44.38
15	3	6	4317	30.98
15	3	7	4317	22.81
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	131.65
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	6.24
1.5	2	540	20.63
2.0	2	961	46.51
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	316.25

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	21.93
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	6003	237.43

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	1.00
1.5	5	540	3.38
2.0	5	961	8.01
2.5	5	1501	15.59
3.0	5	2161	26.80
3.5	5	2942	42.18
4.0	5	3842	62.13
4.5	5	4863	86.85
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	240	.70
1.5	6	540	2.35
2.0	6	961	5.57
2.5	6	1501	10.86
3.0	6	2161	18.71
3.5	6	2942	29.58
4.0	6	3842	43.87
4.5	6	4863	61.88
5.0	6	6003	83.81

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	.51
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	240	.39
1.5	8	540	1.32
2.0	8	961	3.13
2.5	8	1501	6.12
3.0	8	2161	10.56
3.5	8	2942	16.75
4.0	8	3842	24.95
4.5	8	4863	35.41
5.0	8	6003	48.37

APPENDIX B

2

Y-JA-96

EXPERIMENTS WITH SPRINKLER HEAD CANOPIES FOR FIRE PROTECTION

J. R. DeMonbrun
J. W. McCormick

UNION CARBIDE

OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

prepared for the U.S. ATOMIC ENERGY COMMISSION
under U.S. GOVERNMENT Contract W-7405 eng 26

MASTER

Y-JA-96

EXPERIMENTS WITH SPRINKLER HEAD CANOPIES FOR FIRE PROTECTION

J. R. DeMonbrun
J. W. McCormick

July 2, 1973

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EXPERIMENTS WITH SPRINKLER HEAD CANOPIES

FOR FIRE PROTECTION

Test I - Setup and Procedures

Kerosene was placed in a 30-gallon trash can to a level of about 7 inches above the bottom of the can. The sprinkler heads with or without canopy were placed 3 feet above the rim of the can. The canopy was installed between the sprinkler and the elbow fitting that the sprinkler screwed into. The sprinklers were supported on a length of 1-inch pipe and elbow. The test procedure was to light the kerosene in the can and place the different pendant sprinklers in combination with the canopy over the rim of the container. The time required to actuate the sprinklers was recorded. This procedure was repeated 70 times with different combinations of sprinklers and canopies. See Figure I for types of canopies. The results of Test I are shown in Figure II of this report. The painted black sprinklers were sprayed with black paint to determine the effects of heat absorption upon actuation.

Test I - Conclusions

1. The presence of a canopy installed immediately above the sprinkler had a significant effect on the time of sprinkler actuation as opposed to sprinklers without canopies.
2. Canopies II and I produced the shortest actuation times.
3. Sprinklers that were painted black had shorter actuation times than normal (unpainted) sprinklers.
4. Grinnell 135° Quartzoid bulb sprinklers had shorter actuation times than Grinnell 165° Duraspeed sprinklers.

Test II - Setup and Procedures

The actual installation, shown schematically in Figure III, to be simulated basically consisted of an enclosure with a 3-foot wide opening in the ceiling running the length of the enclosure. Due to a complex of piping, fixtures and structural interferences, it was realized that it would be expensive and probably ineffective to install sprinklers near the ceiling as per code. Therefore, it was necessary to determine if sprinklers could be installed 3 feet below the ceiling and still actuate in a reasonable period of time. It was felt that canopies placed immediately above the sprinkler should be an effective heat bank. In the simulated enclosure, sprinklers were placed at high and low positions to determine the difference, if any, in the actuation times. The simulated enclosure and test setup were arranged as shown in Figure III.

The procedure was to install various combinations of canopies and sprinkler positions. The fire was ignited, and the times of actuation were recorded. Tests A-M were run with the results shown in Figure IV. Table I below shows the sequence of operation in the tests. Note that not all positions were tested in the later tests. All sprinklers were 135° Grinnell Quartzoid bulb sprinklers.

Table I

Test	Sequence	Test	Sequence
A	3-4-1-2	H	1-2
B	3-1-2-4	I	1-2
D	3-1-4-2	J	1
E	3-4-2-1	K	1
F	1-3-4-2	L	1
G	1-2	M	1

Test II - Conclusions

1. In most cases, the sprinklers installed under canopies actuated sooner than those not under canopies.

2. Canopies III and I had the shortest actuation times.

Summary

Test I demonstrated that the installation of canopies had a significant effect on sprinkler actuation times. Test II did not demonstrate this so conclusively, probably due to the high heat source used. Test II did demonstrate that the sprinkler position in this specific case had little effect on sprinkler actuation times. Not all fires envisioned in this occupancy will begin as rapidly as that in Test II. Any slow buildup of heat due to smaller fires, which would result in a delay of sprinkler actuation, should be compensated for by the canopies. In this instance, the heat from such a fire will predominately rise through the opening in the ceiling. Therefore, any residual heat must be collected as efficiently as possible to actuate the sprinklers. Test I showed the advantage of canopies in such a limited fire situation.

FIGURE I

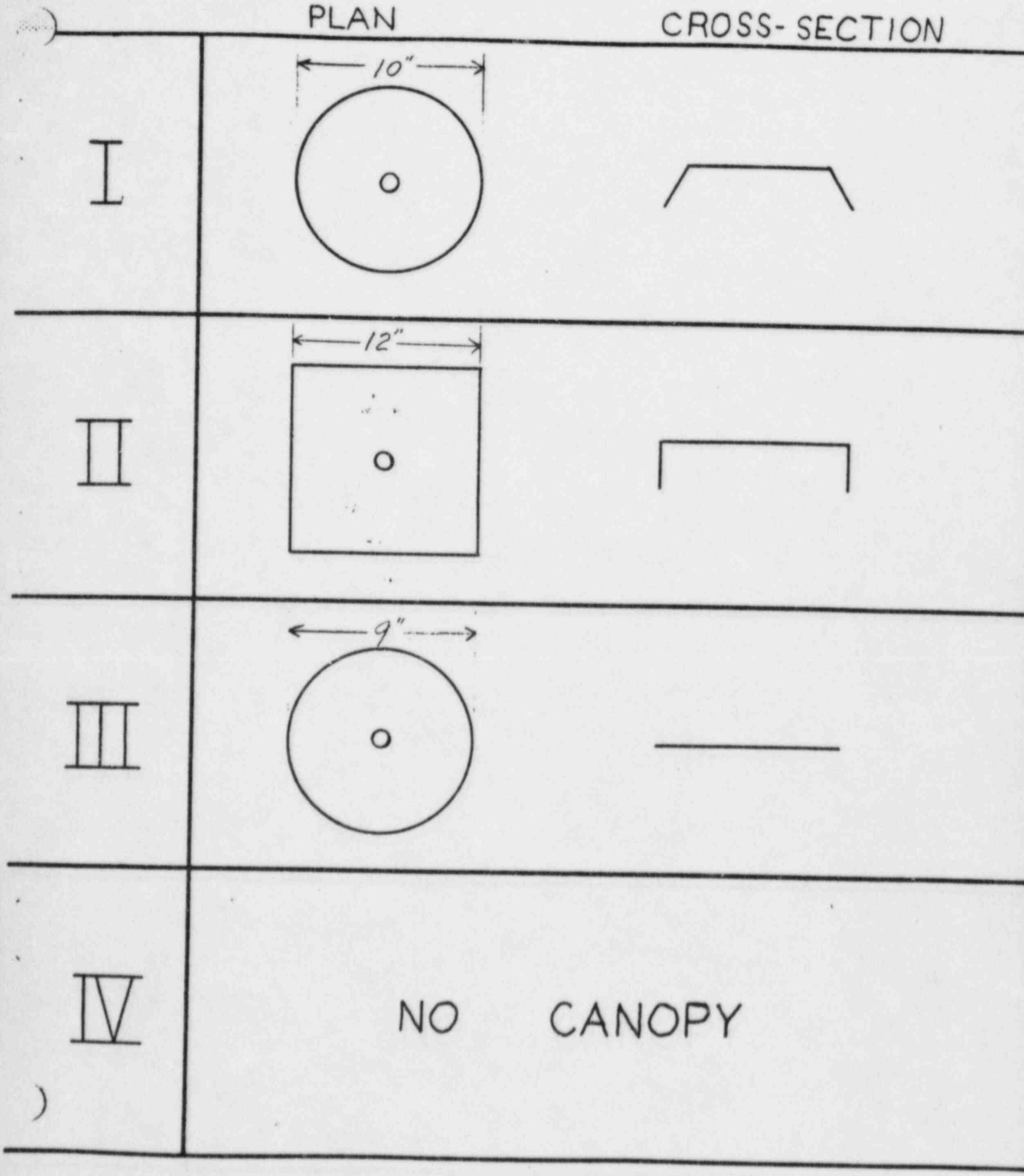


FIGURE II

165°

GRINNELL DURASPEED

A Normal I	A Normal II	A Normal III	A Normal IV	B Painted Black I	B Painted Black II	B Painted Black III	B Painted Black IV
A 9-4:49	A 7-2:52	*B20-6:00+	*B6-7:00+	A29-2:10	A24-1:44	*B23-6:00+	*B 9-7:00+
A11-6:20	A 8-3:33	B21-5:50	*B7-7:00+		A25-1:22	B24-2:45	*B10-7:00+
A12-3:56	A10-1:14	B22-4:00	*B8-7:00+	AVE-2:10	A26-1:51	B25-2:25	*B12-7:00+
A15-2:41	A13-1:05				A27-1:50		
A16-4:46	A14-1:17	AVE-4:55+	AVE-7:00+		A28-0:55	AVE-2:30+	AVE-7:00+
	A17-2:33				B17-1:04		
AVE-4:30	A22-1:51				B33-2:04		
	B 1-2:40						
	B 2-2:46				AVE-1:33		
	B 3-2:15						
	B 4-1:54						
	B 5-1:28						
	B11-1:20						
	B16-2:02						
	AVE-2:03						

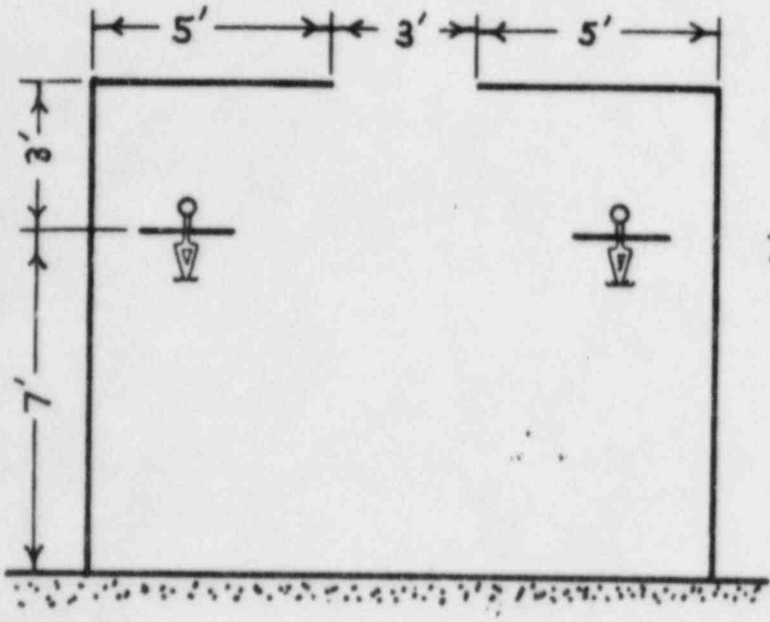
135°

GRINNELL QUARTZOID

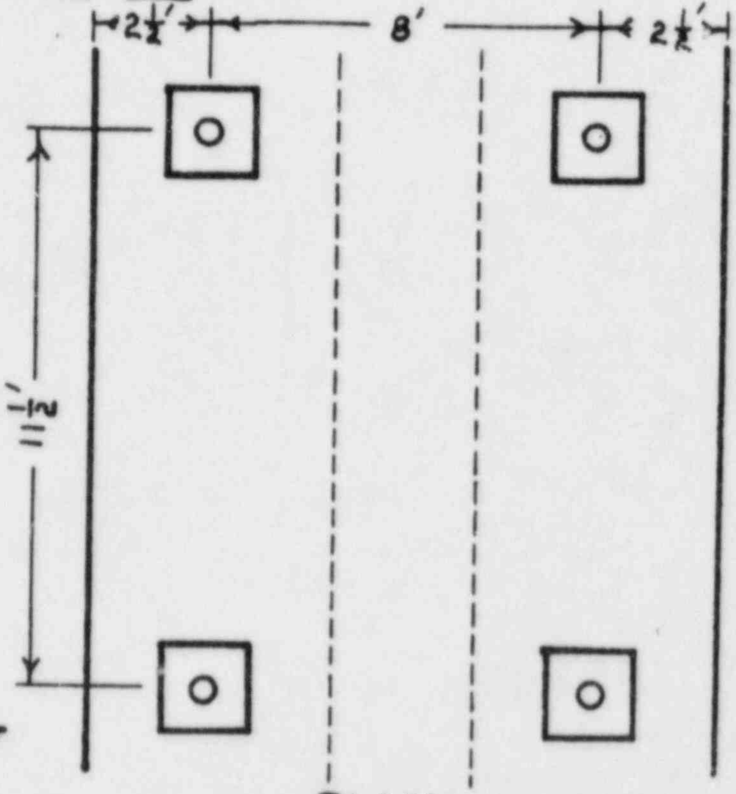
C Normal I	C Normal II	C Normal III	C Normal IV	D Painted Black I	D Painted Black II	D Painted Black III	D Painted Black IV
A23-1:20	A18-1:18	B00-8:00	*B13-7:00+	A35-1:45	A30-1:13	B32-1:34	*B15-8:00+
	A19-1:05	B27-1:50	*B14-9:00+		A31-0:55	B34-4:17	B18-6:24
AVE-1:20	A20-1:45	*B28-9:00+		AVE-1:45	A32-1:13	B35-1:37	*B19-7:00+
	A21-1:36	B30-6:28	AVE-7:00+		A33-1:04		
	B29-1:37	B31-5:30			A34-1:21	AVE-2:29	AVE-7:00+
	AVE-1:28	AVE-6:09			AVE-1:10		

*Did not actuate

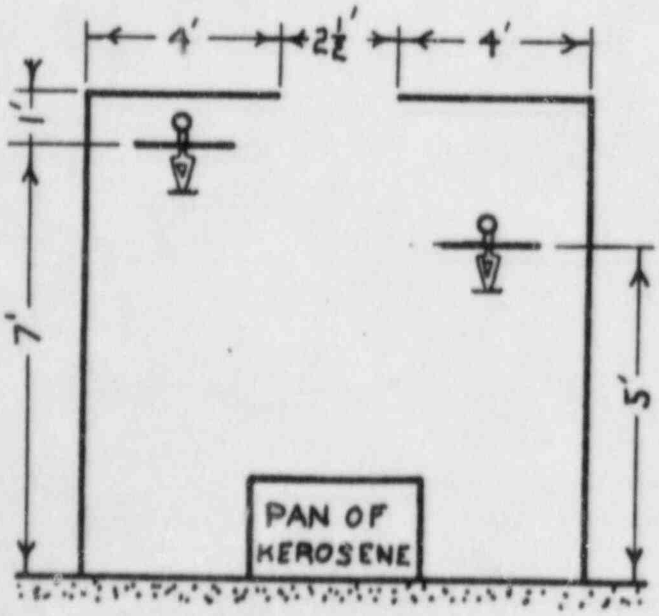
FIGURE III



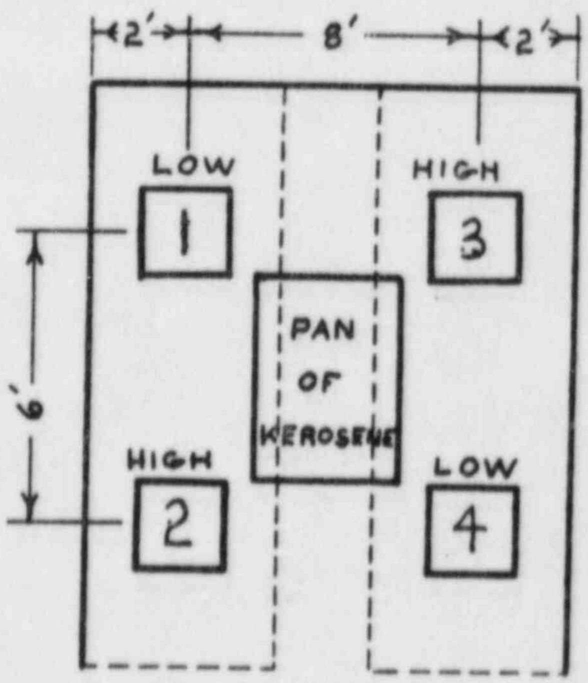
ELEVATION
ACTUAL INSTALLATION



PLAN
ACTUAL INSTALLATION



ELEVATION
TEST SITE



PLAN
TEST SITE

FIGURE IV

Canopy	Position (1)	Position (2)	Position (3)	Position (4)
I	B 0:58 L 0:35 AVE 0:46	A 1:21		
II	A 1:21 I 0:39 K 0:44 AVE 0:54	G 1:09 H 1:02 AVE 1:05		B 1:04
III	H 0:30 J 0:34 AVE 0:32	I 0:55	B 0:50	A 1:14
IV	D 1:00 E 1:25* F 0:40 G 0:44 AVE 0:48	B 1:02 D 1:38 E 1:11 F 1:02 AVE 1:13	D 1:34 E 1:00 F 0:57 AVE 1:10	D 1:17 E 1:07 F 0:57 AVE 1:07

*165° Grinnell Duraspeed

APPENDIX C

CPSES Unit 1 Fire Areas with Non-Standard Automatic Sprinkler Placement

FIRE AREA	FIRE ZONE	ROOM NO. - ROOM NAME	LOCATION
AA	21a	175 - CCW Ht. Exch.	Aux. 790
		179 - Boric Acid Tran. Pumps & Corridor	Aux. 790
		180 - Corridor	Aux. 790
AA	21b	207 - Corridors	Aux. 810
AA	21d	226 - Corridor	Aux. 852
AA	38	241 - Mechanical Equipment Room	Aux. 873
AA	43	113 - Mechanical Area	Aux. 778
SB	4	71 - Corridor	SG - 790
		70 - Corridor	SG - 790
		64 - Chemical Additive Tank	SG - 790
SB	8	79 - Corridor	SG - 810
		82 - Corridor	SG - 810
SB	15	94 - Corridor	SG - 831
		95 - Personnel airlock corridor	SG - 831
SB	144	88 - Non-Rad. Piping Pen. Area	SG - 831

Deviation 2g-1

Subject: Partial Sprinkler Coverage

Location
  Building: Auxiliary
  Elevattion: 822'-0"
  Room: 209
  Fire Area: AA
  Fire Zone: 21c

References:
  DBD-SY-1 Rev. 3 FHA 15 Rev. CP-3
  Grinnel Fire Protection Drawing 18 Rev. 6, Drawing 151 Rev. 3

Deviation: 10CFR50 Appendix R Section III.G.2

Description: The Train A Centrifugal Charging Pump power cables are routed through Fire Zone AA 21c and are protected by a one hour barrier installed around the conduit carrying tthese cables. Automatic suppression is not provided in this valve operating room at Elev. 822'-0". The area contains negilible combustible materials and automatic water sprinkler systems are installed in Fire Zone AA216b adjacent to this room.

Justifications:

1. An area-wide early warning smoke detection system is installed for assuring early detection and response by the plant fire brigade ensuring early fire extinguishment. Manual suppression is available using hose stations and portable extinguishers.

2. Automatic sprinklers are provided in Fire Zone AA21b in the corridor adjacent to this room.

3. This area contains negligible combustibles.

4. Essential redundant cables are protected within this fire zone with a one hour rated barrier.

5. The installation of an automatic suppression system in Fire Zone AA21c would not significantly enhance the fire protection provided by the current configuration.

Deviation 4e

Subject: MSIV/Turbine Stop Valve Separation

Location
- Bldg. Safeguard/Turbine
- Elev. 873'-6"/830'-0"
- Room 108/Turbine Deck
- Fire Area SK17/Outdoors
- Colmn.

References:
DBD SY1 Rev. 3 Drwg FHA-5
FHA-26

Deviation: 10CFR50 Appendix R Section III.G.2

Description: The operation of the Turbine Stop Valve (TS), Steam Dump to Condenser valves (SDC), and Feedwater Pump Turbine Stop valves (FPTS) are relied on for safe shutdown in the event of the failure of Main Steam Isolation Valves (MSIV). The MSIV's have 20 feet of separation from the TS, SDC and FPTS valves but do not have suppression or detection in the entire area.

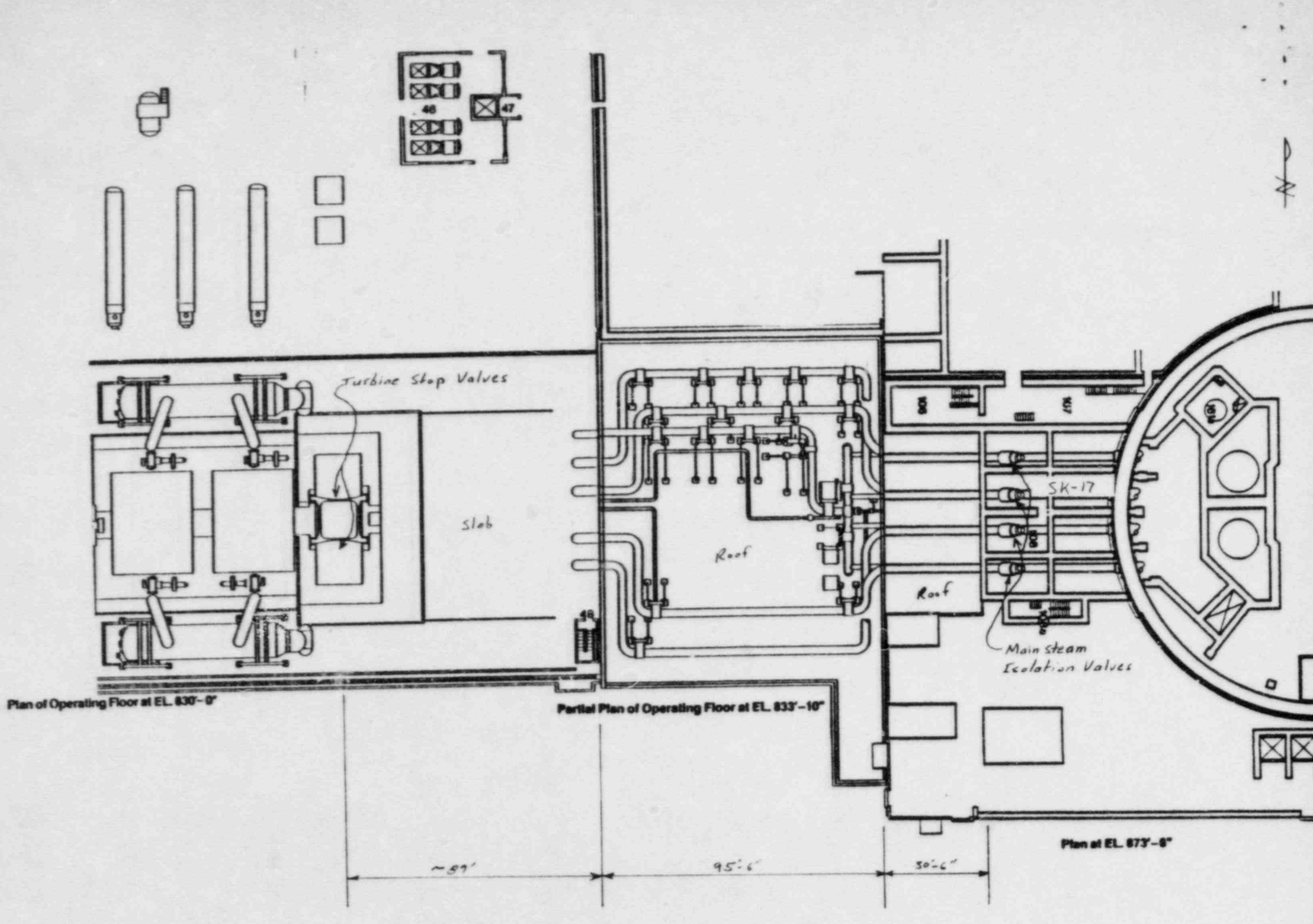
Justifications:

1. Main Steam Isolation Valves are located inside the Safeguard building (Fire Area SK) at elevation 873'-6". This area is protected by an automatic water suppression system and ionization detection.

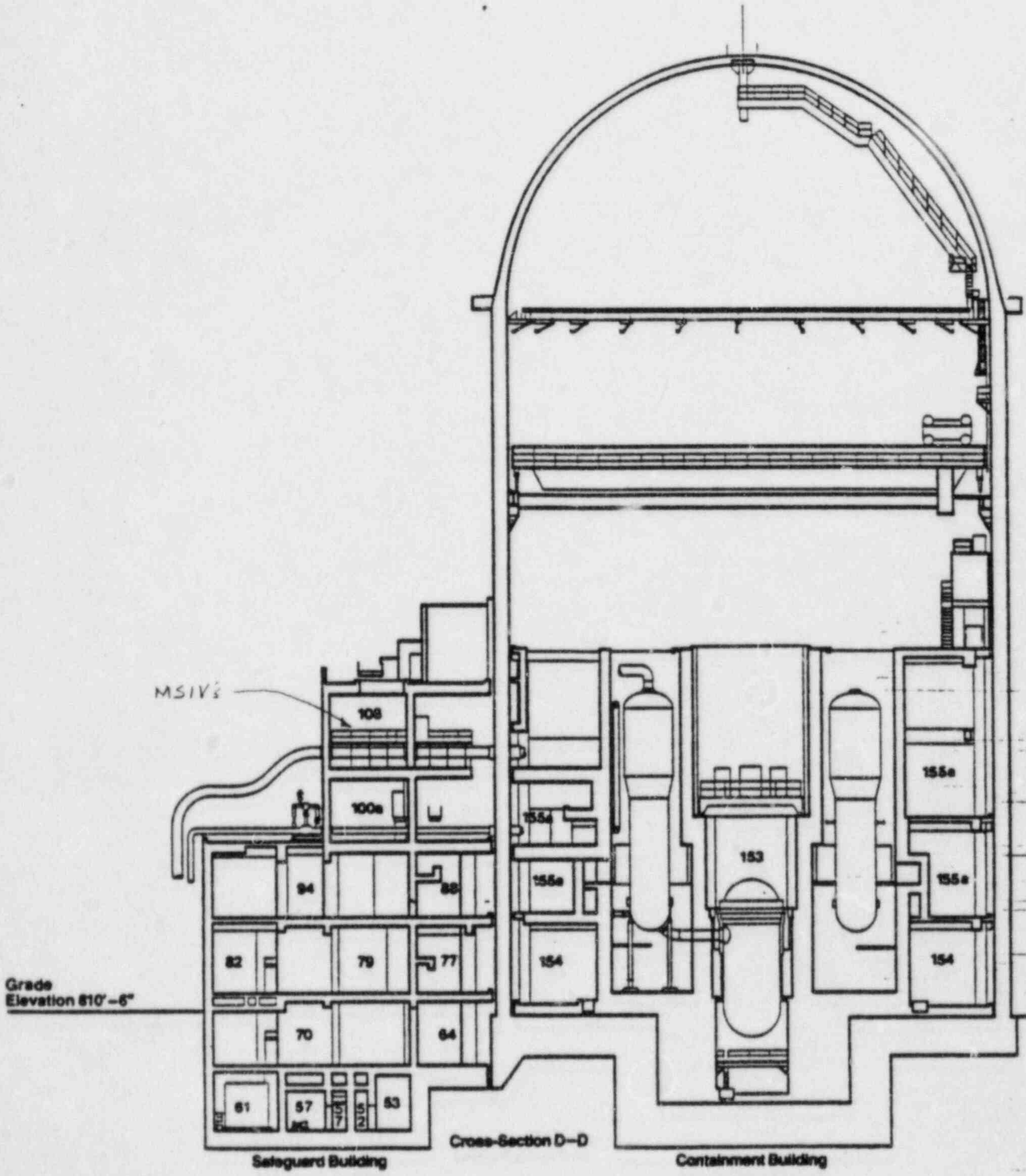
2. The Turbine Stop (TS) valve, Feedwater Pump Turbine Stop Valves (FPTS) and Steam Dump to Condenser (SDC) Valves are located in the Turbine building in the deck at Elevation 830'-0" and are horizontally separated from the outside wall of the Safeguard building by 120 ft.

3. The T.S., FPTs and SDC valves and associated control circuits are separated from Fire Area SK by three hour barriers and 20 foot of open air that does not contain intervening combustibles.

4. The open air space and separation distances provide adequate assurance that a fire will not affect both paths for maintenance of Secondary System Pressure Boundary integrity.



Turbine Stop Valves
Slab
Roof
Roof
SK-17
Main steam Isolation Valves
46
47
48
106
107
108
Plan of Operating Floor at EL. 830'-0"
Partial Plan of Operating Floor at EL. 833'-10"
Plan at EL. 873'-8"
~89'
95'-6"
30'-6"


MSIV's
108
100a
155a
153
155a
155a
155a
94
88
82
79
77
154
154
Grade
Elevation 810'-6"
70
64
61
57
53
Cross-Section D-D
Safeguard Building
Containment Building

Deviation 5b

Subject: Valve Isolation Tank Room - F.A. SB2c

Location
Bldg. Safeguard
Elev. 790-6
Room 65 & 67
F.A. SB2c
Col. N-S ____
E-W ____

Systems Path A ____
Path B ____

Reference Drawings: SK-TFHA-0601-01
SK-TFHA-0601-03

Exception: Appendix R to 10CFR50 Section III.G.2

Description: Redundant essential raceway is protected by a one hour rated envelope system, but general area sprinkler coverage is not provided.

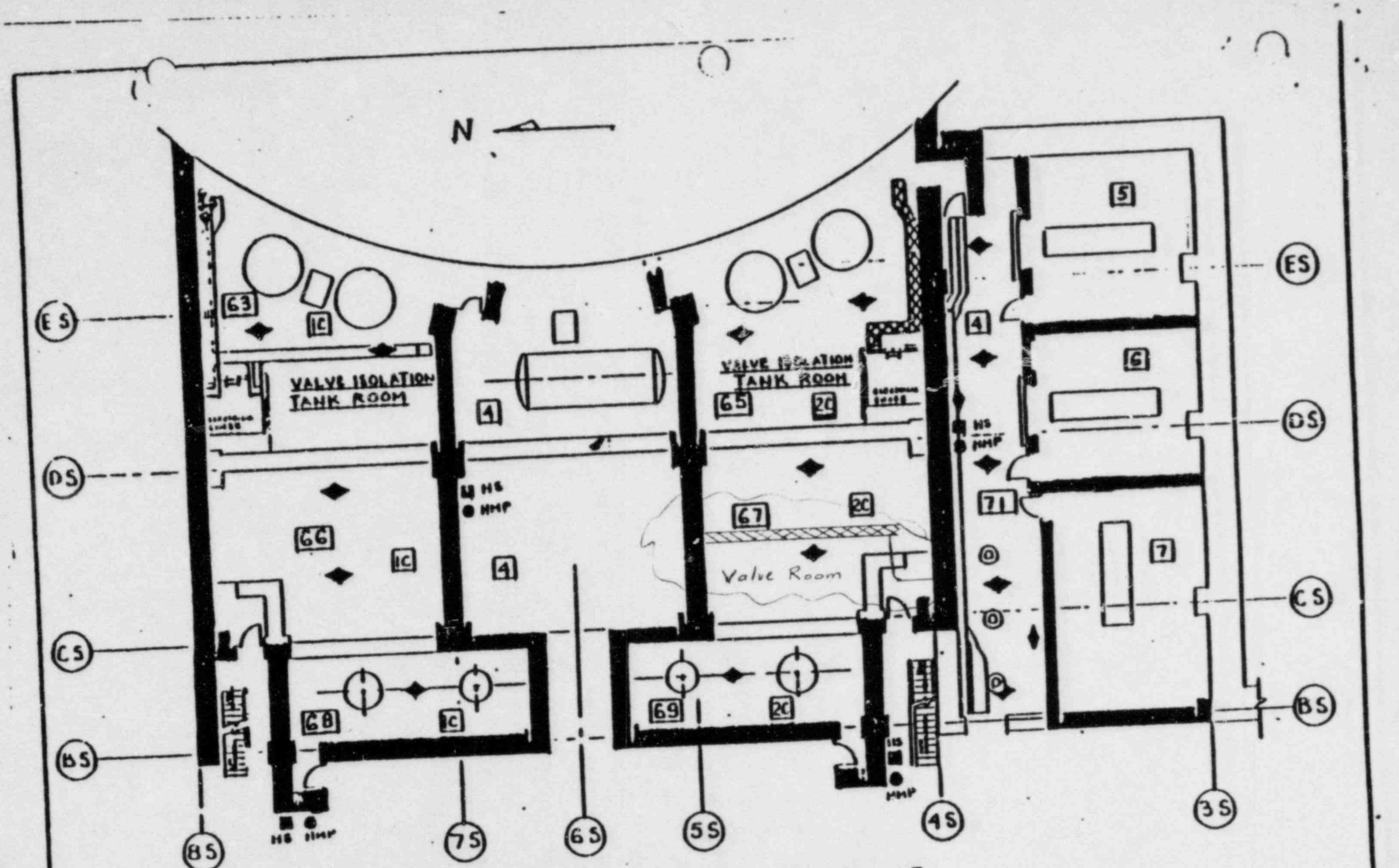
Justification:

1. This area is a low hazard with a fire duration of less than 6 minutes.

2. General area ionization detection is provided.

3. Enclosures of cable and associated circuits of one safe shutdown path in a one hour rated barrier is provided.

4. Hose stations and portable fire extinguishers are provided in nearby areas.



PARTIAL SPRINKLER COVERAGE
SAFEGUARDS BUILDING EL. 790'-6"

SKETCH 5.b

LEGEND
- CABLE TRAY PROTECTION
- AREA PROTECTION
- DETECTORS
- RACE WAYS WITH FIRE BARRIER
- FIRE STOP
- HOSE STATION
- PORTABLE FIRE EXTINGUISHER

Deviation 6c

Subject: Turbine Building 821'-8" slab

Location
- Bldg. Turbine
- Elev. 821'-8"
- Rooms 11 thru 23, 25 thru 30, 32 thru 37, 41, 43, 43A
- Fire Areas TA
- Fire Zone III
- Col. N-S
- E-W

References:
- Deviations 10a-14, 10a-15
- DBD-SY-1, FHA 27-01 R. CP-2, FHA 29 R. CP-3, FHA 30 R. CP-2,
- Grinnell Fire Protection Dwg. 30 R.6 and Dwg. 31 R.8
- 2323-S1-408 R. 8
- 2323-S1-428 R. 2
- 2323-E1-2011, R. 8 E1-2012 R. CP1
- 2009, R. 8
- E2-2009, R. 6

Deviation: Turbine Building slab at 821'-8" elevation is not a three hour rated slab construction.

Description: 1) Deviations 10a-14 and 10a-15 are for HVAC penetrations between the Turbine Building, the Cable Spreading Room and the Auxiliary Building. These deviations referenced the fire rating of the 821'-8" elevation slab as three hour rated. While this barrier is adequate to provide protection against the fire hazards present on both sides it is not a three hour rated design.

2) Construction of Floor slab/ceiling

a. Slab supports: The slab is supported by 6W12 beams, spaced at no greater than 8 ft. intervals. The beams are suspended from the 830'-0" elevation of the Turbine Building by lateral 1¼" 0 steel rods. These rods are protected by fire proof material such that they can withstand the effects of fire for 3 hours.

b. Slab construction: The slab in constructed of 4" thick reinforced concrete utilizing #4 rebar at the top and bottom running in both directions and spaced at 12" intervals in the slab. The rebar is installed at the upper and lower surfaces of the concrete.

c. Suspended ceiling: Below the slab is a non-rated suspended ceiling of perforated metal pan construction. Each pan contains approximately 1" of fiberglass installation contained within a polyethelene bag. The insulation does not present a significant combustible hazard.

d. Space between suspended ceiling and slabs: The space between the suspended ceiling and slab contains no significant quantities of combustibles. All enclosed duct work is of steel construction.

3) Fire Area Description: The areas under the subject slab are either laboratories, locker rooms, showers, restrooms, small storage areas or office areas. The combustible loading of these areas are all light with an equivalent fire severity of less than 15 minutes.

Justification:

1. Fuel Loading: Due to the low combustible loading and the nature of the combustibles contained in the area, only a fire of low severity can be expected.

2. Fire resistance of the suspended ceiling: The non-rated suspended metallic ceiling will act as an effective radiant energy shield and restrict the flow of hot gases, decreasing the exposure of the structural supports to the effects of fire.

3. Thermal inertia of structural supports: The 6W12 structural supports have a significant thermal inertia which can withstand the effects of a low severity fire without any additional protection.

4. Fire Detector installation: Portions of this area are provided ionization smoke detectors under the suspended ceiling. Other portions are continually occupied or have frequent personnel traffic. This ensures prompt fire detection, allowing a timely response from the fire brigade or other plant personnel, limiting fire damage. Hose stations and portable extinguishers are provided for this purpose.

5. Slab Construction: The slab construction is significantly stronger than a number of listed three hour rated constructions. Several designs call for a 2½" thick slab instead of the 4" design provided. The listed design reinforcement is either Q-deck forms beneath or welded wire reinforcement instead of the two layers of perpendicular #4 rebar reinforcement provided in the top and the bottom of the slab.

6. Sprinkler Protection: The portion of the slab closest to the Turbine Building and the 803'-0" elevation of the Turbine Building are protected by a wet pipe sprinkler system. This will limit the exposure of the slab from a Turbine Building Fire.

For the above reasons, it is not considered credible for a fire originating in Fire Area TB105 (The Turbine Building) to penetrate the slab and propagate into Fire Area TA111.

Deviation 6c-1

Subject: Turbine Building 821'-8" slab over Hot Shop

Location
- Bldg. Turbine
- Elev. 821'-8"
- Room 39, 42
- Fire Area TA
- Fire Zone 112
- Col. N-S
- E-W

References: Deviation 10a-16
DBD-SY-1 FHA 27-01, R. CP-2; FHA 30 R. CP-2,
2323-S1-408 R. 8
2323-S1-428 R. 2
2323-E2-2011 R. 3
E2-2012 R. CP1

Deviation: Turbine Building slab at 821'-8" elevation is not a three hour rated slab construction.

Description: 1) Deviation 10a-16 is for an HVAC penetration between the Turbine Building and the Auxiliary Building. This deviation referenced the fire rating of the 821'-8" elevation slab as three hour fire rated. While this barrier is adequate to provide protection against the fire hazards present on both sides it is not a three hour rated design.

2) Construction of Floor slab and fire protection features

a. Slab supports: The slab is supported by 6W12 beams, protected by a fire barrier applied to the steel, spaced no greater than 8 ft. intervals. The beams are suspended from the 830'-0" elevation of the Turbine Building by lateral 1¼" 0 steel rods. These rods are protected by fire proof material such that they can withstand the effects of fire for 3 hours.

b. Slab construction: The slab in constructed of 4" thick reinforced concrete utilizing #4 rebar at the top and bottom running in both directions and spaced at 12" intervals in the slab. The rebar is installed at the upper and lower surfaces of the concrete.

c. Combustible loading: The combustible loading of the hot shop is a light hazard. The flammable materials are ordinary combustibles and some lube oil with a total fire severity of 23 minutes.

d. Area Detection: This area is provided with spot type heat detectors which ensures rapid fire detection.

e. Suppresion capabilities: Hose stations and extinguishers are provided for manual fire suppression activities.

Justification:

1. Fire originating in the Hot Shop: Considering the substantial construction of the slab and the three hour rated protection afforded the 6W12 beams and the light fire severity, it is not considered credible for a fire originating in the Hot Shop to breach the slab separating the hot shop from the turbine building. In addition, the fire detectors installed in the Hot Shop will ensure a rapid fire detection, ensuring a prompt response from the plant fire brigade or other plant personnel, ensuring that the fire will be suppressed by a manual means prior to significant degradation of the barrier.

   The slab is constructed of 4" thick reinforced concrete utilizing #4 rebar top and bottom spaced at 12" intervals in the slab. The rebar is installed at the upper and lower surfaces of the concrete. The resulting design provides significantly greater strength than a number of listed designs.