Construction Warehouse

FPE 596

Culminating Experience

In Fire Protection Engineering

Final Project (Spring 2014)

By Ben Johnson

Statement of Disclaimer

This project report is a result of a class assignment; it has been graded and accepted as fulfillment of the course requirements. Acceptance of this report in fulfillment of the course requirements does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include, but may not be limited to, catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Keywords: Fire, Fire Dynamics Simulator (FDS), fire modeling, Life Safety Code, Performance Based Design, rack storage fire, workstation fire

Table of Contents

List of Appendices

List of Tables

List of Figures

This Page Intentionally Blank

Executive Summary

The purpose of this report is to provide a comprehensive evaluation of the fire protection and life safety design of a warehouse building that serves a large construction project. The results and conclusions from this evaluation are documented herein and supported by analysis when necessary.

The gross floor area per story of the construction warehouse is 39,000 ft^2. This building is used as a warehousing facility in support of a large construction project. Rack storage of Group A plastics is permitted in this facility to a height of 20 ft. beneath a 24 ft. ceiling on the main floor. Shelf and solid pile storage of Group A plastics is permitted on the second floor of this facility to a height of 10 ft. It is also used for office space in large open and enclosed areas for the operations and maintenance personnel. It is classified as a mixed occupancy used for moderate storage (S-1) and business (B) purposes.

The occupant load calculated for this building is 466 occupants.

A walled in mezzanine area, used for business (office) purposes, above the main floor office area is present in this building. The gross floor area of the main floor office and mezzanine office areas is 4,100 ft^2 each.

The structure was constructed in 2002 in accordance with the Uniform Building Code, 1997 Edition, and is a Type II-N structure. The building is evaluated as a Type II-B structure according to the International Building Code, 2009 Edition.

The building is protected throughout by an automatic fire sprinkler system per NFPA 13, 1999 Edition, and a fire alarm system per NFPA 72, 2002 Edition. Life safety for this building is provided according to NFPA 101, 1997 Edition.

The installed fire protection and life safety (egress) systems in this facility are evaluated to NFPA 13, 2010 Edition , NFPA 72, 2010 Edition, and NFPA 101, 2012 Edition.

Main storage (rack storage) floor is protected by an automatic, supervised, Early Suppression Fast Response (ESFR) fire sprinkler system. The second floor is protected by a fire sprinkler system for protection of storage using Control Mode Density / Area (CMDA) design methods. The balance of protected areas, including office areas, loading dock, and tool room areas, are protected as an Ordinary Hazard Group 2 classification.

The overall assessment concludes that the automatic fire sprinkler systems installed in this building meet NFPA standards for the hazard that requires protection. Any design differences noted between the 1999 Edition and 2010 Edition of NFPA 13 will be discussed with the building owner.

The entire facility is monitored and protected by an automatic fire alarm system that serves as a protected premises fire alarm system and a building fire alarm system. For performance based analysis purposes, notification of building occupants is assumed to occur upon audible or visual signals from the building fire alarm system. Initiating devices include manual pull stations at each exit. Smoke detectors (for elevator recall) are located near each elevator door, in the elevator machinery room and at the top of the elevator hoist way. Duct smoke detectors are placed to shutdown air handling units upon detection of smoke in air supply plenums. One fixed temperature detector is installed at the top of the elevator hoist way, and another is installed in the elevator machinery room, to support the elevator shunt trip function.

The fire alarm system automatically reports fire alarm, supervisory, and system trouble signals to the fire department via a high frequency radio transmitter.

Overall, the construction warehouse building is in compliance with NFPA 72, 2010 Edition. Any minor deficiencies noted will be discussed with the building owner.

Four (4) exits are provided on the main floor of the warehouse that discharge directly outdoors. Additionally, four (4) exterior stairwells, each accessible from both the main and second floor of this facility, are provided. The west stairwell provides direct access to an exit from the walled in mezzanine office level. Each stairwell is separated from the building by 2 hour fire-resistive construction and each stairwell discharges outdoors at grade level.

Storage areas within this building are characterized as large, open areas. The maximum travel distance to any exit (or protected exit stairwell enclosure) is less than 300 ft.

There are is one dead end corridor in the warehouse that extends 49 ft. Common path of travel is limited to the distance required to traverse a typical office and no common path of travel exceeds the 100 ft. limitation for an S-1 or B classified occupancy.

The construction warehouse meets prescriptive NFPA 101, 2012 Edition, requirements for egress.

This evaluation documents a performance based life safety analysis. Two (2) fire scenarios are considered:

- A rack storage fire on the main floor involving unexpanded polystyrene cups contained in cardboard cartons, placed in a 4 by 4 by 4 fuel array (stacked four (4) tiers high).
- An office workstation fire on the mezzanine level involving a typical office cubicle

Criteria for the performance based analyses was taken from NFPA 101, 2012 Edition, Section 5.2.2:

5.2.2* *Performance Criterion.*

Any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions.

This performance criterion is met when the calculated available safe egress time (ASET) exceeds the calculated required safe egress time (RSET) (i.e., ASET > RSET).

The calculation of RSET assumes that:

- Detection time is dependent on the specific fire scenario, but that detection occurs upon first sprinkler or smoke detector actuation (detection by human senses is not assumed)
- Notification time is 30 seconds based on fire alarm system electronic processing time
- Pre-movement time is assumed to be 60 seconds for some occupants
- Evacuation time is determined based on Pathfinder egress modeling software in STEERING mode which is shown to be comparable to independent hand calculations for personnel on the second floor to enter the protective enclosure provided by the west stairwell (the west stairwell is the most limiting egress path) – is calculated to be 158 seconds

Tenability limits are established according to external references. For this analysis, tenability limits for visibility, temperature, and carbon monoxide dose are established and documented by this report. A 10 m visibility limit is established for large open areas within this building such as storage areas. For office areas, where occupants are familiar with the location of exits and large travel distances are not required, the visibility limit is established at 3 m. A 100°C temperature limit is established and carbon monoxide dose, measured in terms of Fractional Effective Dose (FED) of 0.3 is also established. The visibility and temperature limits are evaluated at an elevation of 6 ft. (1.82 m) above walking surfaces. The FED is calculated and increases with time and concentration of carbon monoxide by the fire. The concentration of carbon monoxide is determined based on a ratio of the mass of carbon monoxide released into the affected building volume divided by the mass of all gases and products of combustion in the same volume. Appropriate factors must be applied in this calculation to ensure that the parts per million of carbon monoxide is correctly input into the FED equation.

Soot and carbon monoxide yields are input into Fire Dynamics Simulator (FDS) and are calculated in proportion to the mass of each component that makes up the fuel array.

Both fire scenarios are modeled in FDS with the assumption that fire severity is limited to the heat release rate at the time of sprinkler activation. Sprinkler activation time is determined using detector activation (DETACT) analysis.

Growth of the main floor rack storage fire is assumed to follow a "t-cubed" fire growth curve which has been observed in actual fire tests for the initial growth period of this type of fire. This growth is modeled using a ramp function and applying appropriate factors at appropriate times, within FDS. Sixteen (16) burners are modeled representing each carton in the fuel storage array. The burner for each successive tier of cartons turned "on" at 0, 30, 60 and 90 seconds, respectively, to simulate the spread of fire within the rack fuel array.

DETACT analysis predicts ESFR sprinkler actuation for the rack storage fire scenario 60 seconds following ignition. In this scenario, the fire is controlled at 2,592 kW, and the top tier of cartons does not ignite. The fire continues to burn at this rate deep within the fuel array.

The performance based aspects of the main storage floor rack storage fire, with detection time of 60 seconds, provides an RSET value of 308 seconds.

FDS output shows that the time to reach the 10 m visibility limit is 400 seconds.

For the rack storage fire scenario, ASET (400 seconds) > RSET (308 seconds), and this report has determined that the building would meet performance based life safety design criteria for this fire scenario. Additionally, this report concludes that the radiant heat from this fire does not, itself, cause the spread of fire to adjacent racks of storage located 8 ft. away, and that maximum ceiling temperature of does not exceed 180°C (356°F).

The case where sprinklers fail to actuate is also evaluated. In this case the fire is allowed to grow to 36,500 kW in 150 seconds. As a result, this uncontrolled fire is predicted to cause extreme danger to building occupants due to hampered egress, spread to adjacent racks and commodities, and cause significant structural damage to the second floor (maximum temperature at the ceiling is predicted by FDS to reach 877°C (1,611°F)). Sprinklers in the warehouse are deemed to be essential for safe performance based egress and protection of property.

The mezzanine workstation fire scenario follows a "t-squared" fire growth curve. If left unchecked this fire would grow to 6,730 kW in 530 seconds. Sprinkler actuation, predicted to occur 170 seconds following ignition is assumed to control the fire at 694 kW.

The smoke detector located on the ceiling near the elevator door is predicted to detect this fire in 54 seconds by hand calculations. For comparison, FDS predicts heat detector activation 62 seconds into the fire scenario. Detection time is assumed to be 54 seconds.

The calculated value of RSET for the workstation fire is 302 seconds.

FDS output shows that the time to reach the 3 m visibility limit on the mezzanine is 130 seconds.

In this case, ASET (130 seconds) < RSET (302 seconds), leaving a deficit of 172 seconds. This report has determined that the building does not meet performance based life safety design criteria for a fire involving a workstation on the mezzanine office level.

This report evaluates several alternatives for improving performance based egress design:

- Replace standard response sprinklers with quick response sprinklers in the mezzanine area. The corresponding RSET reduction is 30 seconds. This alternative does make up for the 172 deficit between ASET and RSET.
- Remove the suspended ceiling, relocate and replace standard response sprinklers with quick response sprinklers. This alternative provides an 80 second increase in ASET and has no effect on RSET. This alternative does make up for the 172 deficit between ASET and RSET.
- Add an additional protected exterior stairwell on the north side of the mezzanine. This alternative improves the time for all building occupants to exit the building and reduces RSET by 42 seconds. This alternative does make up for the 172 deficit between ASET and RSET.
- Install a mechanical smoke control system. The revised FDS model shows that the value of ASET may be increased indefinitely. This is a costly alternative.
- Remove the mezzanine walls so that this area will be open to the main storage floor below. The rack storage fire scenario would become the bounding scenario but would need to be revised to account for exposure to personnel on the mezzanine. The additional 65 mezzanine occupants would be almost immediately susceptible to tenability limits. This alternative, which would solve the mezzanine workstation fire performance based life safety design issues, is expected to fail the main floor rack storage fire scenario performance based design criteria.
- Do nothing, control the number of occupants on the mezzanine floor, or control combustible loading. The mezzanine currently meets prescriptive egress criteria of NFPA 101, 2012 Edition. This alternative is subject to approval of the Authority Having Jurisdiction. Controlling the number of mezzanine occupants is expected to improve egress time but may not make up the 172 second deficit. Control of combustible (workstation) material is not feasible.

I. Purpose

This report provides a comprehensive evaluation of the fire protection and life safety design of a warehouse building that serves a large construction project. The results and conclusions from this evaluation are documented herein and supported by analysis when necessary.

II. Construction Warehouse Building Description

The construction warehouse provides for storage and staging of materials used in a large construction project. It is a two-story steel building with concrete floors. The warehouse structure is constructed in accordance with the Uniform Building Code, 1997 Edition. The building is classified by the UBC as Type II-N (non-combustible) construction and houses a mixed, Business and Storage, occupancy.

National Fire Protection Association (NFPA) Codes and Standards used for original building design include:

- NFPA 13, 1999 Edition, *Standard for the Installation of Sprinkler Systems*
- NFPA 72, 2002 Edition, *National Fire Alarm Code®*
- NFPA 101, 1997 Edition, *Life Safety Code®*

The building footprint measures 195 ft. by 200 ft., with a first (main) floor, a walled in mezzanine, and second floor. The gross floor area per story is approximately 39,000 ft^2. The mezzanine floor area is approximately 4,100 ft^2. Additionally, an office space is walled in and is located on the main floor beneath the mezzanine. The main floor office space constitutes approximately 4,100 ft^2 of the 39,000 ft^2 on the main floor.

Four enclosed, exterior, exit stairways provide for protected egress from the second floor. Each enclosed stairwell is separated from the main building by a 2-hour fire rated barrier. The exterior walls of the stair enclosure and the adjacent building walls, 10 ft. on either side of the stairwell enclosure, are 1-hour fire rated walls.

The exterior building walls consist of an insulated pre-finished metal wall system. The interior surfaces of each exterior wall are finished with a metal liner system to a level 8 ft. above the finished main and second floors. Above 8 ft. the metal liner system stops and the vapor barrier covering wall insulation is exposed. The outside surfaces of each exterior wall are made up of pre-finished metal siding.

One of these enclosed, exterior stairwells, on the west side of the building, also serves as an exit directly from the mezzanine. A second, unenclosed, interior stairway provides access to the mezzanine from the main floor.

An elevator services the first floor, mezzanine, and second floor areas. An elevator machine room on the first floor supports the elevator equipment. The elevator hoist way and adjacent machine room are each enclosed, and separated from one another, by 1 hour fire-rated walls.

The main floor is a reinforced concrete slab 6 in. thick within an 8 in. thick reinforced concrete foundation.

The ceiling above the main floor is 23 ft. 8-1/2 in. high. The ceiling is exposed steel composite floor deck supported by steel bar joists and beam construction. Typical beams are made up of an 8 in. flange, ½ in. thick, and an 18 in. web, ¼ in. thick. Bar joists are 26-1/2 in. deep and are spaced 6 ft. on center. Beams are spaced 24 ft. on center.

The main floor of the building houses several distinct areas primarily used for storage and staging of commodities and related functions:

- A main area consisting of commodities stored on single or double row racks to a maximum height of 20 ft. with minimum aisle width of 8 ft.
- A fenced tool and consumable supply area, including a tool issue room and counters, and a second small mezzanine above
- A receiving area
- A designated area for performance of receipt inspections
- An fenced employee break area
- A packing area
- An outdoor covered truck loading dock
- An office area enclosed in non-fire rated construction

The enclosed office area on the main floor includes the main building entrance and reception area, a conference room, a common kitchen area, offices with gypsum board walls and other office space provided by standard cubicles.

The office area is accessible from the main entrance on the north side of the building, from the exit stairwell on the west side of the building, internally on the east side of the office area from the main floor storage area. An elevator also serves the main floor office area.

The main office area ceiling height is approximately 8 ft. 5 in. high. A typical suspended ceiling is provided with ceiling tiles. The space between the main office ceiling and the bottom of the mezzanine floor deck above is used to route building services, such as HVAC, electrical and computer cable, etc., to the main floor office spaces.

The mezzanine above the office area contains a conference room and offices with gypsum board walls and other office space provided by standard cubicles. It is accessible from the main floor by one unenclosed interior building stairway and through the enclosed exterior exit stairwell on the west side of the building.

Direct access to the west stairwell from the mezzanine provides an exit at this level, allowing the mezzanine to be walled in and separated from the main floor area in accordance with the exception to the openness criteria of IBC (2009) Section 505.4 and NFPA 101 (2012) Section 8.6.10.3.

The mezzanine floor is 12 ft. above the main floor level. The floor is poured concrete with a 6 in. by 6 in. wire mesh embedded at a depth of approximately 1 in. The maximum thickness of the concrete floor is 3-1/2 in. with 2 in. over the high rib of the composite steel floor deck. The floor deck is supported by structural steel framework from below. The mezzanine floor is designed for a live load of 50 psf.

The ceiling above the mezzanine office area is a typical suspended ceiling with ceiling tiles. The ceiling is generally placed 8 ft. 5 in. above the mezzanine floor. The interstitial space between the ceiling and second floor deck is used for routing of building utilities, such as HVAC and electrical and computer cable, which serves the mezzanine area.

The second floor elevation is 24 ft. above the main floor. The floor has a maximum thickness of concrete of 3-1/2 in. and is 2 in. thick over the high rib of the steel composite floor deck supported as described above. A 6 in. by 6 in. wire mesh is embedded approximately 1 in. below the finished floor surface. The second floor is designed for a live load of 50 psf.

The building roof is an insulated pre-finished metal roofing system. The underside of the roof consists of a vapor barrier over roof insulation.

The ridge line along the roof is 45 ft. 1-1/2 in. above the main floor level and building eave height is 37 ft. 0 in. Accordingly, the second floor ceiling height varies between approximately 13 ft. at the eaves to 21 ft. at the ridge line.

The warehouse is protected throughout by an approved automatic fire sprinkler system and an approved fire alarm system.

III. Assessment of Building Structure and Type

The construction warehouse is assessed to the requirements of the International Building Code (IBC), 2009 Edition, by this report.

The following items are identified for the building:

- The required building type and construction classification in accordance with the requirements of the IBC;
- The fire resistance requirements for the different structural and other building elements (i.e., columns, beams, floor assemblies, roof assembly, exterior walls, interior walls and partitions, door openings, joints and/or penetrations);
- The materials used to construct the columns, beams, floor assemblies, roof assembly, exterior walls and interior walls and partitions.

A. Allowable Building Area and Height Limitations per the IBC

Table 503 of the IBC provides height and area limitations for buildings based on occupancy classification. The allowable building height and area shown in Table 503 may be adjusted

(increased) according to IBC Sections 504.2, 506.2 and 506.3 when automatic sprinklers are installed and when certain building frontage criteria are met.

The building was originally classified as Type II-N by the Uniform Building Code, 1997 Edition (UBC). This most closely corresponds to a Type II-B construction classification when evaluated according to the IBC.

The effect of automatic sprinkler installation, building frontage, and mixed use – separated occupancy classification on the allowable building area, number of stories and building height tabulated in IBC Table 503 are evaluated below.

A.1. <u>Occupancy</u>

The occupancy classification of the construction warehouse, per Chapter 3 and Chapter 5 (Section 508.4) of the IBC, is a "Mixed Use–Separated Occupancy" consisting of both Business 'B' and Moderate Hazard Storage 'S-1' occupancies.

A.2. <u>Building Height and Area Limitations</u>

Table 503 from the IBC provides the allowable area and height for a building containing Business and Storage occupancy groups.

TABLE 503
ALLOWABLE BUILDING HEIGHTS AND AREAS[a]
Building height limitations shown in feet above grade plane. Story limitations shown as stories above grade plane.
Building area limitations shown in square feet, as determined by the definition of "Area, building," per story

		TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
	HEIGHT(feet)	UL	160	65	55	65	55	65	50	40
GROUP		STORIES(S) AREA (A)								
B	S A	UL UL	11 UL	5 37,500	3 23,000	5 28,500	3 19,000	5 36,000	3 18,000	2 9,000
S-1	S A	UL UL	11 48,000	4 26,000	2 17,500	3 26,000	2 17,500	4 25,500	3 14,000	1 9,000

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m^2.
A = building area per story, S = stories above grade plane, UL = Unlimited, NP = Not permitted.
a. See the following sections for general exceptions to Table 503:
1. Section 504.2, Allowable building height and story increase due to automatic sprinkler system installation.
2. Section 506.2, Allowable building area increase due to street frontage.
3. Section 506.3, Allowable building area increase due to automatic sprinkler system installation.
4. Section 507, Unlimited area buildings.

b. For open parking structures, see Section 406.3.
c. For private garages, see Section 406.1.
d. See Section 415.5 for limitations.

Figure 1 – Allowable Building Height and Area per IBC

From IBC Section 508.4.2, in each story, the sum of the ratios of the actual building area for each separated occupancy divided by the allowable building area (from Table 503) for each separated occupancy shall not exceed 1.

The ratio of actual building area for each occupancy to allowable building area (from IBC Table 503 for Type II-B construction – uncorrected for frontage and automatic sprinkler installation) is tabulated below:

Table 1 – Occupancy Area Ratio Calculation, Unadjusted For Sprinklers or Frontage

Floor	Occupancy (ft^2)		Allowable Area for Type II-B (ft^2)		Ratio		Sum
	B	S-1	B	S-1	B	S-1	
First Mezzanine	8,200	33,900	23,000	17,500	0.36	1.94	2.30 N.G.*
Second	23,280	14,720			1.01	0.84	1.85 N.G.*
Totals	31,480	48,620					

*N.G. = No Good.

Since the sum of the ratios of the actual building area for each separated occupancy divided by the allowable building area exceeds the value of 1, the criteria of IBC Section 508.4.2 is not met. Additional factors involving the installation of a supervised automatic fire sprinkler system and building frontage may be applied to adjust building height and allowable area limitations.

A.2.a. Height Limitations

Per IBC Section 508.4.3, each separated occupancy is required to comply with the building height limitations based on the type of construction of the building.

Since the height of the warehouse from grade level to the ridge of the building roof is 45 ft., and since the height restriction from Table 503 for Type II-B construction is 55 ft., the warehouse building is not limited as a Type II-B structure by its height.

A.2.b. Separation Requirements

Per IBC Table 508.4, a 'B' occupancy and 'S-1' occupancy do not require fire separation from one another. See Figure 2 below.

The construction warehouse is allowed by the IBC to house a "Mixed" 'B' and an 'S-1' occupancy without separation.

TABLE 508.4
REQUIRED SEPARATION OF OCCUPANCIES (HOURS)

OCCUPANCY	A[d], E		I-1, I-3, I-4		I-2		R		F-2, S-2[b], U		B, F-1, M, S-1		H-1		H-2		H-3, H-4, H-5	
	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
A[d], E	N	N	1	2	2	NP	1	2	N	1	1	2	NP	NP	3	4	2	3[a]
I-1, I-3, I-4	—	—	N	N	2	NP	1	NP	1	2	1	2	NP	NP	3	NP	2	NP
I-2	—	—	—	—	N	N	2	NP	2	NP	2	NP	NP	NP	3	NP	2	NP
R	—	—	—	—	—	—	N	N	1[c]	2[c]	1	2	NP	NP	3	NP	2	NP
F-2, S-2[b], U	—	—	—	—	—	—	—	—	N	N	1	2	NP	NP	3	4	2	3[a]
B, F-1, M, S-1	—	—	—	—	—	—	—	—	—	—	N	N	NP	NP	2	3	1	2[a]
H-1	—	—	—	—	—	—	—	—	—	—	—	—	N	NP	NP	NP	NP	NP
H-2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	N	NP	1	NP
H-3, H-4, H-5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1[e, f]	NP

For SI: 1 square foot = 0.0929 m^2.

S = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1.

NS = Buildings not equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1.

N = No separation requirement.

NP = Not permitted.

a. For Group H-5 occupancies, see Section 903.2.5.2.

b. The required separation from areas used only for private or pleasure vehicles shall be reduced by 1 hour but to not less than 1 hour.

c. See Section 406.1.4.

d. Commercial kitchens need not be separated from the restaurant seating areas that they serve.

e. Separation is not required between occupancies of the same classification.

f. For H-5 occupancies, see Section 415.8.2.2.

Figure 2 – Allowable Building Height and Area per IBC

A.2.c. Allowable Increases - Automatic Fire Suppression

The construction warehouse is fitted with a supervised automatic fire sprinkler system in accordance with NFPA 13 *Standard for Installation of Sprinkler Systems*.

According to IBC Section 504.2, 504.2 where a building is equipped throughout with an approved automatic sprinkler system, the value specified in Table 503 for maximum building height is increased by 20 feet (6096 mm) and the maximum number of stories is increased by one.

Also, according to IBC Section 506.3, the warehouse building area limitation in Table 503 is permitted to be increased by an additional 200 percent ($I_s = 2$ [$see\ equation$ $5-1$ $below$]) for buildings with more than one story above grade plane. These increases are permitted in addition to the height and story increases in accordance with Section 504.2.

A.2.d. Allowable Increases - Frontage

The frontage an all sides of the building is open and in excess of 30 feet.

The allowable building area shown in Table 503 may be increased according to IBC Section 506.2 according to the following equation:

$A_a = \{A_t + [A_t \ x \ I_f] + [A_t \ x \ I_s]\}$(Equation 5-1)

Where:

$A_a \equiv Allowable\ building\ area\ per\ story\ (ft^2)$

$A_t \equiv Tabular\ building\ area\ per\ story\ in\ accordance\ with\ Table\ 503\ (ft^2)$

$A_{t-B} = 23{,}000\ ft^2$ $\quad$ $A_{t-S1} = 17{,}500\ ft^2$ For Type II-B construction

$I_f \equiv Area\ increase\ factor\ due\ to\ frontage\ as\ calculated\ according\ to$:

$I_f = [F/_P - 0.25]\ ^W/_{30}$ (Equation 5-2)

Where:

$F \equiv Building\ perimeter\ that\ fronts\ on\ a\ public\ way\ or\ open\ space\ having$
$20\ feet\ open\ minimum\ width\ (ft)$

$F = 2\ x\ building\ width + 2\ x\ building\ length$

$F = 2\ x\ 195ft + 2\ x\ 200ft$

$[\boldsymbol{F = 790ft}]$

$P \equiv Perimeter\ of\ entire\ building\ (ft)$

$[\boldsymbol{P = F = 790ft}]$

$W \equiv Width\ of\ public\ way\ or\ open\ space\ (ft) in\ accordance$
$with\ Section\ 506.2.1$

$[\boldsymbol{W = 30\ ft}]$

$I_f = [^{790}/_{790} - 0.25]\ ^{30}/_{30}$

$I_f = 0.75$

$I_s \equiv Area\ increase\ factor\ due\ to\ sprinkler\ protection$

$I_s = 2$

For a 'B' (Business occupancy):

$A_{a-B} = \{23{,}000ft^2 + [23{,}000ft^2\ x\ 0.75] + [23{,}000ft^2\ x\ 2]\}$

$A_{a-B} = 86{,}250ft^2$

For a 'S-1' (Moderate hazard storage occupancy):

$A_{a-S1} = \{17{,}500ft^2 + [17{,}500ft^2\ x\ 0.75] + [17{,}500ft^2\ x\ 2]\}$

$A_{a-S1} = 65{,}625ft^2$

The mixed-use separated occupancy limitations are re-evaluated taking into consideration the allowable increases to building area per Table 503 for Type II-B construction:

Table 2 – Occupancy Area Ratio Calculation, Adjusted For Sprinklers and Frontage

Floor	Occupancy (ft²)		IBC Table 503 Allowable Area for Type II-B (ft²) (CORRECTED)		Ratio		Sum
	B	S-1	B	S-1	B	S-1	
First / Mezzanine	8,200	33,900	86,250	65,625	0.10	0.52	0.62
Second	23,280	14,720			0.27	0.22	0.49
Totals	31,480	48,620					

The criteria of IBC Section 508.4.2 is met considering allowable building area increases for frontage and installation of automatic fire sprinklers.

Type II-B construction is an allowable construction type for the construction warehouse with installation of automatic sprinklers and frontage.

A.3. ***<u>Type II-B Construction Per IBC</u>***

IBC Section 602.2 defines Type II construction as construction in which building elements listed in Table 601 are of noncombustible materials.

Table 601 of the IBC is reproduced below:

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[f, g] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	$1^1/_2$[b]	1[b, c]	1[b, c]	0[c]	1[b, c]	0	HT	1[b, c]	0

Figure 3 – Construction Type and Fire-Resistance Rating of Building Elements

From IBC Table 601, it is seen that the building elements are not required to be fire rated.

IBC Table 602 provides fire rating requirements for exterior walls and partitions:

TABLE 602
FIRE-RESISTANCE RATING REQUIREMENTS FOR EXTERIOR WALLS BASED ON FIRE SEPARATION DISTANCE[a, e]

FIRE SEPARATION DISTANCE = X (feet)	TYPE OF CONSTRUCTION	OCCUPANCY GROUP H[f]	OCCUPANCY GROUP F-1, M, S-1[g]	OCCUPANCY GROUP A, B, E, F-2, I, R, S-2[g], U[b]
X < 5[c]	All	3	2	1
5 ≤ X <10	IA Others	3 2	2 1	1 1
10 ≤ X < 30	IA, IB IIB, VB Others	2 1 1	1 0 1	1[d] 0 1[d]
X ≥ 30	All	0	0	0

Figure 4 –Fire-Resistance Rating of Exterior Walls

The fire separation distance between the building and the property line is greater than 30 ft. $(X \geq 30ft)$. The corresponding value for fire resistance rating for exterior walls for a 'B' and 'S-1' occupancy is 0 hours (i.e., the exterior walls of the warehouse are not required to be fire rated).

B. Fire Barriers

Each enclosed, exterior, exit stairwell is enclosed in minimum 1 hour fire rated construction as required by National Fire Protection Association (NFPA) 101, Life Safety Code®.

The elevator room and shaft are enclosed in 1 hour fire rated construction per IBC Section 708.4.

C. Office Mezzanine and Second Floor Deck and Concrete

The structural steel deck that is part of the first floor mezzanine and second floor assemblies is a 1-1/2 inch deep, 22 gauge, Type B-36 composite deck design by IMSA Building Products, ICBO #2757.

Two (2) inches of 3,000 psi (min.) concrete is placed over the high deck rib so that overall the thickness of the concrete floor deck assembly is 3-1/2 inches.

A minimum 6 inch x 6 inch mesh is placed in the concrete at the approximate center of 2 inches of the concrete fill over the high rib.

The concrete deck is not fire rated.

C.1. Office Mezzanine and Second Floor Concrete Deck

The concrete deck is a 1-1/2 inch, 22 gauge, Type B-36 composite deck design by IMSA, ICBO #2757. The second floor deck is placed on the supporting framework, adjusted and permanently fastened to its final position. The finished deck is 3-1/2 inches thick overall with 2 inches concrete fill over high rib. Concrete strength meets or exceeds 3,000 psi.

The concrete floor deck contains a minimum 6 inch x 6 inch – W1.4 x W1.4 mesh at the approximate center of the 2 inches of concrete fill over the high deck rib.

The maximum dead load for the second floor concrete deck is 125 pounds per square foot (psf). The maximum floor load for the Office Mezzanine is 50 psf.

D. Fire-Resistance Rating of Primary Structural Steel Members

The construction warehouse building primary structural steel is not fire-resistance rated.

IV. Assessment of Occupancy and Egress Design

This evaluation will assess the following life safety aspects of this building according to the criteria and requirements of NFPA 101 *Life Safety Code* – 2012 Edition (LSC).

A. Occupancy Classification

Occupancies are evaluated according to Chapter 6 of NFPA 101, 2012 Edition, *Life Safety Code®* (LSC).

The Warehouse is classified as a mixed occupancy incorporating both Storage and Business occupancy classifications.

For mercantile, storage, business and industrial occupancies, the LSC permits that an incidental occupancy within and involving these classifications, such as where a small portion of a storage occupancy is occupied and used for purposes that are consistent with a business occupancy, may be subject to the provisions of the LSC that apply to the predominant occupancy.

> ***6.1.14.1.3*** *Where incidental to another occupancy, areas used as follows shall be permitted to be considered part of the predominant occupancy and shall be subject to the provisions of the Code that apply to the predominant occupancy.*
>
> *(1) Mercantile, business, industrial, or storage use*
> *(2) Non-residential use . . .*

Accordingly, the few areas of the building located within storage areas and used as office spaces, worker break areas, or to issue tools to workers, and small electrical and mechanical equipment utility rooms are incidental to the predominant storage occupancy. This condition occurs on the main floor of the building.

Other building areas, such as within the walled in office areas on the main floor and the similar area on the mezzanine floor are designated as a business occupancy, and are not incidental to the storage occupancy. Since these business occupancies are not separated from the storage occupancy the overall building is classified as a mixed occupancy.

Since all areas of this building share exit access travel paths, the LSC does not permit the multiple occupancy of this building to be protected as separated occupancies. The LSC states:

> ***6.1.14.1.2*** *Where exit access from an occupancy traverses another occupancy, the multiple occupancy shall be treated as a mixed occupancy.*

The multiple occupancy classification of building must be protected as a mixed occupancy.

Accordingly, the occupancy of this building is described as a mixed occupancy made up of predominantly assembly and business occupancy types, but also to a much lesser extent, other occupancy types that are present include storage and special purpose industrial (to account for mechanical and electrical equipment rooms).

Further, the large open area on the second floor fitted with standard office cubicles and used by the Operations and Maintenance staff is also a business occupancy. Areas on the second floor used for storage are segregated, but not separated, from these business occupancy and use areas.

All utility spaces (e.g., mechanical and electrical rooms) with the Warehouse building are industrial use areas and are incidental to the predominant occupancy in the area in which they are located.

Common areas, such as restrooms, elevators, and stairwells are shared by all occupancies in the Warehouse building.

Figures 5 through 7 below provide a graphical, color-coded, representation of the occupancy classification for all areas of the Warehouse building.

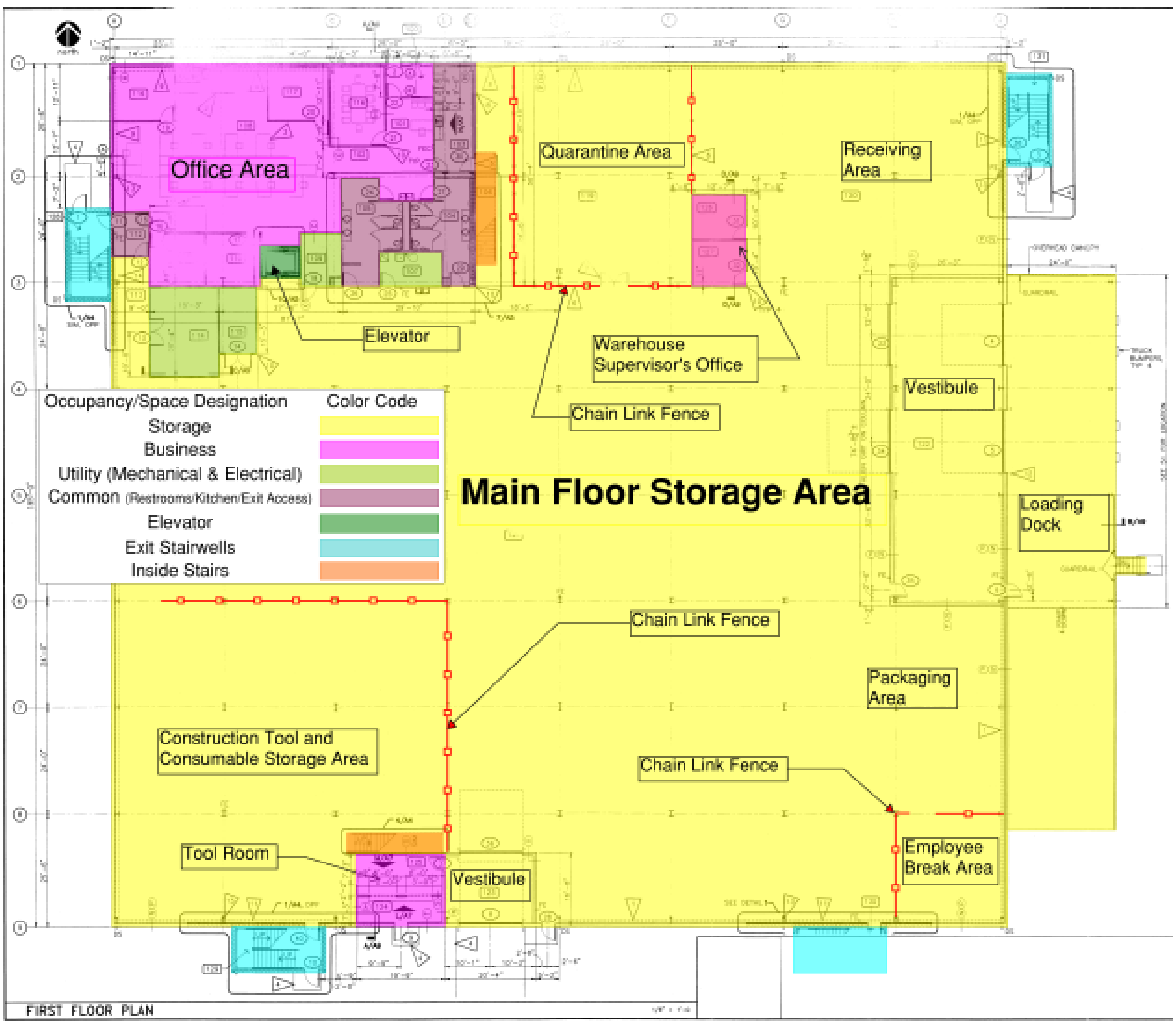


Figure 5 – Construction Warehouse Main Floor (El. 0 ft.) Occupancies

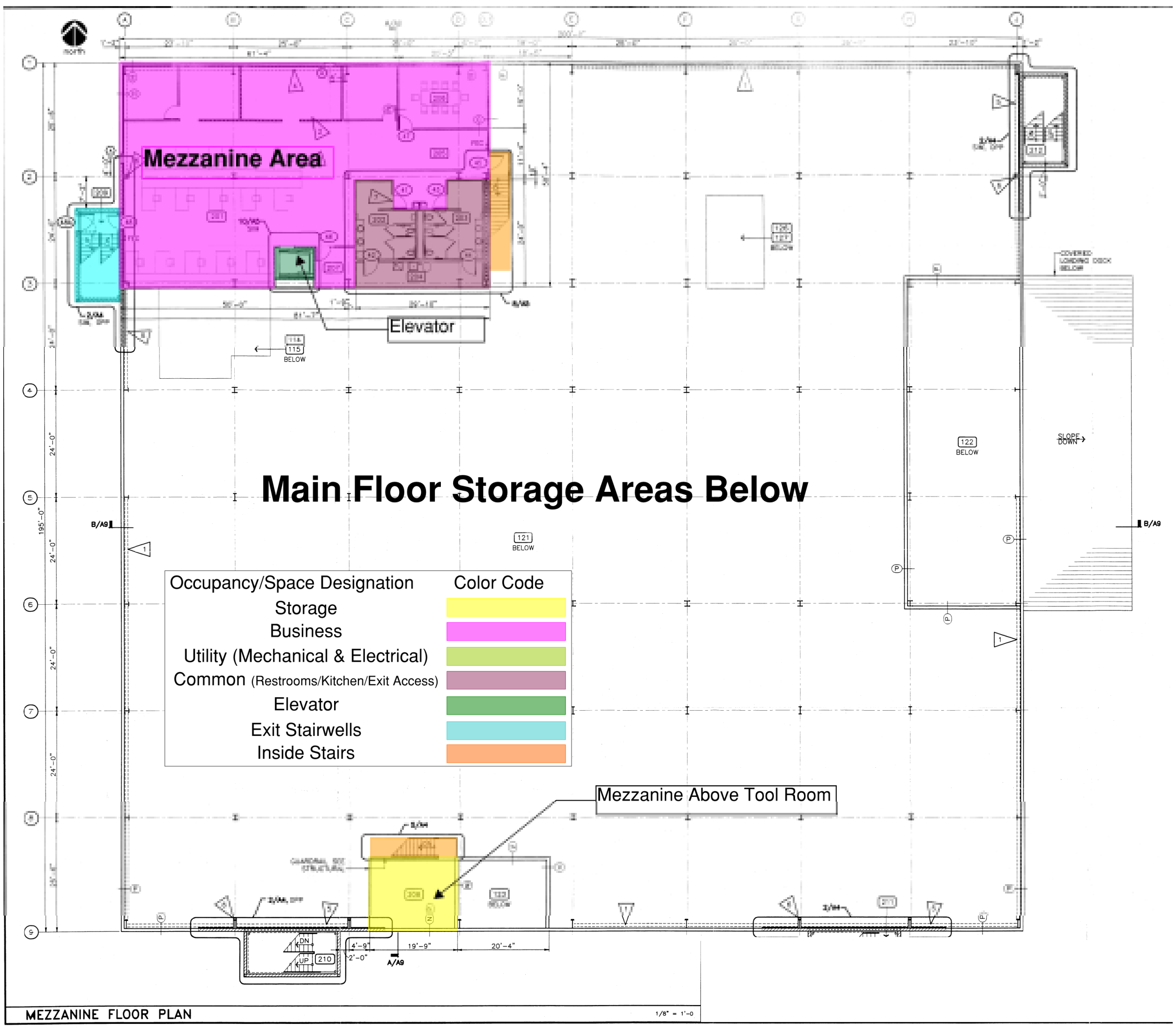


Figure 6 – Construction Warehouse Mezzanine (El. 12 ft.) Occupancies

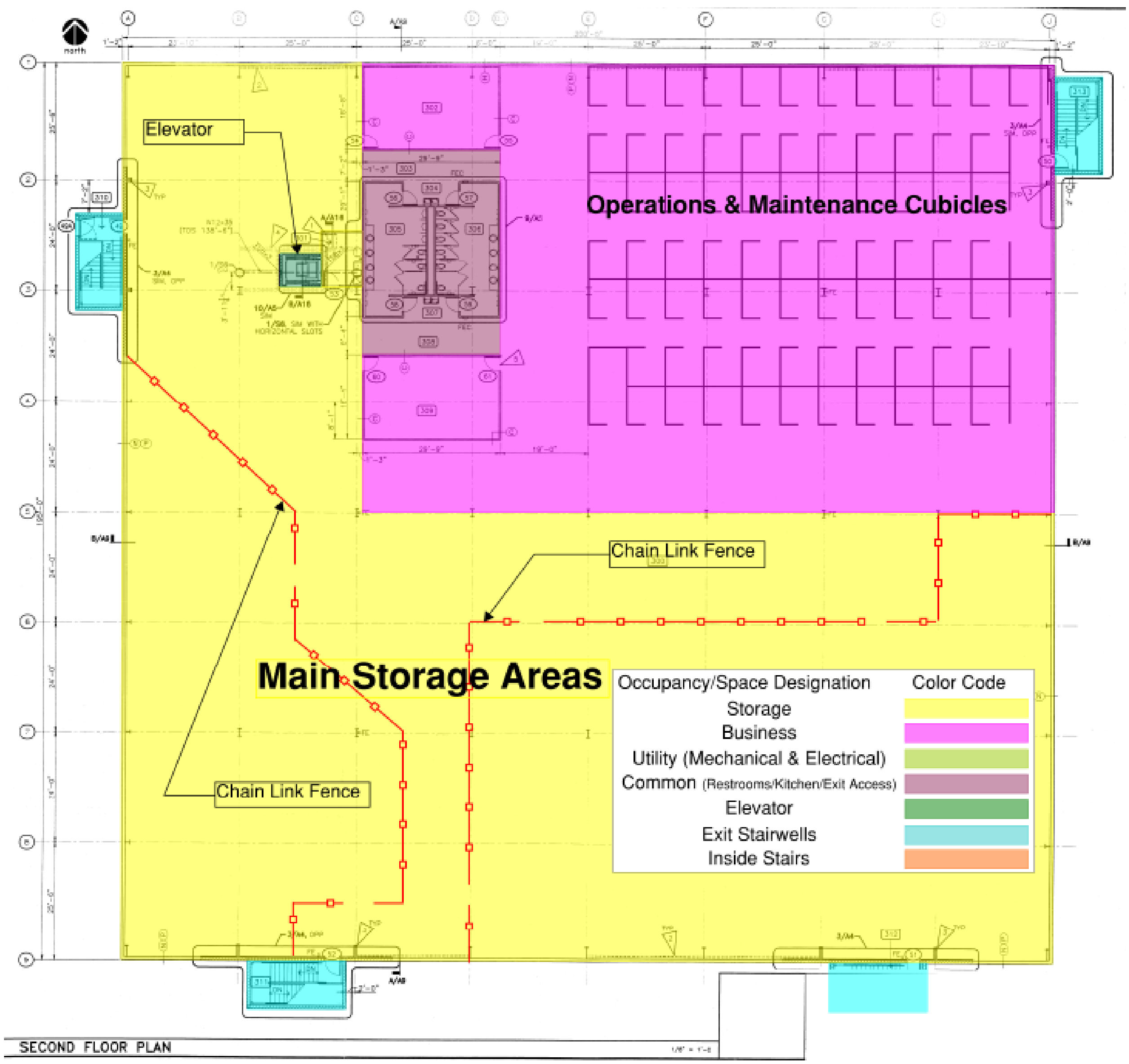


Figure 7 – Construction Warehouse Third Floor (El. 24 ft.) Occupancies

B. Hazard of Contents

The hazard of contents is defined by the LSC as the relative danger of the start and spread of fire, the danger of smoke or gases generated, and the danger of explosion or other occurrence potentially endangering the lives and safety of the occupants of a building or structure. The LSC does not specifically consider the danger posed by toxic chemicals, etiologic contamination, or similar hazards.

Additionally, the hazard of contents as determined by the LSC does not apply to the application of automatic sprinkler protection requirements which are described by NFPA 13.

The construction warehouse is not used to handle, use or store flammable liquids, vapors, or dusts that present an explosion hazard, hazardous chemicals or explosives, or similar hazards.

Accordingly, hazard of contents in warehouse are classified a ordinary hazard.

As defined by the LSC:

> ***6.2.2.3* Ordinary Hazard Contents.*** *Ordinary hazard contents shall be classified as those that are likely to burn with moderate rapidity or to give off a considerable volume of smoke.*

C. Occupant Characteristics

Access to the building is controlled and limited to individuals trained and badged for access to the large construction site or to escorted visitors.

Further, access to storage areas is controlled and limited to authorized persons who are trained and employed as warehouse staff.

Building occupants consist of both young and old workers, male and female, ranging in age from 18 to an estimated maximum of 80 years. The physical mobility and mental ability of these workers varies considerably. However, all workers are trained, of sound mind, and meet the minimum standard for work on a DOE construction site.

All persons who normally work in this building are familiar with the building layout and means of egress. Fire drills are performed annually that exercise the building notification and egress systems.

Characteristics of the building population include:

- A significant number of young to middle aged adults
  - who are active and mobile
  - capable of self preservation
  - some potential for poor decisions due to lack of experience during emergency situations
- A small number of other adults
  - with various physical capability

  - most are active and mobile
  - capable of self preservation
- Some occupants may be visitors who are not familiar with the building but are required to remain under the direct supervision of a qualified building escort while in the building
- Occupancy is characterized by:
  - a low concentration of warehouse workers in all storage use areas
  - a moderate concentration of administrative, office, operations and maintenance workers in all other building use areas (i.e, business use areas)
- Building occupants who work in the building on a daily basis are familiar with building layout, emergency egress and emergency procedures
- Occupants who are transient in the building are not as familiar with building layout
- Very few occupants may be physically handicapped causing impaired or restricted mobility

D. Exits

The LSC defines an exit as:

> ***3.3.81* Exit.*** *That portion of a means of egress that is separated from all other spaces of a building or structure by construction or equipment as required to provide a protected way of travel to the exit discharge.*

Exits include exterior exit doors, exit passageways, horizontal exits, exit stairs, and exit ramps. In the case of a stairway, the exit includes the stair enclosure, the door to the stair enclosure, the stairs and landings inside the enclosure, the door from the stair enclosure to the outside or to the level of exit discharge, and any exit passageway and its associated doors, if such are provided, so as to discharge the stair directly to the outside. In the case of a door leading directly from the street floor to the street or open air, the exit comprises only the door.

Exits provided on each floor of the Warehouse building are shown on Figures 8 through 10.

Note that exits on the first floor consist of exterior doors leading directly from occupied spaces to areas outside of the building.

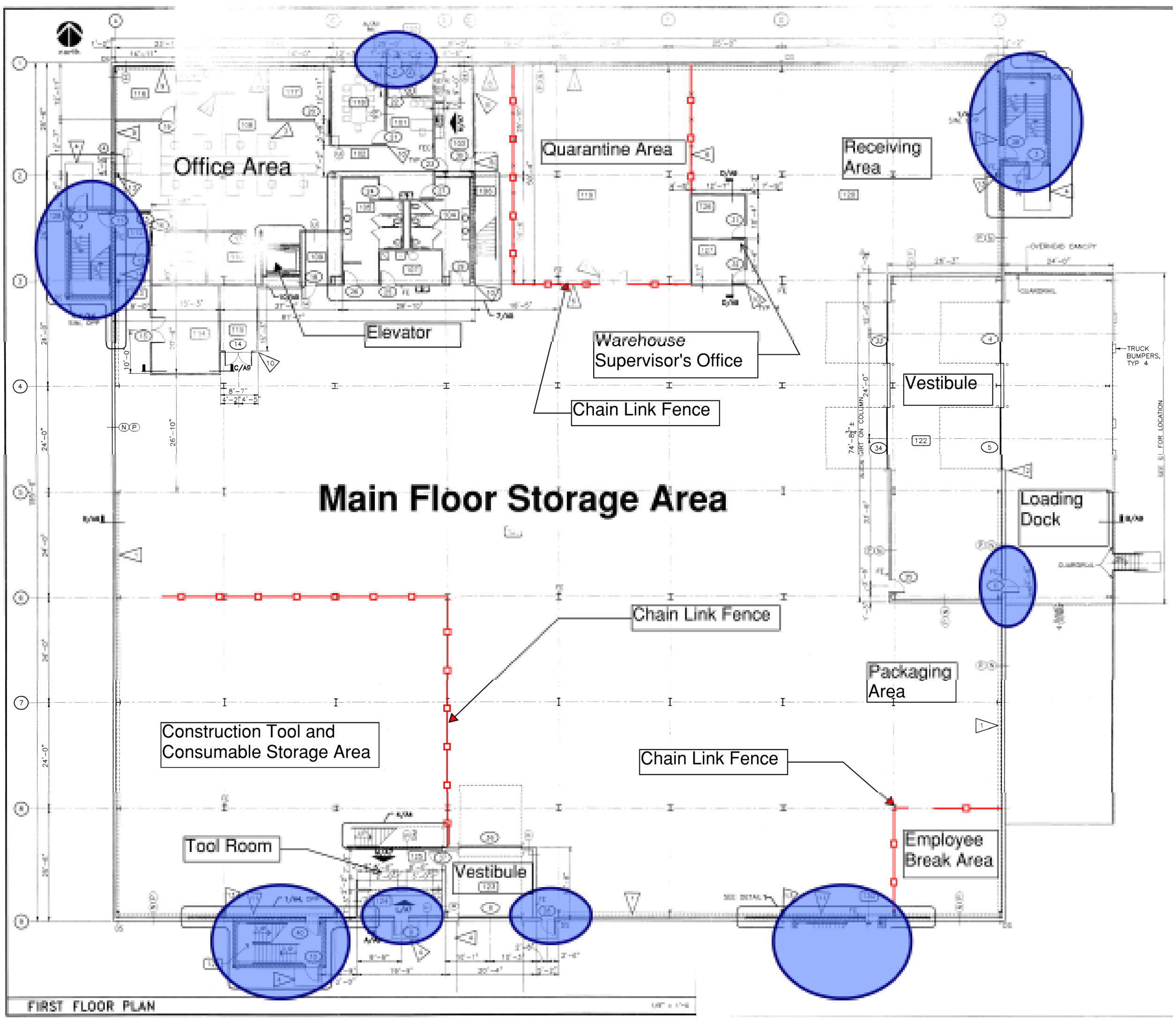


Figure 8 – Construction Warehouse Main Floor (El. 0 ft.) Exit Locations

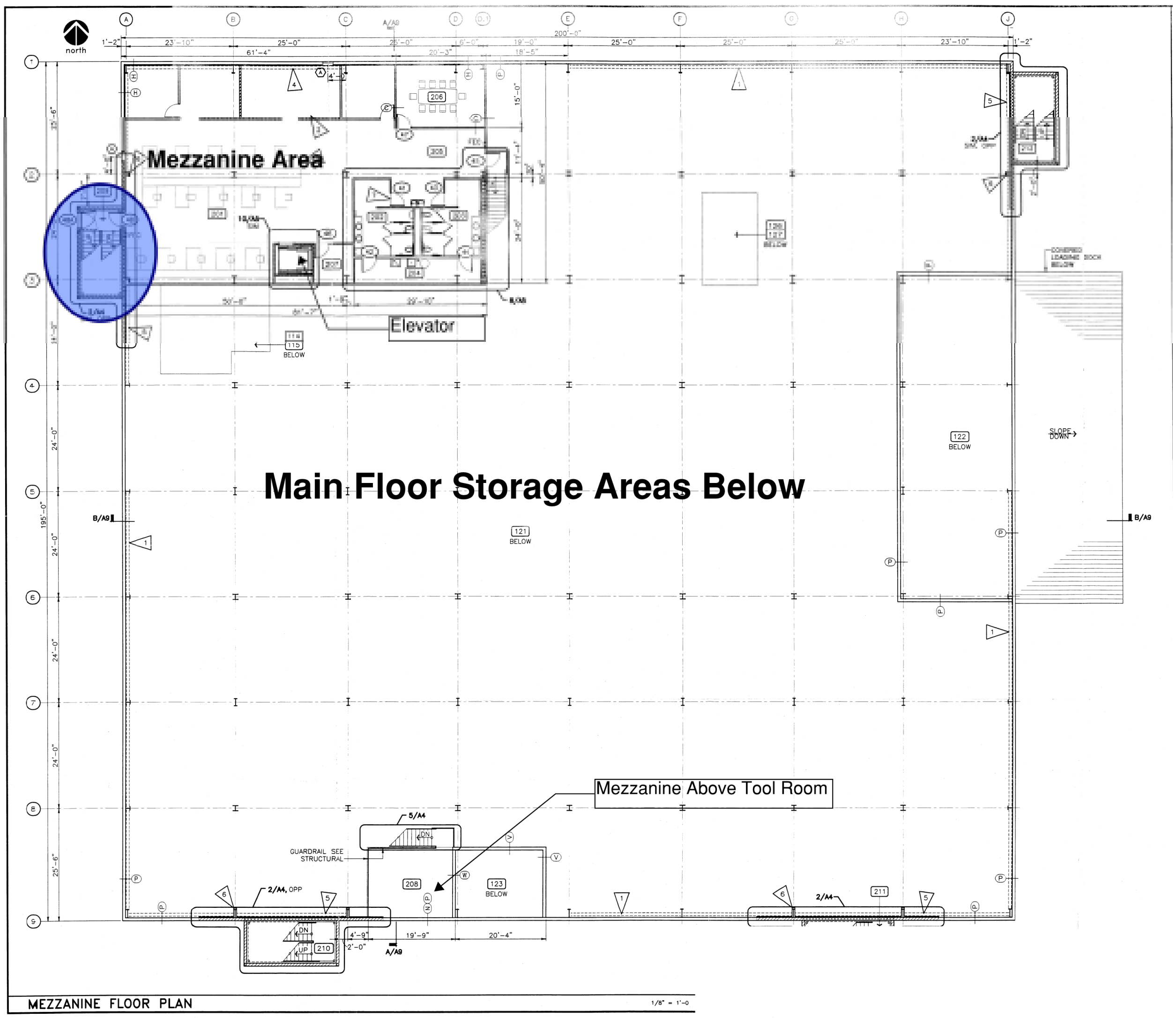


Figure 9 – Construction Warehouse Mezzanine (El. 12 ft.) Exit Locations

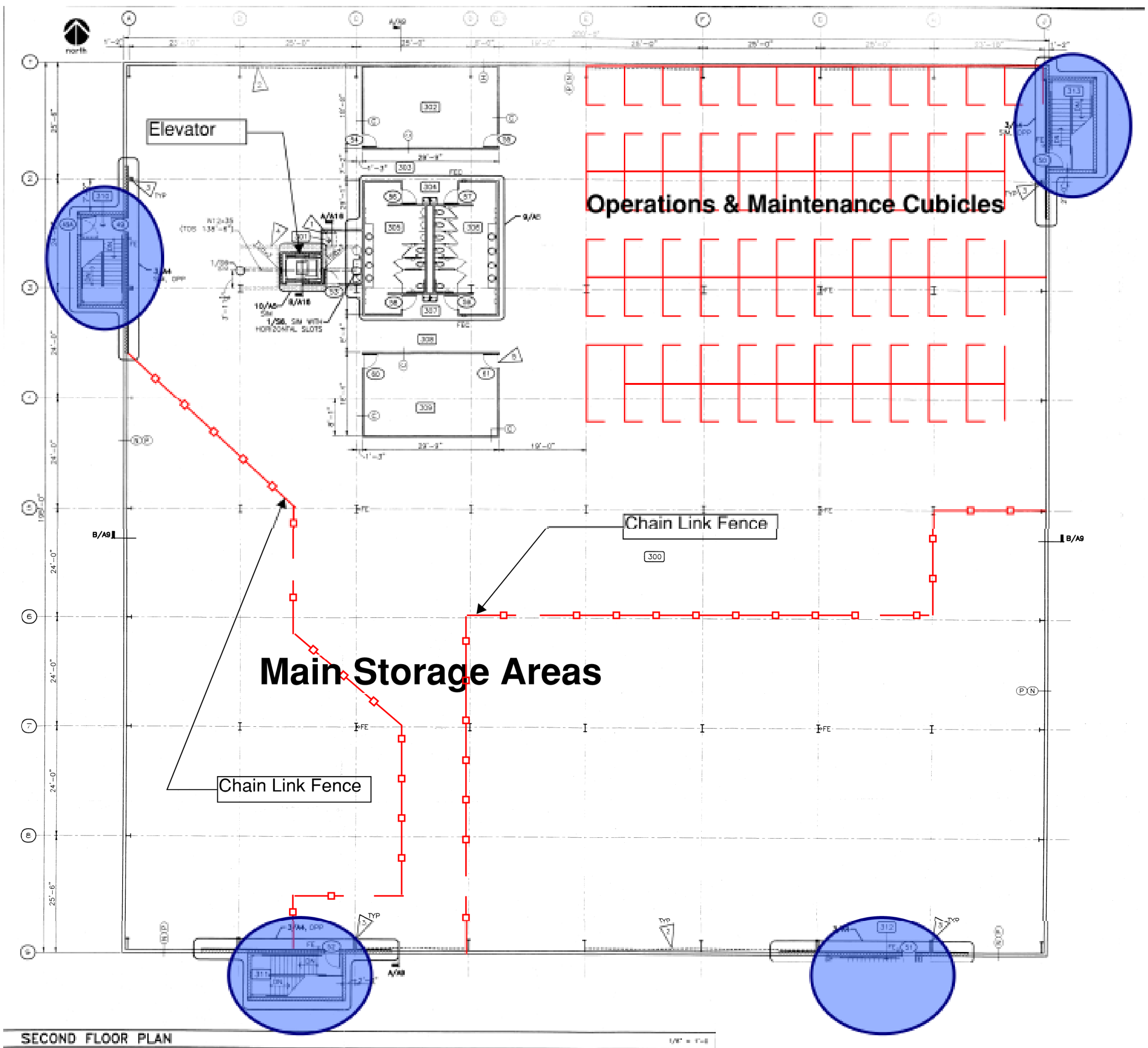


Figure 10 – Construction Warehouse Third Floor (El. 24 ft.) Exit Locations

E. Occupant Load

Occupant load (OL) is calculated according to LSC paragraph 7.3.1.2:

> ***7.3.1.2* Occupant Load Factor.*** *The occupant load in any building or portion thereof shall be not less than the number of persons determined by dividing the floor area assigned to that use by the occupant load factor for that use as specified in Table 7.3.1.2, Figure 7.3.1.2(a), and Figure 7.3.1.2(b). Where both gross and net area figures are given for the same occupancy, calculations shall be made by applying the gross area figure to the gross area of the portion of the building devoted to the use for which the gross area figure is specified and by applying the net area figure to the net area of the portion of the building devoted to the use for which the net area figure is specified.*

Calculation of OL is based on the use of an entire building, or in the case of the construction warehouse building, based on the sum of the OLs calculated according to the use of individual corresponding building areas.

The OL for mezzanines is added to OL for the main floor areas.

> ***7.3.1.6 Egress Capacity from Balconies and Mezzanines.*** *Where any required egress capacity from a balcony or mezzanine passes through the room below, that required capacity shall be added to the required egress capacity of the room below.*

The procedure for calculating the OL of a building or portion of a building is:

1. Determine the "use" of each room, space, or area within a building according to the classification or definition provided by LSC Table 7.3.1.2 *Occupant Load Factor*.

   Note: The term "use" is different from and should not be confused with the term "occupancy" as applied to rooms, spaces or areas within a building.

2. Lookup and specify the Occupant Load Factor (OLF) from LSC Table 7.3.1.2 for each "use". OLF is in units of $ft^2/person$. Note whether the OLF is specified for a "net" area or for "gross" building areas.
3. Tabulate the floor area of each room, space or area (in units of ft^2) with its corresponding "use" determined in step 1. above.
4. Sum and separately specify the total 'net" and "gross" floor areas.
5. Segregate "net" areas from "gross" areas in the tabulation.
6. Calculate the OL for each "net" area. Divide each "net" area by its corresponding OLF. The result of this calculation is the OL for that specific room, space or area.

   Note: The OLF for assembly "use" areas, such as conference rooms, are "net" areas. The following calculation considers the OLF for these areas to be consistent with an assembly "use", less concentrated use, without fixed seating. From LSC Table 7.3.1.2, the OLF for these areas is 15 $ft^2/person$.

7. Sum the OL calculated for all "net" areas.

8. For the aggregate “gross” areas, determine the predominant “use”.

   Note: For the construction warehouse, “gross” areas are predominantly governed by storage and business “use”. For the purpose of determining OLF for common areas, such as restrooms, kitchens, and exit travel paths shared by both storage and business occupancies, the most restrictive OLF will be applied. The most conservative OLF taken from LSC Table 7.3.1.2 in this case is that for business “use”, which is $100\ ft^2/person$. The OLF for storage “use” is the maximum probable number of occupants at any time. For this calculation, the maximum probable number of occupants in storage areas is assumed to be one occupant per every $500\ ft^2$.

9. Calculate the OL for “gross” areas. Divide the total “gross” floor area determined in step 2. above by the OLF for the predominant “use” for the aggregate “gross” floor area.

The results of these OL calculations for each floor of the warehouse building are summarized in the tables below. These calculations provide the area and OL for each floor. Summing the OL for each floor provides the OL for the entire building.

Table 3 – Construction Warehouse Occupant Load Calculation First Floor

Construction Warehouse Main Floor							
Room	Room Description	Area (ft^2)	"Use"	Occupancy Class	OLF (ft^2/person)	net/gross	OL (persons)
103	Break Room	220	Assembly (Kitchen)	Business	15	net	15
118	Conference Room	220	Assembly (Conference Rm)	Business	15	net	15
Total Net Area		**440**				**Total Net**	**30**
100	Vestibule	70	Common Use Area	Business		gross	
101	Reception Area	120	Common Use Area	Business		gross	
102	Hallway	200	Common Use Area	Business		gross	
104	Women's Restroom	260	Common Use Area	Business		gross	
105	Men's Restroom	250	Common Use Area	Business		gross	
108	Open Office Area	1,450	Business (Office)	Business		gross	
110	Office	140	Business (Office)	Business		gross	
111	Office	140	Business (Office)	Business		gross	
112	Vestibule	80	Common Use Area	Business		gross	
116	Office	160	Business (Office)	Business		gross	
117	File Storage	160	Business (Storage)	Business		gross	
124	Dispersal Entry	110	Business (Storage)	Business		gross	
125	Dispersal Area	170	Business (Storage)	Business		gross	
126	Office	120	Business (Storage)	Business		gross	
127	Office	120	Business (Storage)	Business		gross	
128	West Stairwell	190	Enclosed Stairwell	Business		gross	
129	South West Stairwell	190	Enclosed Stairwell	Business		gross	
130	South East Stairwell	190	Enclosed Stairwell	Business		gross	
131	East Stairwell	190	Enclosed Stairwell	Business		gross	
----	Elevator	70	Common Use Area	Business		gross	
Total Gross Area Business		**4,380**		**Business**	**100**	**Total Gross**	**44**
106	Hallway (Electrical)	440	Industrial (Utility)	Storage		gross	
107	Janitor	100	Industrial (Utility)	Storage		gross	
109	Machine Room	100	Industrial (Utility)	Storage		gross	
113	Hallway	220	Industrial (Utility)	Storage		gross	
114	Server/Electrical/Phone	300	Industrial (Utility)	Storage		gross	
115	HVAC	120	Industrial (Utility)	Storage		gross	
119	Quarantine Area	1,970	Storage	Storage		gross	
120	Future Storage Area	3,100	Storage	Storage		gross	
121	Warehouse	25,620	Storage	Storage		gross	
122	Vestibule	1,830	Storage	Storage		gross	
123	Vestibule	300	Storage	Storage		gross	
Total Gross Area Storage		**34,100**		**Storage**	**500**	**Total Gross**	**68**
Total Buildng Floor Area		**38,920**				**Total OL**	**142**

Table 4 – Construction Warehouse Occupant Load Calculation Mezzanine

Construction Warehouse Mezzanine Floor							
Room	Room Description	Area (ft^2)	"Use"	Occupancy Class	OLF (ft^2/person)	net/gross	OL (persons)
206	Conference Room	280	Assembly (Conference Rr	Business	15	net	19
Total Net Area		**280**				**Total Net**	**19**
201	Open Office Area	2,470	Business (Office)	Business		gross	
202	Men's Restroom	200	Common Use Area	Business		gross	
203	Women's Restroom	210	Common Use Area	Business		gross	
204	Janitor	170	Industrial (Utility)	Business		gross	
205	Hallway	420	Common Use Area	Business		gross	
207	File Room	80	Business (Storage)	Business		gross	
209	West Stairwell	200	Enclosed Stairwell	Business		gross	
210	South West Stairwell	200	Enclosed Stairwell	Business		gross	
211	South East Stairwell	200	Enclosed Stairwell	Business		gross	
212	East Stairwell	200	Enclosed Stairwell	Business		gross	
----	Interior Stair (Mezzanir	120	Open Stair	Business		gross	
----	Elevator	70	Common Use Area	Business		gross	
Total Gross Area Business		**4,540**		**Business**	**100**	**Total Gross**	**46**
208	Dispersal Mezzanine	300	Storage	Storage		gross	
----	Interior Stair (Dispersal	80	Open Stair	Storage		gross	
Total Gross Area Storage		**380**		**Storage**	**500**	**Total Gross**	**1**
Total Buildng Floor Area		**5,200**				**Total OL**	**66**

Table 5 – Construction Warehouse Occupant Load Calculation Second Floor

Construction Warehouse Second Floor							
Room	Room Description	Area (ft^2)	"Use"	Occupancy Class	OLF (ft^2/person)	net/gross	OL (persons)
302	Conference Room	520	Assembly (Conference Rr	Business	15	net	35
309	Conference Room	530	Assembly (Conference Rr	Business	15	net	36
Total Net Area		**1,050**				**Total Net**	**71**
300	Open Office Area	11,350	Business (Office)	Business		gross	
301	Janitor	100	Industrial (Utility)	Business		gross	
303	Hallway	200	Common Use Area	Business		gross	
304	EWC Area	60	Common Use Area	Business		gross	
305	Men's Restroom	330	Common Use Area	Business		gross	
306	Women's Restroom	350	Common Use Area	Business		gross	
307	EWC Area	50	Common Use Area	Business		gross	
308	Hallway	240	Common Use Area	Business		gross	
310	West Stairwell	200	Enclosed Stairwell	Business		gross	
311	South West Stairwell	200	Enclosed Stairwell	Business		gross	
312	South East Stairwell	200	Enclosed Stairwell	Business		gross	
313	East Stairwell	200	Enclosed Stairwell	Business		gross	
----	Elevator	70	Common Use Area	Business		gross	
Total Gross Area Business		**13,550**		**Business**	**100**	**Total Gross**	**136**
300	Open Office Area	25,200	Storage	Storage		gross	
Total Gross Area Storage		**25,200**		**Storage**	**500**	**Total Gross**	**51**
Total Buildng Floor Area		**39,800**				**Total OL**	**258**

F. Exit Capacity Calculations

Exit capacity for each floor is calculated below.

The width of egress is determined according to the LSC, paragraph 7.3.2.1, which states:

> ***7.3.2.1*** *The width of means of egress shall be measured in the clear at the narrowest point of the egress component under consideration, unless otherwise provided in 7.3.2.2 or 7.3.2.3.*

Egress capacity factors are provided in LSC Table 7.3.3.1 *Capacity Factors*.

Table 7.3.3.1 Capacity Factors

Area	Stairways (width/person)		Level Components and Ramps (width/person)	
	in.	mm	in.	mm
Board and care	0.4	10	0.2	5
Health care, sprinklered	0.3	7.6	0.2	5
Health care, nonsprinklered	0.6	15	0.5	13
High hazard contents	0.7	18	0.4	10
All others	0.3	7.6	0.2	5

Figure 11 – Capacity Factors

Egress capacity is calculated by dividing the clear width of the component of egress of interest by the corresponding value for that component type taken from LSC Table 7.3.3.1.

Egress from various portions of the building requires that occupants pass through corridors, doors and stairs. These components of egress found in the building are shown, by floor, in the tabular calculation of egress capacity for each component below.

Table 6 – Construction Warehouse Means of Egress Capacity Calculation First Floor

Main Floor - Construction Warehouse Building Means of Egress Capacity				
Component	**Description/Location**	**Clear Width (in.)**	**Capacity Factor (Table 7.3.3.1)**	**Capacity (persons)**
All Single Leaf Personnel Doors	- Exit Discharge Doors - Enclosed Stairwell Entry Doors - Office Space Doors - File Storage Room Door - Utility (Janitor) Room Doors - Restroom Doors - Conference Room Doors - Interior Exit Access Doors	32[a]	0.2	160
All Double Leaf Doors	- Server/Electrical/Phone Room - HVAC Room	68[b]	0.2	340
Hallway (120)	- Office Hallway	82	0.2	410
Hallway (113)	- Main Storage Area Hallway	96	0.2	480
Walkway	- Main Storage Area	48	0.2	240
Aisles	- Between Storage Racks	96	0.2	480
Fenced Area Openings and Gates	- Quarantine Area - Employee Break Area - Construction Tool and Consumable Storage Area	72	0.2	360
Exterior Ramp	- Truck Loading Bay	288	0.2	1440
Exterior Stair	- Truck Loading Bay	40	0.3	133

[a] Actual door opening size is 36 inches. A 32 inch clear width is assumed.

[b] Actual double door opening size is 72 inches. A 68 inch clear width is assumed.

Table 7 – Construction Warehouse Means of Egress Capacity Calculation Mezzanine

Mezzanine - Construction Warehouse Building Means of Egress Capacity				
Component	**Description/Location**	**Clear Width (in.)**	**Capacity Factor (Table 7.3.3.1)**	**Capacity (persons)**
All Single Leaf Personnel Doors	- Enclosed Stairwell Entry Doors - Office Space Doors - File Room Door - Utility (Janitor) Space Doors - Restroom Doors - Conference Room Doors - Interior Exit Access Doors	32[a]	0.2	160
Hallway (205)	- Mezzanine Hallway	132	0.2	660
Stairs	- West Enclosed Stairwell - Mezzanine to Main Floor - Dispersal Mezzanine to Main Floor	48	0.3	160

[a] Actual door opening size is 36 inches. A 32 inch clear width is assumed.

Table 8 – Construction Warehouse Means of Egress Capacity Calculation Second Floor

Second Floor - Construction Warehouse Building Means of Egress Capacity				
Component	**Description/Location**	**Clear Width (in.)**	**Capacity Factor (Table 7.3.3.1)**	**Capacity (persons)**
All Single Leaf Personnel Doors	- Enclosed Stairwell Entry Doors - Utility (Janitor) Room Door - Restroom Doors - Conference Room Doors	32[a]	0.2	160
Openings	- Cubicle Space Openings	48	0.2	240
Aisles	- Between Office Cubicles	72	0.2	360
Hallway (303)	- Common Hallway	82	0.2	410
Hallway (308)	- Common Hallway	96	0.2	480
Walkway	- Exit Access to South West Stair	168	0.2	840
Fenced Area Openings and Gates	- West Storage Area - East Storage Area	72	0.2	360
Stairs	- West Enclosed Stairwell - East Enclosed Stairwell - South East Enclosed Stairwell - South West Enclosed Stairwell	48	0.3	160

[a] Actual door opening size is 36 inches. A 32 inch clear width is assumed.

G. Elevator

The construction warehouse elevator is not a designated means of egress.

H. Corridors

There are no corridors in the construction warehouse.

I. Mezzanine Areas

Mezzanines must meet the area limitations and openness criteria of Chapter 8, "Fire Protection Features", of the LSC.

There are two mezzanines off of the main storage area. One is accessible via internal, unenclosed stair, from the main storage area floor, and is located directly above the office area on the main floor. This mezzanine area is used for office space consistent with a business occupancy. The second mezzanine, the dispersal area mezzanine, is located directly above the dispersal area on the south side of the building.

I.1. <u>Mezzanine Area Limitation</u>

Section 8.6.10.2.1 of the LSC require that the aggregate area of mezzanines located within a room must not exceed one-third the open area of the room, less the area of the mezzanine, in which the mezzanines are located.

> ***8.6.10.2.1*** *The aggregate area of mezzanines located within a room, other than those located in special-purpose industrial occupancies, shall not exceed one-third the open area of the room in which the mezzanines are located. Enclosed space shall not be included in a determination of the size of the room in which the mezzanine is located.*

Accordingly, the main storage area "room", with an aggregate area of 34,900 ft^2, supports a mezzanine of 11,633 ft^2. The area of the mezzanine above the main floor office area is 4,100 ft^2 and is less than the allowable area – the area limitation is met.

The dispersal area mezzanine, at a mere 300 ft^2, is well below the allowable area, and the area limitation is met.

I.2. <u>Mezzanine Openness Criteria</u>

Section 8.6.10.3.2 of the LSC states that a mezzanine having two or more means of egress is not required open into the room in which it is located if not less than one of the means of egress provides direct access from the enclosed area to an exit at the mezzanine level.

> ***8.6.10.3.2*** *A mezzanine having two or more means of egress shall not be required to open into the room in which it is located if not less than one of the means of egress provides direct access from the enclosed area to an exit at the mezzanine level.*

The dispersal area mezzanine is not enclosed and is open to the main storage area. Section 8.6.10.3.2 does not apply to the dispersal area mezzanine.

The mezzanine located above the main floor office area is enclosed. Section 8.6.10.3.2 applies to this area and one exit is provided from the mezzanine to the enclosed, exterior, stairwell on the west side of the building at mezzanine level. This mezzanine is not open to the main storage floor area and complies with the LSC Section 8.6.10.3.2.

J. Number of Exits and Arrangement of Means of Egress

The building is classified as a mixed occupancy by the LSC. It is primarily classified as a storage occupancy with a second, but not insignificant, occupancy classification in specific areas as a business occupancy. For a mixed occupancy, in accordance with the LSC:

> ***6.1.14.3.2**** *The building shall comply with the most restrictive requirements of the occupancies involved, unless separate safeguards are approved.*

LSC requirements that pertain to the number of exits and the arrangement of means of egress are tabulated below for storage occupancies (LSC Chapter 42) and for existing business occupancies (LSC Chapter 39). The warehouse must be evaluated against the most restrictive requirements. These requirements are summarized in Table 9. The applicable LSC paragraphs are shown in parenthesis.

Table 9 – Construction Warehouse Means of Egress Requirements

Parameter/Limitation	Storage Occupancy (Chapter 42)	Existing Business Occupancy (Chapter 39)	LSC Chapter 7 Requirement
Number of Exits	(42.2.4.1) (2) In ordinary hazard storage occupancies, a single means of egress shall be permitted from any story or section, provided that the exit can be reached within the distance permitted as a common path of travel. (42.2.4.1) (3) All buildings or structures not complying with 42.2.4.1(1) or (2) and used for storage, and every section thereof considered separately, shall have not less than two separate means of egress as remotely located from each other as practicable.	(39.2.4.1) Means of egress shall comply with all of the following . . .: (39.2.4.1) (2) Not less than two exits on every story. (39.2.4.1) (3) Not less than two separate exits accessible from every part of every story. (39.2.4.2) A single exit access path is permitted within the distance permitted as common path of travel. (39.2.4.3) A single exit is permitted for a room or area with a total OL less than 100 persons and the exit must discharge directly to outside and the total distance to and within the exit must be less than 100 ft. and total distance of travel must be on the same story or . . . (39.2.4.5) A single means of egress is permitted from a mezzanine within a business occupancy, provided that the common path of travel does not exceed 100 ft. if protected throughout by an approved automatic sprinkler system.	(7.4.1.1) The number of means of egress from any balcony, mezzanine, story, or portion thereof shall be not less than two, except under one of the following conditions: (1) A single means of egress shall be permitted where permitted in Chapters 11 through 43.

Parameter/Limitation	Storage Occupancy (Chapter 42)	Existing Business Occupancy (Chapter 39)	LSC Chapter 7 Requirement
Remoteness of Exits*	(42.2.1.1) Each required means of egress is required to be in accordance with the applicable portions of Chapter 7.	(39.2.1.1) All means of egress is required to be in accordance with Chapter 7.	(7.5.1.3.3) Minimum separation distance between two exits shall not be less than 1/3 the length of the maximum overall diagonal dimension of the building for buildings equipped throughout by a supervised automatic sprinkler system.
Common Path of Travel	(42.2.5, Table-42.2.5) 100 ft. when protected throughout by an approved, supervised, automatic sprinkler system.	(39.2.5.3.1) 100 ft. on a story protected throughout by an approved automatic sprinkler system.	--
Travel Distance to Exits*	(42.2.6, Table-42.2.6) 400 ft. when protected throughout by an approved, supervised automatic sprinkler system.	(39.2.6.3) 300 ft. when protected throughout by an approved, supervised automatic sprinkler system.	--
Dead End Travel	(42.2.5, Table-42.2.5) 100 ft. when protected throughout by an approved, supervised, automatic sprinkler system.	(39.2.5.2) Dead-end corridors shall not exceed 50 ft	(7.5.1.5) No dead end corridors unless permitted by occupancy chapter.

* The building is assumed to be protected throughout by an approved automatic fire sprinkler system.

K. Number of Exits

Two means of egress are required from every room, space and area unless a single exit is permitted by common path of travel criteria. In the construction warehouse, there are not less than two exits from the main storage floor, main floor office area, and the second floor.

The number of exits, common path of travel and dead end limitations are met in each area as described below.

The corresponding LSC requirements are reproduced in Table 9 above.

K.1. __Main Floor Storage Area__

The main floor storage area houses a calculated OL of 68 persons.

Six exits serve the main floor storage area:

- One of these exits (through the base of the enclosed, exterior, stairwell on the west side of the building) is shared with the main floor office area;
- Of the remaining five exits, three pass through the base of the enclosed, exterior, stairwells on the south-west, south-east, and east sides of the building, respectively;
- Exit access is provided through the receiving area vestibule on the east side of the main floor to an exit that discharges directly outdoors to the truck loading bay; and
- Another exit is provided from the main storage area floor on the south side of the building that discharges directly to the outside.

The number of exits provided on the main floor storage area is compliant with the LSC.

K.2. __Main Floor Office Area__

The OL of the main floor office area is 74 persons and two exits are provided from this area.

One exit on the north side of the building discharges directly to the outside.

The second exit, through the enclosed, exterior, stairwell on the west side of the building, also discharges directly to the outside of the building, without having to traverse stairs, at the base of this stairwell. This second exit is a shared exit with the main floor storage area along the west side of the building.

K.3. __Office Mezzanine Area__

The OL for the mezzanine floor, and associated business use, above the office area is 65 persons.

There are two separate means of egress from the mezzanine floor area above the office area. This arrangement provides a compliant number of exits. One of these exits provides direct access at the level of the mezzanine to the enclosed, exterior, protected stairwell on the west side of the building. A second means of egress is provided on the east end of the mezzanine that

leads down an unenclosed, interior, stair to the main floor storage area. The second means of egress leads to any one of the six exits that serve the main floor storage area.

The number of exits provided for the office mezzanine area is in compliance with the LSC.

K.4. __Dispersal Mezzanine Area__

The OL for the mezzanine floor above the dispersal area is 1 person.

Means of egress from the dispersal mezzanine is provided by an unenclosed, interior, stair from the mezzanine level to the main floor storage area. Exit access from the dispersal mezzanine leads to the established exits on the first floor storage area. This arrangement is compliant with the LSC.

K.5. __Second Floor Controlled (Fenced) Storage Areas__

The OL of the second floor storage areas is 51 persons.

The exit stairwells on the west, south west, and east sides of the building are accessible from the fenced storage areas through gates that open the storage areas to common building areas used for egress.

The south east stairwell is directly accessible to the south fenced storage area.

Four exits are provided on the second floor by four enclosed, exterior, protected exit stairwells.

The number of exits that serve the second floor controlled storage areas is compliant with the LSC.

K.6. __Second Floor Office and Common Areas__

The second floor office and common area OL is 207 persons.

Three of the four exterior exit stairwells on the west, south west, and east, sides of the building are accessible from the office and associated common areas on the second floor.

The number of exits that serve the second floor office and common areas is compliant with the LSC.

L. Exit Remoteness

The corresponding LSC requirements for remoteness of exits are reproduced in Table 9 above.

Since the building is fitted with a supervised automatic sprinkler system exits must be separated by a distance of one-third of the maximum overall diagonal dimension of the building. The overall diagonal dimension of the building is approximately 280 ft. which translates to a minimum distance required of 93 ft. between exits to meet the LSC remoteness criteria. Exits on the main floor and second floor are a minimum of 200 ft. apart. The test for remoteness in these areas is met.

The diagonal dimension of the main floor and mezzanine office areas is approximately 96 ft.. One-third of this dimension is 32 ft. The exits from these office areas are in excess of 80 ft. apart and meet the remoteness criteria of the LSC.

M. Common Path of Travel

The corresponding LSC requirements for common path of travel are reproduced in Table 9 above.

Common path of travel limitations for both a business and storage occupancies is 100 ft. There are no areas or corridors within the construction warehouse with a common path of travel in excess of 100 ft.

The LSC criteria for common path of travel is met for the building.

N. Travel Distance to Exits

The corresponding LSC requirements for travel distance to exits are reproduced in Table 9 above.

Since the warehouse is a mixed occupancy, the most restrictive requirements apply. The building is protected by a supervised automatic fire sprinkler system throughout. For a storage occupancy an exit must be capable of being reached within 400 ft. and for a business occupancy an exit must be capable of being reached within 300 ft. The most restrictive travel distance is 300 ft.

At least one exit is within 300 ft. of every point within the building. The construction warehouse meets the LSC travel distance requirements.

O. Dead End Corridors

The corresponding LSC requirements for dead end corridors are reproduced in Table 9 above.

There is one dead end hallway (106) on the main floor of the warehouse that measures 49 ft. The length of this dead end corridor is less than LSC criteria of 50 ft. and it is compliant with the LSC.

P. Other Requirements for Egress Systems

P.1. ***Horizontal Exits***

There are no horizontal exits in the warehouse building.

P.2. ***Corridors***

For existing business occupancies and storage occupancies, the LSC, Chapters 39 (paragraph 39.3.6) and 42 (paragraph 42.3.6) do not require protection of exit access corridors.

There are no corridors in the building.

P.3. ***Stairways***

Four enclosed, exterior, exit stairways provide for protected egress from the second floor. Each enclosed stairwell is separated from the main building by a 2-hour fire rated barrier. The exterior walls of the stair enclosure and the adjacent building walls, 10 ft. on either side of the stairwell enclosure, are 1-hour fire rated walls.

Neither Chapter 39 (Existing Business Occupancies) nor Chapter 42 (Storage Occupancies) of the LSC contain special requirements for enclosure of stairwells.

The LSC provides that:

> ***7.1.3.2.1*** *Where this Code requires an exit to be separated from other parts of the building, the separating construction shall meet the requirements of Section 8.2 and the following:*
>
> *(1)* The separation shall have a minimum 1-hour fire resistance rating where the exit connects three or fewer stories.*
>
> *(3)* The separation shall have a minimum 2-hour fire resistance rating where the exit connects four or more stories, unless one of the following conditions exists:*
>
> > *(b) In existing buildings protected throughout by an approved, supervised automatic sprinkler system in accordance with Section 9.7, existing exit stair enclosures shall have a minimum 1-hour fire resistance rating.*

P.4. ***Placement of Exit Signs***

LSC requirements for placement of exit signs are found in the following LSC paragraphs:

> ***7.10.1.2.1**** *Exits, other than main exterior exit doors that obviously and clearly are identifiable as exits, shall be marked by an approved sign that is readily visible from any direction of exit access.*
>
> ***7.10.1.5.1*** *Access to exits shall be marked by approved, readily visible signs in all cases where the exit or way to reach the exit is not readily apparent to the occupants.*

P.5. ***Interior Finish Requirements***

Interior finish requirements are addressed in Chapter 10 of the LSC. LSC Table A.10.2.2 *Interior Finish Classification Limitations* provides a summary of interior finish criteria for exits, corridors and other spaces.

Class A, B and C finishes apply to wall and ceiling coverings. Class I and II finishes apply to floor finishes.

The flame spread index and smoke developed rating for Class A, B and C interior wall and ceiling finishes are as follows:

Class A – flame spread index of 0 – 25 and smoke developed rating of 0 – 450

Class B – flame spread index of 26 – 75 and smoke developed rating of 0 – 450

Class C – flame spread rating of 76 – 200 and smoke developed rating of 0 - 450

For the construction warehouse, the following interior finish requirements apply (from LSC Table A.10.2.2):

Table 10 – Interior Finish Requirements

Occupancy	**Exits**	**Exit Access Corridors**	**Other Spaces**
Storage	Class A or B	Class A, B or C	Class A, B or C
Business	Class A or B	Class A, B or C	Class A, B or C

V. Fire Suppression Systems

A. Construction Warehouse Fire Suppression System Description

The construction warehouse is protected by an approved, supervised, automatic fire sprinkler system installed accordance with NFPA 13 *Standard for the Installation of Sprinkler Systems*, 1999 Edition.

This evaluation of the fire suppression systems installed in the building is performed based on the criteria and requirements of NFPA 13, 2010 Edition [NFPA 13 (2010)].

B. Water Supply

Water for fire protection is provided on site and is operated and maintained by the operations organization.

The site water supply includes two (2) redundant fire water storage tanks, each with a capacity of 350,000 gallons and dedicated to fire protection service. The tanks are designed and installed in accordance with NFPA 22 *Standard for Water Tanks for Private Fire Protection*.

Two (2) redundant diesel fire pumps are provided in accordance with NFPA 20 *Standard for the Installation of Stationary Pumps for Fire Protection*. The pumps are located in separate pump house structures and each pump is rated at 130 psi and 2,500 gpm.

The underground fire main is looped and gridded around and between each major site building. This arrangement provides two way flow to fire hydrants and fire sprinkler system lead-in piping to improve the reliability of fire water distribution. The underground fire main consists of nominal 12 inch diameter pipe. The underground fire main is designed and installed in accordance with NFPA 24 *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*.

The available source of water for the warehouse building, based on hydrant testing, will flow 2,329 gpm at 124 psi.

For design purposes, criteria was used corresponding to a supply of 100 psi at 2,500 gpm.

Figure 12 below illustrates the available and design water supply.

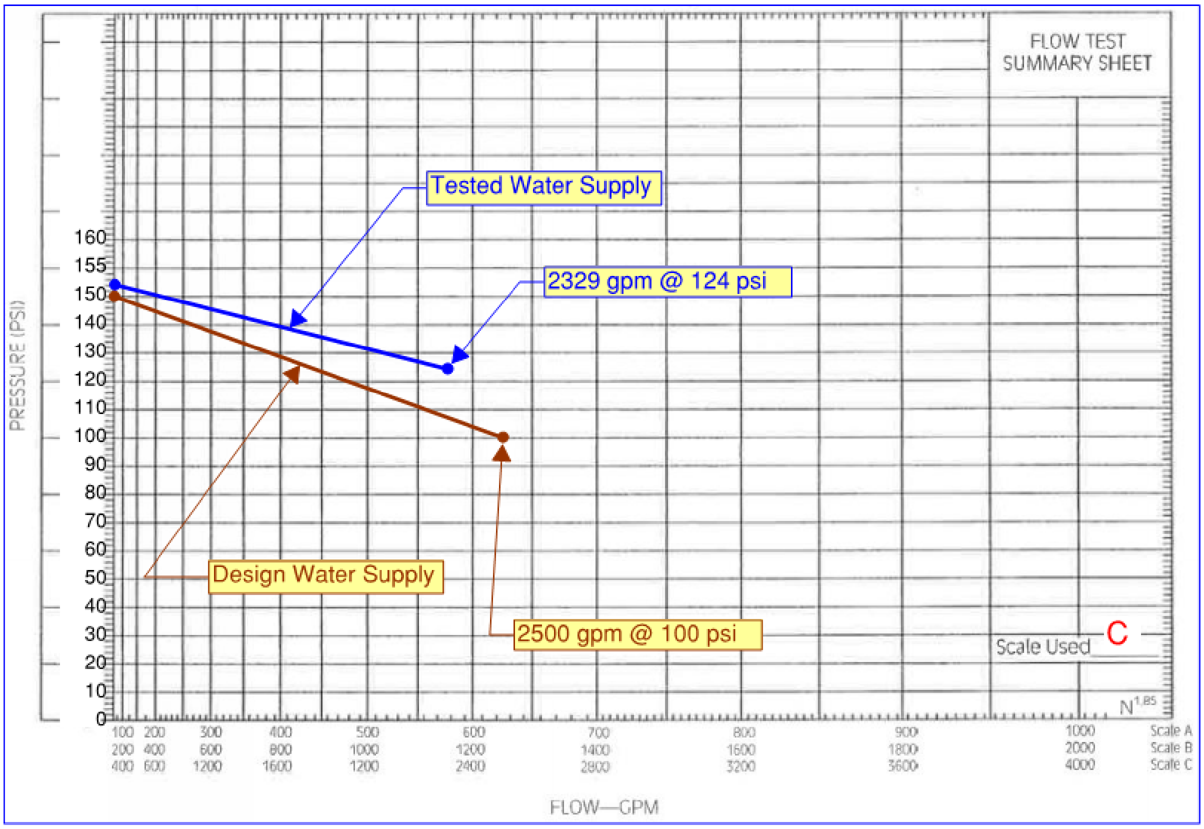


Figure 12 – Construction Warehouse Available Water Supply

C. Building Layout

The building consists of a main floor, two (2) mezzanine areas, and a second floor.

The main floor is primarily used for warehouse operations. These operations are described as:

- Storage of commodities on single or double row racks to a height of 20 feet
- Storage and issue of tools and consumables
- Warehouse receiving operations
- Packing areas
- Two small walled in offices on the storage floor
- An enclosed mechanical room
- An enclosed electrical/server
- Outdoor covered truck loading dock

The main floor ceiling is 24 ft. above the finished floor.

An office area enclosed in non-fire rated construction comprises approximately 10% of the main floor and is located in the north-west corner of the building. This office space has an 8 ft. suspended ceiling with a 4 ft. interstitial space to the mezzanine floor deck above.

Immediately above the main floor office area is a mezzanine enclosed in non-fire rated construction. The mezzanine is used for office space. Both the office and mezzanine areas contain standard office cubicles, walled offices and conference rooms, and restrooms.

Use of the office area and mezzanine are not related to warehouse operations.

The second floor consists of a large open volume and is primarily a storage area. However, a large portion of the second floor is used for open office space and contains open office cubicles. Storage areas are segregated from these office areas by chain link fence.

On the second floor there are two walled conference rooms, restrooms, and a janitor's space.

An elevator connects the main floor, mezzanine level, and second floor areas.

D. Occupancy Hazard Classification

D.1. ***Main Floor Storage Area***

Chapter 5 of NFPA 13 (2010) requires that dedicated and miscellaneous storage be protected in accordance with Chapter 12 General Requirements for Storage or Chapter 13 Miscellaneous Storage, as applicable.

The storage function of the main floor of the building includes the storage of Class IV commodities including unexpanded, exposed, stable Group A plastic material to a maximum height of 20 ft.

Examples of commodities stored on racks in the construction warehouse main floor that are consistent with high hazard materials, or Group A plastics, include:

- Cartons of commodities containing foam packing material
- Electronic equipment packaged in cartons
- Carpet, rugs and rubber mats
- Automobile and truck batteries
- Plastic water bottles
- Numerous plastic containers containing construction related supplies
- Polystyrene cups (Red Solo Cups)
- Plastic trash bags

Since Group A plastic material are stored on racks in a concentrated location above 12 ft. in height, these commodities must be protected according to the requirements of NFPA 13, Chapter 17 – Protection of Plastic and Rubber Commodities that are Stored on Racks. Specifically, Section 17.2 Protection Criteria for Rack Storage of Plastics Commodities Stored Up to and Including 25 ft. in Height.

These materials are judged to be stable.

D.2. Second Floor Storage and Open Office Areas

The second floor design criteria includes the storage of Class IV commodities, including Group A plastic material to a maximum height of 10 ft. On the second floor storage is accomplished on open shelves or in a solid pile configuration.

Criteria for sprinkler protection of the open office area on the second floor is bounded by the criteria provided for the protection of plastic material storage.

Although the height of storage of Group A plastic material on the second floor is less than 12 ft., the provisions for this type of storage under Chapter 13 Miscellaneous Storage does not include solid pile storage arrangements. Therefore, Chapter 15 Protection of Plastic and Rubber Commodities That Are Stored Palletized, Solid Piled, Bin Boxes, Shelf Storage, or Back-to-Back Shelf Storage must be followed to ensure compliant protection.

These materials are judged to be stable.

D.3. Office and Other Non-Storage Areas

The Occupancy Hazard Fire Control Approach of NFPA 13 Section 11.2 is applied to protect office areas, conference rooms, employee break rooms, restrooms, utility (mechanical and electrical/telephone/server) rooms, and tool issue (dispersal) room.

Accordingly, the use and conditions found in the areas main floor, mezzanine, and second floor office areas, conference rooms, restrooms, and break room areas are consistent with a light hazard occupancy in accordance with NFPA 13 (2010).

The quantity and type of combustible material found in the relatively small mechanical and electrical rooms, including the elevator machine room found in the building, does not include combustible and flammable liquid in significant quantity. This assessment concludes that a rapidly developing fire with a high rate of heat release is not expected in these areas. The combustibility in these rooms is low, quantities of combustibles are moderate or less than moderate, stockpiles of combustibles are expected to be well below 8 ft., and a fire with at most a moderate heat release rate would be expected. Additionally these utility rooms are not process areas involving frequent changes in activity.

Characterization of the fire hazards found in these mechanical and electrical utility rooms leads to classification as an ordinary hazard group 1 (OH1) occupancy in accordance with NFPA 13 (2010).

All of these areas, including the small mechanical and electrical utility rooms on the main floor, and tool dispersal area, have been designated as an ordinary hazard occupancy classification. Protection of these areas have been designed to meet criteria for an ordinary hazard group 2 (OH2) occupancy classification.

The covered exterior loading dock is not a storage area and is also classified as an ordinary hazard group 2 occupancy consistent with NFPA 13 (2010).

E. Sprinkler System Layout and Design

E.1. <u>Main Floor Storage Area Sprinkler System Design</u>

The decision tree contained in NFPA 13, Figure 17.1.2.1, further identifies and confirms the appropriate criteria for protection of stable plastics to be taken from Chapter 17:

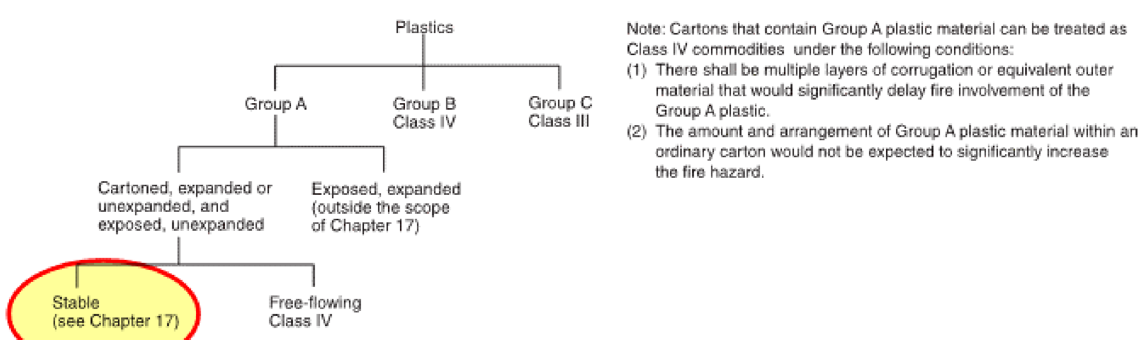


FIGURE 17.1.2.1 Decision Tree.

Figure 13 – Decision Tree for Rack Storage of Stable Plastics

The main floor storage areas of the Warehouse are protected by an installed Early Suppression Fast-Response (ESFR) type sprinkler system. Design criteria requires protection of exposed, unexpanded storage of Group A plastics up to 20 ft. in height.

NFPA 13 Section **17.2.3 Early Suppression Fast-Response (ESFR) Sprinklers for Rack Storage of Plastics Commodities Stored Up to and Including 25 ft in Height** applies.

NFPA 13 Table 17.2.3.1 provides relevant criteria for ESFR sprinkler protection of rack storage. For exposed, unexpanded, storage of plastics commodities to a maximum height of 20 ft. under a 24 ft. ceiling the following ESFR sprinkler criteria applies:

		Maximum Storage Height		Maximum Ceiling/ Roof Height				Minimum Operating Pressure			Hose Stream Allowance		Water Supply Duration (hours)
Storage Arrangement	Commodity	ft	m	ft	m	Nominal K-Factor	Orientation	psi	bar	In-Rack Sprinkler Requirements	gpm	L/min	
Single-row, double-row, and multiple-row rack (no open-top containers)	Cartoned unexpanded	25	7.6	32	9.8	14.0 (200)	Upright/ Pendent	60	4.1	No	250	946	1
						16.8 (240)	Upright/ Pendent	42	2.9	No			
				35	10.7	14.0 (200)	Upright/ |Pendent	75	5.2	No			
						16.8 (240)	Upright/ Pendent	52	3.6	No			
						22.4 (320)	Pendent	35	2.4	No			
						25.2 (360)	Pendent	20	1.4	No			
				40	12.2	14.0 (200)	Pendent	75	5.2	No			
						16.8 (240)	Pendent	52	3.6	No			
						22.4 (320)	Pendent	40	2.8	No			
						25.2 (360)	Pendent	25	1.7	No			
				45	13.7	14.0 (200)	Pendent	90	6.2	Yes			
						16.8 (240)	Pendent	63	4.3	Yes			
						22.4 (320)	Pendent	40	2.8	No			
						25.2 (360)	Pendent	40	2.8	No			
	Exposed unexpanded	20	6.1	25	7.6	14.0 (200)	Pendent	50	3.4	No			
						16.8 (240)	Pendent	35	2.4	No			
				30	9.1	14.0 (200)	Pendent	50	3.4	No			
						16.8 (240)	Pendent	35	2.4	No			
				35	10.7	14.0 (200)	Pendent	75	5.2	No			
						16.8 (240)	Pendent	52	3.6	No			

Figure 14 – Construction Warehouse ESFR Sprinkler Criteria – Pendent Sprinklers

The installation of EFSR sprinklers in the building includes upright ESFR sprinklers. ESFR sprinkler design for exposed, unexpanded plastics storage requires pendent sprinklers.

However, it is permissible to use upright ESFR sprinklers for the protection of both cartoned expanded and unexpanded plastic as shown below:

Storage Arrangement	Commodity	Maximum Storage Height		Maximum Ceiling/ Roof Height		Nominal K-Factor	Orientation	Minimum Operating Pressure		In-Rack Sprinkler Requirements	Hose Stream Allowance		Water Supply Duration (hours)
		ft	m	ft	m			psi	bar		gpm	L/min	
Single-row, double-row, and multiple-row rack (no open-top containers)	Cartoned unexpanded	20	6.1	25	7.6	14.0 (200)	Upright/ Pendent	50	3.4	No	250	946	1
						16.8 (240)	Upright/ Pendent	35	2.4	No			
						22.4 (320)	Pendent	25	1.7	No			
						25.2 (360)	Pendent	15	1.0	No			
				30	9.1	14.0 (200)	Upright/ Pendent	50	3.4	No			
						16.8 (240)	Upright/ Pendent	35	2.4	No			
						22.4 (320)	Pendent	25	1.7	No			
						25.2 (360)	Pendent	15	1.0	No			
				35	10.7	14.0 (200)	Upright/ Pendent	75	5.2	No			
						16.8 (240)	Upright/ Pendent	52	3.6	No			
						22.4 (320)	Pendent	35	2.4	No			
						25.2 (360)	Pendent	20	1.4	No			
				40	12.2	14.0 (200)	Pendent	75	5.2	No			
						16.8 (240)	Pendent	52	3.6	No			
						22.4 (320)	Pendent	40	2.8	No			
						25.2 (360)	Pendent	25	1.7	No			
				45	13.7	14.0 (200)	Pendent	90	6.2	Yes			
						16.8 (240)	Pendent	63	4.3	Yes			
						22.4 (320)	Pendent	40	2.8	No			
						25.2 (360)	Pendent	40	2.8	No			
		25	7.6	30	9.1	14.0 (200)	Upright/ Pendent	50	3.4	No			
						16.8 (240)	Upright/ Pendent	35	2.4	No			
						22.4 (320)	Pendent	25	1.7	No			
						25.2 (360)	Pendent	15	1.0	No			

Figure 15 - Construction Warehouse ESFR Upright Sprinkler Criteria for Cartoned Unexpanded Plastic Commodities

Storage Arrangement	Commodity	Maximum Storage Height		Maximum Ceiling/ Roof Height		Nominal K-Factor	Orientation	Minimum Operating Pressure		In-Rack Sprinkler Requirements	Hose Stream Allowance		Water Supply Duration (hours)
		ft	m	ft	m			psi	bar		gpm	L/min	
Single-row, double-row, and multiple-row rack (no open-top containers)	Exposed unexpanded	20	6.1	40	12.2	14.0 (200)	Pendent	75	5.2	No	250	946	1
						16.8 (240)	Pendent	52	3.6	No			
				45	13.7	14.0 (200)	Pendent	90	6.2	Yes			
						16.8 (240)	Pendent	63	4.3	Yes			
		25	7.6	30	9.1	14.0 (200)	Pendent	50	3.4	No			
						16.8 (240)	Pendent	35	2.4	No			
				32	9.8	14.0 (200)	Pendent	60	4.1	No			
						16.8 (240)	Pendent	42	2.9	No			
				35	10.7	14.0 (200)	Pendent	75	5.2	No			
						16.8 (240)	Pendent	52	3.6	No			
				40	12.2	14.0 (200)	Pendent	75	5.2	No			
						16.8 (240)	Pendent	52	3.6	No			
						22.4 (320)	Pendent	50	3.4	No			
						25.2 (360)	Pendent	50	3.4				
				45	13.7	14.0 (200)	Pendent	90	6.2	Yes			
						16.8 (240)	Pendent	63	4.3	Yes			
	Cartoned expanded	20	6.1	25	7.6	14.0 (200)	Upright/ Pendent	50	3.4	No			
						16.8 (240)	Upright/ Pendent	35	2.4	No			
				30	9.1	14.0 (200)	Upright/ Pendent	50	3.4	No			
						16.8 (240)	Upright/ Pendent	35	2.4	No			
		25	7.6	30	9.1	14.0 (200)	Upright/ Pendent	50	3.4	No			
						16.8 (240)	Upright/ Pendent	35	2.4	No			
				32	9.8	14.0 (200)	Pendent	60	4.1	No			
						16.8 (240)	Upright/ Pendent	42	2.9	No			

Figure 16 - Construction Warehouse ESFR Upright Sprinkler Criteria for Cartoned Expanded Plastic Commodities

For this application, for rack storage of Group A plastics on the main storage floor of the warehouse with maximum storage height of 20 ft. and ceiling height of 24 ft., Table 17.2.3.1 requires ESFR sprinklers with a K-factor of 14.0 operating at a minimum pressure of 50 psi. A 250 gpm hose stream allowance is required and the duration of the water supply is 60 minutes. Additionally, since upright ESFR sprinklers are installed the protection is afforded to cartoned, expanded or unexpanded, plastics.

The required design area of an ESFR sprinkler system consists of the most hydraulically demanding area of 12 sprinklers, consisting of four (4) sprinklers on each of three branch lines.

E.1.a. Hydraulic Calculations

The sprinkler system on the main floor of the construction warehouse is a gridded system and is hydraulically calculated using hydraulic fire sprinkler system analysis software (HASS® Computer Program) by HRS Systems, Inc., Tucker, GA.

Results of this analysis are presented below:

HYDRAULIC CALCULATIONS

FOR

CONSTRUCTION WAREHOUSE
MAIN FLOOR STORAGE AREA

-DESIGN DATA-

OCCUPANCY CLASSIFICATION:	STORAGE
DENSITY:	ESFR (50 PSI MINIMUM)
AREA OF APPLICATION:	NA
COVERAGE PER SPRINKLER:	100 sq. ft. maximum
NUMBER OF SPRINKLERS CALCULATED:	12 sprinklers
TOTAL SPRINKLER WATER FLOW REQUIRED:	1192.8 gpm
TOTAL WATER REQUIRED (including hose):	1442.8 gpm
FLOW AND PRESSURE (@ SRC):	1442.8 gpm @ 91.4 psi
SPRINKLER K FACTOR:	14.0

WATER SUPPLY DATA

SOURCE NODE TAG	STATIC PRESS. (PSI)	RESID. PRESS. (PSI)	@	FLOW (GPM)	AVAIL. PRESS. (PSI)	@	TOTAL DEMAND (GPM)	REQ'D PRESS. (PSI)
SOURCE	150.0	100.0		2500.0	131.9		1442.8	91.4

AGGREGATE FLOW ANALYSIS:

TOTAL FLOW AT SOURCE	1442.8 GPM
TOTAL HOSE STREAM ALLOWANCE AT SOURCE	150.0 GPM
OTHER HOSE STREAM ALLOWANCES	100.0 GPM
TOTAL DISCHARGE FROM ACTIVE SPRINKLERS	1192.8 GPM

Figure 17 - Construction Warehouse Main Floor Storage Area ESFR Sprinkler Hydraulic Calculations

The results of the hydraulic analysis are plotted to graphically show adequacy of the water supply:

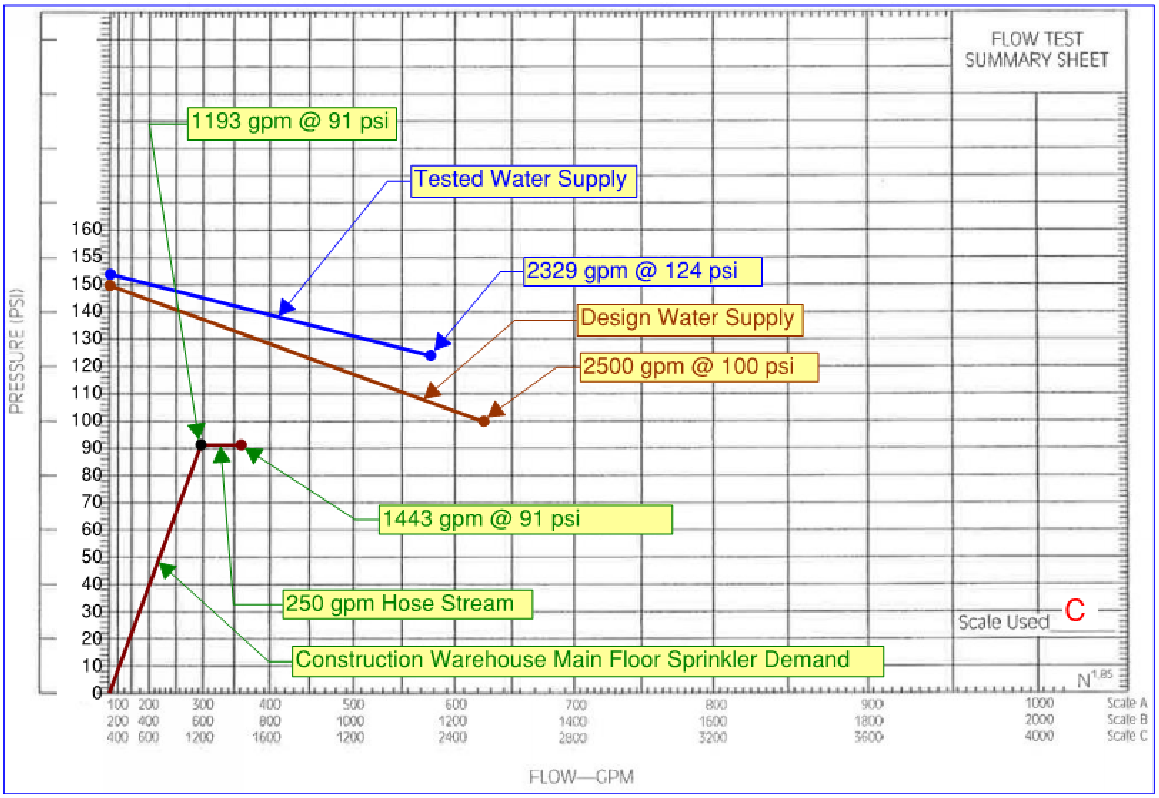


Figure 18 – Construction Warehouse First Floor Sprinkler Demand vs. Water Supply

The sprinkler demand is plotted at the source. This plot shows that the sprinkler demand point, including a 250 gpm hose stream (1,443 gpm @ 91 psi), falls approximately 40 psi below the design water supply curve and 50 psi below the tested water supply curve. The water supply exceeds the fire sprinkler system demand for the main floor storage area fire sprinkler system.

E.1.b. Evaluate Required Volume of Water

Design density, area of application, hose stream allowance and water supply duration are taken from NFPA 13, Table 17.2.3.1.

Inputs to Table 17.2.3.1 include:

- Double row racks with no open top containers, in cartons, expanded plastic commodities
- Maximum storage height of 20 ft. and ceiling height of 25 ft.

From Table 17.2.3.1 and ESFR design criteria, K = 14.0 Upright or Pendant; 250 gpm hose stream allowance; 12 sprinklers with no in-rack sprinklers required at 50 psi and a water supply duration of 60 minutes.

For the main floor storage area, using ESFR sprinklers, the nominal sprinkler flow and water supply duration is calculated:

$$Volume\ of\ Water = \left[\left(K \cdot \sqrt{Minimum\ Pressure} \cdot No.Sprinklers\right) + Hose\ Stream\right] \cdot Duration$$

$$= \left[\left(14.0 \cdot \sqrt{50psi} \cdot 12\ Sprinklers\right) + 250gpm\right] \cdot 60\ minutes$$

$$Volume\ of\ Water = 86{,}276\ gal.$$

The available water supply includes two fire water storage tanks each containing 350,000 gallons and exceeds the volume of water required for this ESFR design.

E.1.c. ESFR Sprinkler Placement and Location

NFPA 13 Table 8.12.2.2.1 provides the maximum spacing for ESFR sprinklers for ceiling heights up to 30 ft:

Table 8.12.2.2.1 Protection Areas and Maximum Spacing of ESFR Sprinklers

	Ceiling/Roof Heights Up to 30 ft (9.1 m)			
	Protection Area		Spacing	
Construction Type	ft^2	m^2	ft	m
Noncombustible unobstructed	100	9.3	12	3.7
Noncombustible obstructed	100	9.3	12	3.7
Combustible unobstructed	100	9.3	12	3.7
Combustible obstructed	N/A		N/A	

Figure 19 – Protection Areas and Maximum Spacing of ESFR Sprinklers

The ESFR sprinklers are nominally spaced 10 ft., but no greater than 12 ft., apart, on each branch line with 8 ft. 4 in. between branch lines. This spacing provides for a maximum protection area of 100 ft^2 per sprinkler in accordance with the maximum spacing required by Table 8.12.2.2.1.

The area of protection for the main floor sprinkler riser is 38,000 ft^2. This floor area is below the maximum area allowed per sprinkler riser of 40,000 ft^2 for high piled storage applications that is delineated by NFPA 13 Section 8.2.1(4). The area covered by ESFR sprinklers is calculated to be 33,900 ft^2 (i.e., 38,000 ft^2 less 4,100 ft^2 that is attributed to the walled in main floor office area).

E.1.d. ESFR Sprinkler Data

NFPA 13 Section 8.4.7.3.3, requires that ordinary, intermediate, or high temperature-rated sprinklers shall be used for wet pipe systems.

In the construction warehouse, in the main floor storage area, Viking Model VK520, Early Suppression, Fast Response Upright Sprinklers, K = 14.0, and intermediate temperature-rated (205°F) sprinkler heads are installed.

See Appendix __ of this report for additional information on Viking VK520 sprinklers.

E.2. ***Second Floor Storage Area Sprinkler System Design***

The decision tree contained in NFPA 13, Figure 15.2.2, further identifies and confirms the appropriate criteria for protection of stable plastics to be taken from Chapter 15:

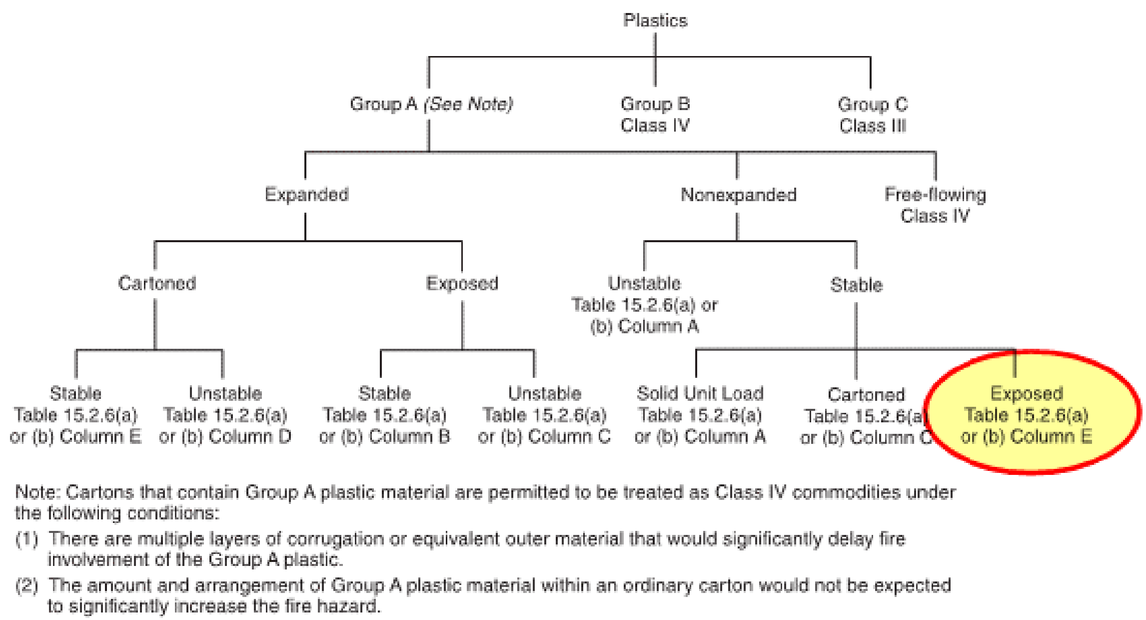


FIGURE 15.2.2 Decision Tree.

Figure 20 – Decision Tree for High Piled or Solid Shelf Storage of Stable Plastics

The second floor storage areas of the Warehouse are protected by an installed Control Mode Density / Area (CMDA) type sprinkler system. This system is designed for exposed, unexpanded Group A plastics in an open shelf or solid piled storage configuration up to 10 ft. in height.

NFPA 13 Section **15.2 Controlled Mode Density/Area Sprinkler Protection Criteria for Palletized, Solid-Piled, Bin Box, Shelf Storage, or Back-to-Back Shelf Storage of Plastic and Rubber Commodities** applies.

Design density is taken from NFPA 13, Table 15.2.6(a), Column 'E', which applies to exposed, unexpanded plastic in an open shelf or solid pile storage configuration.

Entering Table 15.2.6(a) under Column 'E' for the actual facility condition of 10 ft. maximum storage height and a ceiling height of 21 ft. provides a design density of 0.7 gpm/ft^2.

Table 15.2.6(a) Design Densities for Palletized, Solid-Piled, Bin Box, or Shelf Storage of Plastic and Rubber Commodities (U.S. Customary Units)

Storage Height (ft)	Roof/Ceiling Height (ft)	Density (gpm/ft^2) A	B	C	D	E
>5 to ≤12	Up to 15	0.2	EH2	0.3	EH1	EH2
	>15 to 20	0.3	0.6	0.5	EH2	EH2
	>20 to 32	0.4	0.8	0.6	0.45	0.7
15	Up to 20	0.3	0.6	0.5	0.4	0.45
	>20 to 25	0.4	0.8	0.6	0.45	0.7
	>25 to 35	0.45	0.9	0.7	0.55	0.85
20	Up to 25	0.4	0.8	0.6	0.45	0.7
	>25 to 30	0.45	0.9	0.7	0.55	0.85
	>30 to 35	0.6	1.2	0.85	0.7	1.1
25	Up to 30	0.45	0.9	0.7	0.55	0.85
	>30 to 35	0.6	1.2	0.85	0.7	1.1

Notes:
(1) Minimum clearance between sprinkler deflector and top of storage shall be maintained as required.
(2) Column designations correspond to the configuration of plastics storage as follows:
A: (1) Nonexpanded, unstable
(2) Nonexpanded, stable, solid unit load
B: Expanded, exposed, stable
C: (1) Expanded, exposed, unstable
(2) Nonexpanded, stable, cartoned
D: Expanded, cartoned, unstable
E: (1) Expanded, cartoned, stable
(2) Nonexpanded, stable, exposed
(3) EH1 = Density required by Figure 13.2.1 for Curve EH1
EH2 = Density required by Figure 13.2.1 for Curve EH2
(4) Hose streams and durations shall be as follows: ≤5 ft 250 gpm (946 L/min) and 90 minutes; >5 ft to ≤20 ft 500 gpm (1900 L/min) and 120 minutes; >20 ft to ≤25 ft 500 gpm (1900 L/min) and 150 minutes.

Figure 21 - Construction Warehouse Second Floor Control Mode Density/Area Sprinkler Criteria for Solid-Piled and Shelf Storage of Plastic Commodities

Note (4) of Table 15.2.6(a), which requires a 500 gpm hose stream allowance and water supply duration of 120 minutes, is consistent with the hose stream and water supply duration requirements of Table 15.1.1:

Table 15.1.1 Hose Stream Allowance and Water Supply Duration Requirements

Commodity Classification	Storage Height		Inside Hose		Total Combined Inside and Outside Hose		Duration (minutes)
	ft	m	gpm	L/min	gpm	L/min	
Group A plastic	Over 5 up to 20	Over 1.5 up to 6.1	0, 50, or 100	0, 190, or 380	500	1900	120
	Over 20 up to 25	Over 6.1 up to 7.6	0, 50, or 100	0, 190, or 380	500	1900	150

Figure 22 - Construction Warehouse Second Floor Hose Stream Criteria for Solid-Piled and Shelf Storage of Plastic Commodities

The required design area of 2,500 ft^2 is addressed by NFPA 13 (2010) Section 15.2.8:

15.2.8 *For Table 15.2.6(a) and Table 15.2.6(b), the design areas shall be as follows:*

(1) The area shall be a minimum of 2500 ft^2 (232 m^2).

E.2.a. Hydraulic Calculations

The sprinkler system on the second floor of the warehouse is a gridded system and is hydraulically calculated using hydraulic fire sprinkler system analysis software (HASS® Computer Program) by HRS Systems, Inc., Tucker, GA.

Results of this analysis are presented below:

HYDRAULIC CALCULATIONS

FOR

CONSTRUCTION WAREHOUSE
SECOND FLOOR

-DESIGN DATA-

OCCUPANCY CLASSIFICATION:	STORAGE
DENSITY:	0.70 gpm/sq. ft.
AREA OF APPLICATION:	2500 sq. ft.
COVERAGE PER SPRINKLER:	100 sq. ft. maximum
NUMBER OF SPRINKLERS CALCULATED:	34 sprinklers
TOTAL SPRINKLER WATER FLOW REQUIRED:	1844.2 gpm
TOTAL WATER REQUIRED (including hose):	2344.1 gpm
FLOW AND PRESSURE (@ SRC):	2344.1 gpm @ 105.6 psi
SPRINKLER K FACTOR:	16.8

WATER SUPPLY DATA

SOURCE NODE TAG	STATIC PRESS. (PSI)	RESID. PRESS. (PSI)	@ FLOW (GPM)	AVAIL. PRESS. (PSI)	@ TOTAL DEMAND (GPM)	REQ'D PRESS. (PSI)
SOURCE	150.0	100.0	2500.0	105.6	2344.1	79.1

AGGREGATE FLOW ANALYSIS:

TOTAL FLOW AT SOURCE	2344.1 GPM
TOTAL HOSE STREAM ALLOWANCE AT SOURCE	400.0 GPM
OTHER HOSE STREAM ALLOWANCES	100.0 GPM
TOTAL DISCHARGE FROM ACTIVE SPRINKLERS	1844.1 GPM

Figure 23 - Construction Warehouse Second Floor Control Mode Density/Area Sprinkler Hydraulic Calculations

The results of the hydraulic analysis are plotted to graphically show adequacy of the water supply:

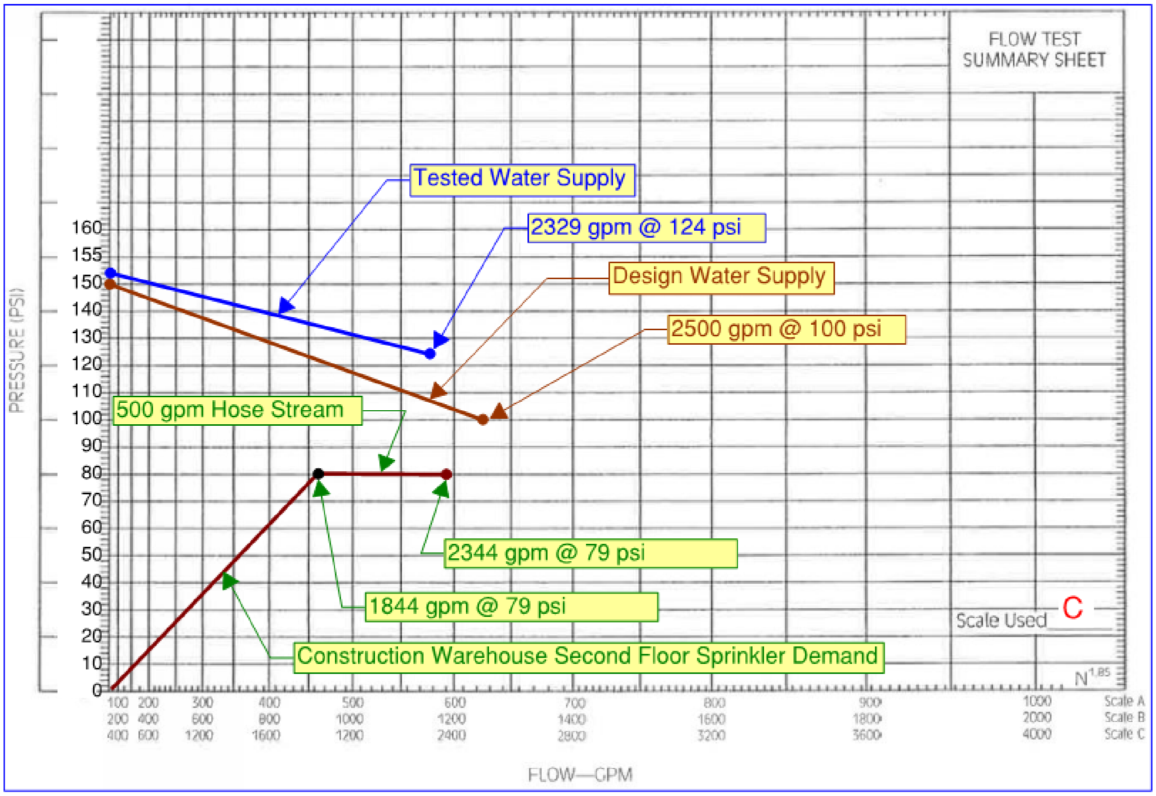


Figure 24 – Construction Warehouse Second Floor Sprinkler Demand vs. Water Supply

The sprinkler demand is plotted at the source. It can be seen from this plot that the sprinkler demand point, including a 500 gpm hose stream (2,344 gpm @ 79 psi), falls approximately 22 psi below the design water supply curve and 40 psi below the tested water supply curve. The water supply exceeds the fire sprinkler system demand for the second floor fire sprinkler system.

E.2.b. Evaluate Required Volume of Water

The required volume of water to be made available for the required area and flow, and duration of the water supply, is calculated to be:

$$Volume\ of\ Water = [(Density\ \cdot Area) + Hose\ Stream\ Allowance] \cdot Duration$$

$$= \left[\left(0.7\frac{gpm}{ft^2}\cdot 2{,}500ft^2\right) + 500gpm\right]\cdot 120min$$

$$Volume\ of\ Water = 270{,}000\ gal$$

The available water supply includes two fire water storage tanks each containing 350,000 gallons and exceeds the volume of water required for this Control Mode Density/Area sprinkler design.

E.2.c. Control Mode Density/Area Sprinkler Placement and Location

Protection of the second floor storage areas follows a Controlled Mode Density/Area design methodology and listed Storage–Density/Area sprinklers for use in protecting high-piled storage.

The standard spray sprinkler spacing requirements of NFPA 13 Section 8.6.2.2.1 and Table 8.6.2.2.1(d) for protection of high-piled storage is followed:

Table 8.6.2.2.1(d) Protection Areas and Maximum Spacing of Standard Pendent and Upright Spray Sprinklers for High-Piled Storage

Construction Type	System Type	Protection Area		Maximum Spacing	
		ft²	m²	ft	m
All	Hydraulically calculated with density ≥0.25	100	9.3	12*	3.7*
All	Hydraulically calculated with density <0.25	130	12.1	15	4.6

*In buildings where solid structural members create bays up to 25 ft (7.6 m) wide, maximum spacing between sprinklers is permitted up to 12 ft 6 in. (3.8 m).

Figure 25 – Protection Areas and Maximum Spacing of Sprinklers for High Piled Storage

Since the design density is 0.7 gpm per ft^2 the maximum protection area for sprinklers installed on the second floor is 100 ft^2 and maximum spacing is 12 ft.

E.2.d. Control Mode Density/Area Sprinkler Data

The Storage-Density/Area sprinkler model installed to protect the second floor area is a ¾ in. Viking Model VK580 upright sprinkler, K-factor of 16.8.

E.3. <u>Office and Other Non-Storage Areas</u>

The main floor office area, mezzanine office area, dispersal area, utility rooms, walled in office areas on the main storage floor, and truck loading dock areas are protected by standard spray upright and standard spray pendent sprinklers spaced according to NFPA 13 Table 8.6.2.2.1(b) providing a maximum protection area of 130 ft^2 spaced no greater than 15 ft. apart.

Table 8.6.2.2.1(b) Protection Areas and Maximum Spacing of Standard Pendent and Upright Spray Sprinklers for Ordinary Hazard

Construction Type	System Type	Protection Area		Maximum Spacing	
		ft^2	m^2	ft	m
All	All	130	12.1	15	4.6

Figure 26 – Protection Areas and Maximum Spacing of Sprinklers for Ordinary Hazard

Ordinary hazard group 2 areas are protected with Reliable Sprinkler Company Model G standard spray upright (SSU), recessed pendent, and horizontal sidewall sprinklers. All Model G sprinklers have a K factor of 5.6. Recessed pendent sprinklers are rated at 165°F, horizontal sidewall sprinklers are rated at 212°F, and standard spray upright sprinklers in above ceiling areas are rated at either 212°F or 286°F.

Protection of the outdoor, covered, truck loading dock with an auxiliary dry pipe sprinkler riser utilizes Reliable Model G SSU sprinkler heads rated at 286°F.

For additional information about sprinklers installed in ordinary hazard areas see Appendix __ of this report.

F. Earthquake Bracing (Sway Bracing) and Hangers

The installation of sway bracing and hangers is addressed in Chapter 9 of NFPA 13. The specific paragraphs that address hanger and bracing requirements are reproduced below.

F.1. Hangers

Hangers are included in the sprinkler system design according to the requirements of Chapter 9 of NFPA 13.

These basic requirements include:

- Hangers are required to be designed to support five times the weight of the water-filled pipe plus 250 lb. (114 kg) at each point of piping support.
- Each point of support is required to be adequate to support the system.
- The maximum spacing between hangers is indicated in NFPA 13 Tables 9.2.2.1(a) or Table 9.2.2.1(b) – provided for reference below:

Table 9.2.2.1(a) Maximum Distance Between Hangers (ft-in.)

	Nominal Pipe Size (in.)											
	¾	1	1¼	1½	2	2½	3	3½	4	5	6	8
Steel pipe except threaded lightwall	N/A	12-0	12-0	15-0	15-0	15-0	15-0	15-0	15-0	15-0	15-0	15-0
Threaded lightwall steel pipe	N/A	12-0	12-0	12-0	12-0	12-0	12-0	N/A	N/A	N/A	N/A	N/A
Copper tube	8-0	8-0	10-0	10-0	12-0	12-0	12-0	15-0	15-0	15-0	15-0	15-0
CPVC	5-6	6-0	6-6	7-0	8-0	9-0	10-0	N/A	N/A	N/A	N/A	N/A
Ductile iron pipe	N/A	N/A	N/A	N/A	N/A	N/A	15-0	N/A	15-0	N/A	15-0	15-0

Figure 27 – Maximum Distance Between Hangers

- Hanger components are required to be ferrous unless specifically permitted to be not listed as addressed by NFPA 13.
- Components of hanger assemblies that directly attach to the pipe or to the building structure shall be listed unless specifically permitted to be not listed by NFPA 13.
- Mild steel hangers formed from rods shall be permitted to be not listed.
- Fasteners shall be listed unless specifically permitted to be not listed as addressed by NFPA 13 for concrete, steel, and wood.
- Nonferrous components that have been proven by fire tests to be adequate for the hazard application that are listed for a specific purpose and that are in compliance with the other requirements of NFPA 13.
- Holes through solid structural members are permitted to serve as hangers for the support of system piping provided such holes are permitted by applicable building codes and the spacing and support provisions for hangers of NFPA 13 are satisfied.
- A hanger is required on each section of branch line pipe. Starter lengths of branch line pipe less than 6 ft. in length do not require a hanger. Where sprinklers are spaced less than 6 ft. apart hangers spaced up to a maximum of 12 ft. is permitted on branch lines.
- A hanger is required on mains between every branch line connection, or on every section of pipe, unless hangers in these locations are permitted to be omitted due to other prescriptive hanger arrangements.

F.2. *Earthquake Protection*

The warehouse sprinkler system is protected from damage caused by an earthquake according to NFPA 13.

Fire sprinkler systems are protected against earthquake damage by:

(1) Use of flexible joints and clearances in and around piping to minimize stresses that would develop due to differential building movement

(2) Use of bracing to ensure that sprinkler piping is maintained fairly rigid when supported by building elements so that the piping and building will move as a unit

The following basic requirements for earthquake protection include:

- Listed flexible couplings are used in the design of sprinkler systems for flexibility during earthquakes. Systems having more flexible couplings than prescribed are required to have additional sway bracing installed.
- The use of flexible couplings for drops are prescribed by NFPA 13 regardless of pipe size.
- Seismic separation is required for fire sprinkler piping that crosses building seismic separation joints.
- Clearance is required to be provided around piping that extends through walls, floors, platforms, and foundations according to the prescriptive requirements of NFPA 13
- Lateral earthquake bracing is provided on all mains regardless of pipe size and on branch line piping 2 ½" and larger.
- Lateral sway bracing is provided at a maximum interval of 40 ft.
- The distance between the last sway brace on a main is provided within 6 ft of the end of the pipe. The last length of pipe at the end of a feed or cross main is provided with a lateral sway brace.
- Longitudinal sway bracing is provided at a maximum interval of 80 ft.
- The distance between the last longitudinal sway brace and the end of the pipe does not exceed 40 ft.

G. Inspection, Testing and Maintenance

Inspection, testing and maintenance of fire sprinkler systems is periodically performed as required by NFPA 13 Chapter 26. NFPA 13 requires that inspection, testing and maintenance be performed by the property owner or authorized representative in accordance with NFPA 25 *Standard for the Inspection, Testing and Maintenance of Water-Based Fire Protection Systems*.

A tabular summary of fire sprinkler system inspection, testing and maintenance requirements is included in Appendix __ of this report.

VI. Fire Detection and Alarm System

A. Fire Alarm System Description

The construction warehouse fire alarm system is designed and installed in accordance with NFPA 72 *National Fire Alarm Code*®, 2002 Edition. This system is evaluated and analyzed to the criteria contained in a later edition of this code, NFPA 72 *National Fire Alarm and Signaling Code*, 2010 Edition.

Fire alarm system equipment within the building includes:

- A Fire Alarm Control Panel
- Four Field Charger Power Supplies for operation of 13 notification appliance circuits
- Manual pull stations
- Photoelectric smoke detectors placed in locations specified by NFPA 72
- Photoelectric duct smoke detectors
- Horn/strobe units and strobes for audible and visual occupant notification
- Fire sprinkler system water flow switches
- Valve tamper switches
- Fixed heat detectors

The warehouse fire alarm system is classified as a Protected Premise Fire Alarm System that also serves as a Building Fire Alarm System in accordance with NFPA 72. As such, the fire alarm system serves the general fire protection needs of the building; provides for automatic fire department notification and initiation of emergency response organizations in the event of fire; and provides for occupant notification.

The fire alarm system automatically reports fire alarm, supervisory and trouble signals to a Remote Supervisory Station serving the construction site and surrounding areas. The Remote Supervisory Station function is served by a Communications Center serving as a dispatch center located at the Fire Department that is dedicated to the site and surrounding areas. Fire related signals are transmitted to the Communications Center via a one-way high frequency radio transmitter. Signals are also received at a second facility that serves to mobilize emergency services on the site and surrounding areas. Repeating stations receive and retransmit fire related signals for greater redundancy and reliability.

The main fire alarm control panel (FACP) (PNL-52001) is a Notifier® Model No. NFS2-3030 Intelligent Addressable Fire Alarm Control Panel. It is located in Room 100 on the first floor alcove at the north entrance to the building. The FACP provides power and monitoring of signaling line circuit(s) (SLCs). From the riser diagram it appears that there are two SLCs that report to the FACP, however the Panel Detail Drawing for the FACP indicates only one SLC. The author suspects that the Panel Detail Drawing for the FACP requires revision.

The fire alarm system includes four additional field charger power supply (FCPS) panels (PNL-52201, PNL-52202, PNL-52203 and PNL-52204). Each FCPS panel contains Notifier® Part No. FCPS-24S8 providing a source of primary and secondary power for their respective notification appliance circuits (NACs) at 24 Vdc with up to 8 amps of output. These FCPS panels monitor signaling line circuit for devices signaling an alarm condition and communicate with one another to initiate notification appliances throughout the building.

B. Initiating Devices

The types, locations, manufacturer, part numbers, and other relevant notes for initiating devices installed in the building, by elevation, is provided in tabular format on the pages that follow.

- Actuation of any one of the initiating devices discussed below causes the fire alarm system to perform the following functions in addition to any additional functions specifically described below:
- Actuates audible and visual notification appliances throughout the warehouse building for evacuation of all building occupants
- Provides audible and visual indication of a fire alarm on the FACP
- Provides remote annunciation to an onsite operations control room (the is a planned function to be provided in the future)
- Sends a signal through the high frequency radio fire alarm reporting system to a Remote Supervising Station function provided by the Fire Department Communications Center

B.1. Addressable manual pull stations (Notifier NBG-12LX)

NFPA 72 Section 17.14.6 requires that a manual pull station shall be located at each exit on each floor. The location of manual pull stations in the warehouse meets this requirement. The actual installation height and proximity to the adjacent exit opening could not be verified.

B.2. Photoelectric smoke detector (Notifier FSP-851)

Photoelectric smoke detectors are placed to initiate the elevator recall function for fire fighter service in accordance with NFPA 72 Section 21.3 Elevator Recall for Fire Fighter Service.

- On each floor (and mezzanine), one smoke detector is located in the elevator lobby, within 21 ft. of the centerline of the elevator door as required by NFPA 72 Section 21.3.5.
- One smoke detector (1D007) is located in the elevator machine room and one smoke detector (1D055) is located at the top of the elevator shaft as permitted by NFPA 72 Section 21.3.3.

For areas that are not continuously occupied, NFPA 72 Section 10.15 requires automatic smoke detection at the location of each fire alarm control unit and notification appliance circuit power extender. The FACP and one FCPS is located in Room 100, and two FCPS panels are located in a common location on the second floor warehouse storage area (Room 300). One smoke

detector (1D001) is placed in Room 100 to protect the FACP and FCPS in this location. One smoke detector (1D040) is placed in Room 300 in the immediate vicinity of the two FCPSs on the second floor of the warehouse. The placement of these smoke detectors is in accordance with NFPA 72.

B.3. ***Fixed heat detector (Notifier FST-851)***

Fixed temperature (135°F) heat detectors are located in the elevator machine room (Room 109) and at the top of the elevator shaft. These fixed temperature detectors actuate the elevator shunt trip circuit and their placement is accordance with NFPA 72 Section 21.4.2 which states that they shall be placed within 24 inches of each sprinkler head. One sprinkler head, and one fixed temperature heat detector is located in the elevator machine room (Room 109). Likewise, one fixed temperature heat detector (1D006) and one sprinkler head is located at the top of the elevator shaft (1D056), in accordance with NFPA 72.

B.4. ***Photoelectric duct detector (Notifier FSD-751-LP)***

Duct smoke detectors provide the signal for shutdown of Air Handling Unit (AHU) supply system fans on the associated AHU. NFPA 90A – 2009 *Standard for the Installation of Air-Conditioning and Ventilating Systems* Section 6.4.2.1 contains requirements for smoke detector placement:

- Downstream of the air filters and ahead of any branch connections in air supply systems having a capacity greater than 2,000 cubic feet per minute, and
- At each story prior to the connection to a common return and prior to any recirculation of fresh air inlet connection in air return systems having a capacity greater than 15,000 cubic feet per minute and serving more than one story

The placement of smoke detectors in accordance with the criteria listed above supports the fan shutdown function required by NFPA 90A paragraph 6.4.3.1 which requires the automatic stopping of fans upon the detection of smoke.

NFPA 72 Section 21.7 governs, and permits, the interface between a fire alarm system and HVAC systems in support of the AHU fan shutdown function provided by the duct smoke detectors in the warehouse building.

Table 11 – Initiating Devices Main Storage Floor

Initiating Devices – Main Storage Floor (Elevation 0'-0")							
Room No.	Use	Device No.	Device Description	Manufacturer	Model No.	Rating	Type/Location/Notes
100	Vestibule	1M001	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1D001	Smoke Detector	Notifier	FSP-851	NA	Photoelectric; FACP and FCPS Coverage
101	Reception Area	NA	NA	NA	NA	NA	
102	Corridor	NA	NA	NA	NA	NA	
103	Break Room	NA	NA	NA	NA	NA	
104	Women's Restroom	NA	NA	NA	NA	NA	
105	Men's Restroom	NA	NA	NA	NA	NA	
106	Corridor	NA	NA	NA	NA	NA	
107	Janitor Closet	NA	NA	NA	NA	NA	
108	Administrative Offices	1D004	Smoke Detector	Notifier	FSP-851	NA	Photoelectric; Elevator Lobby
109	Machine Room	1D006	Heat Detector	Notifier	FST-851	135 F	Fixed Temperature
		1D007	Smoke Detector	Notifier	FSP-851	NA	Photoelectric; Elevator Machine Room
110	Office	NA	NA	NA	NA	NA	
111	Office	NA	NA	NA	NA	NA	
112	Vestibule	1M004	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
113	Corridor	Unknown	Water Flow Switch	Unknown	Unknown	NA	Wet Pipe Sprinkler System
114	Computer Server Room	NA	NA	NA	NA	NA	
115	HVAC Equipment Room	NA	NA	NA	NA	NA	
116	Office	NA	NA	NA	NA	NA	
117	File Storage	1D002	Duct Smoke Detector	Notifier	FSD-751-LP	NA	Photoelectric; AHU Shutdown
118	Conference Room	NA	NA	NA	NA	NA	
119	Quarantine Area	NA	NA	NA	NA	NA	
120	Future Storage	1M016	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		Unknown	Water Flow Switch	Unknown	Unknown	NA	Dry Pipe Sprinkler System
121	Warehouse Storage	1M009	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1M011	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1M012	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
122	Vestibule	1M020	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
123	Vestibule	NA	NA	NA	NA	NA	
124	Dispersal Entry	1M010	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
125	Dispersal Area	NA	NA	NA	NA	NA	
126	Office	NA	NA	NA	NA	NA	
127	Office	NA	NA	NA	NA	NA	
128	Stairwell	NA	NA	NA	NA	NA	
129	Stairwell	NA	NA	NA	NA	NA	
130	Stairwell	NA	NA	NA	NA	NA	
131	Stairwell	NA	NA	NA	NA	NA	

Table 12 – Initiating Devices Office Mezzanine

Initiating Devices – Office Mezzanine (Elevation 12’-0”)							
Room No.	**Use**	**Device No.**	**Device Description**	**Manufacturer**	**Model No.**	**Rating**	**Type/Location/Notes**
201	Administrative Offices	1M030	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1D030	Smoke Detector	Notifier	FSP-851	NA	Photoelectric; Elevator Lobby
		1D032	Duct Smoke Detector	Notifier	FSD-751-LP	NA	Photoelectric; AHU Shutdown
202	Men’s Restroom	NA	NA	NA	NA	NA	
203	Women’s Restroom	NA	NA	NA	NA	NA	
204	Janitor Closet	NA	NA	NA	NA	NA	
205	Corridor	NA	NA	NA	NA	NA	
206	Conference Room	NA	NA	NA	NA	NA	
207	File Room	NA	NA	NA	NA	NA	
208	Dispersal Area	NA	NA	NA	NA	NA	
209	Stairwell	NA	NA	NA	NA	NA	
210	Stairwell	NA	NA	NA	NA	NA	
211	Stairwell	NA	NA	NA	NA	NA	
212	Stairwell	NA	NA	NA	NA	NA	

Table 13 – Initiating Devices Second Floor

Initiating Devices – Second Floor (Elevation 24'-0")							
Room No.	**Use**	**Device No.**	**Device Description**	**Manufacturer**	**Model No.**	**Rating**	**Type/Location/Notes**
300	Warehouse Storage	1M040	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1M041	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1M042	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1M043	Manual Pull Station	Notifier	NBG-12LX	NA	Located at Exit
		1D040	Smoke Detector	Notifier	FSP-851	NA	Photoelectric; FCPS Coverage
		1D041	Smoke Detector	Notifier	FSP-851	NA	Photoelectric; Elevator Lobby
		1D046	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D047	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D048	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D050	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D051	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D052	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D053	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
		1D054	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
301	Janitor Closet	NA	NA	NA	NA	NA	
302	Warehouse Support	NA	NA	NA	NA	NA	
303	Corridor	NA	NA	NA	NA	NA	
304	EWC Area	NA	NA	NA	NA	NA	
305	Men's Restroom	NA	NA	NA	NA	NA	
306	Women's Restroom	NA	NA	NA	NA	NA	
307	EWC Area	NA	NA	NA	NA	NA	
308	Corridor	1D049	Duct Smoke Detector	Notifier	**FSD-751-LP**	NA	Photoelectric; AHU Shutdown
309	Conference Room	NA	NA	NA	NA	NA	
Shaft	Elevator Shaft	1D055	Smoke Detector	Notifier	FSP-851	NA	**Photoelectric; Top of Elevator Shaft**
		1D056	Heat Detector	Notifier	FST-851	135 F	**Fixed Temperature; Top of Elevator Shaft**
310	Stairwell	NA	NA	NA	NA	NA	
311	Stairwell	NA	NA	NA	NA	NA	
312	Stairwell	NA	NA	NA	NA	NA	
313	Stairwell	NA	NA	NA	NA	NA	

B.5. Notification Appliances

The types, locations, manufacturer, part numbers, appliance ratings, and other relevant notes for notification appliances installed in the warehouse building, by elevation, is provided in tabular format on the pages that follow.

B.6. Visual Notification Appliance Location, Sizing and Placement

Placement of visual notification appliances is evaluated against the prescriptive requirements of NFPA 72 Table 18.5.4.3.1(a) for wall mounted visible appliances and NFPA 72 Table 18.5.4.3.1(b) for ceiling mounted visible appliances. These tables are reproduced below for convenience:

TABLE 18.5.4.3.1(a) *Room Spacing for Wall-Mounted Visible Appliances*

Maximum Room Size		Minimum Required Light Output [Effective Intensity (cd)]		
ft	m	One Light per Room	Two Lights per Room (Located on Opposite Walls)	Four Lights per Room (One Light per Wall)
20 × 20	6.10 × 6.10	15	NA	NA
28 × 28	8.53 × 8.53	30	Unknown	NA
30 × 30	9.14 × 9.14	34	15	NA
40 × 40	12.2 × 12.2	60	30	15
45 × 45	13.7 × 13.7	75	Unknown	19
50 × 50	15.2 × 15.2	94	60	30
54 × 54	16.5 × 16.5	110	Unknown	30
55 × 55	16.8 × 16.8	115	Unknown	28
60 × 60	18.3 × 18.3	135	95	30
63 × 63	19.2 × 19.2	150	Unknown	37
68 × 68	20.7 × 20.7	177	Unknown	43
70 × 70	21.3 × 21.3	184	95	60
80 × 80	24.4 × 24.4	240	135	60
90 × 90	27.4 × 27.4	304	185	95
100 × 100	30.5 × 30.5	375	240	95
110 × 110	33.5 × 33.5	455	240	135
120 × 120	36.6 × 36.6	540	305	135
130 × 130	39.6 × 39.6	635	375	185

NA: Not allowable.

TABLE 18.5.4.3.1(b) *Room Spacing for Ceiling-Mounted Visible Appliances*

Maximum Room Size		Maximum Lens Height		Minimum Required Light Output (Effective Intensity); One Light (cd)
ft	m	ft	m	
20 × 20	6.1 × 6.1	10	3.0	15
30 × 30	9.1 × 9.1	10	3.0	30
40 × 40	12.2 × 12.2	10	3.0	60
44 × 44	13.4 × 13.4	10	3.0	75
50 × 50	15.2 × 15.2	10	3.0	95
53 × 53	16.2 × 16.2	10	3.0	110
55 × 55	16.8 × 16.8	10	3.0	115
59 × 59	18.0 × 18.0	10	3.0	135
63 × 63	19.2 × 19.2	10	3.0	150
68 × 68	20.7 × 20.7	10	3.0	177
70 × 70	21.3 × 21.3	10	3.0	185
20 × 20	6.1 × 6.1	20	6.1	30
30 × 30	9.1 × 9.1	20	6.1	45
44 × 44	13.4 × 13.4	20	6.1	75
46 × 46	14.0 × 14.0	20	6.1	80
50 × 50	15.2 × 15.2	20	6.1	95
53 × 53	16.2 × 16.2	20	6.1	110
55 × 55	16.8 × 16.8	20	6.1	115
59 × 59	18.0 × 18.0	20	6.1	135
63 × 63	19.2 × 19.2	20	6.1	150
68 × 68	20.7 × 20.7	20	6.1	177
70 × 70	21.3 × 21.3	20	6.1	185
20 × 20	6.1 × 6.1	30	9.1	55
30 × 30	9.1 × 9.1	30	9.1	75
50 × 50	15.2 × 15.2	30	9.1	95
53 × 53	16.2 × 16.2	30	9.1	110
55 × 55	16.8 × 16.8	30	9.1	115
59 × 59	18.0 × 18.0	30	9.1	135
63 × 63	19.2 × 19.2	30	9.1	150
68 × 68	20.7 × 20.7	30	9.1	177
70 × 70	21.3 × 21.3	30	9.1	185

Figure 28 – Room Spacing for Visible Appliances

Table 14 – Notification Appliances Main Storage Floor

Notification Appliances – Main Storage Floor (Elevation 0'-0")							
Room No.	Use	Device No.	Device Description	Manufacturer	Model No.	Rating	Room Size/Comments
100	Vestibule	NA	NA	NA	NA	NA	Exit
101	Reception Area	NA	NA	NA	NA	NA	HS1-2 visible this location
102	Corridor	HS1-2	Horn/Strobe	Notifier	P2R	15 CD	Less than 20'x20'; Meets NFPA 72
103	Break Room	HS1-1	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
104	Women's Restroom	HS1-5	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
105	Men's Restroom	HS1-6	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
106	Stair	NA	NA	NA	NA	NA	Warehouse area HS visible
107	Janitor Closet	NA	NA	NA	NA	NA	Not required per NFPA 101
108	Administrative Offices	HS1-8	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS1-10	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
109	Machine Room	NA	NA	NA	NA	NA	Not required per NFPA 101
110	Office	HS1-7	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
111	Office	HS1-9	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
112	Vestibule	NA	NA	NA	NA	NA	Not required per NFPA 101
113	Corridor	HS1-11	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
114	Computer Server Room	HS1-12	Horn/Strobe	Notifier	P2R	30 CD	Less than 28'x28': Meets NFPA 72
115	HVAC Equipment Room	NA	NA	NA	NA	NA	Not required per NFPA 101
116	Office	HS1-10	Strobe	Notifier	SR	15CD	Less than 20'x20'; Meets NFPA 72
117	File Storage	HS1-4	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
118	Conference Room	HS1-3	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
119	Quarantine Area	HS6-1	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
120	Future Storage	HS6-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS6-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
121	Warehouse Storage	HS6-7	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS6-8	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS6-9	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-1	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-6	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-7	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS2-8	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS3-1	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS3-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS3-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72

Notification Appliances – Main Storage Floor (Elevation 0’-0”)							
Room No.	**Use**	**Device No.**	**Device Description**	**Manufacturer**	**Model No.**	**Rating**	**Room Size/Comments**
		HS3-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS3-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS4-1	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS4-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS4-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS4-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS4-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS5-1	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS5-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS5-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS5-6	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
122	Vestibule	HS3-6	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
		HS6-6	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63’x63’;Meets NFPA 72
123	Vestibule	HS5-4	Horn/Strobe	Notifier	P2R	30 CD	Less than 28’x28’: Meets NFPA 72
124	Dispersal Entry	NA	NA	NA	NA	NA	Exit
125	Dispersal Area	HS5-3	Horn/Strobe	Notifier	P2R	15 CD	Less than 20’x20’; Meets NFPA 72
126	Office	HS6-2	Horn/Strobe	Notifier	P2R	15 CD	Less than 20’x20’; Meets NFPA 72
127	Office	HS6-3	Horn/Strobe	Notifier	P2R	15 CD	Less than 20’x20’; Meets NFPA 72
128	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
129	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
130	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
131	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101

Table 15 – Notification Appliances Office Mezzanine

Notification Appliances – Office Mezzanine (Elevation 12'-0")							
Room No.	**Use**	**Device No.**	**Device Description**	**Manufacturer**	**Model No.**	**Rating**	**Comments**
201	Administrative Offices	HS7-8	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
202	Men's Restroom	HS7-3	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
203	Women's Restroom	HS7-2	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
204	Janitor Closet	HS7-4	Horn/Strobe	Notifier	P2R	30 CD	Less than 28'x28': Meets NFPA 72
205	Corridor	HS7-1	Horn/Strobe	Notifier	P2R	75 CD	Less than 45'x45';Meets NFPA 72
206	Conference Room	HS7-5	Horn/Strobe	Notifier	P2R	15 CD	Less than 20'x20'; Meets NFPA 72
207	File Room	HS7-6	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
208	Dispersal Area	HS7-7	Strobe	Notifier	SR	15 CD	Less than 20'x20'; Meets NFPA 72
209	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
210	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
211	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
212	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101

Table 16 – Notification Appliances Second Floor

Notification Appliances – Second Floor (Elevation 24'-0")							
Room No.	Use	Device No.	Device Description	Manufacturer	Model No.	Rating	Comments
300	Warehouse Storage	HS13-3	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS13-4	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS13-8	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS14-1	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS14-2	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS14-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS14-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS14-5	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS14-6	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS15-1	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS15-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS15-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS15-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS10-1	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS10-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS10-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS10-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS10-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS11-1	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS11-2	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS11-3	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS11-4	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS11-5	Horn/Strobe (Ceiling)	Notifier	SCRH	150 CD	Less than 63'x63';Meets NFPA 72
		HS11-6	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS12-1	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS12-2	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
		HS12-3	Horn/Strobe	Notifier	P2R	115 CD	Less than 55'x55';Meets NFPA 72
301	Janitor Closet	NA	NA	NA	NA	NA	Not required per NFPA 101
302	Warehouse Support	HS13-1	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
303	Corridor	HS13-2	Horn/Strobe	Notifier	P2R	75 CD	Less than 45'x45';Meets NFPA 72
304	EWC Area	NA	NA	NA	NA	NA	HS13-2 visible from this location
305	Men's Restroom	HS13-5	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
306	Women's Restroom	HS13-7	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
307	EWC Area	NA	NA	NA	NA	NA	No visual appliance
308	Corridor	NA	NA	NA	NA	NA	No visual appliance
309	Conference Room	HS13-6	Strobe	Notifier	SR	75 CD	Less than 45'x45';Meets NFPA 72
310	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
311	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
312	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101
313	Stairwell	NA	NA	NA	NA	NA	Not required per NFPA 101

Per NFPA 101 – 2009, Section 9.6.3.5.1, areas not subject to occupancy by persons who are hearing impaired are not required to comply with provisions for visible signals. A few small spaces in the warehouse with special access such as the janitor's closets and the elevator machine room do not have visual notification appliances installed.

Also, NFPA 101, Sections 9.6.3.5.5 and 9.6.3.5.6 do not require that visual notification signals be provided in exit stair enclosures or elevator cars.

The warehouse fire alarm system includes wall mounted visual notification appliances rated at 15 CD, 30, CD, 75 CD, 115 CD, and ceiling mounted visual notification appliances rated at 150 CD.

Reading directly from these tables:

- A single wall mounted 15 CD strobe is acceptable for coverage of a 20 ft. x 20 ft. area
- A single wall mounted 30 CD strobe is acceptable for coverage of a 28 ft. x 28 ft. area
- A single wall mounted 75 CD strobe is acceptable for coverage of a 45 ft. x 45 ft. area
- A single wall mounted 115 CD strobe is acceptable for coverage of a 55 ft. x 55 ft. area
- A ceiling mounted 150 CD strobe is acceptable for coverage of a 63 ft. x 63 ft. area

The effective intensity of each visual notification appliance for the first and second floors, including the office mezzanine, has been compared to the criteria above for size of room. In all cases the indicated effective intensity of the visual notification appliance exceeds the area of coverage.

This is readily evident for smaller rooms, such as offices, restrooms, break rooms, etc. where the size of the room allows the placement of one visual notification appliance in the room according to either Table 18.5.4.3.1(a) or Table 18.5.4.3.1(b) and the results for individual room evaluations are noted in the "Room Size/Comments" column of the tabular list of every notification appliance in the warehouse.

However, the warehouse storage areas are large open areas with ceiling heights up to 24 ft. high with the potential for high piled storage up to 20 ft. with 8 ft. aisles, leaving only 4 ft. between the ceiling and top of storage. This arrangement creates a barrier between the installed ceiling mounted visual notification devices in this building and the intended receiver of visual notification both directly and indirectly. In short, the high piled storage on the warehouse floor may interfere with the signals conveyed by the ceiling mounted notification appliances. This means that the prescriptive approach for placement and intensity of ceiling mounted notification appliances found in NFPA 72 Table 18.5.4.3.1(b) may not provide an acceptable means of notifying hearing impaired persons in this warehouse.

The fire alarm system designer has included several aspects of the design to attempt to alleviate a problematic visual notification issue:

Placement of ceiling mounted horn/strobe units in locations along the ceiling above the aisles between racks. In this manner, persons in the aisles will have direct line of sight to a visual notification appliance mounted on the ceiling; and

The ceiling mounted horn/strobe units are very conservatively spaced when compared to the NFPA 72 prescriptive spacing requirement for a 150 CD strobe from Table 18.5.4.3.1(b), or 63 ft. by 63 ft. maximum spacing. The actual ceiling mounted horn/strobe unit spacing is a maximum of 30 ft. by 50 ft. which provides for significant overlap between ceiling mounted visual notification appliances.

The marked up sketch below shows the coverage of visual notification appliances on the main storage floor of the construction warehouse:

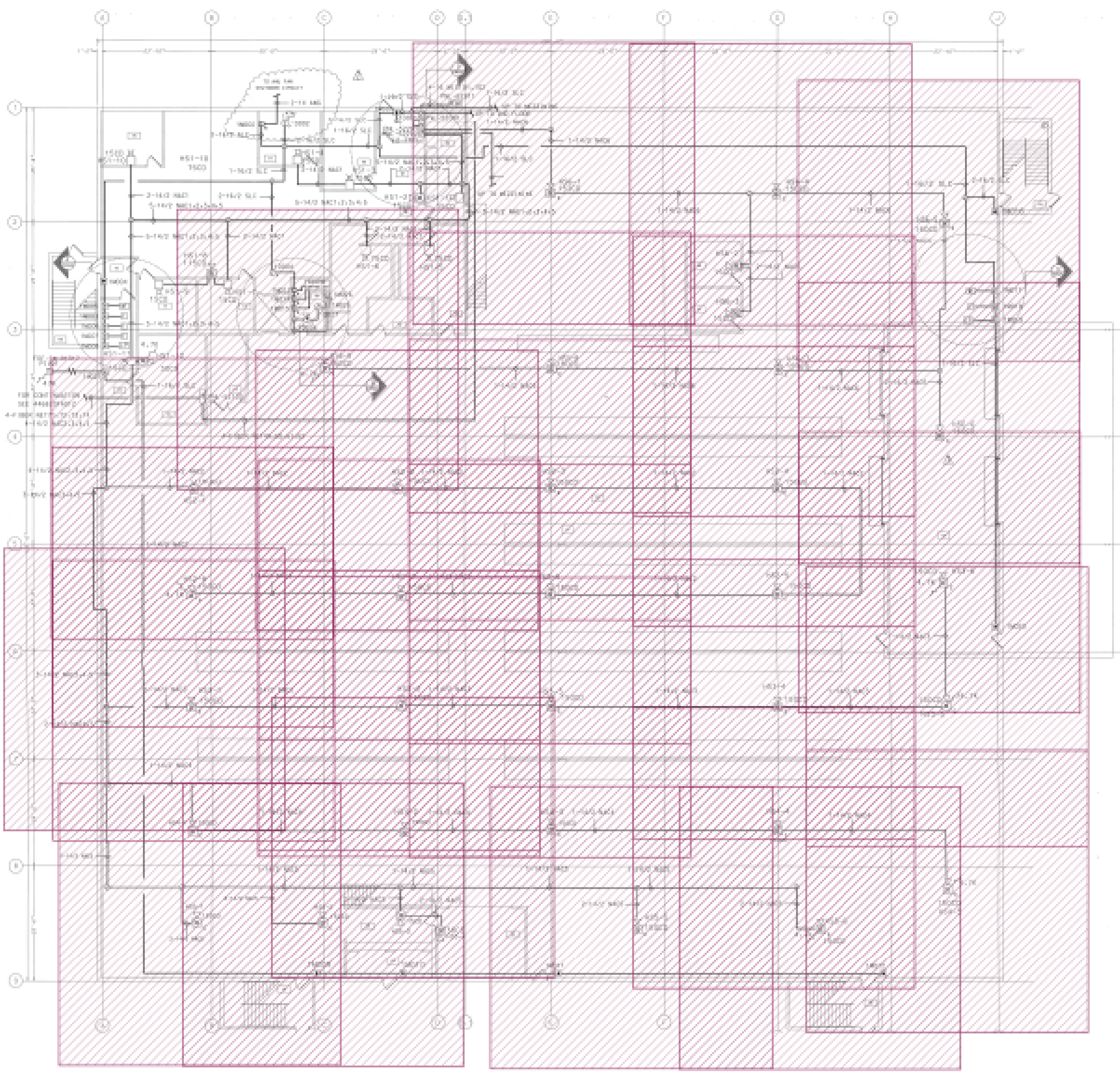


Figure 29 – Visual Notification Appliance Coverage, Main Floor Storage Area

Additionally, on the second floor inside perimeter walls, 115 CD horn/strobe units are installed all around roughly 50 ft. apart. This spacing provides overlap between adjacent horn/strobe units since the prescriptive spacing of wall mounted 115 CD visual notification appliances is 55 ft. by 55 ft. from NFPA 72 Table 18.5.4.3.2(a). Further these wall mounted appliances overlap with the ceiling mounted visual notification appliances spaced above the high piled storage areas within the building.

See the marked up sketch below which shows the second floor warehouse storage area visual appliance overlapping coverage. The red coverage areas correspond to wall mounted 115 CD visual notification appliances and the blue coverage areas correspond to ceiling mounted 150 CD visual notification appliances. Green areas correspond to wall mounted 75 CD appliances.

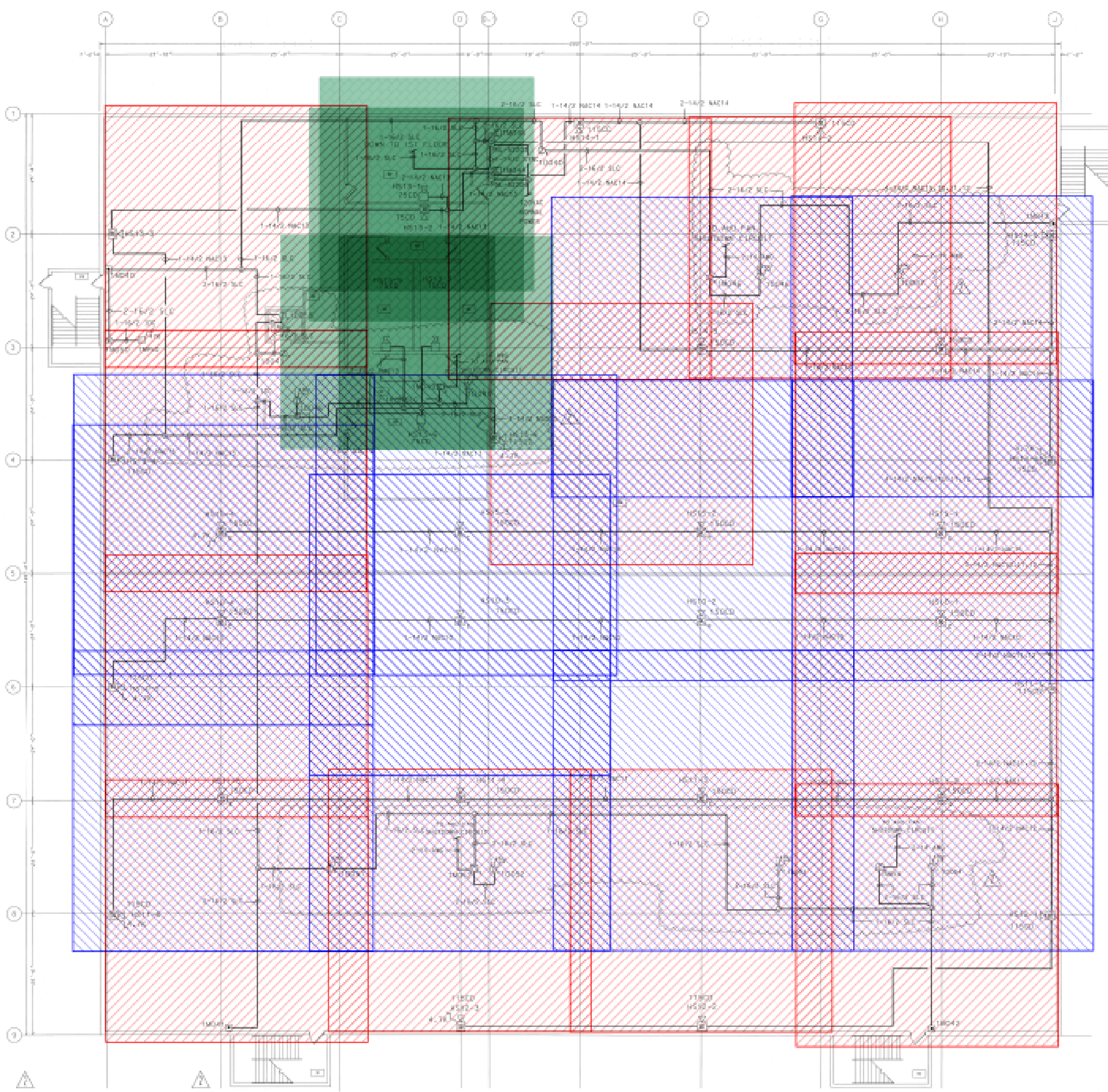


Figure 30 – Visual Notification Appliance Coverage, Second Floor

B.7. ***Audible Notification Appliance Location and Placement***

For Public Mode applications, per NFPA 72, to ensure that audible signals are clearly heard they shall have a sound level at least 15 dB above the average ambient sound level or 5 dB above the maximum sound level having a duration of at least 60 seconds, whichever is greater, measured 5 ft (1.5 m) above the floor in the area required to be served by the system using the A-weighted scale (dBA).

Typical ambient sound levels for office and storage warehouse areas may be found from Table A.18.4.3 in NFPA 72, reproduced here for convenience.

Table A.18.4.3 Average Ambient Sound Level According to Location

Location	Average Ambient Sound Level (dBA)
Business occupancies	55
Educational occupancies	45
Industrial occupancies	80
Institutional occupancies	50
Mercantile occupancies	40
Mechanical rooms	85
Piers and water-surrounded structures	40
Places of assembly	55
Residential occupancies	35
Storage occupancies	30
Thoroughfares, high-density urban	70
Thoroughfares, medium-density urban	55
Thoroughfares, rural and suburban	40
Tower occupancies	35
Underground structures and windowless buildings	40
Vehicles and vessels	50

Figure 31 – Average Ambient Sound Level

From Table A.18.4.3, the average ambient sound level for a business occupancy, similar to the mezzanine and first floor office areas of the building, is 55 dBA. Likewise, for the storage areas

the average ambient sound level is 30 dBA. There are no anticipated elevated maximum sound levels in either of these areas in excess of 60 seconds duration.

Therefore, the minimum compliant sound level for warehouse office spaces is 70 dBA. For the warehouse storage areas the minimum compliant sound level is 45 dBA.

The audible alarm signal follows a standard temporal-three pattern and the rated sound output of Notifier (System Sensor) Model No. P2R and SCRH Horn/Strobe units are 88 dBA.

Using the 6 dBA rule of thumb, the sound level drops by 6 dBA every time the distance from the audible device doubles. The sound level is predicted to fall from 88 dBA a distance 10 ft. from the appliance to 82 dBA 20 ft. from the appliance. The next interval, from 20 ft. to 40 ft., the sound level is predicted to drop another 6 dBA to 76 dBA. At 80 ft. from the appliance the sound level is predicted, using this rule of thumb, to be 70 dBA.

Therefore, for an NFPA 72 compliant system, every point in the first floor office spaces and on the mezzanine should be no further than 80 ft. from a fire alarm audible notification appliance. A review of the location and placement of horn/strobe units in these areas shows that there is at least one a horn/strobe unit within 40 ft. of every first floor office and mezzanine location.

In the warehouse storage areas, horn/strobe units are spaced roughly 50 ft. apart in every location. At this spacing, a building occupant would receive a sufficiently high audible signal, in excess of the 45 dBA required by NFPA 72, for compliant audibility.

B.8. *Secondary Power Supply Requirements*

The FACP contains a secondary power supply and each of the four FCPS's contain secondary power supplies. Two secondary power supply calculations are performed below. The first is for the FACP. The second is for one of the FCPS panels.

Required operating time of secondary power source from NFPA 72, paragraph 10.5.6.3.1:

> ***10.5.6.3.1*** *The secondary power supply shall have sufficient capacity to operate the system under quiescent load (system operating in a nonalarm condition) for a minimum of 24 hours and, at the end of that period, shall be capable of operating all alarm notification appliances used for evacuation or to direct aid to the location of an emergency for 5 minutes, unless otherwise permitted or required by the following:*
>
> *(1) Battery calculations shall include a 20 percent safety margin to the calculated amp-hour rating.*

The fire alarm system specification for the building specifies more stringent requirements. Specifically, the project has specified that under maximum normal load, the battery configuration shall have sufficient capacity to operate the entire system upon loss of normal 120V AC power in a normal supervisory mode for a minimum period of twenty-four (24) hours; and, at the end of that period, shall be capable of operating all alarm notification appliances used for evacuation or

to direct aid to the location of an emergency for fifteen (15) minutes. The required load used to size batteries shall be determined by adding a safety factor of 20% to the calculated load. Battery calculations shall be submitted to justify the battery size.

To complete secondary power (battery) sizing calculations for the FACP the affected components are listed in the table below including supervisory (standby) current demand and alarm current demand for each component. Data was obtained by best effort in a review of manufacturer's cut sheets for each component.

Table 17 – FACP Components Supervisory and Alarm Currents

Fire Alarm Control Panel (FACP) Components			
Part #	Description	Supervisory Current (A)	Alarm Current (A)
CPU2-3030	CPU	0.1200000	0.1200000
Keyboard	Keyboard Display Option	0.2200000	0.2200000
LCM-320	SLC Module	0.1300000	0.4000000
NCM-F	Network Adapter Module	0.1100000	0.1100000
NBG-12LX	Addressable Manual Pull Station	0.0000000	0.0003750
FMM-1	Monitor Module	0.0003750	0.0051000
FRM-1	Control Module (Relay)	0.0002300	0.0065000
FSP-851	Photoelectric Smoke Detector	0.0003600	0.0065000
FSD-751PL	Duct Smoke Detector	0.0003000	0.0870000
DNR	Duct Detector	0.0003000 (typical)	0.0870000 (typical)
FST-851	Fixed Heat Detector	0.0003000	0.0065000
B710LP	Addressable Detector Base	0.0000005	0.0000005

The battery calculation for the FACP and SLC circuit is provided below:

Table 18 – FACP Battery Calculation

Part #	Description	Standby Current (A)	Qty	Total Standby Current (A)	Alarm Current (A)	Qty	Total Alarm Current (A)
CPU2-3030	CPU	0.1200000	1	0.1200000	0.1200000	1	0.1200000
Keyboard	Keyboard Display Option	0.2200000	1	0.2200000	0.2200000	1	0.2200000
LCM-320	SLC Module	0.1300000	1	0.1300000	0.4000000	1	0.1300000
NCM-F	Network Adapter Module	0.1100000	1	0.1100000	0.1100000	1	0.1100000
NBG-12LX	Addressable Manual Pull Station	0.0000000	13	0.0000000	0.0003750	13	0.0048750
FMM-1	Monitor Module	0.0003750	11	0.0041250	0.0051000	11	0.0561000
FRM-1	Control Module (Relay)	0.0002300	9	0.0020700	0.0065000	9	0.0585000
FSP-851	Photoelectric Smoke Detector	0.0003600	9	0.0032400	0.0065000	9	0.0585000
FSD-751PL	Duct Smoke Detector	0.0003000	1	0.0003000	0.0870000	1	0.0870000
DNR	Duct Smoke Detector	0.0003000 (typ.)	9	0.0027000	0.08700 00 (typ.)	9	0.7830000
FST-851	Fixed Heat Detector	0.0003000	2	0.0006000	0.0065000	2	0.0130000
B710LP	Addressable Detector Base	0.0000005	9	0.0000045	0.0000005	9	0.0000045
		Total System Standby Current (A)		**0.5930**	**Total System Alarm Current (A)**		**1.6410**

Required Standby Time (Hrs)	Total Standby Current (A)	Required Standby Capacity (A-H)	Required Alarm Time (Hrs)	Total System Alarm Current (A)	Required Alarm Capacity (A-H)
24	0.5930	14.232	15/60 = 0.25	1.6410	0.411

Required Standby Capacity (A-H)	Required Alarm Capacity (A-H)	Total Required Capacity (A-H)	Factor of Safety	Required Battery Capacity (A-H)
14.232	0.411	14.7	1.2	17.6

A 26 A-H battery is provided for the construction warehouse fire alarm system which exceeds the requirement for 17.6 A-H of capacity calculated above.

The battery calculation for a representative FCPS (PNL-52201) and Notification Appliance Circuits is provided below:

Table 19 – FCPS Components Supervisory and Alarm Currents

Field Charger Power Supply (FCPS) (PNL-52201) Components			
Part #	Description	Supervisory Current (A)	Alarm Current (A)
FCM-1	Control Module	0.000350	0.006500
EOLR-1	Power Supervision Relay	--	0.020000
P2R	Horn/Strobe (15 CD)	--	0.079000
P2R	Horn/Strobe (30 CD)	--	0.107000
P2R	Horn/Strobe (75 CD)	--	0.176000
P2R	Horn/Strobe (115 CD)	--	0.218000
SCRH	Horn/Strobe (Ceiling)(150 CD)	--	0.259000
SR	Strobe (15 CD)	--	0.066000
SR	Strobe (75 CD)	--	0.158000

Table 20 – FCPS Battery Calculation

Part #	Description	Standby Current (A)	Qty	Total Standby Current (A)	Alarm Current (A)	Qty	Total Alarm Current (A)
FCM-1	Control Module	0.000350	1	0.000350	0.006500	1	0.006500
EOLR-1	Power Supervision Relay	0.000000	1	0.000000	0.020000	1	0.020000
P2R	Horn/Strobe (15 CD)	0.000000	1	0.000000	0.079000	1	0.079000
P2R	Horn/Strobe (30 CD)	0.000000	1	0.000000	0.107000	1	0.107000
P2R	Horn/Strobe (75 CD)	0.000000	0	0.000000	0.176000	0	0.000000
P2R	Horn/Strobe (115 CD)	0.000000	1	0.000000	0.218000	1	0.218000
SCRH	Horn/Strobe (150 CD)	0.000000	19	0.000000	0.259000	19	4.921000
SR	Strobe (15 CD)	0.000000	6	0.000000	0.066000	6	0.396000
SR	Strobe (75 CD)	0.000000	3	0.000000	0.158000	3	0.474000
		Total System Standby Current (A)		**0.000350**	**Total System Alarm Current (A)**		**6.2215**

Required Standby Time (Hrs)	Total Standby Current (A)	Required Standby Capacity (A-H)	Required Alarm Time (Hrs)	Total System Alarm Current (A)	Required Alarm Capacity (A-H)
24	0.000350	0.0084	15/60 = 0.25	6.2215	1.555

Required Standby Capacity (A-H)	Required Alarm Capacity (A-H)	Total Required Capacity (A-H)	Factor of Safety	Required Battery Capacity (A-H)
0.0084	1.555	1.564	1.2	1.88

A 7 A-H battery is provided which exceeds the required 1.88 A-H battery capacity.

C. Inspection, Test and Maintenance Requirements

Inspection, Test and Maintenance of fire alarm systems is addressed by NFPA 72 Chapter 14 "Inspection, Testing, and Maintenance".

VII. Performance Based Fire Protection Analysis

A. Human Behavior

A wide range of human behavior has been observed during a fire emergency. People are alerted to a fire or other emergency by different awareness cues. Examples of these cues include smelling smoke, being notified by others, hearing a noise, witnessing smoke or fire, observing or hearing the presence of the fire department.

The process by which a person perceives, identifies, understands and evaluates fire situational cues has been postulated to follow critical factors in their perception of and response to the threat of a fire:

- Recognition. The individual identifies ambiguous cues as an indication of a fire incident. If an immediate danger is not perceived, the individual may respond with confidence given that there is no perception of an immediate threat.
- Validation. The individual often responds to initial cues by attempting to validate the character of the fire incident. The person may be aware of the potential presence of a fire but often will attempt to obtain additional information to define the event.
- Definition. Individuals attempt to place structure to the fire situation by seeking to define the fire qualitatively. The individual feels the need to define the situation so that the threat can be addressed. The physical parameters of the event that the individual may seek may be the extent of generation, intensity, and propagation of smoke, flames, and temperature.
- Evaluation. This is the individual's process of evaluating the fire incident and is necessary for the individual to respond to the threat of the fire, develop alternative actions that may be relied upon to cope with the fire event, and to form the basis of the individual's decision regarding how to respond to the fire. The individual's response may include decisions regarding adapting to the situation, escape strategies, or defense against the effects of the fire.
- Commitment. The individual becomes committed to behavioral response strategies developed during the evaluation phase. Depending on the state of the individual's response and ability to complete the planned strategy, the individual may continue to reassess and evaluate the threatening situation and commitment to action. If the behavioral response results in success then the anxiety and stress created by the situation are relieved even though the fire severity may have increased.
- Reassessment. This process is the result of failed strategies and is characterized by additional stress on the individual. Successive failures of strategies developed by the individual become intensely stressful. As additional successive failures occur, the individual becomes more frustrated, anxiety levels increase, and the probability of success decreases. As the physical variables of a fire incident, such as the appearance of

flame, smoke or proximity of heat, the individual is exposed to higher and higher levels of behavioral response activity. The individual may reach a level of physical activity that is hyperactive, or on the other extreme, the individual may become completely immobile with loss of ability to communicate coherently. The individual may perceive the fire incident as too severe for them to adapt to. They may be overwhelmed by stress and abandon their attempt to respond to the fire incident. In this case the individual may psychologically withdraw from the fire incident environment.

The SPFE Handbook of Fire Protection Engineering, Chapter 3-12 Behavioral Response to Fire and Smoke by John L. Bryan is used for reference.

B. Factors that Influence Egress Times

The fundamental principle and design objective for life safety performance based design is to satisfy the following criteria:

$$ASET > RSET + MoS$$

Where:

ASET is defined as Available Safe Egress Time which is the time from ignition until the tenability limit is reached.

RSET is defined as Required Safe Egress Time which is the time from ignition until evacuation is completed.

MoS is a Margin of Safety, i.e., a safety factor

The factors that influence ASET include:

- The length of time between ignition to when smoke has descended to the level of human occupancy
- The length of time between ignition and the incapacitation occupants due to exposure to untenable conditions from smoke and heat

The factors that influence RSET include:

- Detection Time
    - The length of time between ignition and when the fire is detected. The time to detection is influenced by the method of detection, such as by a fire detection system or detection by human senses.
    - Detection time is assessed by analysis of specific fire scenarios

- Validation of detection time accomplished by comparison of hand calculations to results taken from computer fire modeling (i.e., comparison of DETACT model calculations to FDS output for sprinkler actuation time).

- To protect the occupant working alone in a closed office, or other isolated building area after normal working hours, who may not be in a position to sense the smell of smoke, visually observe the presence of a fire, or hear verbal notification by co-workers of a fire, <u>fire detection by manual pull station is not assumed.</u>

- Detection is assumed to occur upon the first
  - Smoke detector alarm
  - Fire sprinkler activation
  - Occupant senses followed by manual pull station activation

- Notification Time, which is the cumulative time for the following to occur:

  - Following detection, the length of time for occupant notification can be by automatic means, such as would be provided by a fire alarm system, or by depending on human means of notification.

  - Notification is automatic
    - The construction warehouse is provided with a fire alarm system
    - Notification is assumed to be by fire alarm system notification appliances
    - The pressure switch on the construction warehouse sprinkler riser (Model: Potter PS-10 2a) has no adjustable time delay.

  - An inherent delay in notification is assumed due to fire alarm system signal processing. <u>This delay is assumed to add 30 seconds to notification time</u>.

- Pre-Movement Time (includes time for occupants to recognize the fire alarm and respond)

  - Once notified, occupants must recognize and interpret the fire alarm
    - All building occupants and construction site workers are trained to recognize and interpret an audible and visual fire alarm
    - All building occupants and construction site workers are trained to respond to fire alarms by immediately evacuating the building
    - Untrained visitors are escorted by a trained worker

        - Occupants are not required to attempt to put out a fire (e.g., with a fire extinguisher or hose)

    - Most occupants of the warehouse are expected to immediately initiate action to evacuate the building upon notification. However, some are expected react to a fire alarm in any number of ways prior to beginning evacuation, they may:

        - Wait until there is sensory indication of fire or smoke
        - Question whether or not the fire/evacuation alarm is valid
        - Collect personal or work related items prior to beginning evacuation
        - Investigate to determine whether or not there is an actual fire
        - Wander to other parts of the building to warn others
        - Shutdown computers or other equipment
        - Close windows
        - Seek out colleagues and friends
        - Attempt to help or rescue others
        - Attempt to fight the fire
        - Begin evacuation, then return to collect personal or work items, such as car keys, jackets, valuable papers, etc.

    - <u>The impact of warehouse occupant reaction and/or delay is assumed to add 60 seconds to pre-movement time.</u>

- Evacuation Time

    - The length of time it takes occupants to travel from their initial location within the building to a public way, or place of safety away from the fire
        - A place of safety is considered to be within any of the four exterior exit stairwells, each of these exit stairwells is separated from the main warehouse building by a 2-hour fire rated barrier

    - Evacuation time is assessed by two methods:
        - Hand calculations
        - Computer simulation of evacuation using Pathfinder software

B.1. <u>Egress Calculation by Hand</u>

A hand calculation has been performed to assess the evacuation time from the construction warehouse building. This hand calculation is included in Appendix A of this report.

The results of the hand calculation are tabulated below:

Table 21 – Summary of Hand Egress Calculation

	West Stairwell		South-West Stairwell	South-East Stairwell	East Stairwell
Egress Path	**2nd Floor**	**Mezzanine**	**2nd Floor**	**2nd Floor**	**2nd Floor**
$t_{transit}$	$30\ sec$		$30\ sec$	$30\ sec$	$30\ sec$
$+\ t_{floor}$	$20\ sec$	$20\ sec$	$41\ sec$	$41\ sec$	$41\ sec$
$+t_{queue}$	$109\ sec$	$21\ sec$	$29\ sec$	$0\ sec$	$60\ sec$
$+\ t_{floor\ (last\ occupant)}$	$20\ sec$	$20\ sec$	$41\ sec$	$41\ sec$	$41\ sec$
TOTAL Egress Time	$240\ seconds$		$141\ seconds$	$112\ seconds$	$172\ seconds$

The hand calculation shows that the most demanding exit path is through the West Stairwell, with $t_{queue} = 109\ sec$ on the second floor. In contrast, $t_{queue} = 0\ sec$ for the South East stairwell.

B.2. <u>Egress Calculation Using Pathfinder Software</u>

Egress time was also modeled using Pathfinder software.

Inputs to Pathfinder included the occupant load calculated by the hand calculation as described in this report. A total of 466 occupants were input into the Pathfinder model. Each room, space and area on each floor in the model includes the corresponding calculated occupant load.

Pathfinder was run in both SFPE mode and STEERING mode.

B.2.a. SFPE Mode

In SFPE mode, the computer egress model predicted a total egress time of 254 seconds, or 4 minutes, 14 seconds for all 466 building occupants to clear an exit discharge. This egress time is controlled by the egress path provided by the West Stairwell.

The hand calculation predicted an egress time of 240 seconds for all 466 occupants to exit the building. The most limiting exit stairwell is the exterior, enclosed stairwell on the west side of the building. The egress time predicted by the hand calculation is consistent with the time predicted by the Pathfinder model, at 254 seconds, in SFPE mode.

B.2.b. STEERING Mode

STEERING mode is more dependent on collision avoidance and occupant interaction that SFPE mode and often gives solutions similar to experimental data. In STEERING mode, the computer egress model predicted a total egress time of 190 seconds for the 466 building occupants to clear an exit discharge.

STEERING mode evacuation data, which provides more realistic evacuation times, will be used for this evaluation.

B.2.c. Comparison of Results in Hand, SFPE and STEERING Modes

Comparing the hand calculation, SFPE mode and STEERING mode calculations to building egress is summarized in the following table:

Table 22 – Comparison of Egress Calculations – Total Time

Total Building Egress Time and Number of Occupants			
Exit Path	**Hand Calc seconds (# occupants)**	**Pathfinder (SFPE) seconds (# occupants)**	**Pathfinder (STEERING) seconds (# occupants)**
West Stairwell	240 seconds (202)	254 seconds (201)	190 seconds (209)
South-West Stairwell	141 seconds (92)	122 seconds (87)	116 seconds (77)
South-East Stairwell	112 seconds (32)	57 seconds (22)	59 seconds (22)
East Stairwell	172 seconds (69)	129 seconds (94)	112 seconds (90)
North Office Discharge	Not Calculated (52)	48 seconds (38)	47 seconds (44)
Dispersal Area Discharge	Not Calculated (2)	3 seconds (2)	4 seconds (2)
Main Floor South Discharge	Not Calculated (8)	30 seconds (11)	30 seconds (11)
Main Floor East Discharge	Not Calculated (9)	28 seconds (11)	28 seconds (11)
TOTAL OCCUPANTS	466	466	466

Additionally, since the West Stairwell is the limiting egress path, the time to clear each floor into the West Stairwell (i.e., into the West Stairwell exit enclosure) is summarized for the hand calculation, SFPE mode, and STEERING mode calculations:

Table 23 – Comparison of Egress Calculations – Time to Clear Floor

Time to Clear Each Floor and Number of Occupants (West Stairwell)			
Floor Level	**Hand Calc seconds (# occupants)**	**Pathfinder (SFPE) seconds (# occupants)**	**Pathfinder (STEERING) seconds (# occupants)**
Second Floor	159 seconds (103)	176 seconds (86)	158 seconds (100)
Office Mezzanine	71 seconds (33)	147 seconds (48)	132 seconds (46)
Main Floor	Not Calculated (66)	136 seconds (67)	117 seconds (63)
TOTAL OCCUPANTS USING WEST STAIRWELL	202	201	209

The following screenshots from the Pathfinder model are provided:

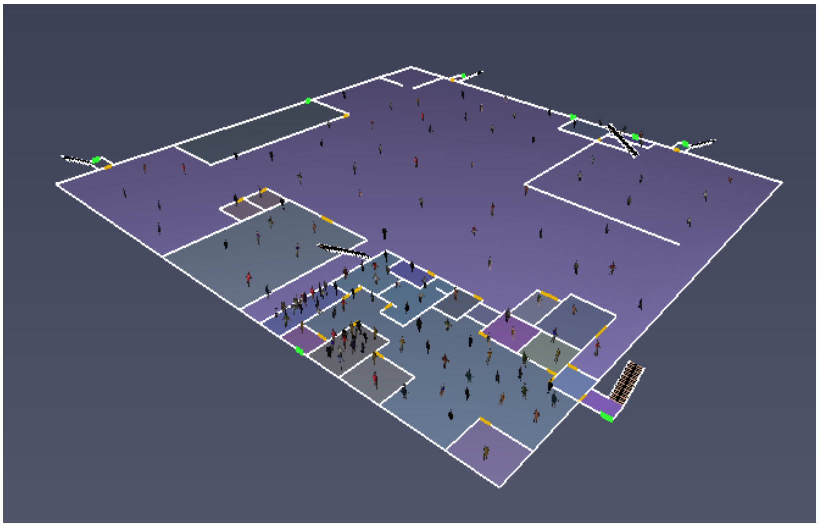


Figure 32 – Pathfinder Construction Warehouse Main Floor (El. 0 ft.)

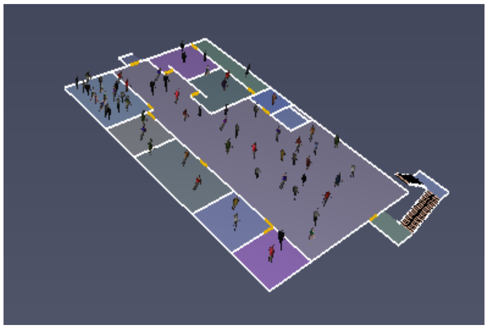


Figure 33 – Pathfinder Construction Warehouse Mezzanine (El. 12 ft.)

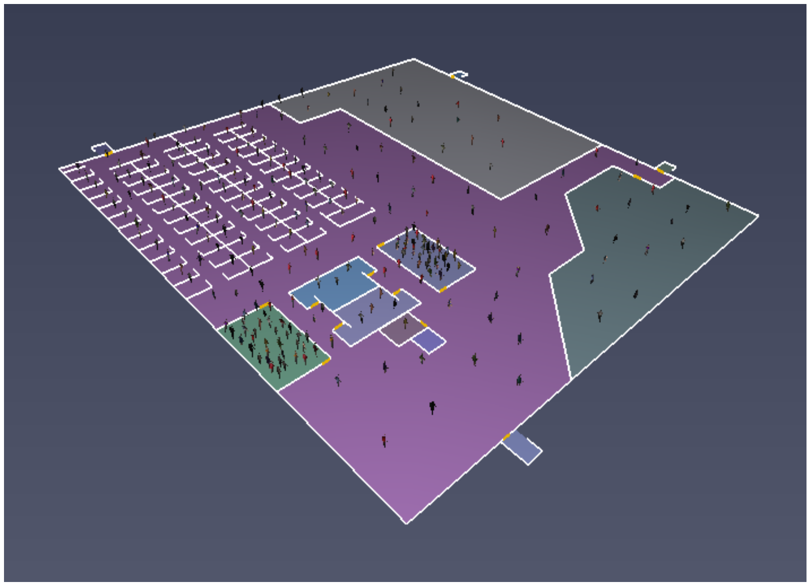


Figure 34 – Pathfinder Construction Warehouse Second Floor (El. 24 ft.)

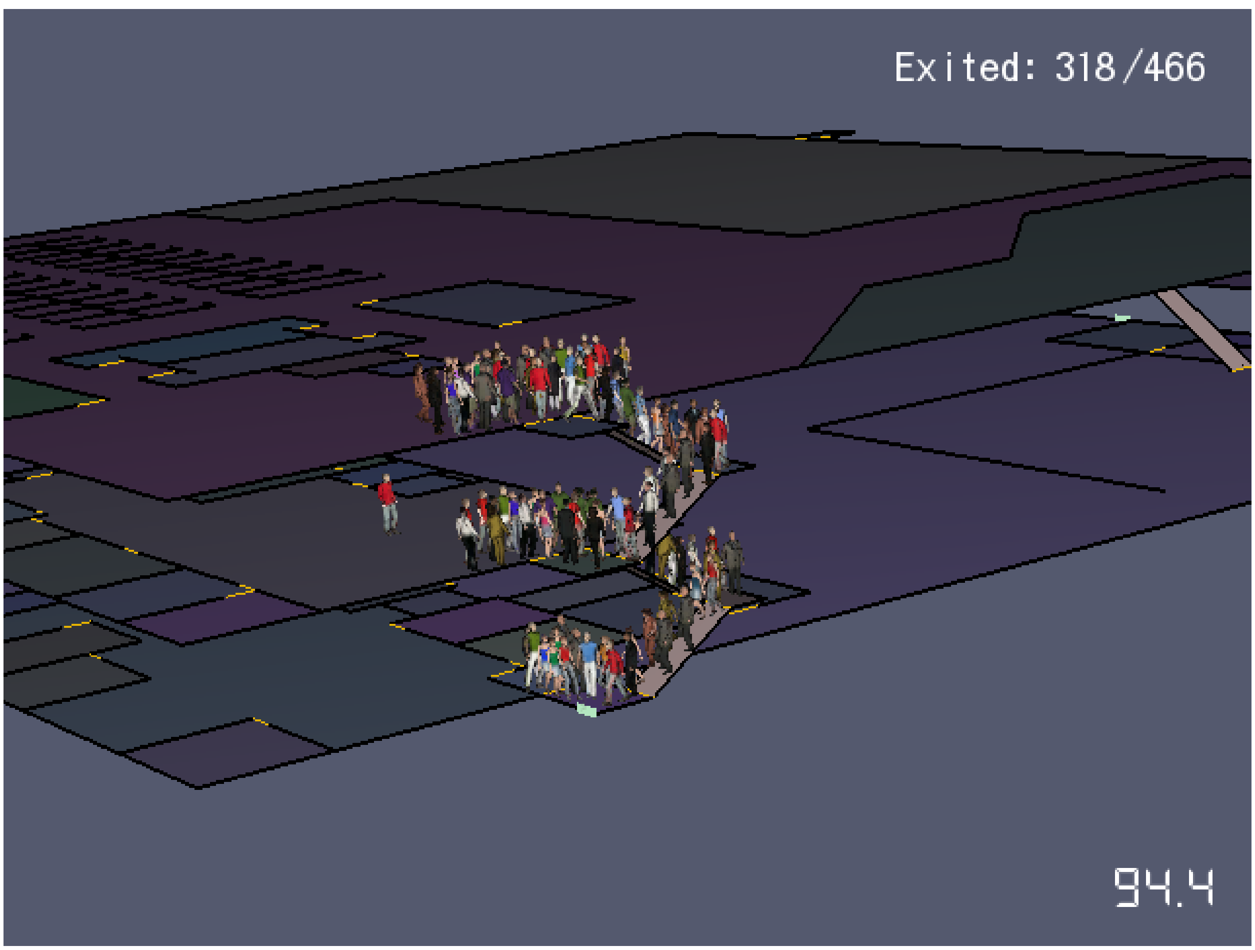


Figure 35 – Pathfinder Construction Warehouse Queuing in West Stairwell

Margin of Safety

- Design criteria - A period of time inserted into the egress system design to account for unknown factors that may delay a particular evacuation effort and to ensure a conservative egress system design

The following graphic illustrates the relationship between ASET, RSET and MoS:

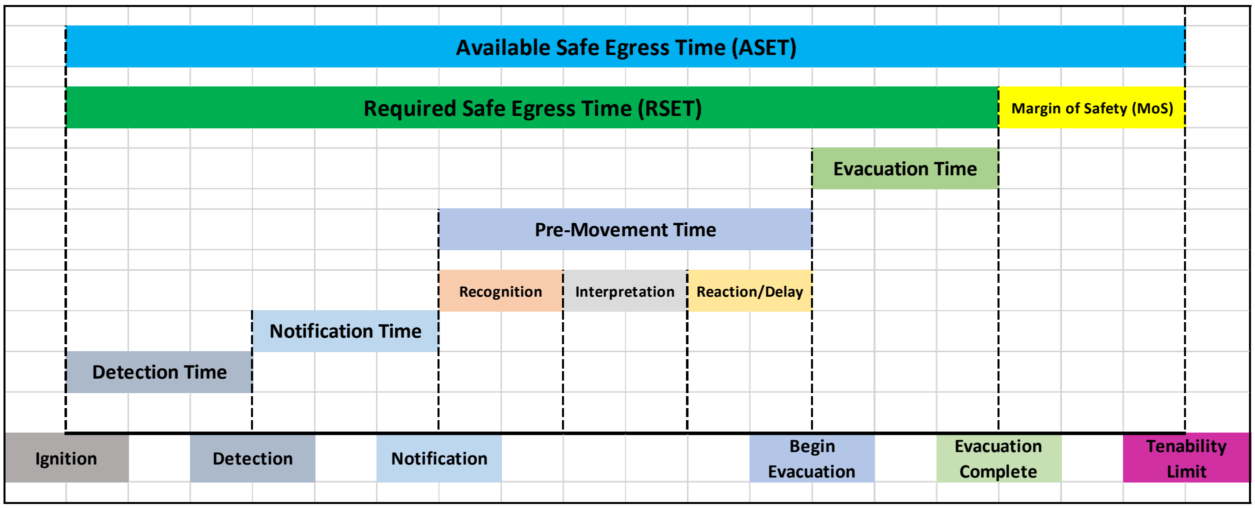


Figure 36 – ASET vs. RSET Graphic

C. Tenability Analysis

Criteria for a performance based life safety analysis are taken from the Chapter 5 of the LSC.

The fundamental performance criterion states:

> ***5.2.2* Performance Criterion.***
> *Any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions.*

This fundamental performance criterion is satisfied by one of four methods specified by the LSC.

Method 1 is identified below and is appropriate for the potential performance based analysis of the construction warehouse:

> ***Method 1.*** *The design team can set detailed performance criteria that ensure that occupants are not incapacitated by fire effects. The SFPE Engineering Guide to Performance-Based*

Fire Protection Analysis and Design of Buildings describes a process of establishing tenability limits.

The methodology required to determine the generation of smoke and gases, including constituents of smoke and gases within the building envelope that could create untenable conditions for building occupants, is fire modeling.

C.1. ***Tenability parameters***

Design for the protection of building occupants during a fire is based on preventing the development of conditions in the building, along the path of egress, that would incapacitate these occupants and prevent their ability to escape. These conditions are tenability limits.

C.2. ***Tenability Criteria***

Tenability criteria include limits on visibility, carbon monoxide dose, and temperature (heat flux). These criteria are established to limit sensory irritation and visual impairment, depression of the central nervous system, and thermal effects to building occupants.

C.2.a. Visibility

Exposure to concentrations of smoke in excess of established tenability limits causes sensory irritation and visual impairment that may be sufficient to cause a building occupant to stop attempting to egress. A specific value used for limiting smoke concentration (visibility) has not been fully agreed upon by the fire protection community.

Mealy, et. al. states that threshold values currently cited for smoke concentration tenability limits include, but are not limited to 0.25 OD/m (4 to 5.2 m), 0.43 OD/m (2.3 to 3.0 m), and 0.87 OD/m (1.1 – 1.5 m). Further Purser suggests, in Table 2-6.10, Reported Effects of Smoke on Visibility and Behavior, contained in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, a tenability limit of 0.2 OD/m (5 m) for small enclosures and travel distances, and 0.08 OD/m (10 m) for large enclosures and travel distances.

The SFPE Handbook of Fire Protection Engineering, 3rd Edition, Section 2, Chapter 4 "Visibility and Human Behavior in Fire Smoke", addresses observed human behavior in fire smoke. For a building open to the general public, in which occupants may not be familiar with the internal geometry of the building, a minimum visibility of 13 m is suggested as an allowable limit that permits safe escape. However, for a building where the occupants are familiar with the building geometry, and familiar with the location of building exits, an extinction coefficient of 0.5 1/m was found to be the point at which the subjects of experiments began to lose steadiness (corresponding to a minimum visibility of 4 m). Table 2-4.2 from the SFPE Handbook contains the suggested allowable smoke densities and visibility that permits safe escape and is reproduced below:

Table 2-4.2 *Allowable Smoke Densities and Visibility That Permits Safe Escape*

Degree of Familiarity with Inside Building	Smoke Density (extinction coefficient)	Visibility
Unfamiliar	0.15 1/m	13 m
Familiar	0.5 1/m	4 m

Figure 37 – Allowable Smoke Densities and Visibility That Permits Safe Escape

Since the occupants of the construction warehouse are familiar with this building, and visitors are escorted, a tenability limit of 4 m is selected for building office areas.

A visibility of 10 m is selected for large open building storage areas.

C.2.b. Exposure to Heat (Temperature)

Purser describes that there are three basis ways that victims of fire may succumb to incapacitation and death due to heat: (1) heat stroke; (2) body surface burns; and (3) respiratory tract burns. Table 2-6.19, Limiting Conditions for Tenability Caused by Heat, found in the SFPE Handbook of Fire Protection Engineering 3rd Edition, suggests that a human being is capable of withstanding temperatures up to 60°C for greater than 30 minutes, 100°C for 12 minutes, and 120°C for 7 minutes.

Mealy, et. al., reports that thermally untenable conditions are generally considered to be reached when temperatures exceed 120°C at a distance of 1.5 m, and then refers to information from Purser leading to a limiting exposure of 7 minutes.

The warehouse is made up a large floor area, of approximately 39,000 ft^2, the travel distance to at least one exit from any point in the building is less than 200 ft. Enclosed, exterior, exit stairwells are protected by 2 hour fire rated construction.

Building egress time has been evaluated to be 190 seconds (3 minutes and 10 seconds) which is less than 12 minutes by a factor of more than three. Temperature tenability criteria of 100°C is selected.

C.2.c. Carbon Monoxide Dose

Carbon monoxide is an asphyxiate that reduces that amount of hemoglobin in the blood that is available for carrying oxygen to the tissues of the body, particularly brain tissue.

Mealy, et. al. describes a means to determine untenable toxic CO gas concentrations by calculating dose (the product of transient gas concentrations and duration of exposure). Values of the fractional effective dose (FED) for CO is calculated according to the following equation:

$$FED_{CO} = \sum_{t_2}^{t_1} \frac{[CO_{ppm}]}{35{,}000\ ppm \cdot min} \Delta t$$

The empirical value of 35,000 ppm-min has been determined to be lethal by some experimental studies. Mealy, et. al. goes on to refer to ISO 13571, *Life-Threatening Components of Fire – Guidelines for the Estimation of Time Available for Escape Using Fire Data*, which suggests that FED threshold criteria for exposure to toxic gas is a value of 0.3. This value is considered to be conservative in light of statistics that indicate that 11 percent of the population is sensitive to a lesser toxic gas exposure.

Assuming a 30 minute exposure and tenability criteria for CO established as an FED of 0.3, a constant concentration of 350 ppm CO over this period results in a cumulative dose of CO to reach this limit of 10,500 ppm-min.

C.3. Summary of Tenability Limits

Table 24 – Tenability Limits

Tenability Criteria	
Parameter	Limit
Visibility	10 m in open warehouse areas 3 m in office areas
Carbon Monoxide Dose	0.3 (FED) [10,500 ppm-min]
Temperature	100°C

VIII. Fire Scenarios

A. Storage Rack Fire

The main floor of the warehouse is permitted to store for rack storage of cartoned, unexpanded, Group A plastics to a maximum height of 20 ft. (6.5 m) beneath a ceiling height of 24 ft. (7.80 m).

The actual storage arrangement found in the Warehouse is bounded by a fuel package consisting of:

- A 4-tier-high rack storage array of corrugated paper cartons on pallets
- Each tier consists of 4 cartons, each carton rests on a pallet (4 pallets)
- Each carton measures 3 ft. (0.91 m) long x 3 ft. (0.91 m) wide x 3 ft. (0.91 m) high
- Each pallet is 6 in. (0.15 m) high

- Each carton contains compartmented polystyrene cups
- The vertical distance between each tier measures 18 in. (0.46 m)
- The flue space between cartons measures 1 ft. (0.3 m)

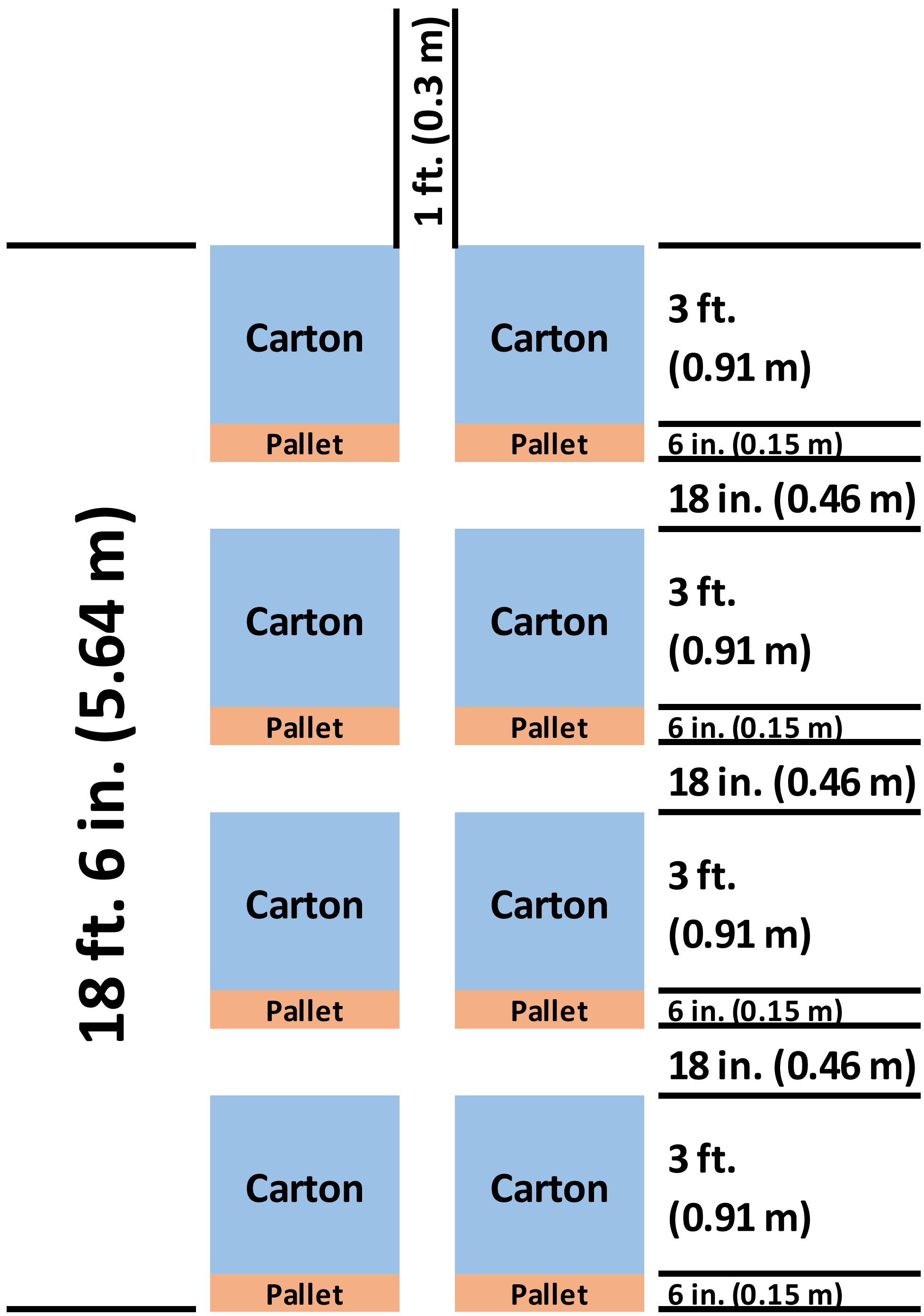


Figure 38 – Representation of Bounding Fuel Array, Section View

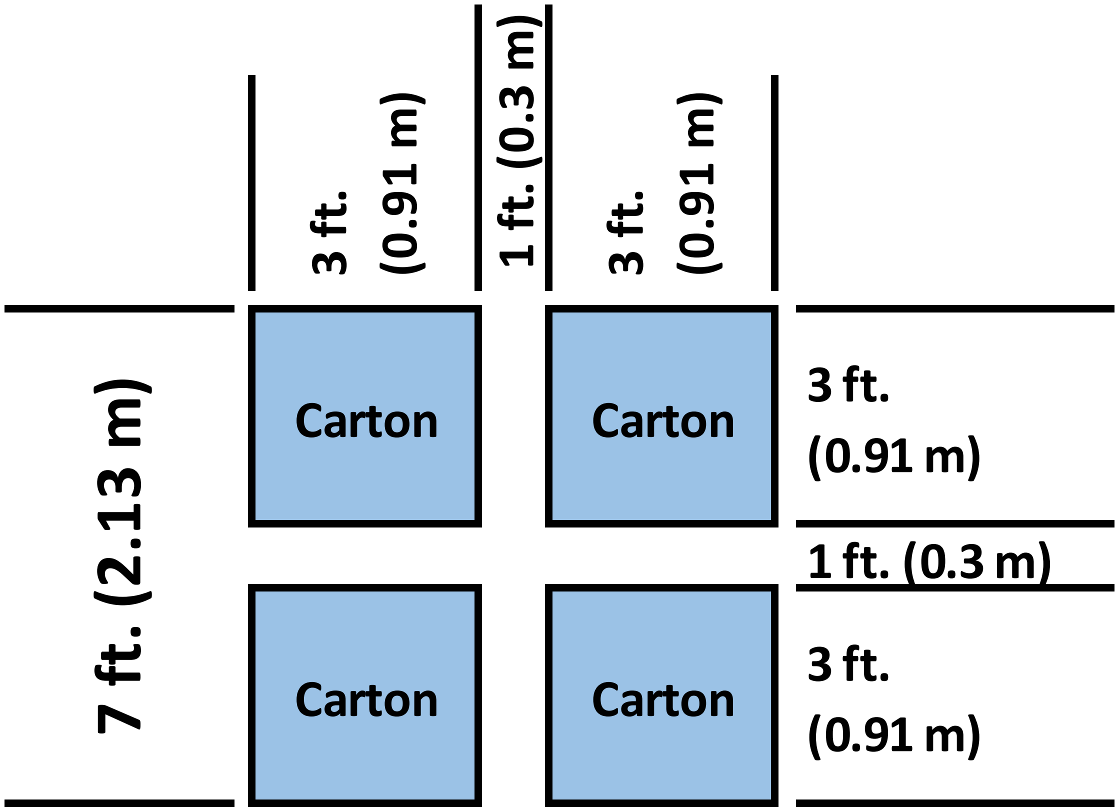


Figure 39 – Representation of Bounding Fuel Array, Plan View

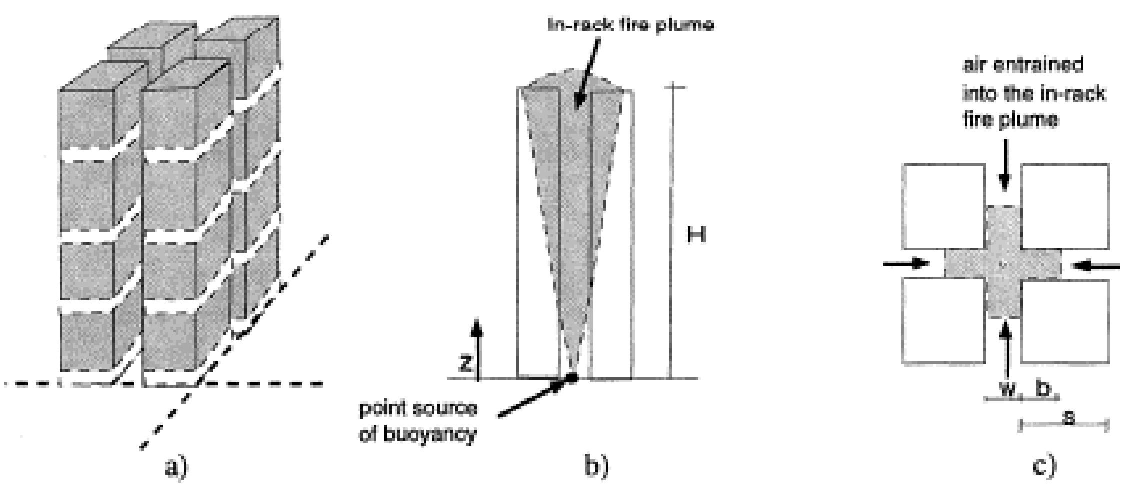


Figure 40 – a) 3D view b) side view c) plan view

Figure 41 is from Ingason, Haukur, *In-Rack Fire Plumes*, Swedish National Testing and Research Institute (SP).

Yu and Straviandis (Yu, Hong-Zeung and Stavrianidis, Paraskevas, *The Transient Ceiling Flows of Growing Rack Storage Fires*, Factory Mutual Research Corporation) investigated transient ceiling flows by growing rack storage fires over periods where convective heat release rates (HRRs) produced by these fires during the initial growth period (approximately 25 seconds) exhibited a growth rate that correlates to the third power. Based on their investigation, empirical correlations were developed for maximum excess gas temperature, maximum gas velocity, temperature profile depth, and velocity profile depth of the transient ceiling flow in terms of a normalized convective HRR of the fire and a normalized radial distance from the fire axis.

The following graphic shows the convective HRR observed by the Yu and Stavrianidis experimental study. Note that the curve fit transposed over this plotted data is taken from a prior experimental study by Yu (Yu, H-Z., *Transient Plume Influence in Measurement of Convective Heat Release Rates of Fast-Growing Fires Using a Large-Scale Fire Products Collector*) for the same fuel arrays.

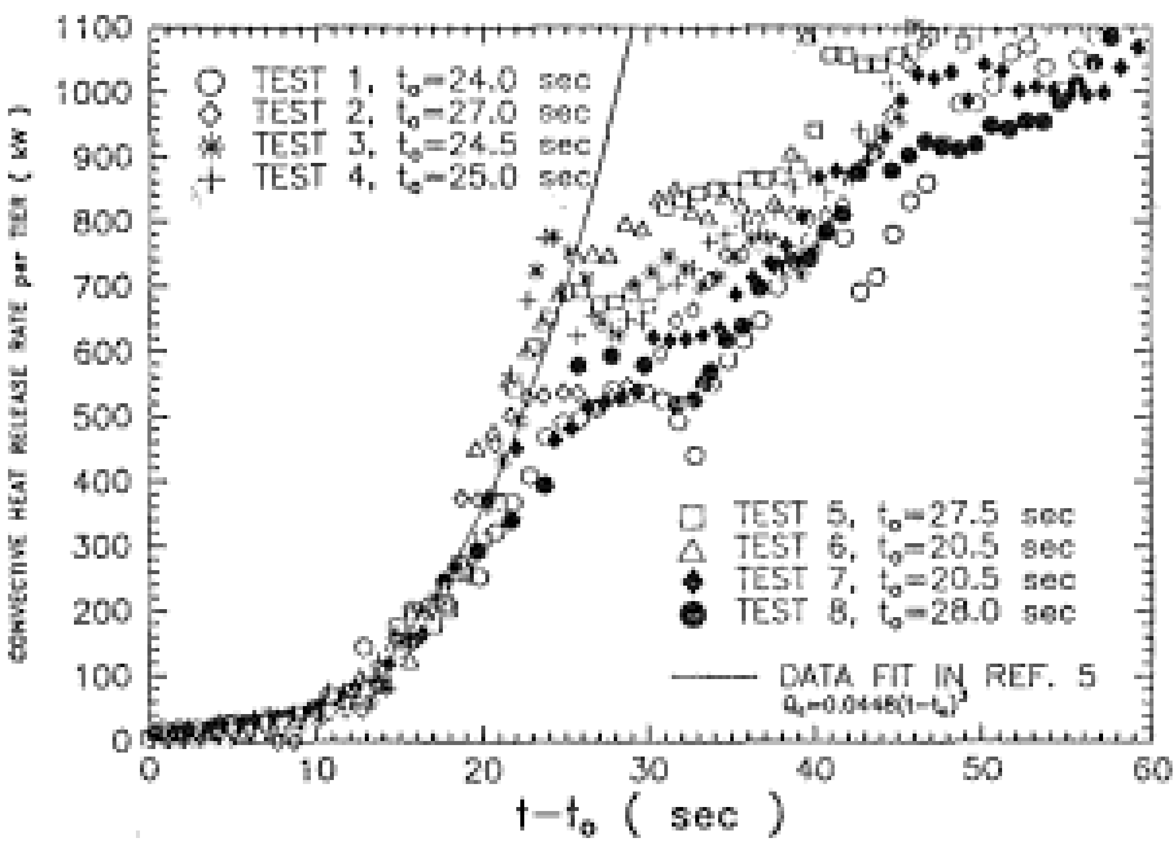


Figure 41 – Rack Storage, Convective Heat Release Rates

The SFPE Handbook of Fire Protection Engineering, 3rd Edition, states that ignition times for rack storage tests are strongly affected by the location of the ignition source. General correlations are not available for ignition time however the following graphic taken from the Handbook (Figure 3-1.34) illustrates that once ignited and established, a rack storage fire grows very rapidly. For the storeroom test it can be seen that the fire grows slowly over the first 500 seconds but then the HRR of this fire changes from 500 kW to over 17,000 kW in approximately 200 seconds.

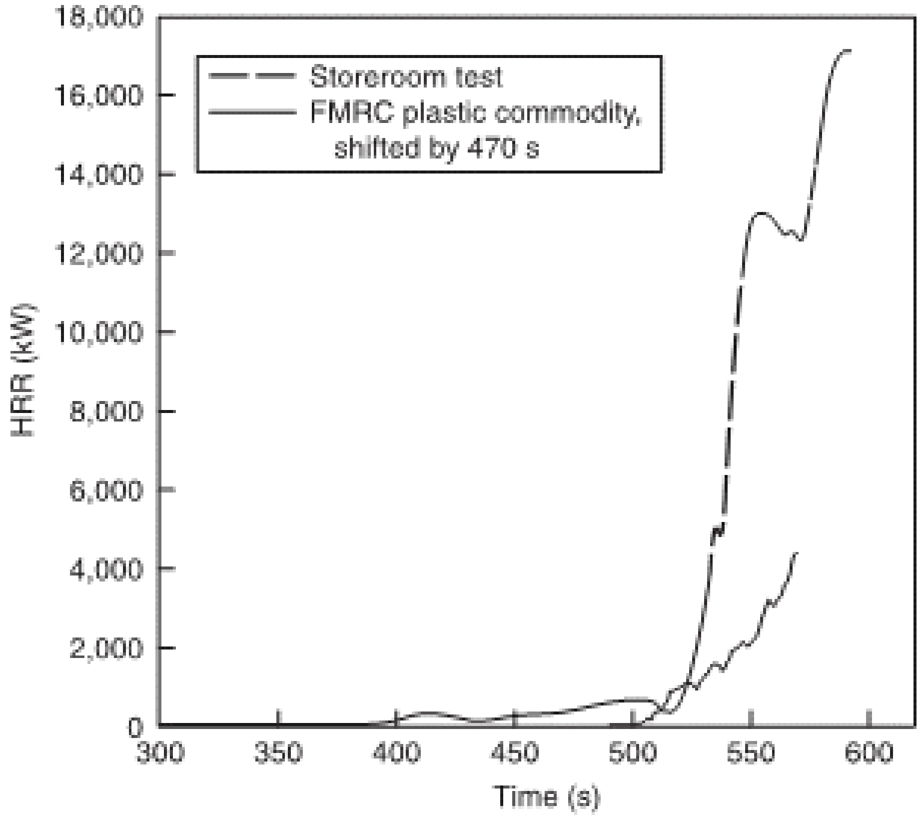


Figure 42 – Rack Storage, Heat Release Rates

The rack storage fire model prepared for the construction warehouse assumes that the fire grows with time to the third power, or "t-cubed".

The SFPE Handbook of Fire Protection Engineering, 3rd Edition, provides a description of and analysis by Heskestad of a series of rack storage fire tests performed by Yu and Kung (Yu, H-Z. and Kung, H-C., *Strong Buoyant Plumes of Growing Rack Storage Fires*, Factory Mutual Research Corporation). The test arrangement was a 2 x 2 array of the standard Factory Mutual Resource Corporation compartmented cardboard cartons containing polystyrene cups. The test arrangements analyzed Heskestad were of varying height and included 2, 3, and 4 pallets with flue spaces running in both directions. The tabulated peak HRR per unit area and time to peak

for various storage heights considered is tabulated in Table 3-1.5 of the SFPE Handbook of Fire Protection Engineering, 3rd Edition,. The test configuration of interest for this fire model is Test RS-11 and is shown in the table below:

Table 3-1.5 ***HRR Values of Palletized and Rack Storage Commodities Tested at FMRC***

Test	Commodity	Storage Height (m)	Peak HRR ($kW \cdot m^{-2}$)	Time of Peak (s)
SP-4	PS jars in compartmented CB cartons	4.11	16,600	439
SP-13	PS foam meat trays, wrapped in PVC film, in CB cartons	4.88	10,900	103
SP-23	PS foam meat trays, wrapped in paper, in CB cartons	4.90	11,700	113
SP-30A	PS toy parts in CB cartons	4.48	5,210	120
SP-35	PS foam insulation	4.21	26,000	373
SP-44	PS tubs in CB cartons	4.17	6,440	447
SP-15	PE bottles in compartmented CB cartons	4.20	5,330	434
SP-22	PE trash barrels in CB cartons	4.51	28,900	578
SP-43	PE bottles in CB cartons	4.41	4,810	190
SP-6	PVC bottles in compartmented CB cartons	4.63	8,510	488
SP-19	PP tubs in compartmented CB cartons	4.26	5,870	314
SP-34	PU rigid foam insulation	4.57	1,320	26
SP-41	Compartmented CB cartons, empty	4.51	2,470	144
RS-1	CB cartons, double triwall, metal liner	2.95	1,680	260
RS-2	" "	2.95	1,490	89
RS-3	" "	2.95	1,680	180
RS-4	" "	4.47	2,520	120
RS-5	" "	4.47	2,250	240
RS-6	" "	5.99	3,260	210
RS-7	PS cups in compartmented CB cartons	2.90	4,420	95
RS-8	" "	2.90	4,420	100
RS-9	" "	2.90	4,420	120
RS-10	" "	4.42	6,580	100
RS-11	" "	5.94	8,030	148

CB, cardboard; PE, polyethylene; PP, polypropylene; PS, polystyrene; PU, polyurethane

Figure 43 – Rack Storage HRR and Time to Peak HRR

The peak HRR values were obtained by Heskestad by dividing the measured value in kilowatts by the floor area occupied by the commodity under test.

To model a rack storage fire on the first floor of the warehouse the peak HRR per unit area provided for Test RS-11 is multiplied by the area of the storage configuration described above to obtain peak HRR. For modeling purposes:

$$Peak\ HRR\ (\dot{Q}) = 8{,}030\ {}^{kW}/_{m^2} \cdot (2.13\ m\ x\ 2.13\ m) = 36{,}500 kW$$

The modeled fire is assumed to grow to its peak HRR in 148 seconds, as is indicated for Test RS-11.

In Fire Dynamics Simulator (FDS), this fire is modeled as a horizontal burner with a surface area of $6.76\ m^2$, the corresponding HRR per unit area of 5,400 ${}^{kW}/_{m^2}$, and is elevated $2\ m\ (6\ ft.7\ in.)$ above the main floor of the building.

The FDS model for the rack storage fuel array assumes that the fire grows predictably according to the "t-cubed" fire growth equation:

$$\alpha = {}^{Peak\ HRR}\!/_{(time\ to\ peak)^3}$$

$$\alpha = {}^{36{,}500kW}\!/_{(148\ seconds)^3}$$

$$\alpha = {}^{0.0113kW}\!/_{sec^3}$$

Each carton in the 4 x 4 x 4 fuel array is modeled as a burner – there are 16 burners modeled to simulate a fire in the rack storage array. The lower tier burners are modeled 1.3 m above the floor, the second tier 2.8 m above the floor, the third tier 4.3 m above the floor, and the fourth tier is modeled 5.8 m above the floor.

Ignition is presumed to occur on the lowest tier.

The HRR of the lower tier 4 by 4 by 4 array of cardboard cartons containing polystyrene cups was modeled so that ignition occurs on the bottom tier of four cartons followed by "t-cubed" fire growth for 30 seconds. After 30 seconds, the HRR is 304 kW, and the second tier burners (2.8 m above the floor) are assumed to ignite. The first and second tier then evenly share the HRR of this fire for the next 30 seconds. After 60 seconds, the third tier burners (4.3 m above the floor) ignite. The HRR after 60 seconds is 2,432 kW. As before, as the fire grows, the burners on all three tiers are assumed to share an equal proportion of the HRR. Ninety seconds following ignition this fire spreads to the top tier of cartons, 5.8 m above the floor. At this time the HRR of this fire is 8,208 kW.

When the fire grows to a HRR of 8,208 kW the fourth and final tier of burners, 5.8 m above the floor are assumed to ignite.

At the time of peak HRR (148 seconds), all four tiers of burners are contributing $\frac{36{,}500kW}{4}$, or 9,125 kW, to this fire.

In FDS, the HRR of each tier is controlled by a ramp function. Due to the nature of this modeling approach, the first tier of burners ramp up to 9,125 kW over the full 148 seconds. The second tier is forced to ramp up to contribute 9,125 kW to the fire in 118 seconds. The third tier, 88 seconds, and the fourth tier ramps up to 9,125 kW in 58 seconds.

An excerpt of the spreadsheet used to calculate the factors (F1, F2, F3 and F4) used to control these ramp functions in FDS is included in Table 25 below:

Table 25 – Ramp Factors for Rack Storage Fire HRR Model

t	Heat Release Rate (kW)						Ramp Factor			
	Total	Tier 1	Tier 2	Tier 3	Tier 4	Total	F1	F2	F3	F4
0	0	0				0	0.000	0.000	0.000	0.000
10	11	11				11	0.001	0.000	0.000	0.000
20	90	90				90	0.010	0.000	0.000	0.000
30	304	152	152			304	0.017	0.017	0.000	0.000
40	721	360	360			721	0.039	0.039	0.000	0.000
50	1407	704	704			1407	0.077	0.077	0.000	0.000
60	2432	811	811	811		2432	0.089	0.089	0.089	0.000
70	3862	1287	1287	1287		3862	0.141	0.141	0.141	0.000
80	5765	1922	1922	1922		5765	0.211	0.211	0.211	0.000
90	8208	2052	2052	2052	2052	8208	0.225	0.225	0.225	0.225
100	11259	2815	2815	2815	2815	11259	0.308	0.308	0.308	0.308
110	14986	3747	3747	3747	3747	14986	0.411	0.411	0.411	0.411
120	19456	4864	4864	4864	4864	19456	0.533	0.533	0.533	0.533
130	24736	6184	6184	6184	6184	24736	0.678	0.678	0.678	0.678
140	30895	7724	7724	7724	7724	30895	0.846	0.846	0.846	0.846
148	36500	9125	9125	9125	9125	36500	1.000	1.000	1.000	1.000

The modeled heat release rate curve, based on a "t-cubed" fire growth rate is shown in the following Figures:

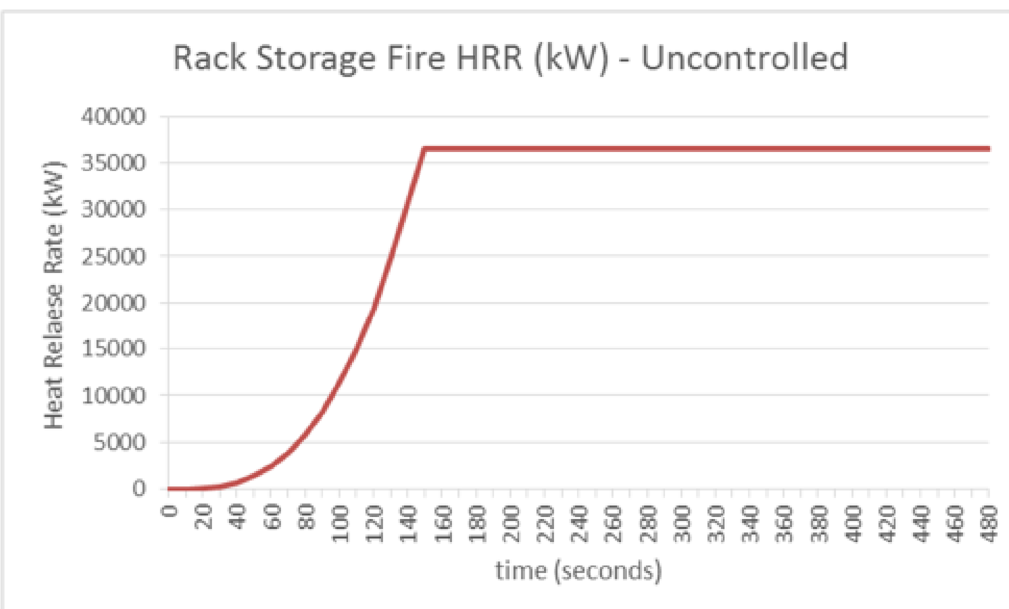


Figure 44 – Heat Release Rate; Uncontrolled Rack Storage Fire

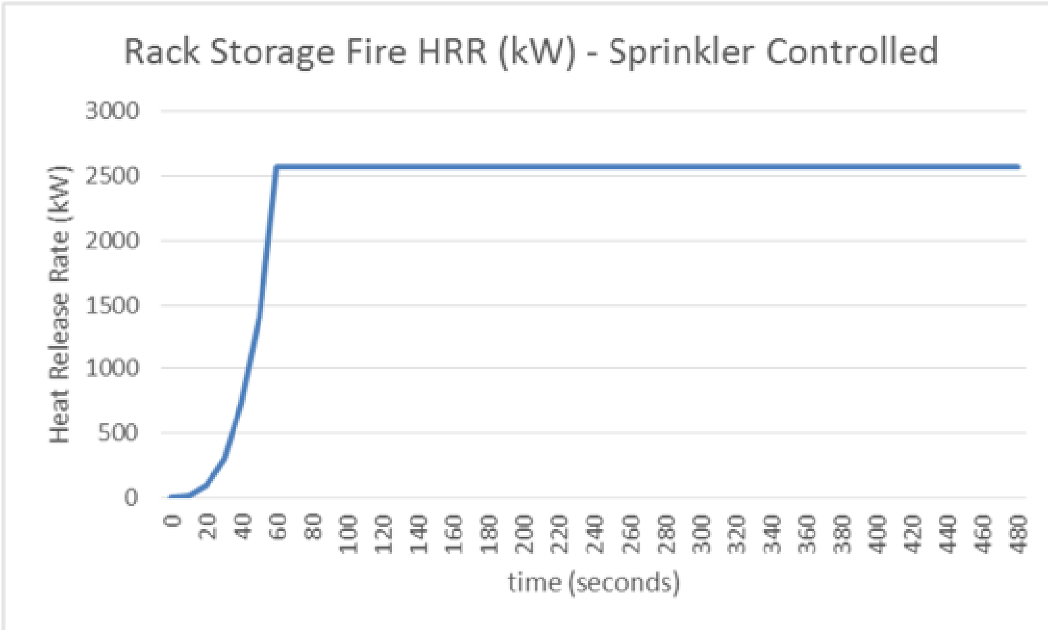


Figure 45 – Heat Release Rate, Sprinkler Controlled Rack Storage Fire

A.1. Additional Modeling Assumptions and Parameters

1. Fuel consists of polystyrene cups contained in compartmented cardboard cartons. The model includes FDS input for an array as follows:

- A 4-tier-high rack storage array of corrugated paper cartons containing polystyrene cups
- Each carton consists of 6.2 kg of polystyrene and 9.5 kg of cardboard
- Each tier consists of 4 cartons
- Each carton measures 1 m long x 1 m wide x 1 m high
- The vertical distance between each tier measures 0.5 m
- The flue space between cartons measures 0.2 m

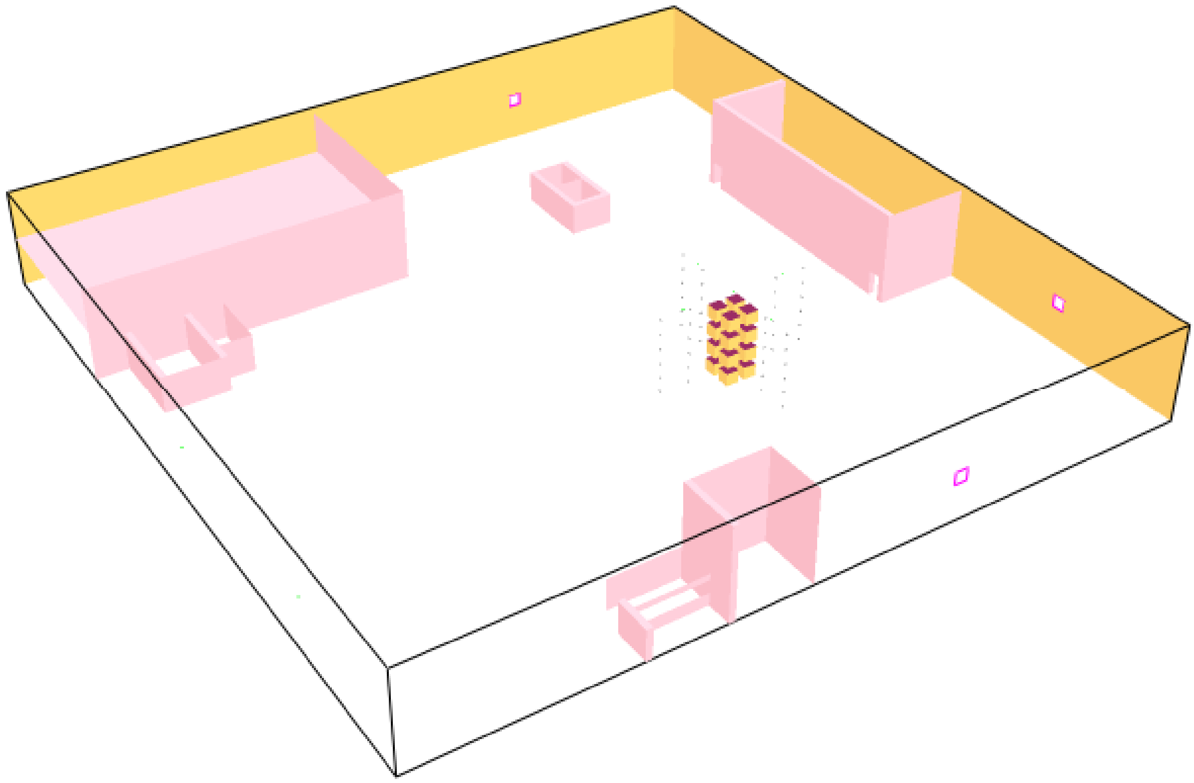


Figure 46 – Rack Storage Fire Model Layout

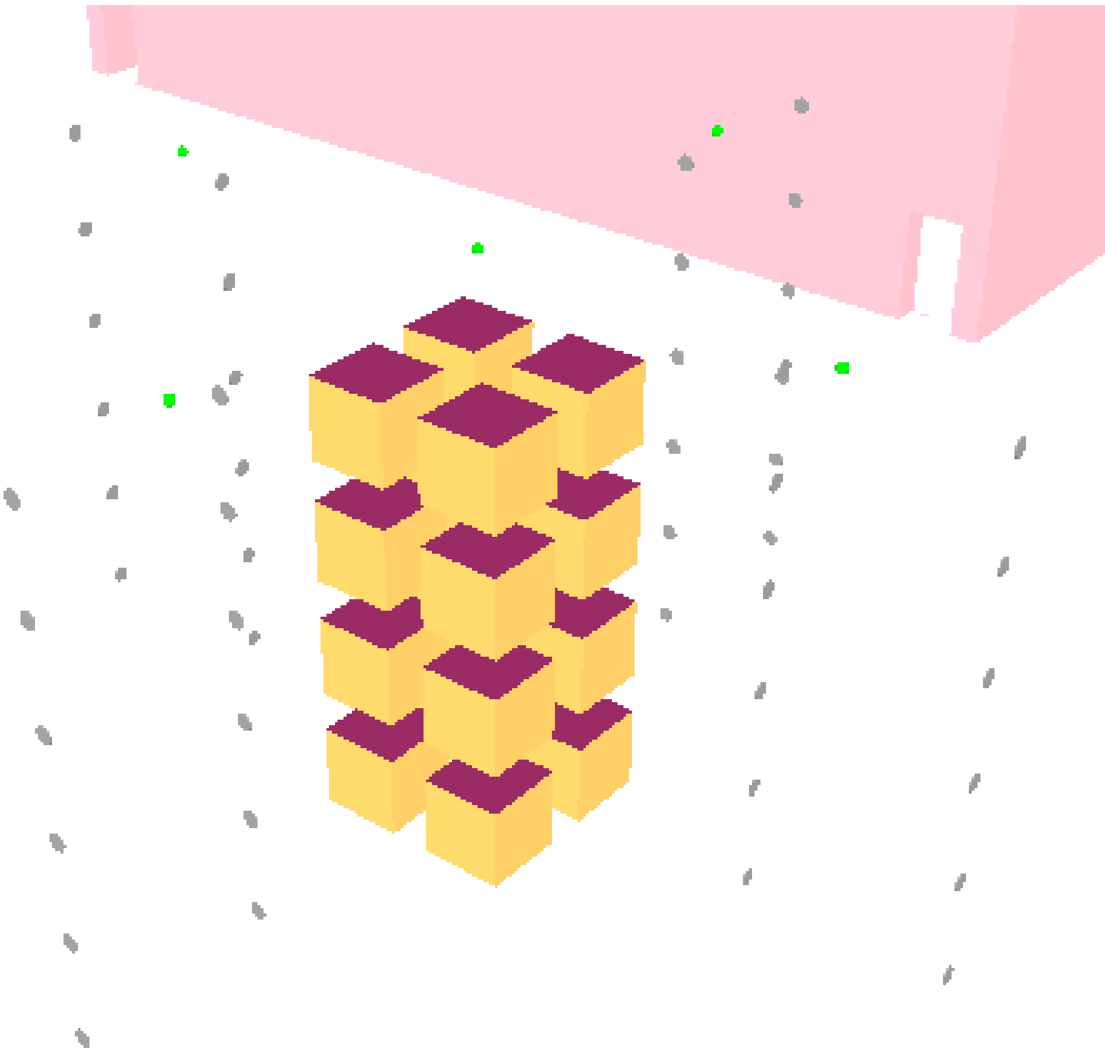


Figure 47 – Rack Storage Fire Model Layout – Close-up View

2. Carbon monoxide and soot yield is based on an estimate of the mass-weighted average of combustible materials in the fuel array (See Appendix B).

   a. Chemical formula: C_8H_8 (Polystyrene)
   b. Carbon Monoxide yield: 0.0261 $^{g}/_{g}$
   c. Soot yield: 0.0738 $^{g}/_{g}$

3. The FDS model is setup with a mesh size of 0.5 m x 0.5 m x 0.5 m.

4. Floors and ceilings are modeled as concrete.
    a. Thickness: $0.2\ m$ ($8\ inches$)
    b. Specific Heat: $0.88\ ^{kJ}/_{kg\ \cdot\ ^{\circ}C}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
    c. Conductivity: $1.37\ ^{W}/_{m\ \cdot\ ^{\circ}C}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
    d. Density: $2{,}300\ ^{kg}/_{m^3}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

5. Exterior walls are modeled as glass wool.
    a. Thickness: $0.2\ m$ ($8\ inches$)
    b. Specific Heat: $0.70\ ^{kJ}/_{kg\ \cdot\ ^{\circ}C}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
    c. Conductivity: $0.038\ ^{W}/_{m\ \cdot\ ^{\circ}C}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
    d. Density: $24\ ^{kg}/_{m^3}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

6. Interior walls are modeled as gypsum plaster.
    a. Thickness: $0.2\ m$ ($8\ inches$)
    b. Specific Heat: $0.84\ ^{kJ}/_{kg\ \cdot\ ^{\circ}C}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
    c. Conductivity: $0.48\ ^{W}/_{m\ \cdot\ ^{\circ}C}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
    d. Density: $1{,}440\ ^{kg}/_{m^3}$

       (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

7. An independent hand calculation to determine sprinkler actuation time has been performed. This detector actuation (DETACT) analysis is included in Appendix C. The results of this DETACT analysis predict that sprinklers activate 60 seconds after ignition. The HRR at sprinkler activation 60 seconds following ignition is 2,592 kW. The DETACT results are graphically represented in the following figure:

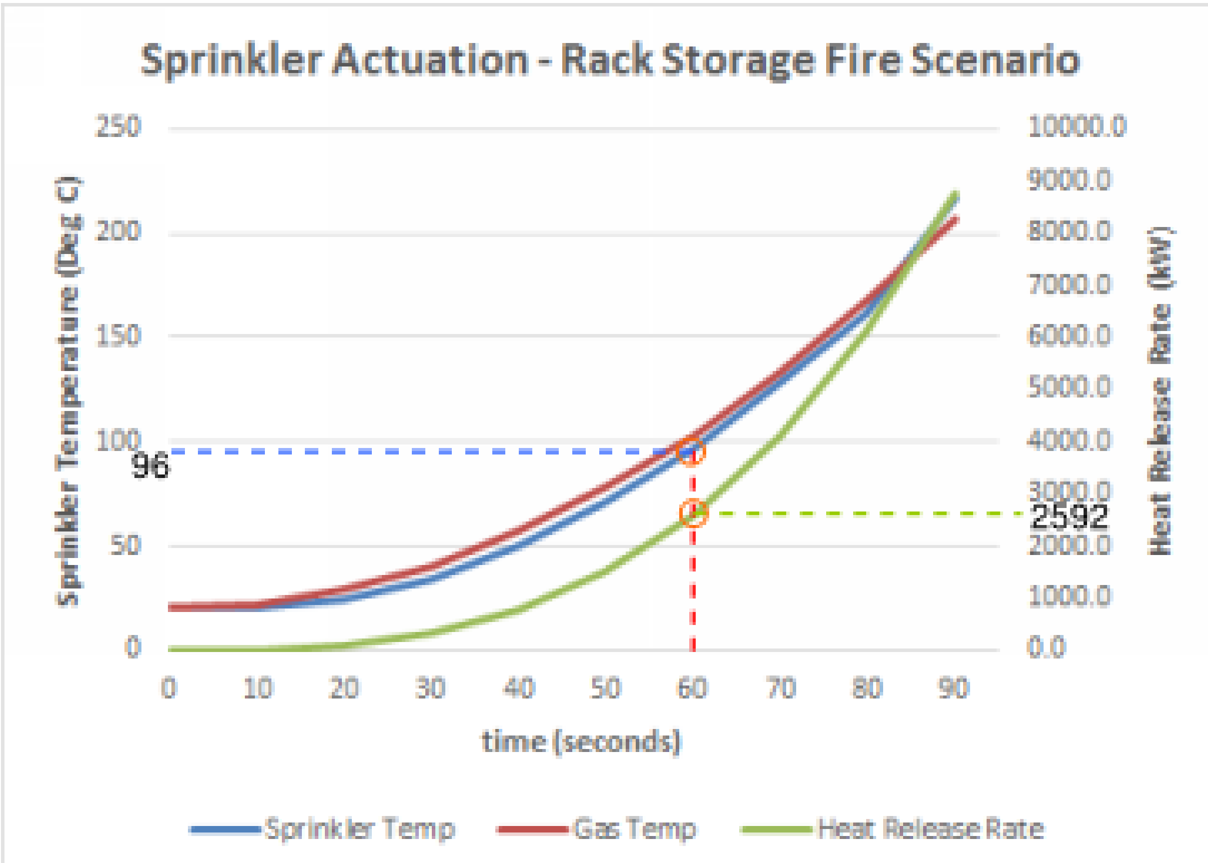


Figure 48 – Rack Storage Fire DETACT Sprinkler Activation

In contrast, automatic sprinkler actuation is predicted by FDS at 80 seconds following ignition. The corresponding HRR of the rack storage fire at 80 seconds is 6,144 kW.

Use of the sprinkler actuation time (60 seconds) and corresponding HRR (2,592 kW) provides an acceptable input to this analysis for the following reasons:

- ESFR type sprinklers are designed to suppress and extinguish a fire. The assumption that sprinklers actuate and control, rather than, suppress, this fire is conservative.
- The capabilities of FDS to show the effect of sprinklers on the suppression of this fire is not employed. An assumption that sprinkler activation within FDS merely controls the rack storage fire is not realistic.

Sprinklers not are included in the model. Instead, the model assumes that sprinklers control the fire at a time 60 seconds from ignition at a HRR of 2,592 kW.

8. There are no fire detectors on the main floor of the building – fire detection is not modeled.

9. Temperature devices are inserted into the model in the following locations:

- One sensor is placed at the ceiling directly above the centerline of the fire plume
- Four sensors are placed at the ceiling 4.3 m (10 $ft.$) away from the plume centerline. One of these four sensors is placed off of each edge of the fuel array (four locations).

10. Radiative heat flux sensors are placed in the model. These sensors are intended to assist with the potential for fire spread from rack to rack within the warehouse. These sensors are placed in the model as a "tree" of targets. Each "tree" contains six radiative heat flux sensors equally spaced vertically 1.2 m (3.9 $ft.$) apart beginning 1.2 m (3.9 $ft.$) above the main floor. The highest sensor in a "tree" is located 7.2 m (23.6 $ft.$) above the main floor. There are eight "trees" placed in the model. Radiative heat flux sensor "trees" are placed as follows:

- One of eight "trees" is placed 2.4 m (8 $ft.$) away from each of the four sides of the fuel array (four locations)
- One of eight "trees" is placed 4.8 m (16 $ft.$) away from each of the four sides of the fuel array (four locations)

11. The model includes four vent openings, the area of each measuring 1 m^2:

- Two open vents are located on the east wall of the building
- One open vent is located on the north wall of the building
- One open vent is located on the south wall of the building

12. The model includes three exhaust fans located on the west wall of the building:

- Two of the three exhaust fans are actuated by a thermostat. The thermostats are modeled as a temperature sensor near each fan. The model turns these two fans "on" when the thermostat senses a temperature of 32°C (90°F). The capacity of these two fans is placed in the model as 8.3 $m^3/_{sec}$ $\left(17{,}500\ ft^3/_{min}\right)$.
- One of the three exhaust fans is modeled to operate continuously with a flow of 0.83 $m^3/_{sec}$ $\left(1{,}750\ ft^3/_{min}\right)$.

B. Analysis of Model Results

B.1. <u>Case– Sprinklers Permitted to Operate</u>

B.1.a. Visibility

The tenability limit for visibility is assessed graphically in FDS. This tenability limit has been established as 10 m at a location 1.82 m (6 ft.) above the floor. The following FDS rendering shows that visibility is reduced to 10 m at time 400 seconds for this scenario in the upper area of the rendered image:

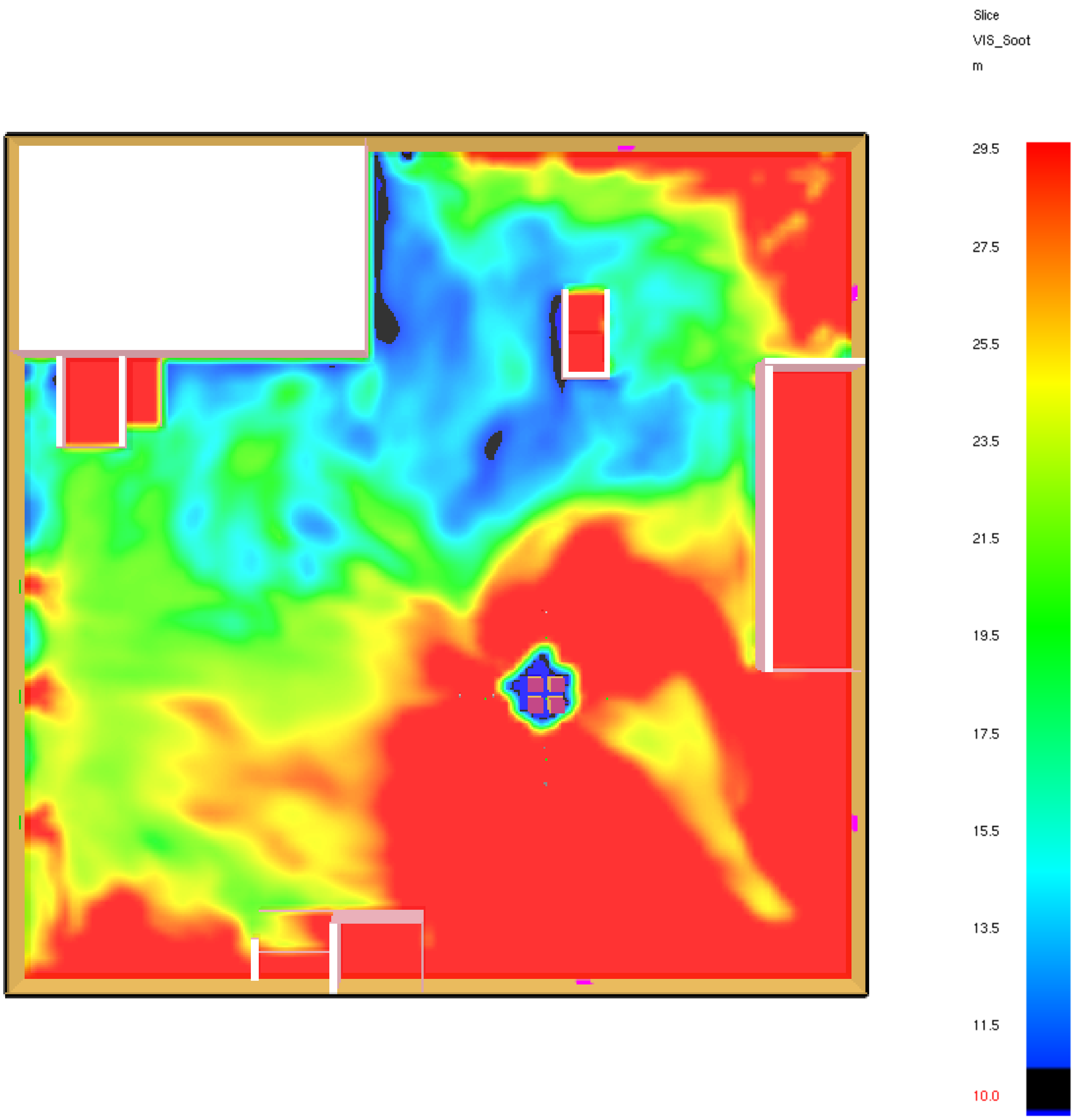


Figure 49 –Visibility @ 400 Seconds and 1.82 m above Main Floor

B.1.b. Temperature

A tenability limit of 100°C has been established for the main floor of the warehouse. The FDS rendering below shows that 100°C is never exceeded over the 480 second duration of this fire as modeled.

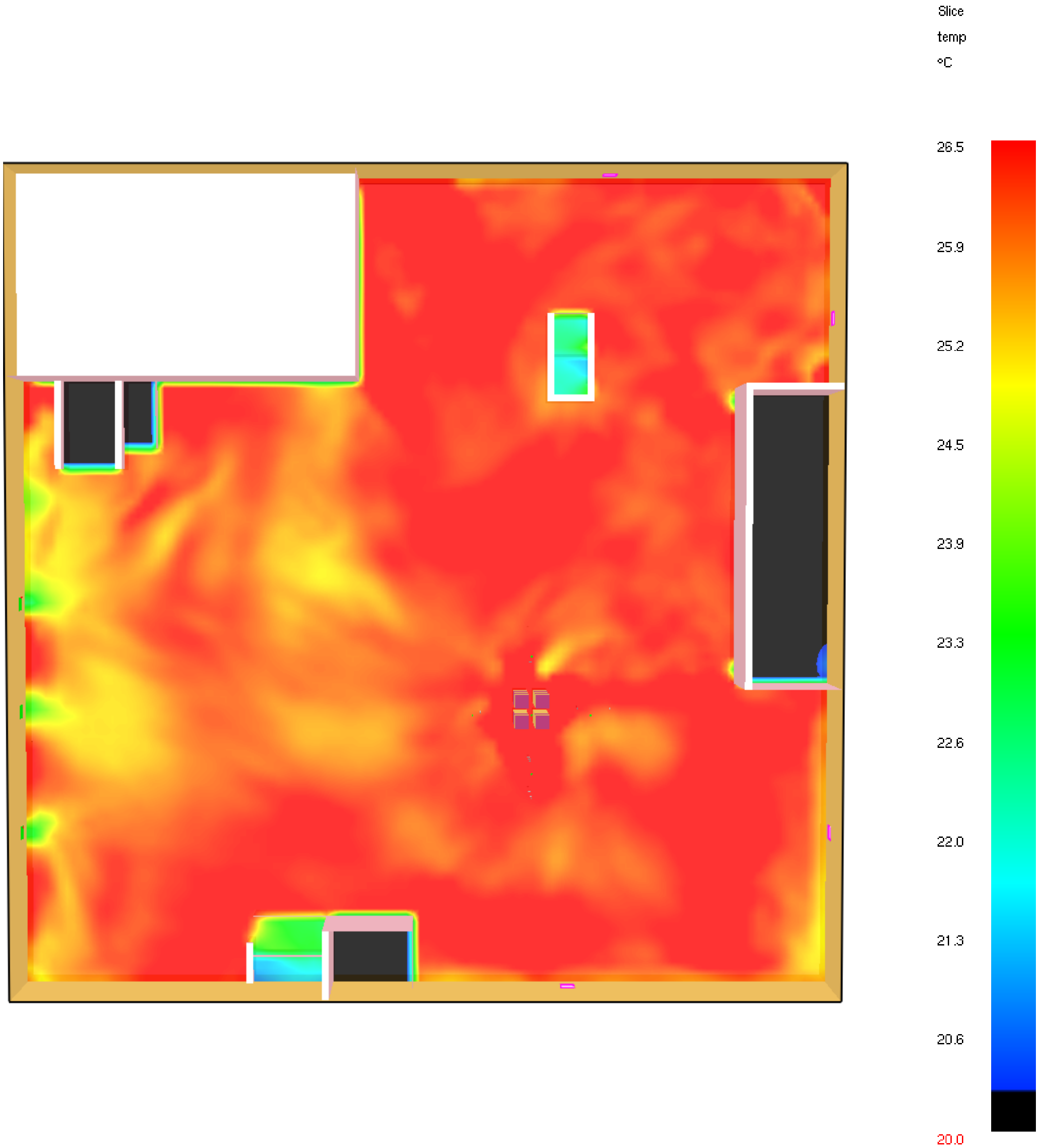


Figure 50 –Temperature @ 480 Seconds and 1.82 m Above Main Floor

B.1.c. CO Dose

The cumulative dose of CO is conservatively assessed based on the mass of CO generated by the fire and released into the volume of the main floor area of the construction warehouse. Based on the input provided to FDS for the configuration of the main floor, the mass of air and combustion products (N_2, O_2, CO_2, CO, soot, and water vapor) in this volume are generated and recorded by FDS.

Assuming that these combustion products are evenly mixed throughout the volume a conservative estimate of CO dose is made and shown to be well below the tenability limit established for CO (Fractional Effective Dose < 0.3).

The concentration of CO in terms of parts per million is represented by:

$$ppm\ CO = \frac{mg\ CO}{kg\ N_2 + kgO_2 + kgCO_2 + kgH_2O + kgCO}$$

The dose of CO over time may then be calculated by summing the product of CO concentration times the time interval. Finally, the FED may be calculated according to the following equation:

$$FED_{CO} = \sum_{t_2}^{t_1} \frac{[CO_{ppm}]}{35{,}000\ ppm \cdot min} \Delta t$$

A spreadsheet was prepared containing the FDS outputs necessary to calculate FED. This spreadsheet, and calculation, is shown in the tabulation below:

Table 26 – Cumulative Carbon Monoxide Dose vs. Time and FED

s	kg	kg		CO	CO Dose	
Time	Total	CO	ppm CO	ppm-min	ppm-min	FED
0	34177	0.0000	0	0.0	0.0	0.0000
30	34172	0.0022	0	0.0	0.0	0.0000
60	34104	0.0325	1	0.5	0.5	0.0000
90	33964	0.0988	3	1.5	2.0	0.0001
120	33837	0.1642	5	2.4	4.4	0.0001
150	33718	0.2280	7	3.4	7.8	0.0002
180	33603	0.2919	9	4.3	12.1	0.0003
210	33495	0.3538	11	5.3	17.4	0.0005
240	33394	0.4114	12	6.2	23.6	0.0007
270	33305	0.4646	14	6.9	30.5	0.0009
300	33220	0.5178	16	7.8	38.4	0.0011
330	33140	0.5680	17	8.5	46.9	0.0013
360	33065	0.6156	19	9.4	56.3	0.0016
390	32998	0.6595	20	9.9	66.2	0.0019
420	32935	0.7022	21	10.7	76.9	0.0022
450	32875	0.7428	23	11.2	88.1	0.0025
480	32819	0.7812	24	11.8	99.9	0.0029

The FED is also shown graphically with time in the figure below:

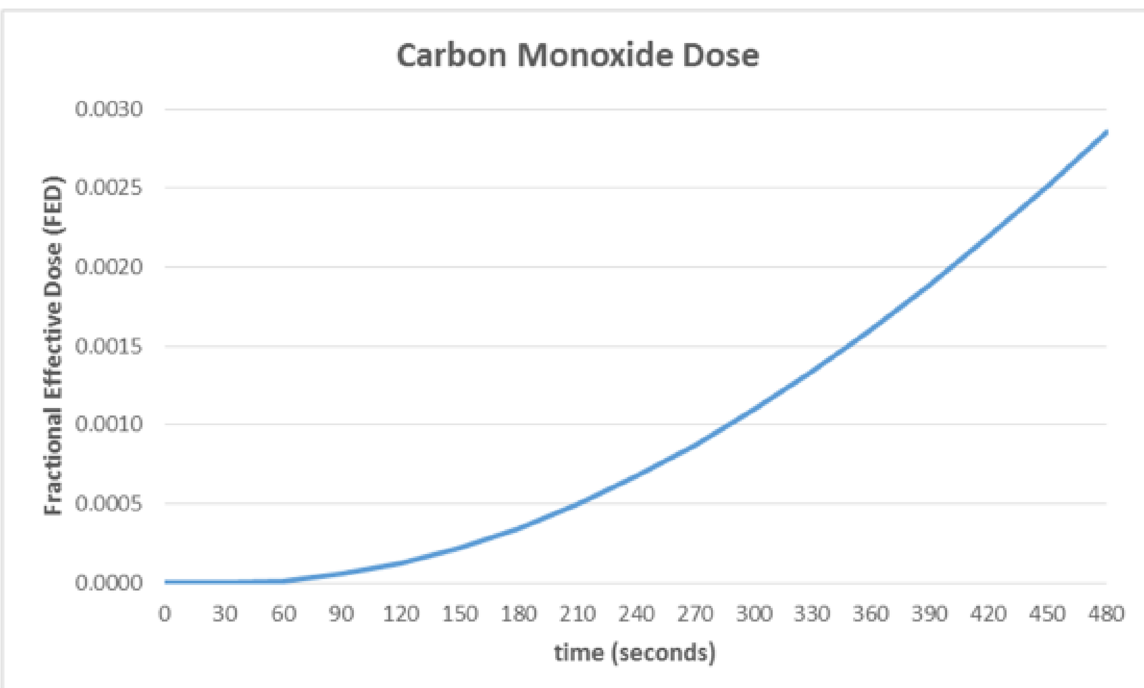


Figure 51 –Carbon Monoxide FED vs. time

It can be seen that after 480 seconds of exposure, the cumulative CO Dose of 99.9 ppm-min results in an FED = 0.0029 which is much less than the established tenability limit of FED = 0.3. It is concluded that the tenability limit for CO will not be exceeded for the rack storage fire scenario.

B.2. HVAC Fans

One of the HVAC exhaust fans runs continuously at a rate of 1,750 cfm.

Two of the HVAC exhaust fans begin operation automatically on actuation of a thermostatic switch. Each of these exhaust fans provides 17,500 cfm of exhaust from the first floor volume. The temperature at which each switch actuates is 90°F (32°C).

FDS predicts that first and second exhaust fans automatically start 191 seconds and 203 seconds following ignition, respectively.

B.3. Ceiling Temperature

FDS predicts that the maximum ceiling temperature at the center of the fire plume to be 180°C (356°F) and is quickly turned at 60 seconds when sprinklers are predicted to activate by the DETACT model. Figure 52 below graphically shows ceiling temperature with time.

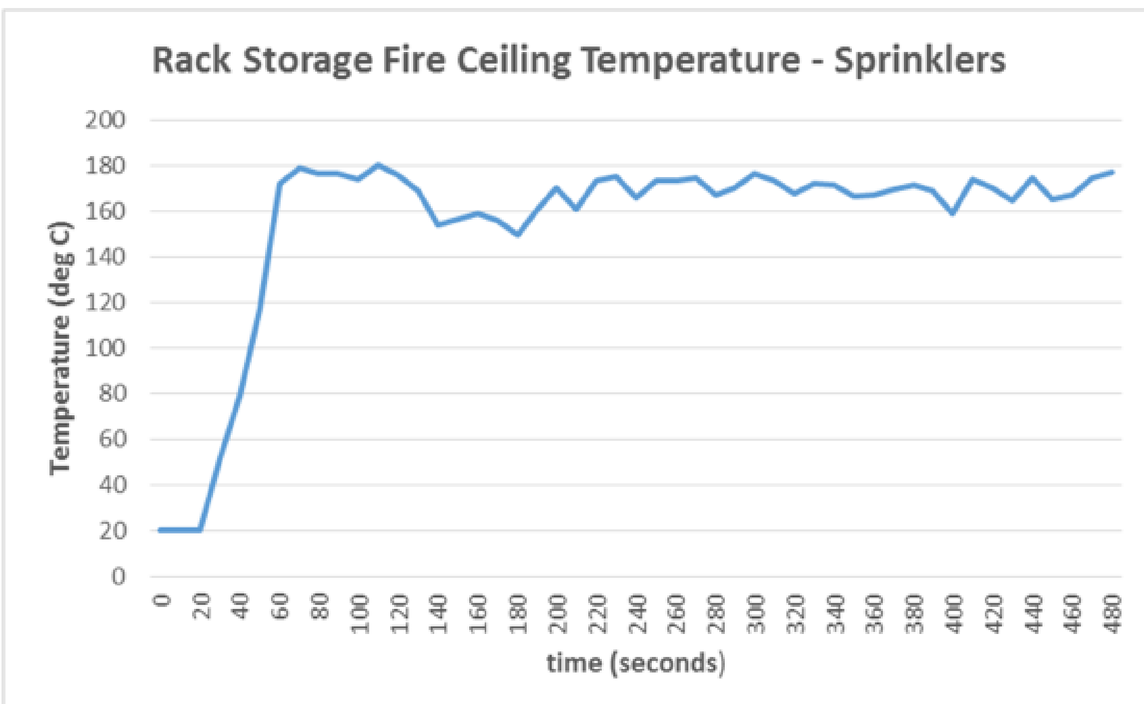


Figure 52 –Ceiling Temperature, DETACT Predicted Sprinkler Actuation

B.4. Radiative Flux

To assess the potential for spread of fire to commodities on adjacent storage racks, a series of radiative heat flux detectors are placed in the FDS model.

These FDS predicted radiative heat flux values are compared to the Critical Heat Flux (CHF) documented by the SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table 3-4.2, for both corrugated paper (cardboard) and polystyrene:

Table 3-4.2 ***Critical Heat Flux and Thermal Response Parameter of Materials***

Materials	CHF (kW/m^2) ASTM E2058 Fire Propagation Apparatus	TRP ($kW \cdot s^{1/2}/m^2$) ASTM E2058 Fire Propagation Apparatus	TRP ($kW \cdot s^{1/2}/m^2$) ASTM E1354-90[a]
Natural materials			
Flour	10	218	—
Sugar	10	255	—
Tissue paper	10	95	—
Newspaper	10	108	—
Wood (red oak)	10	134	—
Wood (Douglas fir)	10	138	—
Corrugated paper (light	10	152	—
Corrugated paper (heavy)			
No coating	10	189	—
Coating (10% by weight)	15	435	—
Coating (15% by weight)	15	526	—
Coating (20% by weight)	15	714	—
Wood (hemlock)	—	—	175
Wool 100%	—	—	252
Wood (Douglas fir/fire retardant, FR)	10	251	—
Synthetic materials			
Epoxy resin	—	—	457
Polystyrene (PS)	13	162	—
Acrylic fiber 100%	—	—	180
Polypropylene (PP)	15	193	291

Figure 53 – Critical Heat Flux

From this table the CHF for corrugated cardboard and polystyrene are seen to be 10 $^{kW}/_{m^2}$ and 13 $^{kW}/_{m^2}$, respectively.

Comparing these CHF values to the point at which the trend lines plotted in Figure 54 below cross an FDS predicted radiant heat flux value of $10\ {}^{kW}/_{m^2}$ provides the time at which it may conservatively be assessed that ignition of adjacent commodities is possible.

The radiant heat flux from the FDS model at a height of 8 ft. (2.4 m) above the floor and at a distances of 8 ft. (2.4 m) and 16 ft. (4.8 m) from the edge of the fuel array, respectively, with time, is represented graphically in Figure 54:

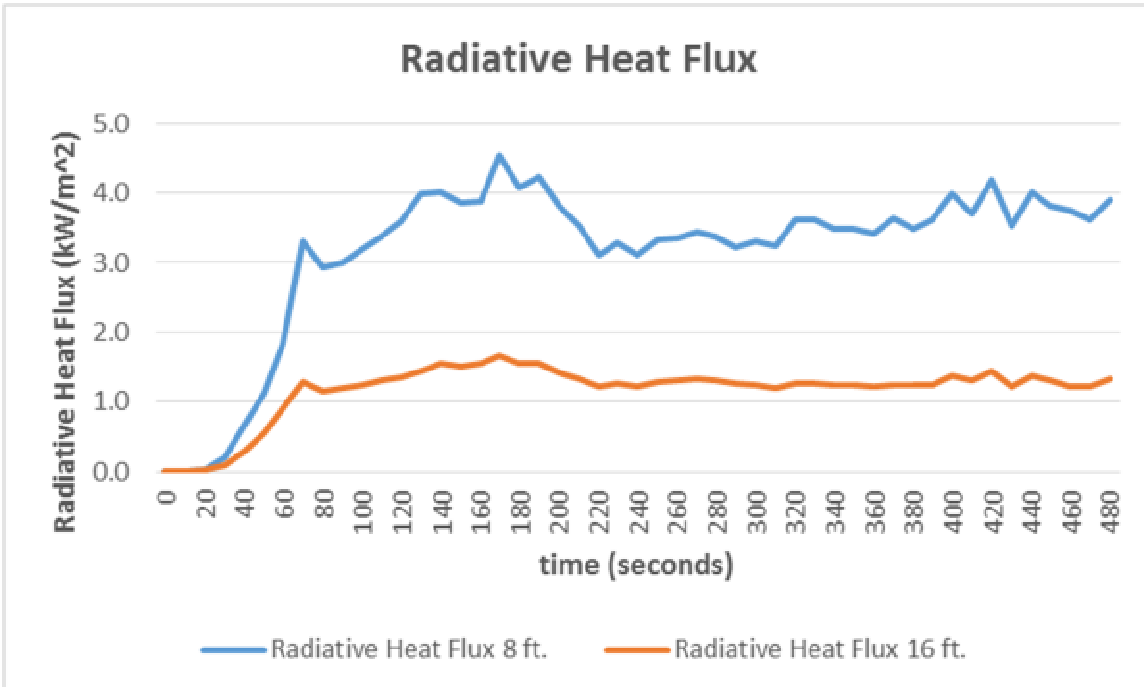


Figure 54 –Comparison of Radiative Heat Flux – DETACT Predicted Sprinkler Actuation

Radiative heat flux data from FDS shows that the CHF of $10\ {}^{kW}/_{m^2}$ is never reached if sprinkler activation is assumed and limits HRR to 2,592 kW.

B.5. *__RSET vs. ASET__*

B.5.a. *Detection Time*

Detection time is based on sprinkler actuation. Using the DETACT model to predict sprinkler activation, sprinklers activate approximately 60 seconds into the fire scenario.

Main storage area occupants may be alerted to the fire by the sight and smell of smoke and sound of the fire before sprinkler actuation. However, due to the volume of the space, and the time for smoke to fill this large space, occupant notification by these means may not be significantly less than that afforded by sprinkler actuation.

Detection time is determined to be 60 seconds, either by occupant detection or by sprinkler system actuation.

B.5.b. Notification Time

There is no time delay on the sprinkler system pressure switch that provides for automatic detection.

However, as previously discussed, notification time is 30 seconds to account for processing of signals from initiation devices and sounding of notification appliances by the automatic fire alarm system.

B.5.c. Pre-Movement Time

Most construction warehouse occupants are expected to act as trained and immediately take action to evacuate the building in response to a fire alarm. However, some building occupants are expected to react in a way that delays action to evacuate the building especially if the means of fire detection is by means of an occupant smelling, seeing, or hearing the fire prior to sprinkler system activation. This means of occupant notification and efforts to warn other building occupants will cause a delay in this occupant, or occupants, beginning evacuation. To account for this effect, and other unforeseen occupant actions and delays, pre-movement time is assumed to be 60 seconds.

B.5.d. Evacuation Time

As seen by the building evacuation analysis in Section VIII.B., building evacuation is limited by the west stairwell. Using the results of the Pathfinder egress model in STEERING mode, Table 22 identifies that the west stairwell serves 209 occupants during a building evacuation. Building evacuation time as predicted by the STEERING mode of the Pathfinder egress model results and is 190 seconds.

Additionally, of interest, is that the maximum time for all building occupants to have entered a 2-hour fire-resistance rated stairwell enclosure is 158 seconds based on the west stairwell as shown in Table 23. The hand calculation and Pathfinder simulation both agree on this period of time.

For comparison, from the results of the hand calculation shown in Table 21, it can be seen that the corresponding time for building occupants to pass into the south-west, south-east, and east stairwell enclosures is 100 seconds, 71 seconds, and 131 seconds, respectively. It is evident that the west stairwell, at 158 seconds, is the limiting egress path from the building.

The 2-hour fire-resistance rated stairwells, including the west stairwell, are credited in this analysis for effectively separating building occupants from a fire inside of the building.

Therefore, an evacuation time of 158 seconds is used as input to the RSET calculation.

B.5.e. Required Safe Egress Time (RSET)

$$RSET = Detection\,Time + Notification\,Time + Pre - Movement\,Time + Evacuation\,Time$$

$$RSET = 60\,seconds + 30\,seconds + 60\,seconds + 158\,seconds$$

$$\boldsymbol{RSET = 308\,seconds\,(5\,minutes, 8\,seconds)}$$

B.5.f. Available Safe Egress Time (ASET)

$$ASET = Time\,From\,Ignition\,Until\,a\,Tenability\,Limit\,is\,Reached$$

$$\boldsymbol{ASET = 400\,seconds\,based\,on\,10\,m\,visility\,tenability\,criteria}$$

B.5.g. Margin of Safety (MoS)

$$MoS = ASET - RSET = 400\,seconds - 308\,seconds$$

$$\boldsymbol{MoS = 92\,seconds}$$

B.5.h. Conclusion

Because $ASET\ (400\,seconds) > RSET\ (308\,seconds)$ it is concluded that the fundamental performance based criteria of taken from the Chapter 5 of the LSC is met for the first floor of the building:

> ***5.2.2* Performance Criterion.***
> *Any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions.*

The spread of fire from the rack storage fire to adjacent commodities with sprinkler actuation is not predicted. The CHF of $10\,{}^{kW}/_{m^2}$ is not reached for the duration of the fire.

Peak ceiling temperature, at 180℃ (356°F), does not exceed 1,000°F. Collapse or significant damage to the ceiling (second floor) is not expected.

B.6. Case– Sprinklers Not Permitted to Operate

This scenario is prepared to assess the impact to the building of a failure of the fire sprinkler system to function as designed. The potential for fire spread to adjacent commodities and the impact to the ceiling (second floor) is assessed. Tenability is not assessed.

B.7. Sprinkler Actuation

Automatic sprinklers are assumed to fail to activate in response to the rack storage fire.

B.8. HVAC Fans

The normally operating 1,750 cfm exhaust fan is modeled in FDS as functional per design.

FDS predicts that the two 17,500 cfm exhaust fans automatically start on high temperature at 104 seconds and 114 seconds following ignition, respectively.

B.9. Ceiling Temperature

The maximum ceiling temperature predicted by FDS under this fire scenario predicts that the peak ceiling temperature at the center of the fire plume to be 877℃ (1,611°F) at a time 130 seconds following ignition. This temperature is the result of direct flame impingement on the ceiling directly above the fire. Figure 55 below graphically shows this ceiling temperature with time.

This ceiling temperature rapidly falls beginning at 130 seconds due to the descent of the upper gas layer to the level of the fire which prevents combustion of upper layer gases due to lack of oxygen.

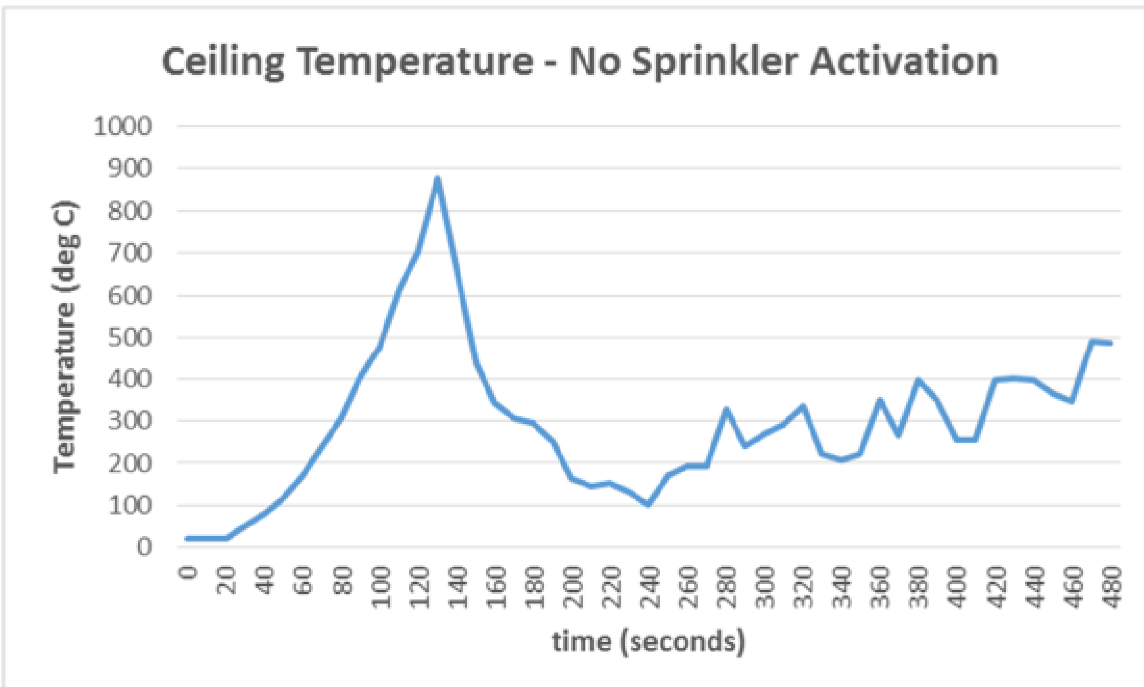


Figure 55 –Ceiling Temperature, No Sprinkler Actuation

B.10. Radiative Flux

FDS predicted radiative heat flux output data is erratic. These FDS predicted radiative heat flux values are compared to the Critical Heat Flux (CHF) values described above for both corrugated paper (cardboard) $\left(10\ {}^{kW}/_{m^2}\right)$and polystyrene $\left(13\ {}^{kW}/_{m^2}\right)$:

Comparing these CHF values to the point at which the trend lines plotted in Figure 56 below cross an FDS predicted radiant heat flux value of $10\ {kW}/{m^2}$ provides the time at which it may conservatively be assessed that ignition of adjacent commodities is possible.

The maximum radiant heat flux predicted by the FDS model at distances of 8 ft. (2.4 m) and 16 ft. (4.8 m) from the edge of the fuel array, respectively, with time, is represented graphically in Figure 56:

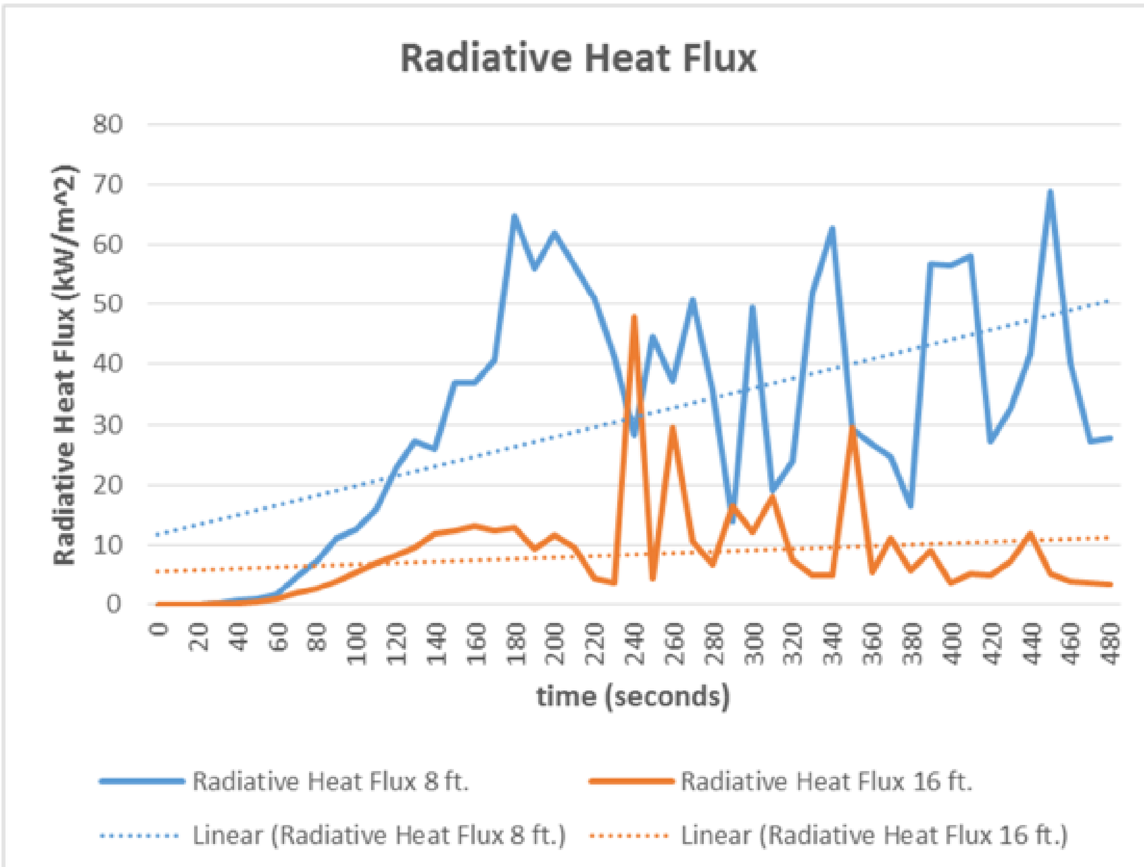


Figure 56 –Comparison of Radiative Heat Flux – No Sprinkler Actuation

The radiative heat flux data from FDS is erratic, however, the plotted data and linear trend lines plotted in Figure 56 shows that the CHF of $10\ {kW}/{m^2}$ is reached approximately 80 seconds following ignition for an 8 ft. (2.4 m) rack separation if the point at which the trend line intersects the CHF is used. For a 16 ft. separation, the time at which the CHF is exceeded is approximately 400 seconds.

B.10.a. Conclusion

Fire sprinklers are essential to the survivability of the warehouse building during a fire involving rack storage of plastic material. Without an automatic fire suppression system the spread of fire

from the rack storage fire to adjacent commodities is certain and an uncontrollable fire in the building is the result.

Due to the high temperature experienced by the ceiling, well over 1,000°F, significant damage is expected. With the involvement of additional commodities, the extent of damage, property loss, and threat to life safety increases. Since the structure is not fire-resistive, there is significant potential for the collapse of the second floor and involvement of second floor materials in the fire.

C. Workstation Fire on the Mezzanine above the Main Floor Office Area

The mezzanine above the office area contains a conference room and offices with gypsum board walls and other office space provided by standard work station type cubicles. It is accessible from the main floor by one unenclosed interior building stairway and through the enclosed exterior exit stairwell on the west side of the building (i.e., the west stairwell).

The ceiling above the mezzanine office area is a typical suspended ceiling with acoustic ceiling tiles. The ceiling is placed 8 ft. 5 in. above the mezzanine floor. The interstitial space between the ceiling and second floor deck is used for routing of building utilities, such as HVAC and electrical and computer cable, which serves the mezzanine area.

The fuel package contents of a generic workstation, summarized from Table 2-1, "Contents of Generic Workstation," NIST NCSTAR 105C, Federal Building and Fire Safety Investigation of the World Trade Center Disaster, *Fire Tests of Single Office Workstations*, September 2005, include:

- Melamine laminate work surfaces over medium density fiber-board (4 pieces – 6.1 m long x 0.61 m wide x 28 mm thick)
- 27 Reams of paper and 14 document boxes
- Plastic kick plates and trim (base of walls, inside and outside)
- Computer keyboard
- Plastic waste basket
- 36 nylon carpet tiles with rubber backing
- Shelf ends – particle board or dense foam
- Office desk chair – fabric, foam, thermoplastic shell and base
- Computer monitor – ABS
- Computer processor
- 9 Wall panels with aluminum angle, wood frames, fiberglass, and metal mesh
- Book shelf
- 3 Two-drawer steel filing cabinets (0.91 m long x 0.51 m deep x 0.76 m high)

The generic workstation is nominally 2.44 m (8 ft.) long x 2.44 m (8 ft.) deep x 1.22 m (4 ft.) high.

Heat release and growth rate data for the FDS model of a standard workstation type fire were taken from Table 3-1, "Key Results From the Workstation Fire Test Burns", Test Number 2, of the NIST NCSTAR 105C report.

The peak HRR for the standard work station type fire modeled by this paper is consistent with the net peak HRR measured during the NIST test, a value of 6.73 MW is used.

The time to peak HRR as measured by NIST is stated to be 530 seconds.

The FDS model assumes that the standard work station fire grows predictably according to the "t-squared" fire growth equation. The calculated fire growth coefficient is consistent with a medium-fast fire growth rate:

$$\alpha = {}^{Peak\ HRR}\!/_{(time\ to\ peak)^2}$$

$$\alpha = {}^{6{,}730kW}\!/_{(530seconds)^2}$$

$$\alpha = {}^{0.02396kW}\!/_{sec^2}$$

In Fire Dynamics Simulator (FDS), this work station fire is modeled as a horizontal burner with a surface area of $1\,m^2$, the corresponding HRR per unit area of 6,730 ${}^{kW}\!/_{m^2}$, and is elevated $0.8\ m\ (32\ in.)$ above the mezzanine floor.

Figure 57 – Heat Release Rate, Un-Controlled Workstation Fire

C.1. <u>*Additional Modeling Assumptions and Parameters*</u>

1. The size and combustible material contents of the assumed workstation is described previously. Carbon monoxide and soot yield is based on an estimate of the mass-weighted average of combustible materials that makeup the workstation (See Appendix D).

   a. Chemical formula: $C_{15}H_{17}N$
   b. Carbon Monoxide yield: $0.0220\ {}^{g}/_{g}$
   c. Soot yield: $0.0369\ {}^{g}/_{g}$

2. The FDS model is setup with a mesh size of $0.25\ m\ x\ 0.25\ m\ x\ 0.25\ m$.

3. Floors and ceilings are modeled as concrete.

   a. Thickness: $0.2\ m\ (8\ inches)$
   b. Specific Heat: $0.88\ {}^{kJ}/_{kg\cdot°C}$

      (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)
   c. Conductivity: $1.37\ {}^{W}/_{m\cdot°C}$

      (Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

d. Density: $2{,}300\ {}^{kg}/_{m^3}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

4. Exterior walls are modeled as glass wool.

a. Thickness: $0.2\ m\ (8\ inches)$

b. Specific Heat: $0.70\ {}^{kJ}/_{kg\cdot°C}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

c. Conductivity: $0.038\ {}^{W}/_{m\cdot°C}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

d. Density: $24\ {}^{kg}/_{m^3}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

5. Interior walls are modeled as gypsum plaster.

a. Thickness: $0.2\ m\ (8\ inches)$

b. Specific Heat: $0.84\ {}^{kJ}/_{kg\cdot°C}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

c. Conductivity: $0.48\ {}^{W}/_{m\cdot°C}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

d. Density: $1{,}440\ {}^{kg}/_{m^3}$

(Ref: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table B.7)

6. A hand calculation has been performed to determine sprinkler actuation time. This DETACT analysis is included in Appendix E. The results of this DETACT analysis predict that sprinklers activate 170 seconds after ignition. The HRR at sprinkler activation 170 seconds following ignition is 694 kW. The DETACT results are graphically represented in the following figure:

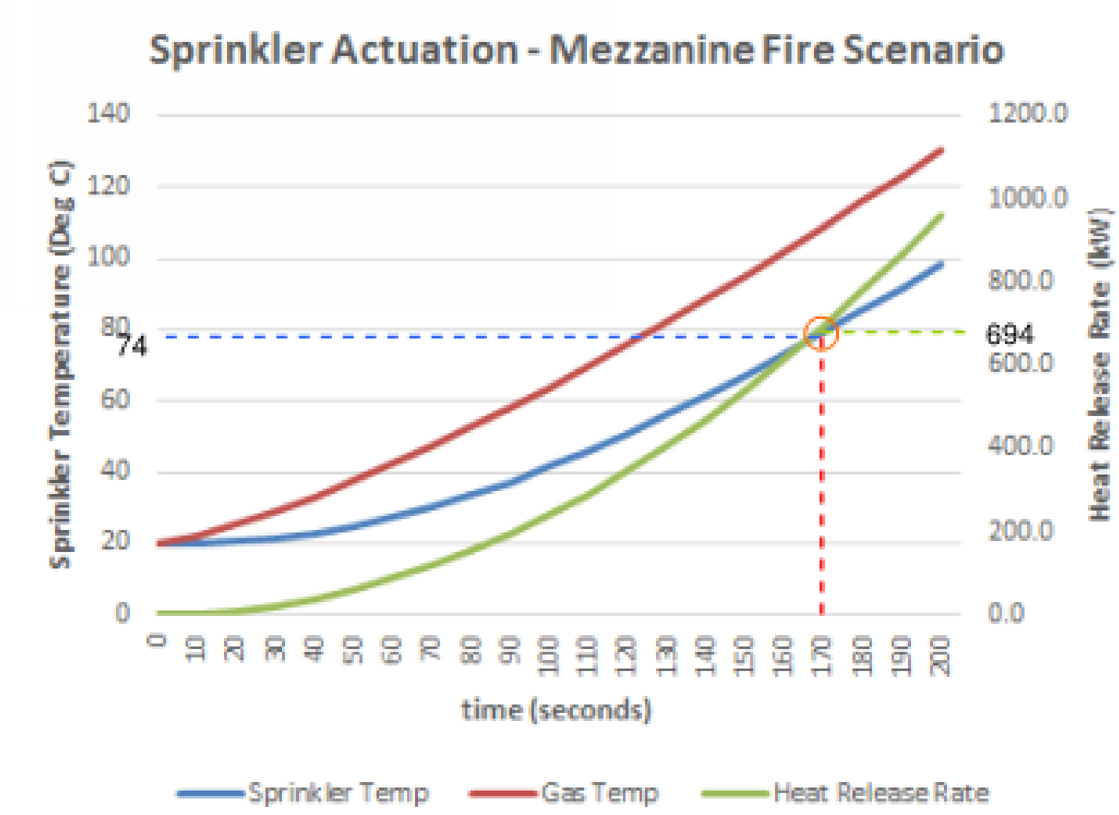


Figure 58 – Mezzanine Fire DETACT Sprinkler Activation

Automatic sprinkler actuation is predicted by FDS at 180 seconds following ignition. The corresponding HRR of the rack storage fire at 180 seconds is 778 kW.

Use of the sprinkler actuation time (170 seconds) and corresponding HRR (694 kW) is used for the FDS model input. The full capability of FDS to predict the effect of sprinklers on the suppression of this fire is not used in this analysis.

7. There is one photoelectric smoke detector on the mezzanine floor located on the ceiling near the elevator door.

8. Temperature devices are inserted into the model in the following locations:

- One sensor is placed at the ceiling directly above the centerline of the fire plume
- Four sensors are placed at the ceiling 1.0 m (3 $ft.$) away from the plume centerline. One of the four sensors is placed off of each edge of the fuel array.

9. The model includes 16 sources of forced supply air in the ceiling each measuring 0.25 m^2:

- Eight supply air openings provide $280cfm$ $\left(0.1192\,{m^3}/{sec}\right)$
- Three supply air openings provide $200cfm\ to\ 220cfm$ $\left(0.0908\,{m^3}/{sec}\right)$
- Three supply air openings provide $150cfm$ $\left(0.0578\,{m^3}/{sec}\right)$
- One supply air opening provides $290cfm$ $\left(0.1239\,{m^3}/{sec}\right)$
- One supply air opening provides $350cfm$ $\left(0.1522\,{m^3}/{sec}\right)$

10. The model includes seven forced air exhaust vents in the ceiling each measuring $0.25\ m^2$:

- Three exhaust vents provide $900cfm$ $\left(0.4248\,{m^3}/{sec}\right)$
- One exhaust vent provides $600cfm$ $\left(0.2843\,{m^3}/{sec}\right)$
- One exhaust vent provides $100cfm$ $\left(0.0708\,{m^3}/{sec}\right)$
- One exhaust vent provides $350cfm$ $\left(0.1653\,{m^3}/{sec}\right)$
- Two exhaust vents provide $150cfm$ $\left(0.0472\,{m^3}/{sec}\right)$

D. Analysis of Model Results

D.1. <u>Case– Workstation Fire Scenario</u>

D.1.a. Visibility

The tenability limit for visibility is assessed graphically in FDS. This tenability limit has been established as 3 m at a location 1.82 m (6 ft.) above the floor. The following FDS renderings, Figures 59 and 60, show that visibility is reduced to 3 m at time 130 seconds in the north-west and south-west corners of the mezzanine and that visibility is severely reduced below 3 m at the time corresponding to RSET, or 302 seconds:

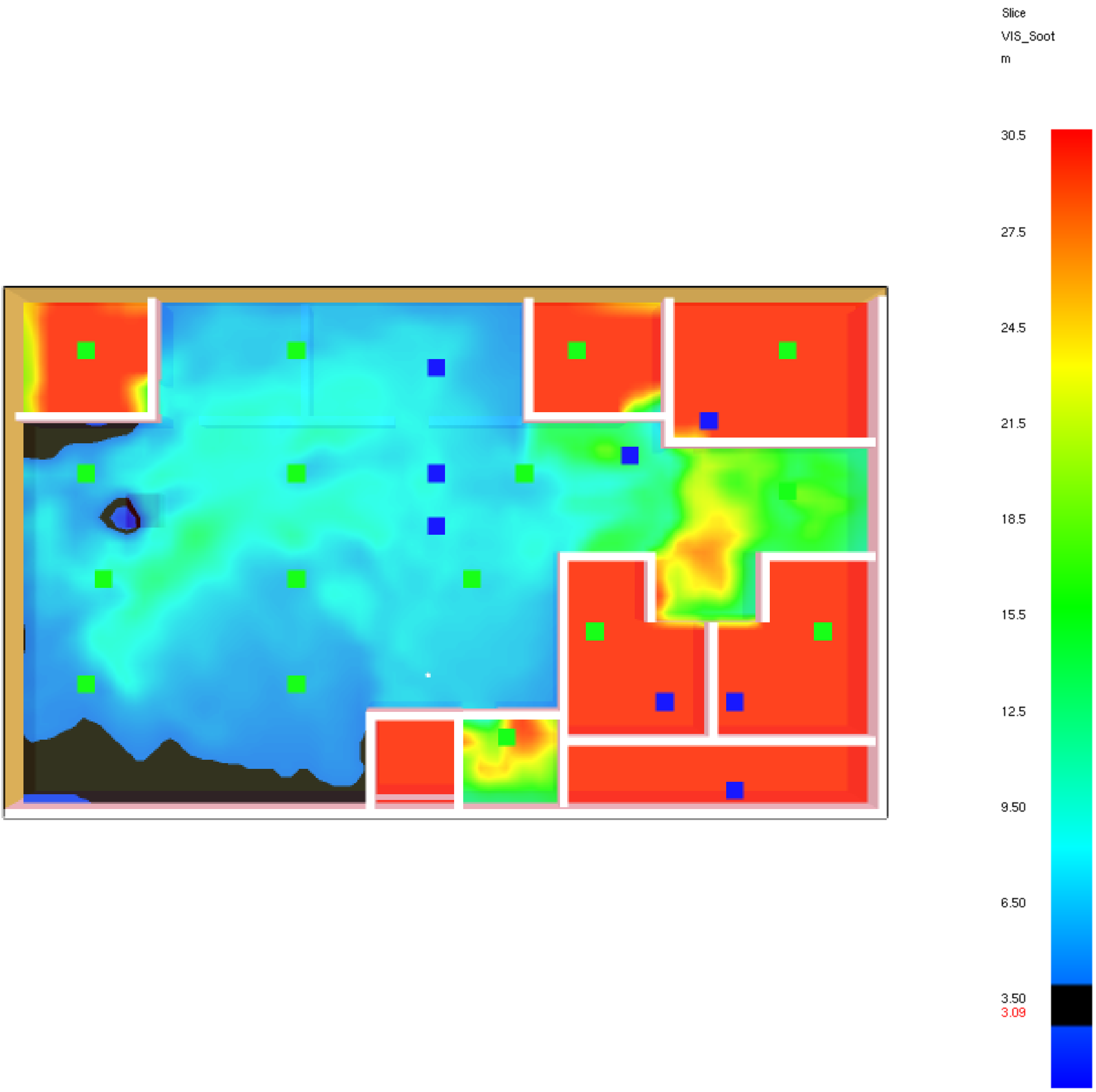


Figure 59 –Visibility @ 130 Seconds and 1.82 m above Mezzanine Floor

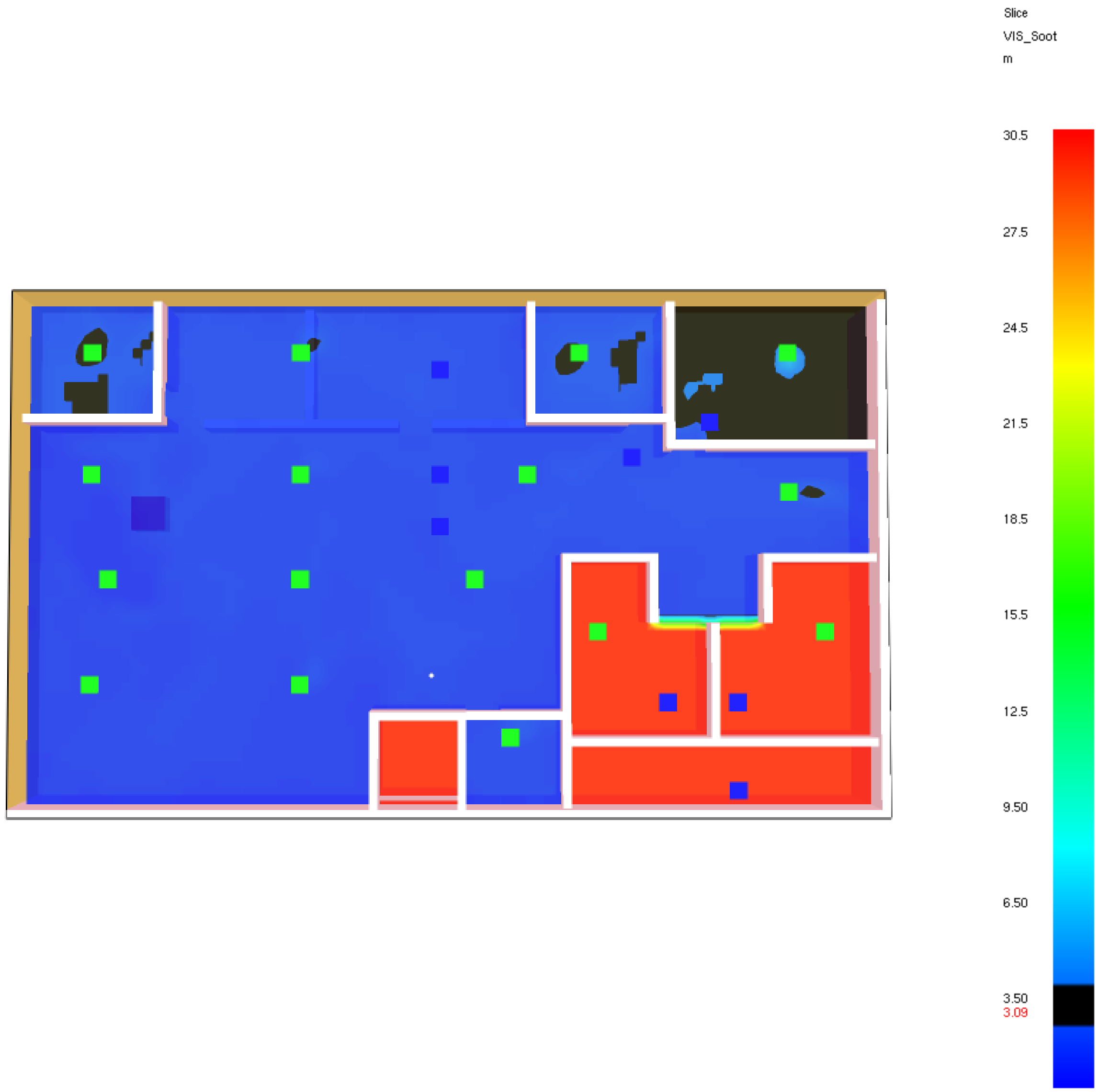


Figure 60 –Visibility @ 302 Seconds (RSET) and 1.82 m above Mezzanine Floor

D.1.b. Temperature

A tenability limit of 100°C has been established for the mezzanine floor. The FDS renderings, Figures 61 and 62, below show that a temperature of 100°C is first exceeded 1.82 m (6 ft.) above the floor 150 seconds after ignition and that the temperature at the time corresponding to RSET exceeds as shown in the image below along the bottom of the rendering.

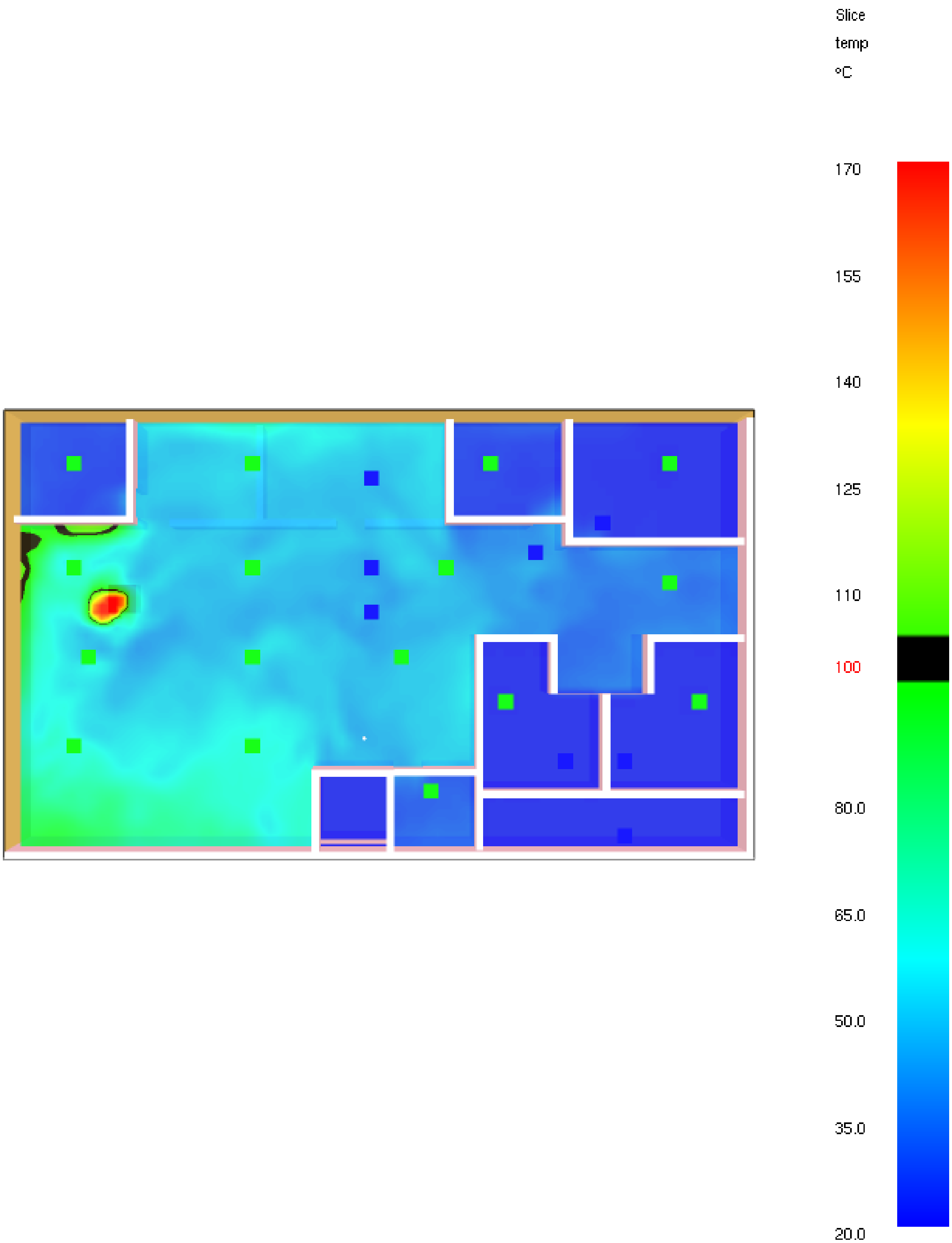


Figure 61 –Temperature @ 150 Seconds and 1.82 m above Mezzanine Floor

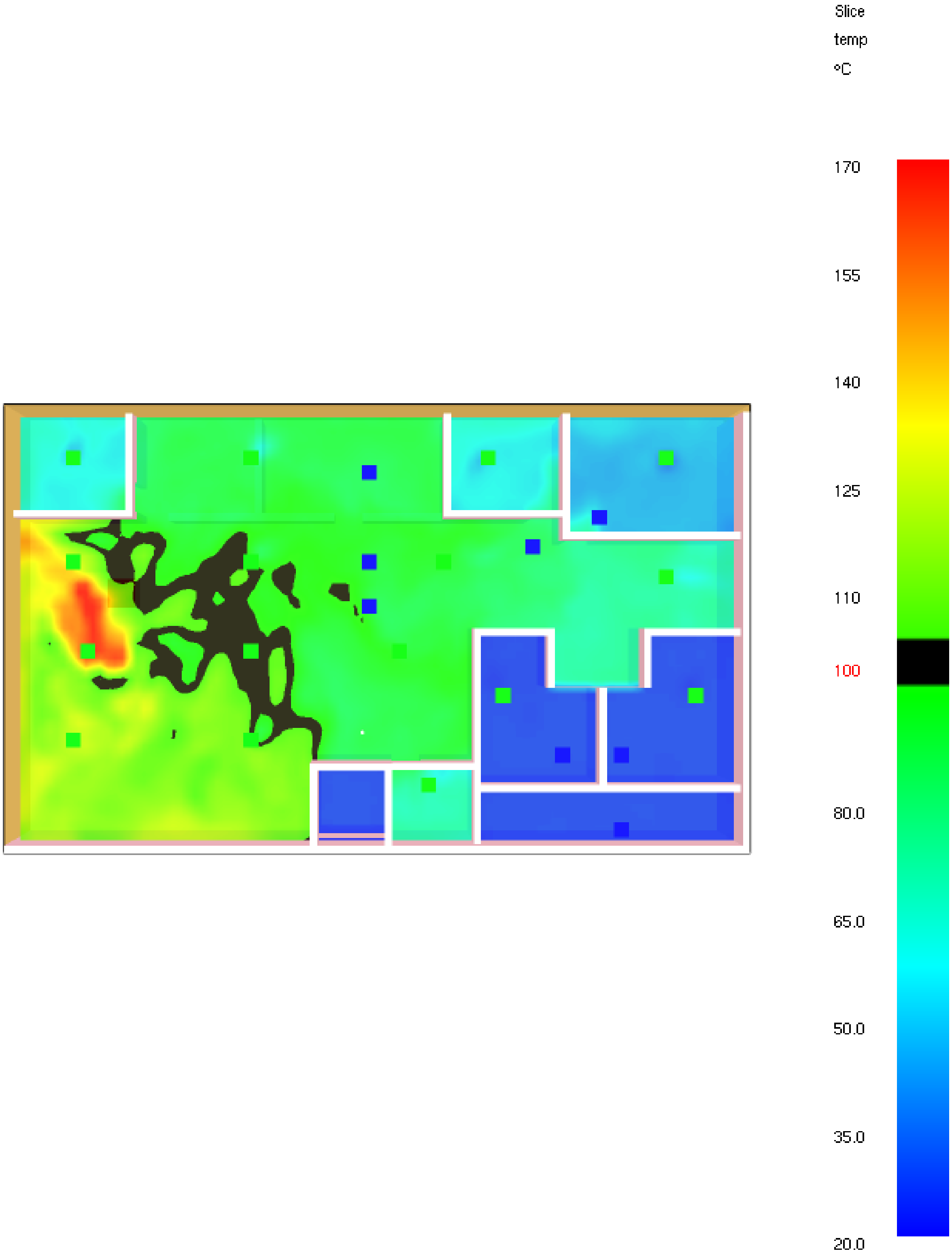


Figure 62 –Temperature @ 302 Seconds (RSET) and 1.82 m above Mezzanine Floor

D.1.c. CO Dose

An FED of 0.3 has been established as the tenability limit for carbon monoxide. Again, the FED may be calculated according to the following equation:

$$FED_{CO} = \sum_{t_2}^{t_1} \frac{[CO_{ppm}]}{35{,}000\ ppm \cdot min} \Delta t$$

The results of this calculation for the mezzanine are represented by the table below:

Table 27 – Cumulative Carbon Monoxide Dose vs. time and FED; Workstation Fire

s	kg	kg		CO	CO Dose	
Time	Total	CO	ppm CO	ppm-min	ppm-min	FED
0	1011	0.0000	0	0.0	0.0	0.000
30	1003	0.0002	0	0.1	0.1	0.000
60	994	0.0014	1	0.7	0.8	0.000
90	986	0.0045	5	2.3	3.1	0.000
120	980	0.0101	10	5.1	8.2	0.000
150	977	0.0188	19	9.6	17.9	0.001
180	977	0.0310	32	15.8	33.7	0.001
210	980	0.0431	44	22.0	55.7	0.002
240	983	0.0546	56	27.8	83.5	0.002
270	988	0.0655	66	33.1	116.7	0.003
300	992	0.0759	76	38.2	154.9	0.004
330	997	0.0857	86	43.0	197.8	0.006
360	1002	0.0948	95	47.2	245.1	0.007
390	1008	0.1029	102	51.0	296.1	0.008
420	1014	0.1103	109	54.4	350.5	0.010
450	1020	0.1174	115	57.5	408.0	0.012
480	1026	0.1237	121	60.3	468.3	0.013

The FED is also shown graphically with time in the figure below:

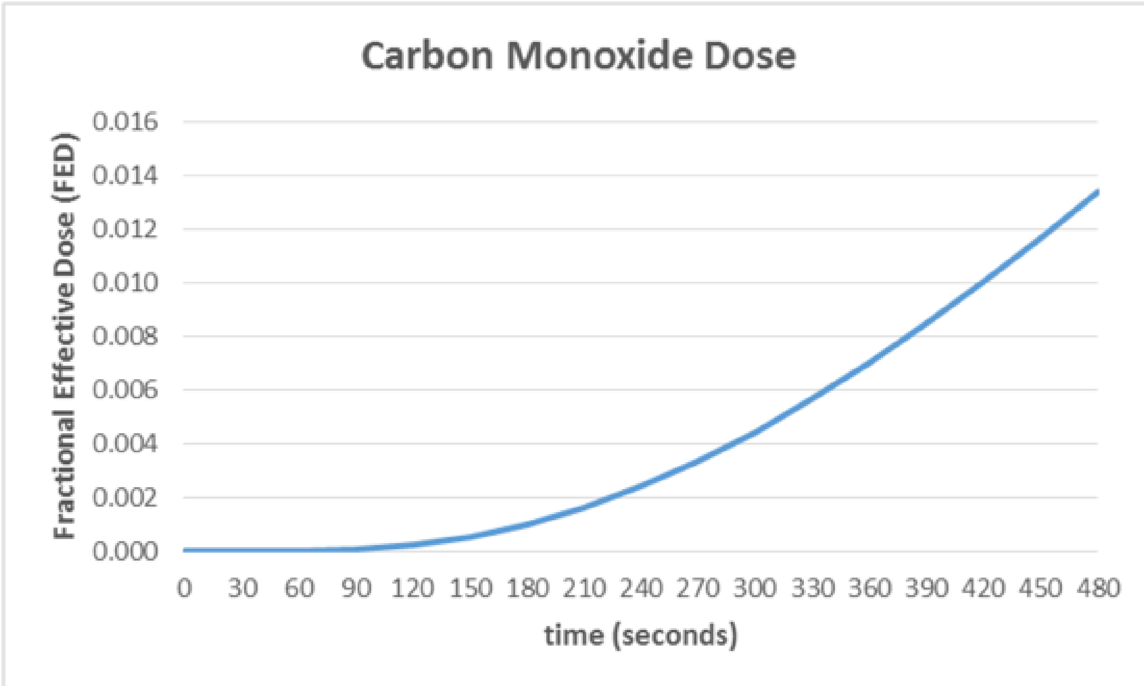


Figure 63 –Carbon Monoxide FED vs. time; Workstation Fire

After 480 seconds of exposure, the cumulative CO Dose of 468 ppm-min results in an FED = 0.013 which is much less than the established tenability limit of FED = 0.3. It is concluded that the tenability limit for CO will not be exceeded for the mezzanine fire scenario.

D.2. Smoke Detector Actuation

Fire alarm system performance is evaluated to estimate the time to actuation of a detector (in this case smoke detector) and the size of the fire at actuation.

FDS predicts that the photoelectric smoke detector placed near the mezzanine elevator door actuates 62 seconds after ignition.

A hand calculation is also performed to evaluate the expected fire alarm system response to a fire on the mezzanine level in the building. The fire scenario analyzed involving a computer workstation located on a desk in an open office area on the mezzanine level. This hand calculation predicts that smoke detector activation will occur 54 seconds from ignition. At the time of detector activation, this calculation predicts that the HRR of this fire will have grown to 70 kW. This hand calculation is included as Appendix F of this report.

D.3. HVAC Fans

The HVAC system is assumed to operate normally throughout the mezzanine fire scenario.

D.4. RSET vs. ASET

D.4.a. Detection Time

Detection time is based on actuation of the photoelectric smoke detector near the elevator door.

Mezzanine area occupants are mostly in plain view of a workstation fire, however, one or more may not be alerted by sight and smell of smoke and sound of the fire as they may be behind a closed office door.

Smoke detector actuation is predicted by hand calculation (Appendix F) 54 seconds from ignition. FDS approximates smoke detector activation 61 seconds from ignition.

Detection time is determined to be 54 seconds based on the hand calculation.

D.4.b. Notification Time

As previously discussed, notification time is 30 seconds to account for processing of signals from initiation devices and sounding of notification appliances by the automatic fire alarm system.

D.4.c. Pre-Movement Time

Most building occupants are expected to act as trained and immediately take action to evacuate the building in response to a fire alarm. However, some building occupants are expected to react in a way that delays action to evacuate the building. To account for this effect, pre-movement time is assumed to be 60 seconds.

D.4.d. Evacuation Time

Two means of egress are available from the mezzanine office area. This area is dependent on the west stairwell for safe egress. As previously discussed, the west stairwell is the limiting path of safe egress for the warehouse building and for the mezzanine office area.

Using the results of the Pathfinder egress model in STEERING mode, Table 22 identifies that the west stairwell serves 209 occupants during a building evacuation. Building evacuation time as predicted by the STEERING mode of the Pathfinder egress model results and is 190 seconds.

The maximum time for all building occupants to have entered a 2-hour fire-resistance rated stairwell enclosure is 158 seconds based on the west stairwell as shown in Table 23. The hand calculation and Pathfinder simulation both agree on this period of time.

For comparison, from the results of the hand calculation shown in Table 21, it can be seen that the corresponding time for building occupants to pass into the south-west, south-east, and east stairwell enclosures is 100 seconds, 71 seconds, and 131 seconds, respectively. It is evident that the west stairwell, at 158 seconds, is the limiting egress path from the building.

The 2-hour fire-resistance rated stairwells, including the west stairwell, are credited in this analysis for effectively separating building occupants from a fire inside of the building.

Therefore, an evacuation time of <u>158 seconds</u> is used as input to the RSET calculation.

D.4.e. Required Safe Egress Time (RSET)

$$RSET = Detection\,Time + Notification\,Time + Pre - Movement\,Time + Evacuation\,Time$$

$$RSET = 54\,seconds + 30\,seconds + 60\,seconds + 158\,seconds$$

$$\boldsymbol{RSET = 302\,seconds\,(5\,minutes\,2\,seconds)}$$

D.4.f. Available Safe Egress Time (ASET)

$$ASET = Time\,From\,Ignition\,Until\,a\,Tenability\,Limit\,is\,Reached$$

$$ASET = 130\,seconds\,based\,on\,3\,m\,visility\,tenability\,criteria$$

D.4.g. Conclusion

Because $ASET\ (130\,seconds) < RSET\ (302\,seconds)$ (a deficit of 172 seconds) it is concluded that the fundamental performance based criteria taken from the Chapter 5 of the LSC is NOT met for the office mezzanine of the construction warehouse.

Prescriptively, the mezzanine area meets IBC and NFPA requirements.

Alternatives for compliance with performance based criteria are evaluated in Appendix G and summarized below:

<u>Alternatives for Compliance with Performance Based Design Criteria</u>

A combination of one or more of the following actions should be considered:

1. ***Replace standard response sprinklers (RTI > 80) with quick response sprinklers (RTI < 50):***

   DETACT analysis indicates that replacement of standard response sprinklers with quick response sprinklers improves the time to sprinkler activation from 170 seconds to 140 seconds, or 30 seconds.

   An improvement in RSET of 30 seconds can be accomplished by replacing the standard response sprinklers with quick response sprinklers. RSET would be reduced from 302 seconds to 272 seconds by implementing this alternative. <u>The revised deficit between ASET and RSET would become 142 seconds</u>.

2. ***Provide more overhead volume by removing the suspended ceiling (exposing the second floor deck) and raise sprinklers. An additional 1 m of ceiling height may be accomplished in this manner. Sprinklers would be required to be raised to comply with NFPA 13.***

   DETACT and FDS models were created to reflect the higher ceiling space with DETACT assuming quick response sprinklers.

   The DETACT analysis shows sprinkler actuation at 170 seconds.

Evaluation of the revised FDS model for visibility and temperature tenability limits shows an improvement in ASET. Visibility tenability criteria (3 m) improves from 130 seconds to 210 seconds, an improvement of 80 seconds.

A reduction in RSET of 80 seconds can be accomplished by increasing ceiling height and replacing the standard response sprinklers with quick response sprinklers. Implementing this alternative would revise the deficit between ASET and RSET from 172 seconds to 92 seconds.

3. *Improve Egress Efficiency in the West Stairwell*

Implement two (2) suggested improvements

a. Provide an additional protected exterior exit enclosure on the north side of the mezzanine
b. Remove obstruction to egress on second floor along east wall in the large open office area

To evaluate this alternative, an additional exit was input into the Pathfinder egress simulation on the north wall of the mezzanine. This arrangement provides means of egress through three of the four walls bounding the perimeter of the mezzanine.

As previously discussed, the 2-hour fire-rated exterior stairwells are credited in this paper for protecting building occupants from fire – once all building occupants have entered a protected stair enclosure, they can safely make their way down the stairs to discharge at ground level. RSET is based on the time required for all building occupants to have entered an exit stairwell enclosure or have directly exited the building. Therefore, it is imperative that the new exterior exit stair on the north side of the mezzanine be of appropriate fire-rated construction.

Also an improvement in egress access on the second floor is made by removing a barrier allowing better access to the east exterior exit stairwell.

In STEERING mode, the Pathfinder model shows a reduction in the predicted time for all mezzanine occupants to leave the mezzanine from 132 seconds to 65 seconds, a reduction of 67 seconds. Also, a reduction in the time for all building occupants to enter a 2-hour fire-rated exit enclosure of 42 seconds, is predicted.

With the implementation of this alternative, the time RSET is improved by 42 seconds. RSET would be reduced from 302 seconds to 260 seconds by implementing this alternative. The revised deficit between ASET and RSET would become 130 seconds.

4. *Evaluate and install a mechanical smoke control system*

The evaluation of technical feasibility does not purport to be a design of a mechanical smoke control system.

A mechanical smoke control system was input into the FDS model based on the methodology of NFPA 204 "Standard for Smoke and Heat Venting" for sizing and placement of vents and sizing of mechanical smoke exhaust systems. Sizing, placement and mechanical flow rate were specified to prevent plugholing.

Four ceiling vents were placed in the model, each 1m^2 in area (a total of 4 m^2). These vents were placed between 5 m to 8 m apart, and 3 m to 4 m minimum from any wall. The specified flow rate was 2.0 m^3/second.

The FDS input for mechanical vents is reproduced in Appendix K of this report.

The mechanical smoke removal system is shown within FDS to maintain visibility in the mezzanine area during the first 300 seconds of the work station fire scenario below the established visibility tenability criteria of 3 m.

The FDS rendering below illustrates visibility greater than 3 m in the mezzanine area with the mechanical smoke exhaust system in service. This FDS scenario also assumes that the workstation fire is controlled to a maximum heat release rate of 694 kW by actuation of sprinklers 170 seconds from ignition as predicted by DETACT analysis.

5. ***Remove walls and open up the mezzanine to the main floor area***

   Removing the mezzanine walls eliminates restrictions on movement of smoke and hot gas between the mezzanine and main floor storage areas. Egress analysis is bounded by the storage rack fire scenario.

   This alternative may solve the issues associated with a mezzanine workstation fire, but also provides exposure of mezzanine occupants to the storage rack fire scenario. Prior to implementing this alternative, critical consideration must be given to the impact of a main floor storage rack fire on the occupants of the mezzanine.

6. ***Do nothing, implement combustible loading controls, or implement occupancy limits***

   The "do nothing alternative" based on the prescriptive requirements that are currently met is viable, but must be understood by the Authority Having Jurisdiction.

   Implementation of combustible loading controls to limit the size of a fire, or limiting the occupancy of the mezzanine office area to a number of personnel that can be safety egress by the current exit arrangement is a possible alternative.

E. Recommendations

E.1. <u>Rack Storage Fire Performance Improvements</u>

The margin of safety calculated for the rack storage fire scenario, at 92 seconds, provides a 30% margin to RSET, which is calculated to be 308 seconds (ASET is calculated to be 400 seconds).

No additional recommendations are provided for this scenario.

E.2. Mezzanine Workstation Fire Performance Improvements

Several alternatives were evaluated above and in Appendix G of this report in an effort to provide viable resolution to the performance based design deficiency identified for the mezzanine office area.

These recommendation is not intended to prevent further evaluation.

Replacement of standard response sprinklers with quick response sprinklers and removal of the suspended ceiling (a reduction in RSET of 80 seconds) coupled with the addition of a protected exit at the level of the mezzanine along the north wall (a reduction in RSET of 42 seconds) has the combined effect of reducing RSET by 122 seconds, or approximately 2 minutes.

However, this 122 second reduction in RSET does not completely overcome the originally determined deficit between ASET and RSET of 172 seconds. It is therefore necessary to evaluate additional alternative.

Two recommendations are evident from this evaluation.

The first is to install a mechanical smoke control system as described by alternative 4. above. Such a system would provide a compliant performance based design for the mezzanine office area. This alternative

The second recommendation depends on the reliance on compliance with the prescriptive requirements of the Life Safety Code, coupled with a limitation on the number of persons allowed on the mezzanine office area at any one time and potentially supported by a limitation on combustible materials.

IX. References

Technical Reports and Publications

(1) Buchanan, Andrew H., Structural Design for Fire Safety, 2002, John Wiley & Sons, Ltd.

(2) Drysdale, Dougal, An Introduction to Fire Dynamics, Third Edition, John Wiley & Sons, Ltd.

(3) Fire Protection Handbook, Twentieth Edition, National Fire Protection Association

(4) Ingason, Haukur, *In-Rack Fire Plumes*, Swedish National Testing and Research Institute (SP)

(5) Mealy, Christopher L., Wolfe, Andrew, Gottuck, Daniel T., *Smoke Alarm Response: Estimation Guidelines and Tenability Issues – Part 2,* Hughes Associates, Inc., Baltimore, MD

(6) NIST NCSTAR 105C, Federal Building and Fire Safety Investigation of the World Trade Center Disaster, *Fire Tests of Single Office Workstations*, September 2005

(7) NIST Special Publication 1019, Fire Dynamics Simulator User's Guide, Sixth Edition

(8) Pathfinder User Manual, 2014, Thunderhead Engineering, Inc.

(9) SFPE Handbook of Fire Protection Engineering, Third Edition, 2002, Society of Fire Protection Engineers and National Fire Protection Association

(10) SFPE Handbook of Fire Protection Engineering, Fourth Edition, 2008, Society of Fire Protection Engineers and National Fire Protection Association

(11) Yu, Hong-Zeung and Stavrianidis, Paraskevas, *The Transient Ceiling Flows of Growing Rack Storage Fires*, Factory Mutual Research Corporation

(12) Yu, H-Z., Transient Plume Influence in Measurement of Convective Heat Release Rates *of Fast-Growing Fires Using a Large-Scale Fire Products Collector*

(13) Yu, H-Z. and Kung, H-C., *Strong Buoyant Plumes of Growing Rack Storage Fires*, Factory Mutual Research Corporation

Codes and Standards

International Building Code (IBC), 2009

Uniform Building Code (UBC), 1997

NFPA 13 *Standard for the Installation of Sprinkler Systems*

NFPA 20 *Standard for the Installation of Stationary Pumps for Fire Protection*.

NFPA 22 *Standard for Water Tanks for Private Fire Protection*.

NFPA 24 *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*.

NFPA 25 *Standard for the Inspection, Testing and Maintenance of Water-Based Fire Protection Systems*

NFPA 72 *National Fire Alarm and Signaling Code*

NFPA 72H *National Fire Alarm and Signaling Code Handbook*

NFPA 90A *Standard for the Installation of Air-Conditioning and Ventilating Systems*

NFPA 92 *Standard for Smoke Control Systems*

NFPA 101 *Life Safety Code*

NFPA 204 *Standard for Smoke and Heat Venting*

ISO 13571 *Life-Threatening Components of Fire – Guidelines for the Estimation of Time Available for Escape Using Fire Data*

Appendix A
Hand Calculation for Evaluation of Evacuation Time

The construction warehouse is a two story building is used for storage and business purposes. The occupant load for each floor is tabulated below:

Floor	Occupant Load (Persons)
1 (includes mezzanines)	208
2	258
Total	466

The building is served by the following stairwells and doors provided for emergency egress:

- Four main exterior exit stairwells, each enclosed and rated for 2-hour fire-resistance, on the west, south west, south east, and east side of the building
- The level of exit discharge from the warehouse building for each of these four main exit stairwells, is at the same elevation as the first, or main, floor where exterior exit doors lead to a staging area across a road along a gravel path consistent with the surrounding topography
- On the main floor, a third exit discharges to the outdoors directly along the south side of the building
- Another exit on the main floor discharges to the truck loading dock on the east side of the building followed by a set of stairs from the elevated platform to grade or alternatively by a ramp to a large paved lay down area behind the building
- From the walled in office area on the main floor an additional exit is located on the north side of the building that discharges and follows a path down a set of concrete stairs to the building parking lot
- The mezzanine above the main floor office is provided with an exit directly into the west stairwell and a second means of egress on the east end of the mezzanine down a flight of indoor stairs to the main storage area floor.
- The main floor occupants, including occupants of the main floor office area and mezzanine office area, are assumed to exit directly to ground level. Egress from the first floor is not served by exit stairwells and time to egress the first floor will not be addressed by this analysis.

Each exit stairwell and associated door in construction warehouse, the number of floor occupants assumed to make use of each egress path, and other relevant information for this analysis, is tabulated below:

Construction Warehouse – Main Floor – Exit Discharge						
# of Occupants	**Location**	**Likely Exit Stair/Discharge**	**Exit Door Width (in.)**	**Stair Width (in.)**	**Floor Height (ft.)**	**Level of Exit**
22 + 12 + 32 = 66*	Office	West Stairwell	36	44	0	1
52	Office	North Discharge	36	44	0	1
14	East Storage Area	East Stairwell	36	44	0	1
9	East Truck Dock	East Discharge	36	44	0	1
12	South East Storage	South East Stairwell	36	44	0	1
8	South Storage Area	South Discharge (1)	36	44	0	1
2	Tool Room	South Discharge (2)	36	44	0	1
11 + 1**	South West Storage	South West Stairwell	36	44	0	1
Total: 142 + 32 + 1						

* 22 from office area plus 12 from main storage floor plus 32 from office mezzanine via interior stairs = 66 occupants

**11 from construction tool and consumables area plus 1 from dispersal mezzanine

Construction Warehouse – Mezzanine Level – Exit Stair						
# of Occupants	**Location**	**Likely Exit Stair/Discharge**	**Exit Door Width (in.)**	**Stair Width (in.)**	**Floor Height (ft.)**	**Level of Exit**
33	West Side Mezzanine	West Stairwell	36	44	12	M
32◊	East Side Mezzanine	Interior Stair	NA	44	12	1
1◊◊	Dispersal Mezzanine	Interior Stair	NA	44	10	1
Total: 66						

◊ 32 Mezzanine occupants exit via the interior stair the main storage floor to the West Stairwell

◊◊ 1 Mezzanine occupant exits via interior stair to the main storage floor to the South West Stairwell

Construction Warehouse – Second Floor – Exit Stair						
# of Occupants	**Location**	**Likely Exit Stair/Discharge**	**Exit Door Width (in.)**	**Stair Width (in.)**	**Floor Height (ft.)**	**Level of Exit**
103	West Side	West Stairwell	36	44	24	2
55	East Side	East Stairwell	36	44	24	2
20	South East Side	South East Stairwell±	36	44	24	2
80	South West Side	South West Stairwell	36	44	24	2
Total: 258						

± Only available to occupants of the south east storage area (Maximum of 20 occupants)

Assumptions:

- The primary factor that will determine the time to evacuate the floor (i.e., all people have left the floor and have entered the stairway) is the width of the stairway or the width of the exit door leading into the stairway
- All occupants of the building are assumed to begin egress at the same time
- The number of occupants using each exit is shown in the tables above
- Stairs correspond to a nominal 7 inch riser and a 11 inch tread depth
- Assume that each landing along the path of travel down the stairs between floors adds an additional 8 ft of travel
- Assume that the time to reach an exit from any part of the second floor is 30 seconds
- One half of the occupants in the mezzanine office area seek to exit through the west stairwell exit (at elevation 12 ft.)
- One half of the occupants in the mezzanine office area seek egress down the interior stairs on the east side of the mezzanine to the main floor then discharge through the base of the west stairwell (at main floor level)
- One half of the occupants (twenty two (22)) in the main floor office area seek to exit through the base of the west stairwell (at main floor level)
- Twelve (12) of the occupants in the main floor storage area seek to exit through the base of the west stairwell (at main floor level)
- All other building occupants on the main floor are not considered in this analysis

The following analysis utilizes the method described in SFPE Handbook of Fire Protection Engineering, 3rd Edition, Section 3, Chapter 14, *Emergency Movement*.

Estimate the flow capacity through an exit door:

Table 3-14.5 *Maximum Specific Flow, F_{sm}*

Exit Route Element		Maximum Specific Flow	
		Persons/min/ft of Effective Width	Persons/s/m of Effective Width
Corridor, Aisle, Ramp, Doorway		24.0	1.3
Stairs			
Riser (in.)	Tread (in.)		
7.5	10	17.1	0.94
7.0	11	18.5	1.01
6.5	12	20.0	1.09
6.5	13	21.2	1.16

From Table 3-14.5, the maximum specific flow (F_{SM}) through a doorway is 24 persons/min/ft of effective width. The initial specific flow through the doorway (F_S) is assumed to be equal to F_{SM} .

$F_{S_{Door}} = 24\, persons/min/ft.$

All single leaf door widths in the building are 36 inches wide.

Table 3-14.1 *Boundary Layer Widths*

Exit Route Element	Boundary Layer	
	(in.)	(cm)
Stairways—wall or side of tread	6	15
Railings, handrails[a]	3.5	9
Theater chairs, stadium benches	0	0
Corridor, ramp walls	8	20
Obstacles	4	10
Wide concourses, passageways	<18	46
Door, archways	6	15

[a]Where handrails are present, use the value if it results in a lesser effective width.

From Table 3-14.1, the boundary layer width of a door is 6 inches. The effective width W_e of a door is $W_{e_{Door}} = Door\ Width - 2(Boundary\ Layer)$.

For a 36 inch door, $W_{e_{Door}} = 36\ inches - 2(6\ inches) = 24\ inches\ (2\ ft)$

$F_C = F_S \cdot W_e$ (Equation 6)

Using Equation 6, the calculated flow (F_C) through each exit door is calculated to be:

For a 36 inch wide door:

$F_C = F_{S_{Door}} \cdot W_{e_{Door}} = (24\ persons/min/ft)(2\ ft) = 48\ persons/min$

Estimate the flow capability of a stairway:

From Table 3-14.5, the maximum specific flow (F_{SM}) of a stairway is 18.5 $persons/min/ft$ of effective width. The initial specific flow of each stairway (F_S) is assumed to be equal to F_{SM}.

$F_{S_{Stair}} = 18.5\ persons/min/ft.$

All stairs in the building are 44 inches wide.

From Table 3-14.1, the boundary layer width of a stairway is 6 inches. The effective width W_e of a stairway is $W_{e_{Stair}} = Stair\ Width - 2(Boundary\ Layer)$.

For a 44 inch wide stair:

$W_{e_{Stair}} = 44\ inches - 2(6\ inches) = 32\ inches\ (2.67\ ft)$, and

$F_C = F_{S_{Stair}} \cdot W_{e_{Stair}} = (18.5\ persons/min/ft)(2.67\ ft) = 49\ persons/min$

Flow is initially limited by the exit door $([F_{S_{Door}} \cdot W_{e_{Door}}] < [F_{S_{Stair}} \cdot W_{e_{Stair}}])$, as persons develop a queue waiting to exit on each floor. The specific flow of each stairwell must be calculated using Equation (10a):

$F_{S_{(out)}} = \frac{F_{S_{(in)}} \cdot W_{e_{(in)}}}{W_{e_{(out)}}}$ (Equation 10a)

$$F_{S_{Stair}} = \frac{F_{S_{Door}} W_{e_{Door}}}{W_{e_{Stair}}}$$

For a 36 $inch$ wide door:

$F_{S_{Door}} = 24\ persons/min/ft$

$W_{e_{Door}} = 2\ ft$

For a 44 $inch$ wide stair:

$W_{e_{Stair}} = 2.67\ ft$

The following tabulation contains the calculated value of $F_{S_{Stair}}$. The lesser of the calculated value of $F_{S_{Stair}}$ and $F_{SM_{Stair}}$ is used. The value of $F_{SM_{Stair}}$ (18.5 $persons/min/ft$) is taken from Table 3-14.5.

Stairwell	$F_{S_{Door}}$	$W_{e_{Door}}$	$W_{e_{Stair}}$	$F_{S_{Stair}}$	**Use** $F_{S_{Stair}}$
West Stairwell	24 $persons/min/ft$	2 ft	2.67 ft	18.0	18.0 $persons/min/ft$
South West Stairwell	24 $persons/min/ft$	2 ft	2.67 ft	18.0	18.0 $persons/min/ft$
South East Stairwell	24 $persons/min/ft$	2 ft	2.67 ft	18.0	18.0 $persons/min/ft$
East Stairwell	24 $persons/min/ft$	2 ft	2.67 ft	18.0	18.0 $persons/min/ft$

To determine the speed (S) of travel down the stairs the density (D) must be determined. Use Equation (5) and Table 3-14.2 to solve D for stairway flow.

$F_S = (1 - aD)kD$ (Equation 5)

Table 3-14.2 ***Constants for Equation 2, Evacuation Speed***

Exit Route Element		k_1	k_2
Corridor, Aisle, Ramp, Doorway		275	1.40
Stairs			
Riser (in.)	Tread (in.)		
7.5	10	196	1.00
7.0	11	212	1.08
6.5	12	229	1.16
6.5	13	242	1.23

1 in. = 25.4 mm.

$F_S = (1 - aD)kD = kD - akD^2$

$akD^2 - kD + F_S = 0$

Solve for F_S as a quadratic equation $AD^2 + BD + C = 0$; where $A = ak$, $B = -k$, and $C = F_{S_{Stair}}$.

$S = k - akD$ (Equation 3)

Where:
$S = speed\ along\ the\ line\ of\ travel$
$D = density\ in\ persons\ per\ unit\ area$
$k = constant, as\ shown\ in\ Table\ 3 - 14.2$
$= k_1; and\ a = 2.86\ for\ speed\ in\ ft/\text{min}\ and\ density\ in\ persons/ft^2$

From Equation 3, $a = 2.86\ ft^2/person$

From Table 3-14.2, $k_1 = 212\ ft/min$

$$D = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

$$A = ak = (2.86\ ft^2/person)(212\ ft/min) = 606\ ft^3/person/min$$

$$B = -212\ ft/min$$

$$C = F_{S_{Stair}}$$

$$D = \frac{-(-212\ ft/min) \pm \sqrt{(-212\ ft/min)^2 - 4(606\ ft^3/person/min)\left(F_{S_{Stair}}\right)}}{2(606\ ft^3/person/min)}$$

The following is a tabulation of the value of D for each stairway solved for its previously determined common value of $F_{S_{Stair}}$.

Stairwell	$\boldsymbol{F_{S_{Stair}}}$	$\boldsymbol{D}$
West Stairwell	18.0 $persons/min/ft$	0.145 $persons/ft^2$
South West Stairwell	18.0 $persons/min/ft$	0.145 $persons/ft^2$
South East Stairwell	18.0 $persons/min/ft$	0.145 $persons/ft^2$
East Stairwell	18.0 $persons/min/ft$	0.145 $persons/ft^2$

$S = k - akD$ (Equation 3)

Using Equation (3), the speed (S) along the path of stair travel for each stairway is solved for the corresponding value of D and tabulated below:

Stairwell	D	a	k	S
West Stairwell	$0.145\ persons/ft^2$	$2.86\ ft^2/person$	$212\ ft/min$	$124\ ft/min$
South West Stairwell	$0.145\ persons/ft^2$	$2.86\ ft^2/person$	$212\ ft/min$	$124\ ft/min$
South East Stairwell	$0.145\ persons/ft^2$	$2.86\ ft^2/person$	$212\ ft/min$	$124\ ft/min$
East Stairwell	$0.145\ persons/ft^2$	$2.86\ ft^2/person$	$212\ ft/min$	$124\ ft/min$

Table 3-14.3 ***Conversion Factors for Relating Line of Travel Distance to Vertical Travel for Various Stair Configurations***

Stairs Riser (in.)	Tread (in.)	Conversion Factor
7.5	10.0	1.66
7.0	11.0	1.85
6.5	12.0	2.08
6.5	13.0	2.22

Floor to floor height is tabulated below.

Since the West Stairwell serves both the second floor (El. 24 ft.) and mezzanine above the office area (El. 12 ft.), it is divided into upper and lower sections. Also, each stair landing is assumed to require $8\ ft$ of travel. Using the conversion factor from Table 3-14.3 (1.85) the travel distance per floor is calculated according to:

$$Travel\ Distance = (floor\ height)(1.85) + \ (No.of\ Landings\ between\ floors\ x\ 8\ ft)$$

Stairwell	**Floor Height (ft.)**	$\boldsymbol{Table\ 3-14.3\ Factor}$	$\boldsymbol{Landings}$	$\boldsymbol{Travel\ Distance}$
West Stairwell (Upper)	12	1.85	$20\ ft$	$42\ ft$
West Stairwell (Lower)	12	1.85	$20\ ft$	$42\ ft$
South West Stairwell	24	1.85	$40\ ft$	$85\ ft$
South East Stairwell	24	1.85	$40\ ft$	$85\ ft$
East Stairwell	24	1.85	$40\ ft$	$85\ ft$

The travel distance and speed (S) are used to estimate the time to travel from floor to floor:

$$t_{floor} = {}^{(travel\ distance)}/_{S}$$

Stairwell	$Travel\ Distance$	S	t_{floor}
West Stairwell (Upper)	$42\ ft$	$124\ ft/min$	$0.34\ min$
West Stairwell (Lower)	$42\ ft$	$124\ ft/min$	$0.34\ min$
South West Stairwell	$85\ ft$	$124\ ft/min$	$0.68\ min$
South East Stairwell	$85\ ft$	$124\ ft/min$	$0.68\ min$
East Stairwell	$85\ ft$	$124\ ft/min$	$0.68\ min$

For each stair, estimate the calculated flow ($F_{C_{Stair}}$) down the stairs based on the values of $W_{e_{Stair}}$ and $F_{S_{Stair}}$ tabulated previously:

$$F_{C_{Stair}} = F_{S_{Stair}} \cdot W_{e_{Stair}}$$

Stairwell	$F_{S_{Stair}}$	$W_{e_{Stair}}$	$F_{C_{Stair}}$
West Stairwell	18.0 $persons/min/ft$	2.67 ft	48.0 $persons/min$
South West Stairwell	18.0 $persons/min/ft$	2.67 ft	48.0 $persons/min$
South East Stairwell	18.0 $persons/min/ft$	2.67 ft	48.0 $persons/min$
East Stairwell	18.0 $persons/min/ft$	2.67 ft	48.0 $persons/min$

It has been assumed that flow on each floor will reach the door into the stairwell in 30 $seconds$.

After a period of time (t_{floor}) the number of persons from each floor in each exit stairway is estimated to be:

$$No.of\ persons\ in\ stairwells\ serving\ each\ floor\ =\ F_{C_{Stair}} \cdot\ t_{floor}$$

The number of persons queued at each stairwell door and waiting to enter the stairwell is also estimated to be:

$$No.of\ persons\ in\ queue\ on\ each\ floor\ =\ No.of\ Occupants - No.of\ persons\ in\ stairwells\ serving\ each\ floor$$

The number of persons between floors in each stairwell is tabulated according to this equation below:

# of Occupants	Stairwell	$F_{C_{Stair}}$	t_{floor}	$No. of\ Persons\ in\ Stairwell$	$No. of\ Persons\ in\ Queue$
103	West (2nd Floor)	$48.0\ persons/min$	$0.34\ min$	$16\ persons$	$87\ persons$
33	West (Mezzanine)	$48.0\ persons/min$	$0.34\ min$	$16\ persons$	$17\ persons$
55	South West Stairwell	$48.0\ persons/min$	$0.68\ min$	$32\ persons$	$23\ persons$
20	South East Stairwell	$48.0\ persons/min$	$0.68\ min$	$20\ persons$	$0\ persons$
80	East Stairwell	$48.0\ persons/min$	$0.68\ min$	$32\ persons$	$48\ persons$
			Total	$116\ persons$	$175\ persons$

The West Stairwell (Upper) merges with the West Stairwell (Lower). At this merger, for the West Stairwell, the impact to $F_{S_{Stair}}$ must be recalculated according to equation (10b):

$$F_{S(out)} = \frac{F_{S(in.1)} \cdot W_{e(in.1)} + F_{S(in.2)} \cdot W_{e(in.2)}}{W_{e(out)}} \qquad \text{(Equation 10b)}$$

Estimate the impact of merging stairway flow and stairway entry flow from the mezzanine into the West Stairwell on exit flow using Equation (10b):

$$F_{S_{Stairway-Out}} = \frac{F_{S_{Door-Mezz}} \cdot W_{e_{Door-Mezz}} + F_{S_{Stairway-In}} \cdot W_{e_{Stairway-In}}}{W_{e_{Stairway-Out}}}$$

The revised value of $F_{S_{Stair}}$ for the West Stairwell where the merger at the mezzanine level occurs is tabulated below:

West Stairwell	$F_{S_{Door-Mezz}}$	$W_{e_{Door-Mezz}}$	$F_{S_{Stair-In}}$	$W_{e_{Stair-In}}$	$W_{e_{Stair-Out}}$	$F_{S_{Stair-Out}}$
2nd Floor	$24\ persons/min/ft$	$2\ ft$	$18.0\ persons/min/ft$	$2.67\ ft$	$2.67\ ft$	$36\ persons/min/ft$
Mezzanine	$24\ persons/min/ft$	$2\ ft$	$18.0\ persons/min/ft$	$2.67\ ft$	$2.67\ ft$	$36\ persons/min/ft$

Since $F_{S_{Stair-Out}} > F_{S_{Stair-In}}$, the value of $F_{S_{Stair-In}}$, or $18.0\ persons/min/ft$, must be used.

The capacity of exit doors has been previously calculated:

For a 36 inch wide door:

$F_C = F_S \cdot W_e = (24\, persons/min/ft)(2\, ft) = 48\, persons/min$

The capability of each stairway and exit door remains as tabulated below:

Stairwell No.	$F_{C_{Stair}}$	$F_{C_{Door}}$	Use Value of F_C
West Stairwell (2nd Floor)	48.0 $persons/min$	48.0 $persons/min$	48.0 $persons/min$
West Stairwell (Mezzanine)	48.0 $persons/min$	48.0 $persons/min$	48.0 $persons/min$
South West Stairwell	48.0 $persons/min$	48.0 $persons/min$	48.0 $persons/min$
South East Stairwell	48.0 $persons/min$	48.0 $persons/min$	48.0 $persons/min$
East Stairwell	48.0 $persons/min$	48.0 $persons/min$	48.0 $persons/min$

After the initial time to fill the stairwell$(\, t_{floor})$ plus the transit time to reach an exit door ($t_{transit} = 30\, seconds$), the time for the remaining on each floor to enter the stairwell and clear the floor below is estimated to be:

$t_{queue} = (No. of\ persons\ in\ queue/F_C)$

# of Occupants	Stairwell	$No. of\ Persons\ in\ Queue$	F_C	t_{queue}
103	West (2nd Floor)	87 $persons$	48.0 $persons/min$	109 sec
33	West (Mezzanine)	17 $persons$	48.0 $persons/min$	21 sec
55	South-West	23 $persons$	48.0 $persons/min$	29 sec
20	South-East	0 $persons$	48.0 $persons/min$	0 sec
80	East	48 $persons$	48.0 $persons/min$	60 sec

For each egress path, the values of t_{queue} are summed, and added to the value of t_{floor} plus $t_{transit}$ to provide an estimate the duration of time for all occupants have left the floor but ends with occupants still in the stairwell. To obtain the total time for all building occupants to pass through an exit discharge at ground level the value of $t_{floor} = 41\, seconds$ must be added into the calculation to account for the last occupant to travel from the top of the stairs to the level of exit discharge at ground level.

The results of this calculation are tabulated below:

	West Stairwell		South-West Stairwell	South-East Stairwell	East Stairwell
Egress Path	**2nd Floor**	**Mezzanine**	**2nd Floor**	**2nd Floor**	**2nd Floor**
$\boldsymbol{t_{transit}}$	$30\ sec$		$30\ sec$	$30\ sec$	$30\ sec$
$+\boldsymbol{t_{floor}}$	$20\ sec$	$20\ sec$	$41\ sec$	$41\ sec$	$41\ sec$
$+\boldsymbol{t_{queue}}$	$109\ sec$	$21\ sec$	$29\ sec$	$0\ sec$	$60\ sec$
$+\boldsymbol{t_{floor\ (last\ occupant)}}$	$20\ sec$	$20\ sec$	$41\ sec$	$41\ sec$	$41\ sec$
TOTAL Egress Time	$240\ seconds$		$141\ seconds$	$112\ seconds$	$172\ seconds$

The hand calculation shows that the most demanding exit involves the West Stairwell, with $t_{queue} = 109\ sec$ on the second floor. In contrast, $t_{queue} = 0\ sec$ for the South East stairwell.

Appendix B
Estimation of Carbon Monoxide Yield, Soot Yield, and Heat of Combustion
For The
Rack Storage Fire Fuel Array

Input for carbon monoxide and soot yield for materials is taken from The SFPE Handbook for Fire Protection Engineers, 3rd Edition, Table 3-4.14.

Input for the heat of combustion for materials is taken from the NFPA Fire Protection Handbook, Twentieth Edition, Table 6.17.1.

<u>Assumptions:</u>

1. The properties of corrugated cardboard carton materials are assumed to be consistent with those of red oak.
2. To determine soot and carbon monoxide yields, each carton is assumed to be packed in a manner that is proportional to that of the Factory Mutual Standard Plastic Commodity. A Factory Mutual Standard Plastic Commodity consists of unexpanded polystyrene cups packaged in compartmented, single-wall corrugated paper cartons; each measuring 21 inches (0.533 m) by 21 inches (0.533 m) by 20 inches (0.508 m) high, and containing 125 compartments (five levels of compartments with 25 compartments on each level).
3. The corrugated cardboard is assumed to be ¼ inches thick.
4. The density of corrugated cardboard is assumed to be $\rho = 0.022\ lb/in^3$.
5. The thickness of each surface making up a cup is assumed to be 1/16 inch thick.

Calculations:

The volume of corrugated cardboard that makes up the carton and compartments is calculated to be:

$$V_{carton} = V_{sides} + V_{top/bottom} + V_{horizontal\ separations} + V_{vertical\ separations}$$

$Where$:

$$V_{sides} = (4)(20in\ x\ 21in)\left(\frac{1}{8}in\right) = 210\ in^3$$

$$V_{top/bottom} = (2)(21in\ x\ 21in)\left(\frac{1}{8}in\right) = 110\ in^3$$

$$V_{horizontal\ separations} = (4)(21in\ x\ 21in)\left(\frac{1}{8}in\right) = 420\ in^3$$

$$V_{vertical\ separations} = (4)(20in\ x\ 21in)\left(\frac{1}{8}in\right) = 210\ in^3$$

$$V_{carton} = 210\ in^3 + 110\ in^3 + 420\ in^3 + 210\ in^3$$

$$V_{carton} = 950\ in^3$$

The mass of a corrugated cardboard carton is calculated to be:

$$m_{carton} = \rho V_{carton}$$

$$m_{carton} = (0.022\ lb/in^3)\ (950\ in^3)$$

$$m_{carton} = 21\ lb = 9.5kg$$

Each compartment measures 4 ¼ inches by 4 ¼ inches by 4 inches high and is assumed to contain a cylindrical unexpanded polystyrene cup 3 inches in diameter and 3 inches tall.

The volume of each cup is calculated to be:

$$V_{cup} = 2\pi(r_o - r_i)h + \pi {r_i}^2 t$$

$Where$:

$(r_o - r_i) = \frac{1}{16}in$ $\quad h = 3in$ $\quad r_i = 3in$ $\quad t = \frac{1}{16}in$

$$V_{cup} = 2\pi\left(\frac{1}{16}in\right)(3in) + \pi(3in)^2\left(\frac{1}{16}in\right)$$

$$V_{cup} = 3in^3$$

The density of unexpanded polystyrene is $\rho_{PS} = 0.036\ lb/in^3$.

The mass of polystyrene cups in each cardboard carton is calculated to be:

$$m_{PS} = 125\ cups\ \rho_{PS} V_{cup}$$

$$m_{PS} = 125(0.036\ lb/in^3)\ (3\ in^3)$$

$$m_{PS} = 14\ lb = 6.2kg$$

Mass Weighted Average Contribution of Carbon Monoxide Yield, Soot Yield, and Heat of Combustion

For the

Rack Storage Fuel Array

(Per Corrugated Cardboard Carton)

Component	Combustible Mass (kg)	Combustible Mass Fraction	Material	Mat'l Soot Yield (g/g)	Soot Contribution (g/g)	Mat'l CO Yield (g/g)	CO Contribution (g/g)	HOC (kJ/kg)	HOC Contribution (kJ/kg)
Cardboard Carton	9.5	0.605	Cardboard (Wood-Red Oak)	0.015	0.0091	0.004	0.0024	20200	12223
Polystyrene Cups	6.2	0.395	Polystyrene	0.164	0.0648	0.060	0.0237	42500	16783
Total	15.7	1.000	---	---	0.0738	---	0.0261	---	29006

This Page Intentionally Blank

Appendix C
DETACT Analysis of Sprinkler Actuation Time
Rack Storage Fire Fuel Array

		INPUT			CALCULATED
Ceiling Height	H	7.32	m	r/H	0.30
Radial Distance Plume Axis	r	2.16	m		
Ambient Temperature	Tamb	20	Deg C		
Response Time Index	RTI	50	(m-sec)^1/2		
Fire Growth Coefficient	alpha	0.012	kW/sec^2		
Fire Growth Power	p	3	--		
Actuation Temperature	Tact	96	Deg C		
Time Increment	Delta t	10	sec		

t (sec)	Qdot (kW)	ΔTg (°C)	Tg(°C)	ug(m/s)	ΔTs (°C)	Ts(°C)
0	0.0	0	20	0.0000	0	20
10	12.0	2	22	0.6521	0	20
20	96.0	9	29	1.3042	4	24
30	324.0	21	41	1.9562	14	34
40	768.0	37	57	2.6083	30	50
50	1500.0	58	78	3.2604	51	71
60	2592.0	83	103	3.9125	77	97
70	4116.0	113	133	4.5646	109	129
80	6144.0	148	168	5.2166	142	162
90	8748.0	187	207	5.8687	196	216

$$Qdot = alpha \times t^{p}$$

Where r/H > 0.18: $$\Delta Tg = \left[\frac{5.38(Qdot/r)^{2/3}}{H}\right]$$

Where r/H ≤ 0.18: $$\Delta Tg = \left[\frac{16.9 Qdot^{2/3}}{H^{5/3}}\right]$$

$$Tg = \Delta Tg + Tamb$$

Where r/H > 0.15: $$ug = \left[\frac{0.20 Qdot^{1/3} H^{1/2}}{r^{5/6}}\right]$$

Where r/H ≤ 0.15: $$ug = 0.95\left(Qdot/H\right)^{1/3}$$

$$\Delta Ts = \left[\frac{ug^{1/2}(Tg - Ts)}{RTI}\right]\Delta t$$

$$Ts = \Delta Ts + \text{Tamb}$$

This Page Intentionally Blank

Appendix D
Estimation of Carbon Monoxide Yield, Soot Yield, and Heat of Combustion
For The
Mezzanine Workstation Fire

Input for carbon monoxide and soot yield for materials is taken from The SFPE Handbook for Fire Protection Engineers, 3rd Edition, Table 3-4.14.

Input for the heat of combustion for materials is taken from the NFPA Fire Protection Handbook, Twentieth Edition, Table 6.17.1.

<u>Assumptions:</u>

1. The properties of wood and paper materials are assumed to be consistent with those of red oak.
2. The properties of general plastic trim materials and the office chair are assumed to be consistent with those of polyethylene.
3. The properties of ABS plastic, nylon, and polyurethane foam are as found in the SFPE and NFPA references.
4. The combustible mass fraction of the standard workstation is as found in Table 2-1 of the NIST NCSTAR 105C report cited in this report.

Mass Weighted Average Contribution of Carbon Monoxide Yield, Soot Yield, and Heat of Combustion

For the

Mezzanine Level Standard Workstation Fire

Workstation Component	Combustible Mass (kg)	Combustible Mass Fraction	Material (Assumed)	Mat'l Soot Yield (g/g)	Soot Contribution (g/g)	Mat'l CO Yield (g/g)	CO Contribution (g/g)	HOC (kJ/kg)	HOC Contribution (kJ/kg)
Work Surface - melamine laminate over medium density fiber-board	82.8	0.333	Melamine Faced PB (Wood - Red Oak)	0.015	0.0050	0.025	0.0083	20200	6725
27 reams of paper and 14 document boxes	63.7	0.256	Wood - Red Oak	0.015	0.0038	0.004	0.0010	20200	5174
Plastic kick plates and trim (base of walls, inside and outside)	7.1	0.029	Polyethylene	0.060	0.0017	0.024	0.0007	46500	1328
Computer keyboard	1.2	0.005	ABS	0.105	0.0005	0.087	0.0004	39840	192
Plastic waste basket	0.7	0.003	Polyethylene	0.060	0.0002	0.024	0.0001	46500	131
36 nylon carpet tiles with rubber backing	34.2	0.138	Nylon	0.075	0.0103	0.038	0.0052	31700	4359
Shelf ends - particle board or dense foam	3.4	0.014	PU Foam (Rigid)	0.125	0.0017	0.038	0.0005	31600	432
Bulldog chair - fabric, foam, thermoplastic shell and base	15.5	0.062	Polyethylene	0.060	0.0037	0.024	0.0015	46500	2898
Computer monitor	5.3	0.021	ABS	0.105	0.0022	0.087	0.0019	39840	849
Computer processor	3.7	0.015	ABS	0.105	0.0016	0.087	0.0013	39840	593
9 wall panels with aluminum angle, wood frames, fiberglass, and metal mesh	25.3	0.102	Wood - Red Oak	0.015	0.0015	0.004	0.0004	20200	2055
	5.0	0.020	PU Foam (Flex)	0.227	0.0046	0.031	0.0006	31600	635
Book shelf	0.8	0.003	Wood - Red Oak	0.015	0.0000	0.004	0.0000	20200	65
3 two-drawer steel filing cabinets	0.0	0.000	Steel	0.000	0.0000	0.000	0.0000	0	0
Total	248.7	1.000	---	---	0.0369	---	0.0220	---	25436

Appendix E
DETACT Analysis of Sprinkler Actuation Time
Mezzanine Workstation Fire

		INPUT			CALCULATED
Ceiling Height	H	2.59	m	r/H	0.96
Radial Distance Plume Axis	r	2.48	m		
Ambient Temperature	Tamb	20	Deg C		
Response Time Index	RTI	120	(m-sec)^1/2		
Fire Growth Coefficient	alpha	0.024	kW/sec^2		
Fire Growth Power	p	2	--		
Actuation Temperature	Tact	74	Deg C		
Time Increment	Delta t	10	sec		

t (sec)	*Qdot (kW)*	*ΔTg (°C)*	*Tg(°C)*	*ug(m/s)*	*ΔTs (°C)*	*Ts(°C)*
0	0.0	0	20	0.0000	0	20
10	2.4	2	22	0.2022	0	20
20	9.6	5	25	0.3209	0	20
30	21.6	9	29	0.4205	1	21
40	38.4	13	33	0.5094	3	23
50	60.0	17	37	0.5911	5	25
60	86.4	22	42	0.6675	7	27
70	117.6	27	47	0.7398	10	30
80	153.6	33	53	0.8087	13	33
90	194.4	38	58	0.8747	17	37
100	240.0	44	64	0.9384	21	41
110	290.4	50	70	0.9999	26	46
120	345.6	56	76	1.0596	31	51
130	405.6	62	82	1.1177	36	56
140	470.4	69	89	1.1743	41	61
150	540.0	75	95	1.2296	47	67
160	614.4	82	102	1.2837	53	73
170	693.6	89	109	1.3366	59	79
180	777.6	96	116	1.3885	65	85
190	866.4	103	123	1.4395	72	92
200	960.0	110	130	1.4896	78	98

$$Qdot = alpha\ x\ t^{p}$$

Where r/H > 0.18: $$\Delta Tg = \left[\frac{5.38(Qdot/r)^{2/3}}{H}\right]$$

Where r/H ≤ 0.18: $$\Delta Tg = \left[\frac{16.9Qdot^{2/3}}{H^{5/3}}\right]$$

$$Tg = \Delta Tg + Tamb$$

Where r/H > 0.15: $$ug = \left[\frac{0.20Qdot^{1/3}H^{1/2}}{r^{5/6}}\right]$$

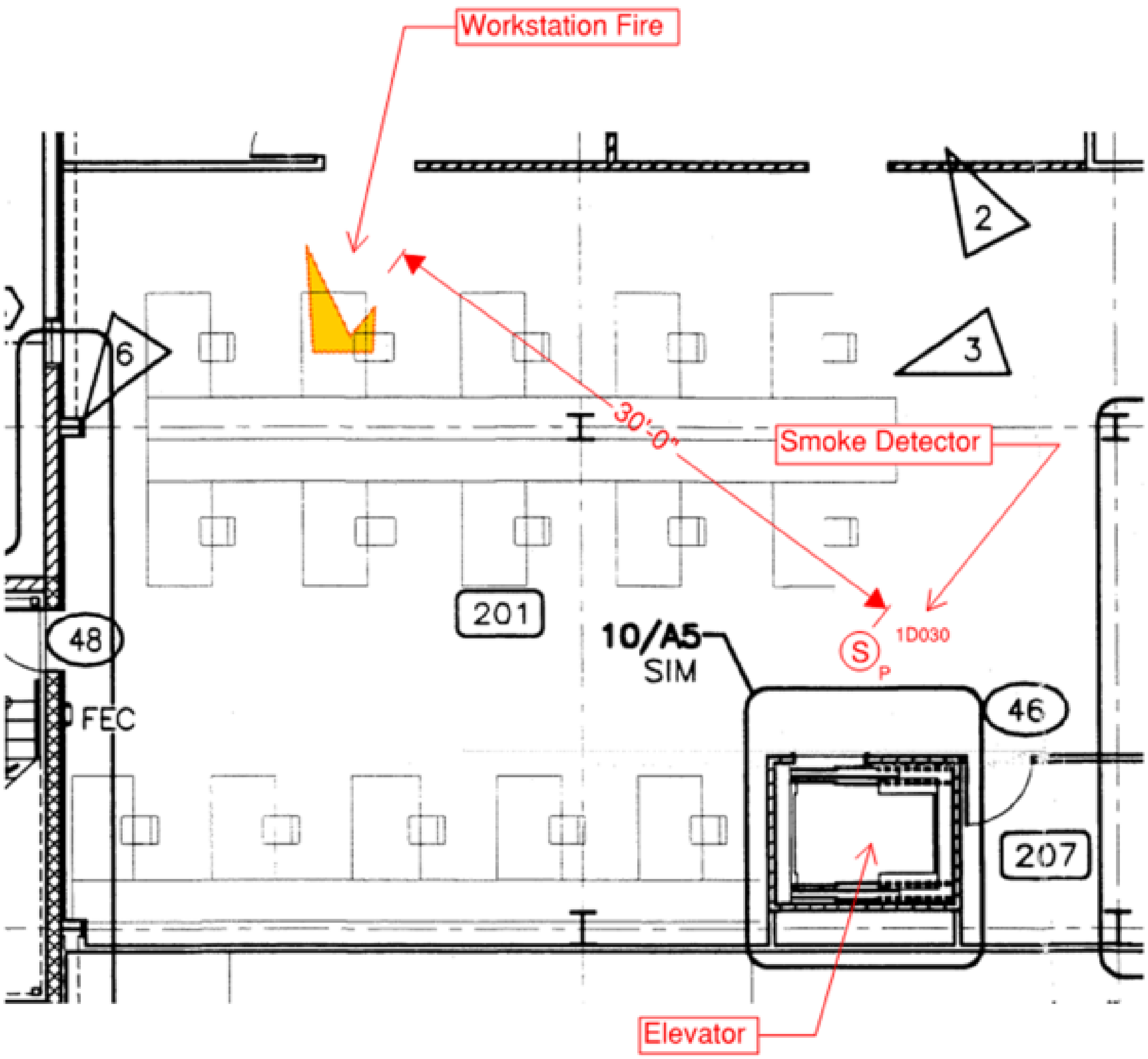
Where r/H ≤ 0.15: $$ug = 0.95\left(Qdot/_{H}\right)^{1/3}$$

$$\Delta Ts = \left[\frac{ug^{1/2}(Tg - Ts)}{RTI}\right]\Delta t$$

$$Ts = \Delta Ts + \text{Tamb}$$

This Page Intentionally Blank

Appendix F
Analysis of Smoke Detector Actuation Time
Mezzanine Workstation Fire



Warehouse Fire Scenario - Plan View

Computer Workstation Fire

The ceiling height at the warehouse mezzanine level is 8 ft. 5 in. (2.6 m) and is not obstructed.

NFPA 72, Annex B, Section B.4.8, describes several methods for estimating smoke detector response.

The following calculation follows the Annex B guide for performance of the mass optical density method.

Analysis

Assume that the detectors, listed by UL, will respond to an optical density of $0.14\ m^{-1}$ (NFPA 72, Annex B, paragraph B.4.8.2.7). Then

$$D_A = 0.14m^{-1} = {D_m M}/{V_c} \qquad \text{(NFPA 72, Annex B, Equation B.46)}$$

Assume that V_c corresponds to the cylindrical volume of the ceiling jet:

$$V_c = \pi r^2 h$$

Where h is the depth of the ceiling jet and is further assumed to be 20% of ceiling height (NFPA 72 Handbook, Annex B, B.4.8.2.6)

Rearranging:

$$M = {D_A \pi r^2 h}/{D_m}$$

Where:

$M \equiv \mathit{the\ mass\ of\ material\ released\ by\ the\ fire}$

$D_A \equiv \mathit{Optical\ Density\ required\ for\ detector\ actuation}\ (D_A = 0.14m^{-1})$

$r\ \equiv \mathit{distance\ of\ detector\ from\ plume\ centerline}$

$r = 30\ ft. = 9.14m$

$h \equiv \mathit{depth\ of\ ceiling\ jet, assumed\ to\ be}\ 20\%\ \mathit{of\ ceiling\ height}$

$(\mathit{NFPA\ Handbook}, B.4.8.2.6)$

$H = 8\ ft\ 5\ in. = 2.6\ m$, therefore $h = 2.6\ m\ x\ 0.20 = 0.52\ m$

$D_m \equiv \mathit{Mass\ Optical\ Density\ of\ smoke}$

Assume that the computer monitor is made of ABS plastic. From Table 2-13.5, SFPE Handbook of Fire Protection Engineering, 3rd Edition, $D_m\ \mathit{for\ ABS\ Plastic} = 0.52\ {m^2}/{g}$

$$D_m = 0.52\ {m^2}/{g}$$

The value of M at smoke detector actuation is calculated to be:

$$M = {(0.14m^{-1})\pi(9.14m)^2(0.52m)}/{0.52\ {m^2}/{g}}$$

$$M = 36.7g$$

Assume that the fire may be characterized as a medium t-squared fire with a fire growth coefficient of $\alpha = 0.02396\, {}^{kW}/_{sec^2}$.

Heat release rate at a specific time for a power growth fire is calculated according to:

$$\dot{Q} = \alpha t^2$$

Additionally, heat release rate is calculated according to:

$$\dot{Q} = \dot{m}\Delta H_c$$

Where:

$\dot{m} \equiv mass\ loss\ rate$

$\Delta H_c \equiv heat\ of\ combustion\ (in\ this\ case\ for\ ABS\ plastic).$

$$\Delta H_c = 35.25\, {}^{kJ}/_{g}$$

(SFPE Handbook of Fire Protection Engineering, 3rd Edition, Table C.3)

$$\dot{Q} = \dot{m}\Delta H_c = \alpha t^2$$

And mass release rate from the fire is:

$\dot{m} = {}^{\alpha t^2}/_{\Delta H_c}$, or $\frac{dm}{dt} = {}^{\alpha t^2}/_{\Delta H_c}$

Integrating to get the value of M as a function time:

$$dm = \left({}^{\alpha t^2}/_{\Delta H_c}\right) dt$$

$$M = \int_0^t \left({}^{\alpha t^2}/_{\Delta H_c}\right) dt$$

$M = {}^{\alpha t^3}/_{3\Delta H_c}$ (NFPA 72, Annex B, Equation B.48)

Rearranging and substituting values for, $\Delta H_c\ and\ \alpha$:

$$t = \left({}^{3M\Delta H_c}/_{\alpha}\right)^{1/3}$$

$$t = \left({}^{3(36.7g)\left(35.25\, {}^{kJ}/_{g}\right)} \Big/ {}_{0.02396\, {}^{kW}/_{sec^2}} \right)^{1/3}$$

$t = 54\ seconds$

The time to activation of the smoke detector under this scenario is expected to be at least 54 seconds.

The heat release and fire department response may also be evaluated:

Heat release rate at predicted detector actuation time ($t = 54\ seconds$) is calculated according to:

$$\dot{Q} = \alpha t^2$$

$$\dot{Q} = \left(0.02396\ {}^{kW}/_{sec^2}\right)(54\ sec)^2$$

$$\dot{Q} = 70\ kW$$

Therefore, the heat release rate when the detector actuates is predicted to be at least 70 kW.

Assuming the fire department is capable of responding in 7 minutes, the heat release rate of the fire when the fire department arrives is predicted to be:

$$\dot{Q} = \alpha t^2$$

$$\dot{Q} = \left(0.02396\ {}^{kW}/_{sec^2}\right)(54 + [7][60]\ sec)^2$$

$$\dot{Q} = 5{,}383\ kW$$

If the fire were to continue to grow, and involve adjacent work stations, the heat release rate of the fire when the fire department arrives is predicted to be at least 5,383 kW, or approximately 5 MW.

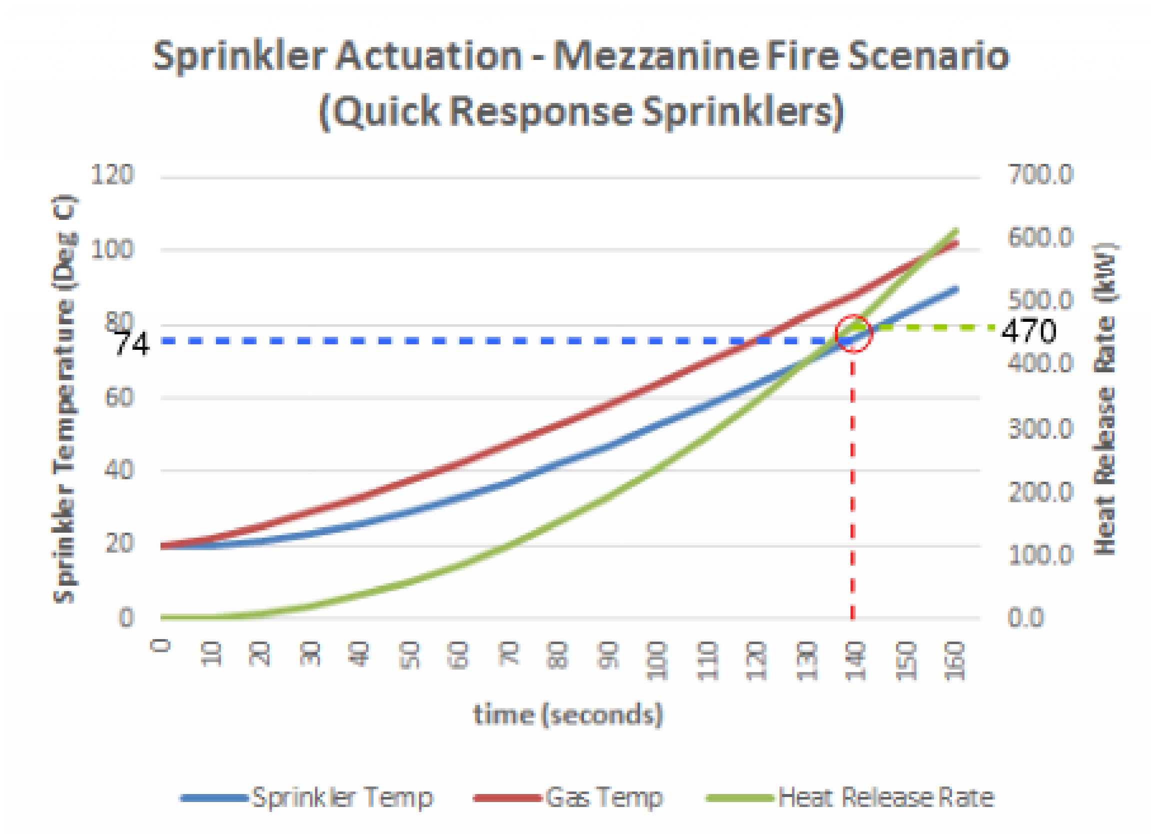
Appendix G
Evaluation of Alternatives for Performance Based Design of Mezzanine Workstation Fire

Alternatives for Compliance with Performance Based Design Criteria

A combination of one or more of the following actions should be considered:

1. ***Replace standard response sprinklers (RTI > 80) with quick response sprinklers (RTI < 50):***

   DETACT analysis indicates that replacement of standard response sprinklers with quick response sprinklers improves the time to sprinkler activation from 170 seconds to 140 seconds, or 30 seconds. The figure below illustrates the results of the DETACT analysis with quick response sprinklers.



Mezzanine DETACT Analysis Results with Quick Response Sprinklers

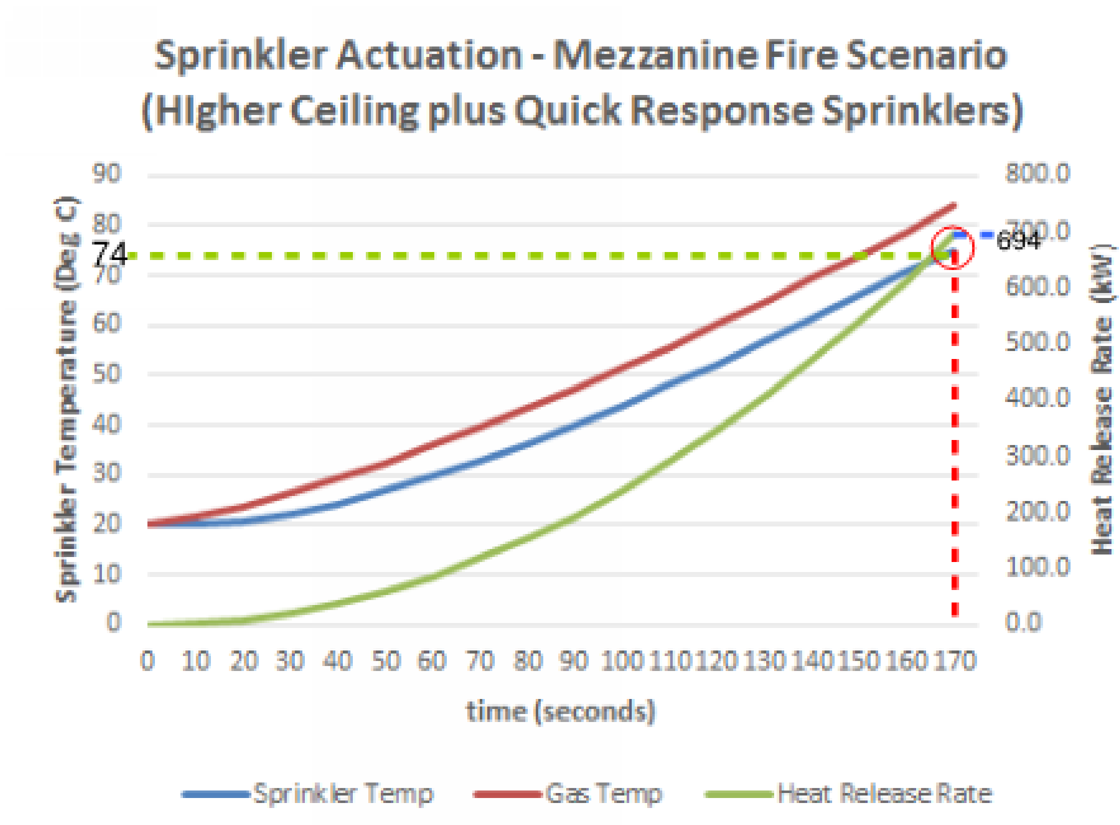
2. ***Provide more overhead volume by removing the suspended ceiling (exposing the second floor deck) and raise sprinklers. An additional 1 m of ceiling height may be accomplished in this manner. Sprinklers would be required to be raised to comply with NFPA 13.***

The DETACT and FDS models were revised to reflect the higher ceiling space with DETACT assuming quick response sprinklers.

The DETACT analysis shows that increasing the height of the ceiling nullifies the time advantage gained by installation of quick response sprinklers to the same effectiveness as the current use of standard response sprinklers with the current ceiling height.

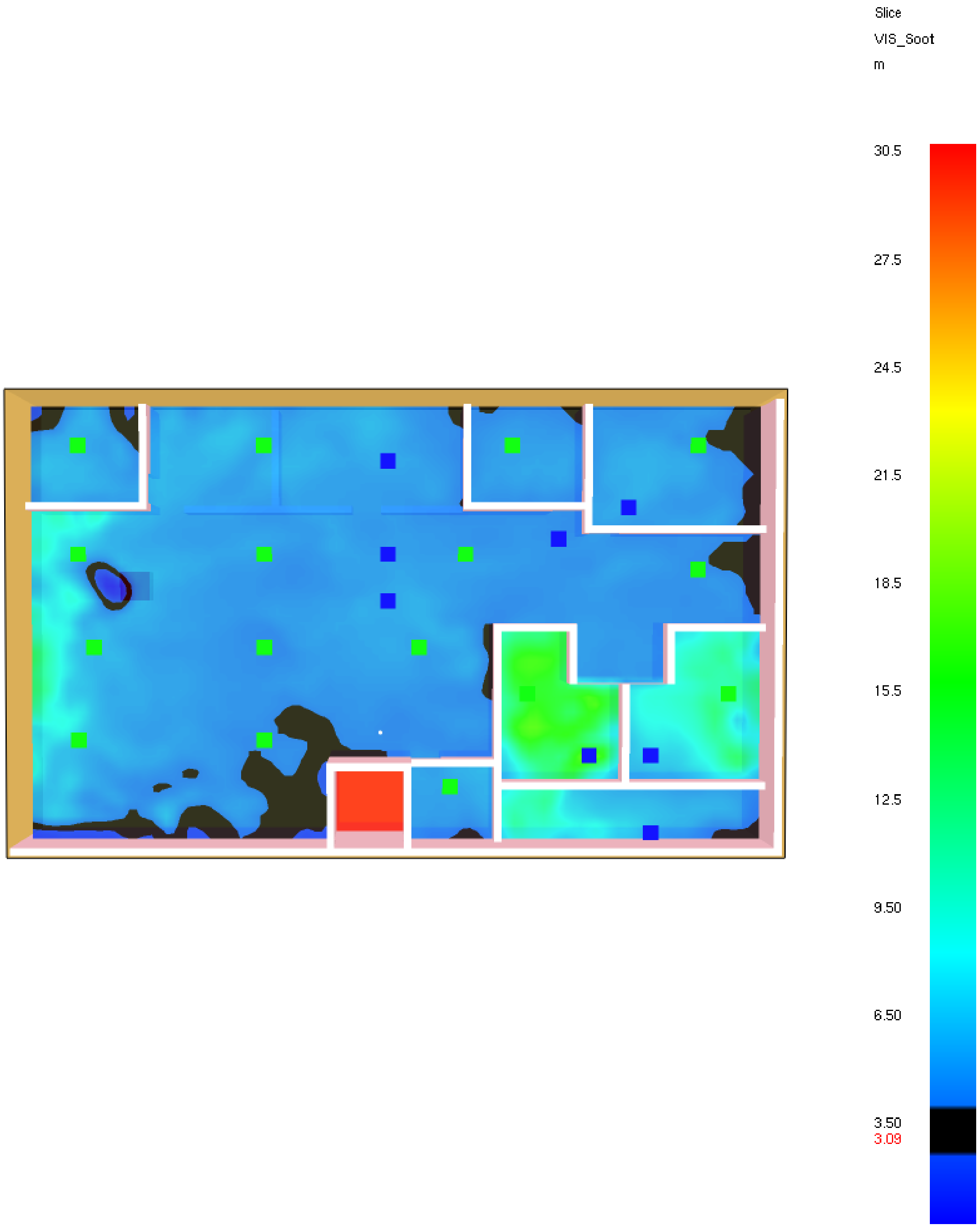
The DETACT analysis shows sprinkler actuation at 170 seconds.

The results of the DETACT analysis are shown in the figure below:

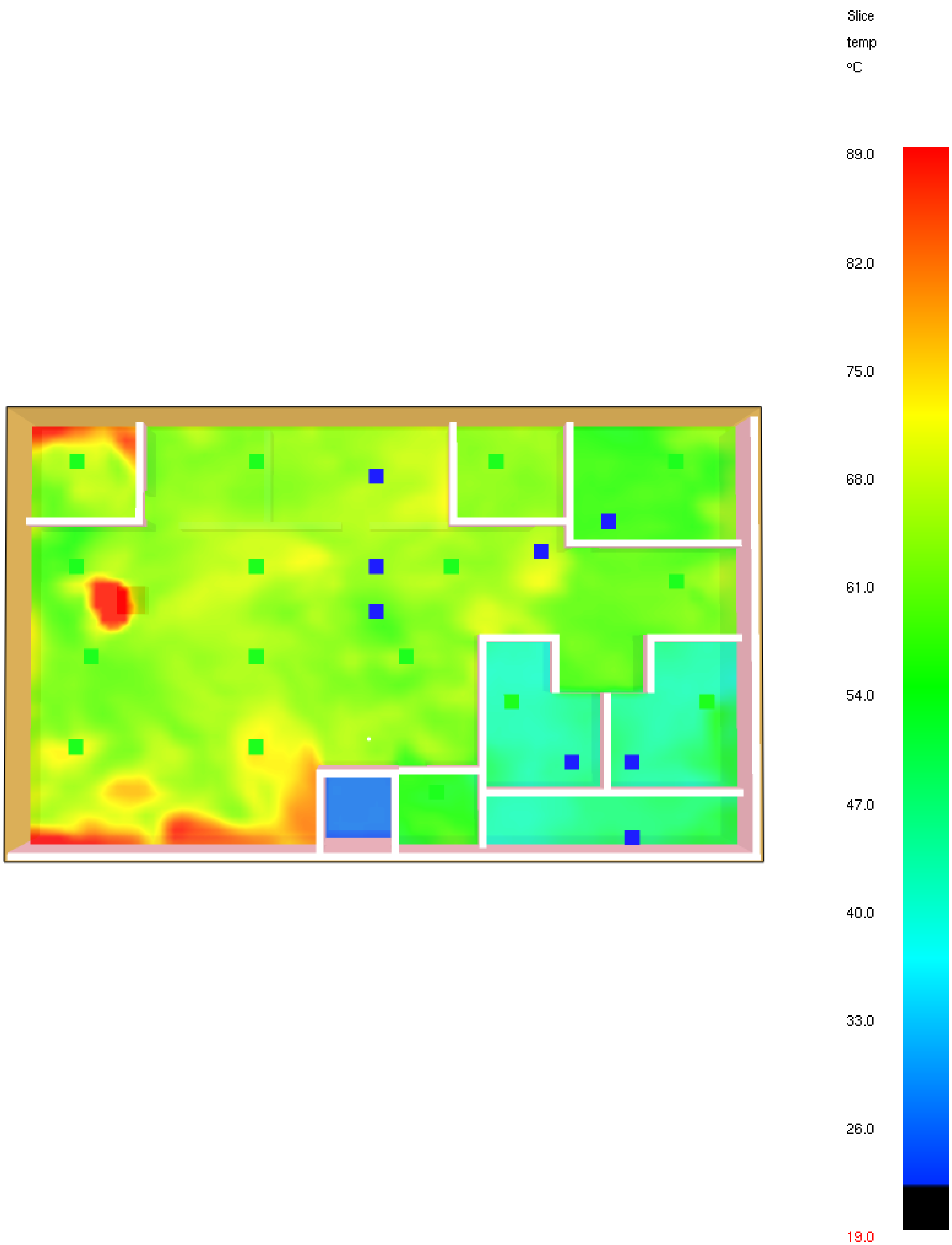


Mezzanine DETACT Analysis; High Ceiling and Quick Response Sprinklers

Evaluation of the revised FDS model for visibility and temperature tenability limits shows an improvement in the time to reach tenability limits. Visibility tenability criteria (3 m) improves from 130 seconds to 210 seconds, an improvement of 80 seconds, Temperature tenability improves from 150 seconds to See the FDS rendering below.



Visibility @ 210 Seconds and 1.82 m above Mezzanine Floor; Quick Response Sprinklers and Raised Ceiling



Temperature @ 302 Seconds and 1.82 m above Mezzanine Floor; Quick Response Sprinklers and Raised Ceiling; Tenability Limit of 100℃ in not Exceeded

3. Improve Egress Efficiency in the West Stairwell

Implement two (2) suggested improvements

a. Provide an additional protected exterior exit enclosure from the mezzanine area
b. Remove obstruction to egress on second floor along east wall in the large open office area

To evaluate this alternative, an additional exit was input into the Pathfinder egress simulation on the north wall of the mezzanine. This arrangement provides means of egress through three of the four walls bounding the perimeter of the mezzanine. The additional, third, exit would require the installation of a fifth exterior building stair on the north side of the building.

In STEERING mode, the revised Pathfinder simulation included a new exit on the north wall of the mezzanine office area.

These improvements result in a reduction in the predicted time for all mezzanine occupants to leave the mezzanine from 132 seconds to 65 seconds, a reduction of 67 seconds.

Pathfinder also predicts that the addition of a third mezzanine exit path and removal of the obstruction to egress on the second floor improves the efficiency and effectiveness of the west stairwell.

RSET has previously been established based on crediting the 2-hour fire-resistance rated stairwells, including the west stairwell, for effectively separating building occupants from a fire inside the building. The prior value of RSET had established that 158 seconds of evacuation time would be required to evacuate all building occupants into the protective enclosure of the west stairwell (the west stairwell is the most limiting stairwell for evacuation). The time to evacuate has been reduced by this alternative from 158 seconds to 116 seconds, corresponding to a reduction of RSET of 42 seconds to a value of 116 seconds.

These improvements in evacuation time, as predicted by the Pathfinder egress model in STEERING mode, are summarized below:

Total Building Egress Time and Number of Occupants			
Exit Path	**Original Pathfinder (STEERING) seconds (# occupants)**	**Revised Pathfinder (STEERING) w/added Mezzanine Egress Path seconds (# occupants)**	**Egress Time Improvement Seconds (Delta # occupants)**
New Mezzanine Egress Path	NA	51 seconds (32)	NA (+ 32)
West Stairwell	190 seconds (209)	152 seconds (164)	-38 seconds (- 45)
South-West Stairwell	116 seconds (77)	122 seconds (81)	+6 seconds (+4)
South-East Stairwell	59 seconds (22)	59 seconds (22)	0 seconds (0)
East Stairwell	112 seconds (90)	124 seconds (99)	+12 seconds (+9)
North Office Discharge	47 seconds (44)	47 seconds (44)	0 seconds (0)
Dispersal Area Discharge	4 seconds (2)	4 seconds (2)	0 seconds (0)
Main Floor South Discharge	30 seconds (11)	30 seconds (11)	0 seconds (0)
Main Floor East Discharge	28 seconds (11)	28 seconds (11)	0 seconds (0)
TOTAL OCCUPANTS	466	466	NA

Time to Clear Each Floor and Number of Occupants (West Stairwell)			
Floor Level	**Original Pathfinder (STEERING) seconds (# occupants)**	**Revised Pathfinder (STEERING) w/added Mezzanine Egress Path seconds (# occupants)**	**Egress Time Improvement Seconds (Delta # occupants)**
Second Floor	158 seconds (100)	116 seconds (87)	- 42 seconds (-13)
Office Mezzanine	132 seconds (46)	65 seconds (34)	-67 seconds (-12)
Main Floor	117 seconds (63)	70 seconds (43)	-47 seconds (-20)
TOTAL OCCUPANTS USING WEST STAIRWELL	209	164	-45

4. ***Evaluate and install a mechanical smoke control system***

The evaluation of technical feasibility does not purport to be a design of a mechanical smoke control system.

A mechanical smoke control system was input into the FDS model based on the methodology of NFPA 204 "Standard for Smoke and Heat Venting" for sizing and placement of vents and sizing of mechanical smoke exhaust systems. Sizing, placement and mechanical flow rate were specified to prevent plugholing.

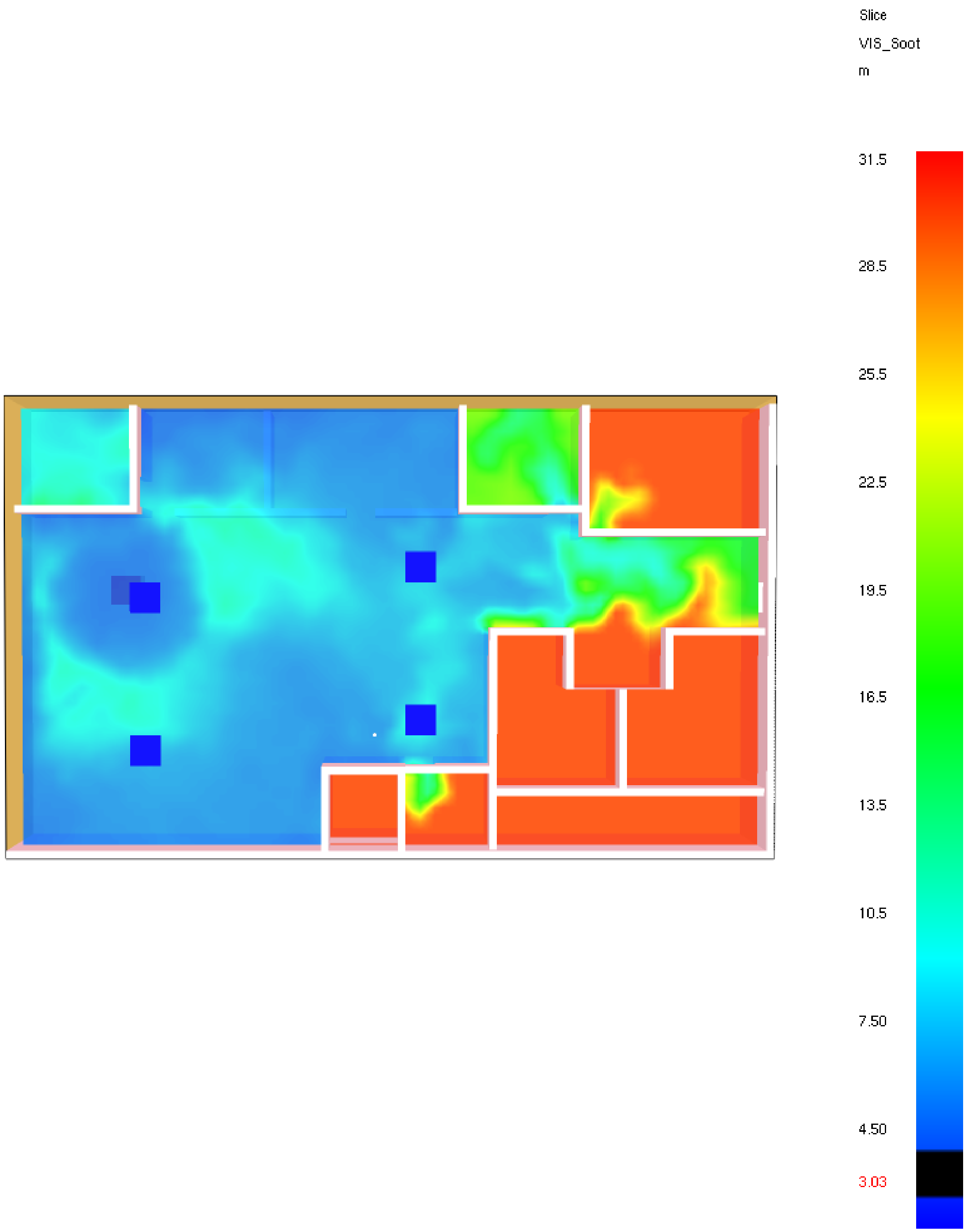
Four ceiling vents were placed in the model, each 1m^2 in area (a total of 4 m^2). These vents were placed between 5 m to 8 m apart, and 3 m to 4 m minimum from any wall. The specified flow rate was 2.0 m^3/second.

The FDS input for mechanical vents is reproduced in Appendix K of this report.

The mechanical smoke removal system is shown within FDS to maintain visibility in the mezzanine area during the first 300 seconds of the work station fire scenario below the established visibility tenability criteria of 3 m.

The FDS rendering below illustrates visibility greater than 3 m in the mezzanine area with the mechanical smoke exhaust system in service. This FDS scenario also assumes that the

workstation fire is controlled to a maximum heat release rate of 694 kW by actuation of sprinklers 170 seconds from ignition as predicted by DETACT analysis.



5. ***Remove walls and open up the mezzanine to the main floor area***

Removing the mezzanine walls eliminates restrictions on movement of smoke and hot gas between the mezzanine and main floor storage areas. Egress analysis is bounded by the storage rack fire scenario.

This alternative may solve the issues associated with a mezzanine workstation fire, but also provides exposure of mezzanine occupants to the storage rack fire scenario. Prior to implementing this alternative, critical consideration must be given to the impact of a main floor storage rack fire on the occupants of the mezzanine.

6. ***Do nothing, implement combustible loading controls, or implement occupancy limits***

The "do nothing alternative" based on the prescriptive requirements that are currently met is viable, but must be understood by the Authority Having Jurisdiction.

Implementation of combustible loading controls to limit the size of a fire, or limiting the occupancy of the mezzanine office area to a number of personnel that can be safety egress by the current exit arrangement is a possible alternative.

Appendix H

FDS Input File; Rack Storage Fire – Sprinklers Permitted

First Floor Rack Fire Model NWOSDETACT.fds - Limiting HRR to 2592 kW (DETACT Sprinkler Actuation time)

```
&HEAD CHID='FIRST FLOOR RACK FIRE MODEL NWOSDETACT'/
&TIME T_END=480.00/
&DUMP RENDER_FILE='FIRST_FLOOR_RACK_FIRE_MODEL_NWOSDETACT.GE1'/
&DUMP MASS_FILE=.TRUE.
&DUMP DT_DEVC

&MISC VISIBILITY_FACTOR=3.00/

&MESH IJK=120,120,16, XB=0.00,60.00,0.00,60.00,0.00,8.00 /

/ See SFPE Handbook 3rd Edition Tables C.3 and 3-4.14 /
/ See NFPA Handbook, Table 6.17.2 /

&REAC FUEL      = 'Polystyrene Cups'
        FORMULA='C8H8'
        CO_YIELD=0.0261
        SOOT_YIELD=0.0738
        HEAT_OF_COMBUSTION=29006. /

&MATL ID='EXT WALL',
    SPECIFIC_HEAT=0.70,
    CONDUCTIVITY=0.038,
    DENSITY=24.00  / Glass Wool; SFPE Handbook 4th Edition Table B.7

&MATL ID='INT WALL',
    SPECIFIC_HEAT=0.84,
    CONDUCTIVITY=0.48,
    DENSITY=1440.00  / Plaster, Gypsum; SFPE Handbook 4th Edition Table B.7

&MATL ID='CONCRETE',
    SPECIFIC_HEAT=0.88,
    CONDUCTIVITY=1.37,
    DENSITY=2300.00  / SFPE Handbook 4th Edition Table B.7

&SPEC ID='SOOT', MASS_EXTINCTION_COEFFICIENT=8.7000000E003/

&SURF ID='Fire_1', RAMP_Q='tcubed_1', HRRPUA=2281.3, COLOR='RASPBERRY' /
```

```
&RAMP ID='tcubed_1', T= 0.0, F=0.000 /
&RAMP ID='tcubed_1', T= 10.0, F=0.001 /
&RAMP ID='tcubed_1', T= 20.0, F=0.010 /
&RAMP ID='tcubed_1', T= 29.0, F=0.030 /
&RAMP ID='tcubed_1', T= 30.0, F=0.017 /
&RAMP ID='tcubed_1', T= 40.0, F=0.039 /
&RAMP ID='tcubed_1', T= 50.0, F=0.077 /
&RAMP ID='tcubed_1', T= 59.0, F=0.127 /
&RAMP ID='tcubed_1', T= 60.0, F=0.089 /
/ &RAMP ID='tcubed_1', T= 70.0, F=0.141 /
/ &RAMP ID='tcubed_1', T= 80.0, F=0.211 /
/ &RAMP ID='tcubed_1', T= 89.0, F=0.290 /
/ &RAMP ID='tcubed_1', T= 90.0, F=0.225 /
/ &RAMP ID='tcubed_1', T= 100.0, F=0.308 /
/ &RAMP ID='tcubed_1', T= 110.0, F=0.411 /
/ &RAMP ID='tcubed_1', T= 120.0, F=0.533 /
/ &RAMP ID='tcubed_1', T= 130.0, F=0.678 /
/ &RAMP ID='tcubed_1', T= 140.0, F=0.846 /

&SURF ID='Fire_2', RAMP_Q='tcubed_2', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_2', T= 0.0, F=0.000 /
&RAMP ID='tcubed_2', T= 29.0, F=0.000 /
&RAMP ID='tcubed_2', T= 30.0, F=0.017 /
&RAMP ID='tcubed_2', T= 40.0, F=0.039 /
&RAMP ID='tcubed_2', T= 50.0, F=0.077 /
&RAMP ID='tcubed_2', T= 59.0, F=0.127 /
&RAMP ID='tcubed_2', T= 60.0, F=0.089 /
/ &RAMP ID='tcubed_2', T= 70.0, F=0.141 /
/ &RAMP ID='tcubed_2', T= 80.0, F=0.211 /
/ &RAMP ID='tcubed_2', T= 89.0, F=0.290 /
/ &RAMP ID='tcubed_2', T= 90.0, F=0.225 /
/ &RAMP ID='tcubed_2', T= 100.0, F=0.308 /
/ &RAMP ID='tcubed_2', T= 110.0, F=0.411 /
/ &RAMP ID='tcubed_2', T= 120.0, F=0.533 /
/ &RAMP ID='tcubed_2', T= 130.0, F=0.678 /
/ &RAMP ID='tcubed_2', T= 140.0, F=0.846 /

&SURF ID='Fire_3', RAMP_Q='tcubed_3', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_3', T= 0.0, F=0.000 /
&RAMP ID='tcubed_3', T= 59.0, F=0.000 /
&RAMP ID='tcubed_3', T= 60.0, F=0.089 /
/ &RAMP ID='tcubed_3', T= 70.0, F=0.141 /
/ &RAMP ID='tcubed_3', T= 80.0, F=0.211 /
/ &RAMP ID='tcubed_3', T= 89.0, F=0.290 /
```

```
/ &RAMP ID='tcubed_3', T= 90.0, F=0.225 /
/ &RAMP ID='tcubed_3', T= 100.0, F=0.308 /
/ &RAMP ID='tcubed_3', T= 110.0, F=0.411 /
/ &RAMP ID='tcubed_3', T= 120.0, F=0.533 /
/ &RAMP ID='tcubed_3', T= 130.0, F=0.678 /
/ &RAMP ID='tcubed_3', T= 140.0, F=0.846 /

&SURF ID='Fire_4', RAMP_Q='tcubed_4', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_4', T= 0.0, F=0.000 /
&RAMP ID='tcubed_4', T= 89.0, F=0.000 /
/ &RAMP ID='tcubed_4', T= 90.0, F=0.225 /
/ &RAMP ID='tcubed_4', T= 100.0, F=0.308 /
/ &RAMP ID='tcubed_4', T= 110.0, F=0.411 /
/ &RAMP ID='tcubed_4', T= 120.0, F=0.533 /
/ &RAMP ID='tcubed_4', T= 130.0, F=0.678 /
/ &RAMP ID='tcubed_4', T= 140.0, F=0.846 /

&OBST XB=36.40,37.40,20.90,21.90,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad A Level 1

&OBST XB=37.90,38.90,20.90,21.90,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad B Level 1

&OBST XB=37.90,38.90,19.40,20.40,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad C Level 1

&OBST XB=36.40,37.40,19.40,20.40,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad D Level 1


&OBST XB=36.40,37.40,20.90,21.90,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad A Level 2

&OBST XB=37.90,38.90,20.90,21.90,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad B Level 2

&OBST XB=37.90,38.90,19.40,20.40,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad C Level 2

&OBST XB=36.40,37.40,19.40,20.40,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad D Level 2


&OBST XB=36.40,37.40,20.90,21.90,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad A Level 3

&OBST XB=37.90,38.90,20.90,21.90,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad B Level 3

&OBST XB=37.90,38.90,19.40,20.40,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad C Level 3

&OBST XB=36.40,37.40,19.40,20.40,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad D Level 3
```

&OBST XB=36.40,37.40,20.90,21.90,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad A Level 4

&OBST XB=37.90,38.90,20.90,21.90,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad B Level 4

&OBST XB=37.90,38.90,19.40,20.40,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad C Level 4

&OBST XB=36.40,37.40,19.40,20.40,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad D Level 4

&SURF ID='Exterior Wall', MATL_ID='EXT WALL', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Ceiling', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Second Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Mezzanine Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='PINK' /

&SURF ID='Main Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='WHITE' /

&SURF ID='Interior Wall', MATL_ID='INT WALL', THICKNESS=0.20, COLOR='PINK' /

&OBST XB=0.00,60.00,0.00,0.20,0.00,7.60, SURF_ID='Exterior Wall'/ South Wall

&OBST XB=0.00,0.20,0.20,59.80,0.00,7.60, SURF_ID='Exterior Wall'/ West Wall

&OBST XB=0.00,60.00,59.80,60.00,0.00,7.60, SURF_ID='Exterior Wall'/ North Wall

&OBST XB=59.80,60.00,0.20,59.80,0.00,7.60, SURF_ID='Exterior Wall'/ East Wall

&OBST XB=0.20,59.80,0.20,59.80,7.40,7.60, SURF_ID='Second Floor'/ Mezzanine Ceiling, Second Floor

&OBST XB=0.20,24.80,45.20,59.80,3.80,4.00, SURF_ID='Mezzanine Floor'/ Office Ceiling, Mezzanine Floor

&OBST XB=0.20,59.80,0.20,59.80,0.00,0.20, SURF_ID='Main Floor'/ Main Floor

&OBST XB=0.20,25.00,45.00,45.20,0.20,7.40, SURF_ID='Interior Wall'/ South Wall Office, Mezzanine

&OBST XB=24.80,25.00,45.00,59.80,0.20,7.40, SURF_ID='Interior Wall'/ /East Wall Office, Mezzanine

&OBST XB=53.20,59.80,22.40,22.60,0.20,7.40, SURF_ID='Interior Wall'/ South Wall, Receiving Area

&OBST XB=53.20,53.40,22.60,44.20,0.20,7.40, SURF_ID='Interior Wall'/ West Wall, Receiving Area

&HOLE XB=53.19,53.41,22.80,23.80,0.20,2.20 / Open Door Receiving Area

&HOLE XB=53.19,53.41,43.00,44.00,0.20,2.20 / Open Door Receiving Area

&OBST XB=53.20,59.80,44.20,44.40,0.20,7.40, SURF_ID='Interior Wall'/ North Wall, Receiving Area

&OBST XB=39.20,39.40,43.60,50.00,0.20,2.60, SURF_ID='Interior Wall'/ West Wall, Supervisor's Office

&OBST XB=39.40,42.20,43.60,43.80,0.20,2.60, SURF_ID='Interior Wall'/ Sout Wall, Supervisor's Office

&OBST XB=39.40,42.20,50.00,50.20,0.20,2.60, SURF_ID='Interior Wall'/ North Wall, Supervisor's Office

&OBST XB=42.20,42.40,43.60,50.00,0.20,2.60, SURF_ID='Interior Wall'/ East Wall, Supervisor's Office

&HOLE XB=42.19,42.41,43.80,44.80,0.20,2.20 / Open Door Supervisor's Office

&HOLE XB=42.19,42.41,47.20,48.20,0.20,2.20 / Open Door Supervisor's Office

&OBST XB=39.40,42.20,46.80,47.00,0.20,2.60, SURF_ID='Interior Wall'/ Separation Wall, Supervisor's Office

&OBST XB=39.40,42.40,43.60,50.20,2.60,2.80, SURF_ID='Ceiling'/ Ceiling, Supervisor's Office

&OBST XB=16.60,16.80,0.20,2.80,0.20,2.60, SURF_ID='Interior Wall'/ West Wall, Tool Room

&OBST XB=22.60,22.80,0.20,5.00,0.20,7.40, SURF_ID='Interior Wall'/ East Wall, Tool Room

&OBST XB=16.80,22.60,4.80,5.00,0.20,2.60, SURF_ID='Interior Wall'/ North Wall, Tool Room

&OBST XB=16.80,22.60,2.00,2.20,0.20,2.60, SURF_ID='Interior Wall'/ Counter, South Wall, Tool Room

&HOLE XB=17.00,22.40,1.99,2.21,1.20,2.20 / Open Tool Issue Window

&OBST XB=16.60,22.60,0.20,5.00,2.60,2.80, SURF_ID='Ceiling'/ Ceiling, Tool Room

&OBST XB=28.80,29.00,0.20,5.00,0.20,7.40, SURF_ID='Interior Wall'/ East Wall, Tool Room Vestibule

&OBST XB=22.80,28.80,4.80,5.00,0.20,7.40, SURF_ID='Interior Wall'/ North Wall, Tool Room Vestibule

&OBST XB=2.60,2.80,38.60,45.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=2.60,7.40,38.40,38.60,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=7.20,7.40,38.60,45.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=7.40,10.00,39.80,40.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=9.80,10.00,40.00,45.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=2.60,7.40,38.40,45.00,3.00,3.20, SURF_ID='Ceiling'/ Ceiling

&OBST XB=7.40,10.00,40.00,45.00,3.00,3.20, SURF_ID='Ceiling'/ Ceiling

&SPEC ID='WATER VAPOR'/

&PART ID='water drops', SPEC_ID='WATER VAPOR', AGE=4.00, DIAMETER=300, COLOR='BLUE' /

&PROP ID='ESFR', QUANTITY='SPRINKLER LINK TEMPERATURE', RTI=50., C_FACTOR=0.7, ACTIVATION_TEMPERATURE=96., OFFSET=0.10, PART_ID='water drops', FLOW_RATE=380, PARTICLE_VELOCITY=10., SPRAY_ANGLE=30.,80. / Viking VK520, K=14.0, RTI = 28 (Nominal RTI = 50 assumed)

/ &DEVC ID='SPR_A', XYZ=36.15,22.15,7.20, PROP_ID='ESFR' /
/ &DEVC ID='SPR_B', XYZ=39.15,22.15,7.20, PROP_ID='ESFR' /
/ &DEVC ID='SPR_C', XYZ=39.15,19.15,7.20, PROP_ID='ESFR' /
/ &DEVC ID='SPR_D', XYZ=36.15,19.15,7.20, PROP_ID='ESFR' /

&DEVC ID='center temperature',XYZ=37.65,20.65,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='west temperature',XYZ=33.40,20.65,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='east temperature',XYZ=41.90,20.65,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='north temperature',XYZ=37.65,24.90,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='south temperature',XYZ=37.65,16.40,7.40,QUANTITY='TEMPERATURE' /

&PROP ID='target',SMOKEVIEW_ID='target' /

&DEVC ID='Flux8S1.2',XYZ=37.65,17.00,1.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S2.4',XYZ=37.65,17.00,2.40,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

```
&DEVC ID='Flux8S3.6',XYZ=37.65,17.00,3.60,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S4.8',XYZ=37.65,17.00,4.80,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S6.0',XYZ=37.65,17.00,6.00,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S7.2',XYZ=37.65,17.00,7.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16S1.2',XYZ=37.65,14.60,1.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S2.4',XYZ=37.65,14.60,2.40,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S3.6',XYZ=37.65,14.60,3.60,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S4.8',XYZ=37.65,14.60,4.80,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S6.0',XYZ=37.65,14.60,6.00,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S7.2',XYZ=37.65,14.60,7.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8W1.2',XYZ=34.00,20.65,1.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W2.4',XYZ=34.00,20.65,2.40,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W3.6',XYZ=34.00,20.65,3.60,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W4.8',XYZ=34.00,20.65,4.80,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W6.0',XYZ=34.00,20.65,6.00,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W7.2',XYZ=34.00,20.65,7.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16W1.2',XYZ=31.60,20.65,1.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W2.4',XYZ=31.60,20.65,2.40,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W3.6',XYZ=31.60,20.65,3.60,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W4.8',XYZ=31.60,20.65,4.80,ORIENTATION=1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
```

&DEVC ID='Flux16W6.0',XYZ=31.60,20.65,6.00,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W7.2',XYZ=31.60,20.65,7.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8N1.2',XYZ=37.65,24.30,1.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N2.4',XYZ=37.65,24.30,2.40,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N3.6',XYZ=37.65,24.30,3.60,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N4.8',XYZ=37.65,24.30,4.80,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N6.0',XYZ=37.65,24.30,6.00,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N7.2',XYZ=37.65,24.30,7.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16N1.2',XYZ=37.65,26.70,1.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N2.4',XYZ=37.65,26.70,2.40,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N3.6',XYZ=37.65,26.70,3.60,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N4.8',XYZ=37.65,26.70,4.80,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N6.0',XYZ=37.65,26.70,6.00,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N7.2',XYZ=37.65,26.70,7.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8E1.2',XYZ=41.30,20.65,1.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E2.4',XYZ=41.30,20.65,2.40,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E3.6',XYZ=41.30,20.65,3.60,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E4.8',XYZ=41.30,20.65,4.80,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E6.0',XYZ=41.30,20.65,6.00,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E7.2',XYZ=41.30,20.65,7.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

```
&DEVC ID='Flux16E1.2',XYZ=43.70,20.65,1.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E2.4',XYZ=43.70,20.65,2.40,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E3.6',XYZ=43.70,20.65,3.60,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E4.8',XYZ=43.70,20.65,4.80,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E6.0',XYZ=43.70,20.65,6.00,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E7.2',XYZ=43.70,20.65,7.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /

&SURF ID='EF01', VOLUME_FLUX=8.3, COLOR='GREEN' /
&VENT XB=0.20,0.20,28.00,29.00,3.00,4.00, SURF_ID='EF01', DEVC_ID='fantemp01' /
0.20,0.20,28.00,29.20,3.00,4.20
&DEVC ID='fantemp01',
XYZ=0.20,29.00,4.00,QUANTITY='TEMPERATURE',SETPOINT=32.00,INITIAL_STATE=.FALSE. /

&SURF ID='EF02', VOLUME_FLUX=8.3, COLOR='GREEN' /
&VENT XB=0.20,0.20,11.00,12.00,3.00,4.00, SURF_ID='EF02', DEVC_ID='fantemp02' /
0.20,0.20,11.00,12.20,3.00,4.20
&DEVC ID='fantemp02',
XYZ=0.20,12.00,4.00,QUANTITY='TEMPERATURE',SETPOINT=32.00,INITIAL_STATE=.FALSE. /

&SURF ID='EF03', VOLUME_FLUX=0.83, COLOR='GREEN' /
&VENT XB=0.20,0.20,20.00,21.00,3.00,4.00, SURF_ID='EF01' / 0.20,0.20,19.80,20.20,3.40,3.80

&SURF ID='OPEN', COLOR='FLESH' /
&VENT XB=43.00,44.00,60.00,60.00,3.00,4.00, SURF_ID='OPEN' /
&VENT XB=60.00,60.00,49.00,50.00,3.00,4.00, SURF_ID='OPEN' /
&VENT XB=60.00,60.00,11.00,12.00,3.00,4.00, SURF_ID='OPEN' /
&VENT XB=40.00,41.00,0.00,0.00,3.00,4.00, SURF_ID='OPEN' /

&SLCF QUANTITY='TEMPERATURE',PBX=15.0 /
&SLCF QUANTITY='TEMPERATURE',PBX=30.0 /
&SLCF QUANTITY='TEMPERATURE',PBX=45.0 /
&SLCF QUANTITY='TEMPERATURE',PBY=15.0 /
&SLCF QUANTITY='TEMPERATURE',PBY=30.0 /
&SLCF QUANTITY='TEMPERATURE',PBY=45.0 /
&SLCF QUANTITY='TEMPERATURE',PBZ=7.20 /
&SLCF QUANTITY='TEMPERATURE',PBZ=2.02 /
&SLCF QUANTITY='TEMPERATURE',PBZ=1.20 /
```

```
&SLCF QUANTITY='VISIBILITY',PBX=15.0 /
&SLCF QUANTITY='VISIBILITY',PBX=30.0 /
&SLCF QUANTITY='VISIBILITY',PBX=45.0 /
&SLCF QUANTITY='VISIBILITY',PBY=15.0 /
&SLCF QUANTITY='VISIBILITY',PBY=30.0 /
&SLCF QUANTITY='VISIBILITY',PBY=45.0 /
&SLCF QUANTITY='VISIBILITY',PBZ=7.20 /
&SLCF QUANTITY='VISIBILITY',PBZ=2.02 /
&SLCF QUANTITY='VISIBILITY',PBZ=1.20 /

&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBX=15.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBX=30.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBX=45.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBY=15.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBY=30.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBY=45.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBZ=7.20 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBZ=2.02 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBZ=1.20 /

&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=15.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=30.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=45.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=15.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=30.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=45.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ=7.20 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ=2.02 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ=1.20 /

&TAIL /
```

Appendix I

FDS Input File; Rack Storage Fire – Sprinklers Not Permitted

First Floor Rack Fire Model NWOSNL.fds - No Limit HRR Due to Sprinklers, No Sprinklers

```
&HEAD CHID='FIRST FLOOR RACK FIRE MODEL NWOSNL'/
&TIME T_END=480.00/
&DUMP RENDER_FILE='FIRST_FLOOR_RACK_FIRE_MODEL_NWOSNL.GE1'/
&DUMP MASS_FILE=.TRUE.
&DUMP DT_DEVC

&MISC VISIBILITY_FACTOR=3.00/

&MESH IJK=120,120,16, XB=0.00,60.00,0.00,60.00,0.00,8.00 /

/ See SFPE Handbook 3rd Edition Tables C.3 and 3-4.14 /
/ See NFPA Handbook, Table 6.17.2 /

&REAC FUEL      = 'Polystyrene Cups'
        FORMULA='C8H8'
        CO_YIELD=0.0261
        SOOT_YIELD=0.0738
        HEAT_OF_COMBUSTION=29006. /

&MATL ID='EXT WALL',
    SPECIFIC_HEAT=0.70,
    CONDUCTIVITY=0.038,
    DENSITY=24.00  / Glass Wool; SFPE Handbook 4th Edition Table B.7

&MATL ID='INT WALL',
    SPECIFIC_HEAT=0.84,
    CONDUCTIVITY=0.48,
    DENSITY=1440.00  / Plaster, Gypsum; SFPE Handbook 4th Edition Table B.7

&MATL ID='CONCRETE',
    SPECIFIC_HEAT=0.88,
    CONDUCTIVITY=1.37,
    DENSITY=2300.00  / SFPE Handbook 4th Edition Table B.7

&SPEC ID='SOOT', MASS_EXTINCTION_COEFFICIENT=8.7000000E003/

&SURF ID='Fire_1', RAMP_Q='tcubed_1', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_1', T= 0.0, F=0.000 /
```

```
&RAMP ID='tcubed_1', T= 10.0, F=0.001 /
&RAMP ID='tcubed_1', T= 20.0, F=0.010 /
&RAMP ID='tcubed_1', T= 29.0, F=0.030 /
&RAMP ID='tcubed_1', T= 30.0, F=0.017 /
&RAMP ID='tcubed_1', T= 40.0, F=0.039 /
&RAMP ID='tcubed_1', T= 50.0, F=0.077 /
&RAMP ID='tcubed_1', T= 59.0, F=0.127 /
&RAMP ID='tcubed_1', T= 60.0, F=0.089 /
&RAMP ID='tcubed_1', T= 70.0, F=0.141 /
&RAMP ID='tcubed_1', T= 80.0, F=0.211 /
&RAMP ID='tcubed_1', T= 89.0, F=0.290 /
&RAMP ID='tcubed_1', T= 90.0, F=0.225 /
&RAMP ID='tcubed_1', T= 100.0, F=0.308 /
&RAMP ID='tcubed_1', T= 110.0, F=0.411 /
&RAMP ID='tcubed_1', T= 120.0, F=0.533 /
&RAMP ID='tcubed_1', T= 130.0, F=0.678 /
&RAMP ID='tcubed_1', T= 140.0, F=0.846 /

&SURF ID='Fire_2', RAMP_Q='tcubed_2', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_2', T= 0.0, F=0.000 /
&RAMP ID='tcubed_2', T= 29.0, F=0.000 /
&RAMP ID='tcubed_2', T= 30.0, F=0.017 /
&RAMP ID='tcubed_2', T= 40.0, F=0.039 /
&RAMP ID='tcubed_2', T= 50.0, F=0.077 /
&RAMP ID='tcubed_2', T= 59.0, F=0.127 /
&RAMP ID='tcubed_2', T= 60.0, F=0.089 /
&RAMP ID='tcubed_2', T= 70.0, F=0.141 /
&RAMP ID='tcubed_2', T= 80.0, F=0.211 /
&RAMP ID='tcubed_2', T= 89.0, F=0.290 /
&RAMP ID='tcubed_2', T= 90.0, F=0.225 /
&RAMP ID='tcubed_2', T= 100.0, F=0.308 /
&RAMP ID='tcubed_2', T= 110.0, F=0.411 /
&RAMP ID='tcubed_2', T= 120.0, F=0.533 /
&RAMP ID='tcubed_2', T= 130.0, F=0.678 /
&RAMP ID='tcubed_2', T= 140.0, F=0.846 /

&SURF ID='Fire_3', RAMP_Q='tcubed_3', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_3', T= 0.0, F=0.000 /
&RAMP ID='tcubed_3', T= 59.0, F=0.000 /
&RAMP ID='tcubed_3', T= 60.0, F=0.089 /
&RAMP ID='tcubed_3', T= 70.0, F=0.141 /
&RAMP ID='tcubed_3', T= 80.0, F=0.211 /
&RAMP ID='tcubed_3', T= 89.0, F=0.290 /
&RAMP ID='tcubed_3', T= 90.0, F=0.225 /
```

```
&RAMP ID='tcubed_3', T= 100.0, F=0.308 /
&RAMP ID='tcubed_3', T= 110.0, F=0.411 /
&RAMP ID='tcubed_3', T= 120.0, F=0.533 /
&RAMP ID='tcubed_3', T= 130.0, F=0.678 /
&RAMP ID='tcubed_3', T= 140.0, F=0.846 /

&SURF ID='Fire_4', RAMP_Q='tcubed_4', HRRPUA=2281.3, COLOR='RASPBERRY' /
&RAMP ID='tcubed_4', T= 0.0, F=0.000 /
&RAMP ID='tcubed_4', T= 89.0, F=0.000 /
&RAMP ID='tcubed_4', T= 90.0, F=0.225 /
&RAMP ID='tcubed_4', T= 100.0, F=0.308 /
&RAMP ID='tcubed_4', T= 110.0, F=0.411 /
&RAMP ID='tcubed_4', T= 120.0, F=0.533 /
&RAMP ID='tcubed_4', T= 130.0, F=0.678 /
&RAMP ID='tcubed_4', T= 140.0, F=0.846 /

&OBST XB=36.40,37.40,20.90,21.90,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad A Level 1

&OBST XB=37.90,38.90,20.90,21.90,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad B Level 1

&OBST XB=37.90,38.90,19.40,20.40,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad C Level 1

&OBST XB=36.40,37.40,19.40,20.40,0.50,1.50, SURF_IDS='Fire_1','INERT','INERT' / Quad D Level 1


&OBST XB=36.40,37.40,20.90,21.90,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad A Level 2

&OBST XB=37.90,38.90,20.90,21.90,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad B Level 2

&OBST XB=37.90,38.90,19.40,20.40,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad C Level 2

&OBST XB=36.40,37.40,19.40,20.40,2.00,3.00, SURF_IDS='Fire_2','INERT','INERT' / Quad D Level 2


&OBST XB=36.40,37.40,20.90,21.90,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad A Level 3

&OBST XB=37.90,38.90,20.90,21.90,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad B Level 3

&OBST XB=37.90,38.90,19.40,20.40,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad C Level 3

&OBST XB=36.40,37.40,19.40,20.40,3.50,4.50, SURF_IDS='Fire_3','INERT','INERT' / Quad D Level 3


&OBST XB=36.40,37.40,20.90,21.90,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad A Level 4
```

&OBST XB=37.90,38.90,20.90,21.90,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad B Level 4

&OBST XB=37.90,38.90,19.40,20.40,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad C Level 4

&OBST XB=36.40,37.40,19.40,20.40,5.00,6.00, SURF_IDS='Fire_4','INERT','INERT' / Quad D Level 4

&SURF ID='Exterior Wall', MATL_ID='EXT WALL', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Ceiling', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Second Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Mezzanine Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='PINK' /

&SURF ID='Main Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='WHITE' /

&SURF ID='Interior Wall', MATL_ID='INT WALL', THICKNESS=0.20, COLOR='PINK' /

&OBST XB=0.00,60.00,0.00,0.20,0.00,7.60, SURF_ID='Exterior Wall'/ South Wall

&OBST XB=0.00,0.20,0.20,59.80,0.00,7.60, SURF_ID='Exterior Wall'/ West Wall

&OBST XB=0.00,60.00,59.80,60.00,0.00,7.60, SURF_ID='Exterior Wall'/ North Wall

&OBST XB=59.80,60.00,0.20,59.80,0.00,7.60, SURF_ID='Exterior Wall'/ East Wall

&OBST XB=0.20,59.80,0.20,59.80,7.40,7.60, SURF_ID='Second Floor'/ Mezzanine Ceiling, Second Floor

&OBST XB=0.20,24.80,45.20,59.80,3.80,4.00, SURF_ID='Mezzanine Floor'/ Office Ceiling, Mezzanine Floor

&OBST XB=0.20,59.80,0.20,59.80,0.00,0.20, SURF_ID='Main Floor'/ Main Floor

&OBST XB=0.20,25.00,45.00,45.20,0.20,7.40, SURF_ID='Interior Wall'/ South Wall Office, Mezzanine

&OBST XB=24.80,25.00,45.00,59.80,0.20,7.40, SURF_ID='Interior Wall'/ /East Wall Office, Mezzanine

&OBST XB=53.20,59.80,22.40,22.60,0.20,7.40, SURF_ID='Interior Wall'/ South Wall, Receiving Area

&OBST XB=53.20,53.40,22.60,44.20,0.20,7.40, SURF_ID='Interior Wall'/ West Wall, Receiving Area

&HOLE XB=53.19,53.41,22.80,23.80,0.20,2.20 / Open Door Receiving Area

&HOLE XB=53.19,53.41,43.00,44.00,0.20,2.20 / Open Door Receiving Area

&OBST XB=53.20,59.80,44.20,44.40,0.20,7.40, SURF_ID='Interior Wall'/ North Wall, Receiving Area

&OBST XB=39.20,39.40,43.60,50.00,0.20,2.60, SURF_ID='Interior Wall'/ West Wall, Supervisor's Office

&OBST XB=39.40,42.20,43.60,43.80,0.20,2.60, SURF_ID='Interior Wall'/ Sout Wall, Supervisor's Office

&OBST XB=39.40,42.20,50.00,50.20,0.20,2.60, SURF_ID='Interior Wall'/ North Wall, Supervisor's Office

&OBST XB=42.20,42.40,43.60,50.00,0.20,2.60, SURF_ID='Interior Wall'/ East Wall, Supervisor's Office

&HOLE XB=42.19,42.41,43.80,44.80,0.20,2.20 / Open Door Supervisor's Office

&HOLE XB=42.19,42.41,47.20,48.20,0.20,2.20 / Open Door Supervisor's Office

&OBST XB=39.40,42.20,46.80,47.00,0.20,2.60, SURF_ID='Interior Wall'/ Separation Wall, Supervisor's Office

&OBST XB=39.40,42.40,43.60,50.20,2.60,2.80, SURF_ID='Ceiling'/ Ceiling, Supervisor's Office

&OBST XB=16.60,16.80,0.20,2.80,0.20,2.60, SURF_ID='Interior Wall'/ West Wall, Tool Room

&OBST XB=22.60,22.80,0.20,5.00,0.20,7.40, SURF_ID='Interior Wall'/ East Wall, Tool Room

&OBST XB=16.80,22.60,4.80,5.00,0.20,2.60, SURF_ID='Interior Wall'/ North Wall, Tool Room

&OBST XB=16.80,22.60,2.00,2.20,0.20,2.60, SURF_ID='Interior Wall'/ Counter, South Wall, Tool Room

&HOLE XB=17.00,22.40,1.99,2.21,1.20,2.20 / Open Tool Issue Window

&OBST XB=16.60,22.60,0.20,5.00,2.60,2.80, SURF_ID='Ceiling'/ Ceiling, Tool Room

&OBST XB=28.80,29.00,0.20,5.00,0.20,7.40, SURF_ID='Interior Wall'/ East Wall, Tool Room Vestibule

&OBST XB=22.80,28.80,4.80,5.00,0.20,7.40, SURF_ID='Interior Wall'/ North Wall, Tool Room Vestibule

&OBST XB=2.60,2.80,38.60,45.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=2.60,7.40,38.40,38.60,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=7.20,7.40,38.60,45.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=7.40,10.00,39.80,40.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=9.80,10.00,40.00,45.00,0.20,3.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=2.60,7.40,38.40,45.00,3.00,3.20, SURF_ID='Ceiling'/ Ceiling

&OBST XB=7.40,10.00,40.00,45.00,3.00,3.20, SURF_ID='Ceiling'/ Ceiling

&SPEC ID='WATER VAPOR'/

&PART ID='water drops', SPEC_ID='WATER VAPOR', AGE=4.00, DIAMETER=300, COLOR='BLUE' /

&PROP ID='ESFR', QUANTITY='SPRINKLER LINK TEMPERATURE', RTI=50., C_FACTOR=0.7, ACTIVATION_TEMPERATURE=96., OFFSET=0.10, PART_ID='water drops', FLOW_RATE=380, PARTICLE_VELOCITY=10., SPRAY_ANGLE=30.,80. / Viking VK520, K=14.0, RTI = 28 (Nominal RTI = 50 assumed)

/ &DEVC ID='SPR_A', XYZ=36.15,22.15,7.20, PROP_ID='ESFR' /
/ &DEVC ID='SPR_B', XYZ=39.15,22.15,7.20, PROP_ID='ESFR' /
/ &DEVC ID='SPR_C', XYZ=39.15,19.15,7.20, PROP_ID='ESFR' /
/ &DEVC ID='SPR_D', XYZ=36.15,19.15,7.20, PROP_ID='ESFR' /

&DEVC ID='center temperature',XYZ=37.65,20.65,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='west temperature',XYZ=33.40,20.65,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='east temperature',XYZ=41.90,20.65,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='north temperature',XYZ=37.65,24.90,7.40,QUANTITY='TEMPERATURE' /
&DEVC ID='south temperature',XYZ=37.65,16.40,7.40,QUANTITY='TEMPERATURE' /

&PROP ID='target',SMOKEVIEW_ID='target' /

&DEVC ID='Flux8S1.2',XYZ=37.65,17.00,1.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S2.4',XYZ=37.65,17.00,2.40,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8S3.6',XYZ=37.65,17.00,3.60,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S4.8',XYZ=37.65,17.00,4.80,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S6.0',XYZ=37.65,17.00,6.00,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8S7.2',XYZ=37.65,17.00,7.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16S1.2',XYZ=37.65,14.60,1.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S2.4',XYZ=37.65,14.60,2.40,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S3.6',XYZ=37.65,14.60,3.60,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S4.8',XYZ=37.65,14.60,4.80,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S6.0',XYZ=37.65,14.60,6.00,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16S7.2',XYZ=37.65,14.60,7.20,ORIENTATION=0,1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8W1.2',XYZ=34.00,20.65,1.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W2.4',XYZ=34.00,20.65,2.40,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W3.6',XYZ=34.00,20.65,3.60,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W4.8',XYZ=34.00,20.65,4.80,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W6.0',XYZ=34.00,20.65,6.00,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8W7.2',XYZ=34.00,20.65,7.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16W1.2',XYZ=31.60,20.65,1.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W2.4',XYZ=31.60,20.65,2.40,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W3.6',XYZ=31.60,20.65,3.60,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W4.8',XYZ=31.60,20.65,4.80,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16W6.0',XYZ=31.60,20.65,6.00,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16W7.2',XYZ=31.60,20.65,7.20,ORIENTATION=1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8N1.2',XYZ=37.65,24.30,1.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N2.4',XYZ=37.65,24.30,2.40,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N3.6',XYZ=37.65,24.30,3.60,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N4.8',XYZ=37.65,24.30,4.80,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N6.0',XYZ=37.65,24.30,6.00,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8N7.2',XYZ=37.65,24.30,7.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux16N1.2',XYZ=37.65,26.70,1.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N2.4',XYZ=37.65,26.70,2.40,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N3.6',XYZ=37.65,26.70,3.60,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N4.8',XYZ=37.65,26.70,4.80,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N6.0',XYZ=37.65,26.70,6.00,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16N7.2',XYZ=37.65,26.70,7.20,ORIENTATION=0,-1,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

&DEVC ID='Flux8E1.2',XYZ=41.30,20.65,1.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E2.4',XYZ=41.30,20.65,2.40,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E3.6',XYZ=41.30,20.65,3.60,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E4.8',XYZ=41.30,20.65,4.80,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E6.0',XYZ=41.30,20.65,6.00,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux8E7.2',XYZ=41.30,20.65,7.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE HEAT FLUX GAS',PROP_ID='target' /

```
&DEVC ID='Flux16E1.2',XYZ=43.70,20.65,1.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E2.4',XYZ=43.70,20.65,2.40,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E3.6',XYZ=43.70,20.65,3.60,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E4.8',XYZ=43.70,20.65,4.80,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E6.0',XYZ=43.70,20.65,6.00,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /
&DEVC ID='Flux16E7.2',XYZ=43.70,20.65,7.20,ORIENTATION=-1,0,0,QUANTITY='RADIATIVE
HEAT FLUX GAS',PROP_ID='target' /

&SURF ID='EF01', VOLUME_FLUX=8.3, COLOR='GREEN' /
&VENT XB=0.20,0.20,28.00,29.00,3.00,4.00, SURF_ID='EF01', DEVC_ID='fantemp01' /
0.20,0.20,28.00,29.20,3.00,4.20
&DEVC ID='fantemp01',
XYZ=0.20,29.00,4.00,QUANTITY='TEMPERATURE',SETPOINT=32.00,INITIAL_STATE=.FALSE. /

&SURF ID='EF02', VOLUME_FLUX=8.3, COLOR='GREEN' /
&VENT XB=0.20,0.20,11.00,12.00,3.00,4.00, SURF_ID='EF02', DEVC_ID='fantemp02' /
0.20,0.20,11.00,12.20,3.00,4.20
&DEVC ID='fantemp02',
XYZ=0.20,12.00,4.00,QUANTITY='TEMPERATURE',SETPOINT=32.00,INITIAL_STATE=.FALSE. /

&SURF ID='EF03', VOLUME_FLUX=0.83, COLOR='GREEN' /
&VENT XB=0.20,0.20,20.00,21.00,3.00,4.00, SURF_ID='EF01' / 0.20,0.20,19.80,20.20,3.40,3.80

&SURF ID='OPEN', COLOR='FLESH' /
&VENT XB=43.00,44.00,60.00,60.00,3.00,4.00, SURF_ID='OPEN' /
&VENT XB=60.00,60.00,49.00,50.00,3.00,4.00, SURF_ID='OPEN' /
&VENT XB=60.00,60.00,11.00,12.00,3.00,4.00, SURF_ID='OPEN' /
&VENT XB=40.00,41.00,0.00,0.00,3.00,4.00, SURF_ID='OPEN' /

&SLCF QUANTITY='TEMPERATURE',PBX=15.0 /
&SLCF QUANTITY='TEMPERATURE',PBX=30.0 /
&SLCF QUANTITY='TEMPERATURE',PBX=45.0 /
&SLCF QUANTITY='TEMPERATURE',PBY=15.0 /
&SLCF QUANTITY='TEMPERATURE',PBY=30.0 /
&SLCF QUANTITY='TEMPERATURE',PBY=45.0 /
&SLCF QUANTITY='TEMPERATURE',PBZ=7.20 /
&SLCF QUANTITY='TEMPERATURE',PBZ=2.02 /
&SLCF QUANTITY='TEMPERATURE',PBZ=1.20 /
```

```
&SLCF QUANTITY='VISIBILITY',PBX=15.0 /
&SLCF QUANTITY='VISIBILITY',PBX=30.0 /
&SLCF QUANTITY='VISIBILITY',PBX=45.0 /
&SLCF QUANTITY='VISIBILITY',PBY=15.0 /
&SLCF QUANTITY='VISIBILITY',PBY=30.0 /
&SLCF QUANTITY='VISIBILITY',PBY=45.0 /
&SLCF QUANTITY='VISIBILITY',PBZ=7.20 /
&SLCF QUANTITY='VISIBILITY',PBZ=2.02 /
&SLCF QUANTITY='VISIBILITY',PBZ=1.20 /

&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBX=15.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBX=30.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBX=45.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBY=15.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBY=30.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBY=45.0 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBZ=7.20 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBZ=2.02 /
&SLCF QUANTITY='MASS FRACTION',SPEC_ID='CARBON MONOXIDE',PBZ=1.20 /

&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=15.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=30.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=45.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=15.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=30.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=45.0 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ=7.20 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ=2.02 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ=1.20 /

&TAIL /
```

Appendix J

FDS Input File; Mezzanine Workstation Fire

Mezzanine Fire NWOSDETACT.fds - Run Limiting to 694kW (DETACT Sprinkler Actuation time)

```
&HEAD CHID='MEZZANINE FIRE NWOSDETACT'/
&TIME T_END=600.00/
&DUMP RENDER_FILE='MEZZANINE_FIRE_NWOSDETACT.GE1'/
&DUMP MASS_FILE=.TRUE.
&DUMP DT_DEVC

&MESH IJK=100,60,12, XB=0.00,25.00,45.00,60.00,3.60,6.60 / Mesh for Mezzanine

&REAC FUEL                        = 'Workstation'
        FYI                       = 'SFPE Handbook 3rd Edition Tables C.3 and 3-4.14'
        FYI                       = 'NIST The Effect of Oxygen Concentration on CO and Smoke
Produced by Flames Table 1'
        FYI                       = 'Defining primitive species assumed to be ABS plastic'
        FYI                       = 'Soot and CO yields are calculated in proportion to
combustible workstation components'
    FORMULA                  = 'C15H17N'
        SOOT_YIELD                = 0.0369
        CO_YIELD                  = 0.0220
        HEAT_OF_COMBUSTION        = 25436. /

&MATL ID='EXT WALL',
    SPECIFIC_HEAT=0.70,
    CONDUCTIVITY=0.038,
    DENSITY=24.00  / Glass Wool; SFPE Handbook 4th Edition Table B.7

&MATL ID='INT WALL',
    SPECIFIC_HEAT=0.84,
    CONDUCTIVITY=0.48,
    DENSITY=1440.00  / Plaster, Gypsum; SFPE Handbook 4th Edition Table B.7

&MATL ID='CONCRETE',
    SPECIFIC_HEAT=0.88,
    CONDUCTIVITY=1.37,
    DENSITY=2300.00  / SFPE Handbook 4th Edition Table B.7

&MISC VISIBILITY_FACTOR=3.00/

&SPEC ID='SOOT', MASS_EXTINCTION_COEFFICIENT=8.7000000E003/
```

```
&SURF ID='BURNER', HRRPUA=694, TAU_Q=-170, COLOR='RED' /

&OBST XB=3.00,4.00,53.30,54.30,3.80,4.60, SURF_IDS='BURNER','INERT','INERT'/ Fire

&SURF ID='Exterior Wall', MATL_ID='EXT WALL', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Second Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE'  /

&SURF ID='Mezzanine Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE'  /

&SURF ID='Mezzanine Ceiling', MATL_ID='INT WALL', THICKNESS=0.20, COLOR='INVISIBLE'  /

&SURF ID='Interior Wall', MATL_ID='INT WALL', THICKNESS=0.20, COLOR='PINK'  /

&SURF ID='MEZZSUPPLYA', VOLUME_FLUX=-0.1192, COLOR='GREEN' /
&VENT XB=2.00,2.50,48.50,49.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=2.50,3.00,51.50,52.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=2.00,2.50,54.50,55.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=2.00,2.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=8.00,8.50,48.50,49.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=8.00,8.50,51.50,52.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=8.00,8.50,54.50,55.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
&VENT XB=8.00,8.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYA' /

&SURF ID='MEZZSUPPLYB', VOLUME_FLUX=-0.0908, COLOR='GREEN' /
&VENT XB=13.00,13.50,51.50,52.00,6.40,6.40, SURF_ID='MEZZSUPPLYB' /
&VENT XB=14.50,15.00,54.50,55.00,6.40,6.40, SURF_ID='MEZZSUPPLYB' /
&VENT XB=16.00,16.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYB' /

&SURF ID='MEZZSUPPLYC', VOLUME_FLUX=-0.0578, COLOR='GREEN' /
&VENT XB=14.00,14.50,47.00,47.50,6.40,6.40, SURF_ID='MEZZSUPPLYC' /
&VENT XB=16.50,17.00,50.00,50.50,6.40,6.40, SURF_ID='MEZZSUPPLYC' /
&VENT XB=23.00,23.50,50.00,50.50,6.40,6.40, SURF_ID='MEZZSUPPLYC' /

&SURF ID='MEZZSUPPLYD', VOLUME_FLUX=-0.1239, COLOR='GREEN' /
&VENT XB=22.00,22.50,54.00,54.50,6.40,6.40, SURF_ID='MEZZSUPPLYD' /

&SURF ID='MEZZSUPPLYE', VOLUME_FLUX=-0.1522, COLOR='GREEN' /
&VENT XB=22.00,22.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYE' /

&SURF ID='MEZZEXHAUSTA', VOLUME_FLUX=0.4248, COLOR='BLUE' /
&VENT XB=12.00,12.50,53.00,53.50,6.40,6.40, SURF_ID='MEZZEXHAUSTA' /
&VENT XB=12.00,12.50,54.50,55.00,6.40,6.40, SURF_ID='MEZZEXHAUSTA' /
```

```
&VENT XB=12.00,12.50,57.50,58.00,6.40,6.40, SURF_ID='MEZZEXHAUSTA' /

&SURF ID='MEZZEXHAUSTB', VOLUME_FLUX=0.0708, COLOR='BLUE' /
&VENT XB=18.50,19.00,48.00,48.50,6.40,6.40, SURF_ID='MEZZEXHAUSTB' /
&VENT XB=20.50,21.00,48.00,48.50,6.40,6.40, SURF_ID='MEZZEXHAUSTB' /

&SURF ID='MEZZEXHAUSTC', VOLUME_FLUX=0.0472, COLOR='BLUE' /
&VENT XB=20.50,21.00,45.50,46.00,6.40,6.40, SURF_ID='MEZZEXHAUSTC' /

&SURF ID='MEZZEXHAUSTD', VOLUME_FLUX=0.2843, COLOR='BLUE' /
&VENT XB=17.50,18.00,55.00,55.50,6.40,6.40, SURF_ID='MEZZEXHAUSTD' /

&SURF ID='MEZZEXHAUSTE', VOLUME_FLUX=0.1652, COLOR='BLUE' /
&VENT XB=19.70,20.20,56.00,56.50,6.40,6.40, SURF_ID='MEZZEXHAUSTE' /

&OBST XB=0.00,25.00,45.00,45.20,3.60,7.40, SURF_ID='Interior Wall'/ South Wall

&OBST XB=24.80,25.00,45.20,59.80,3.60,7.40, SURF_ID='Interior Wall'/ East Wall

&OBST XB=0.00,25.00,59.80,60.00,3.60,7.60, SURF_ID='Exterior Wall'/ North Wall

&OBST XB=0.00,0.20,45.20,59.80,3.60,7.60, SURF_ID='Exterior Wall'/ Exterior Wall

&OBST XB=0.20,4.20,56.20,56.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=5.20,11.00,56.20,56.40,3.80,5.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=12.00,14.80,56.20,56.40,3.80,5.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=14.80,18.80,56.20,56.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&HOLE XB=17.80,18.80,56.19,56.41,3.80,5.80 / Open Door

&OBST XB=4.00,4.20,56.40,59.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&HOLE XB=3.99,4.21,56.40,57.40,3.80,5.80 / Open Door

&OBST XB=8.20,8.40,56.40,59.80,3.80,5.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=14.80,15.00,56.40,59.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=18.80,19.00,55.60,59.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=19.00,24.80,55.60,55.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall
```

```
&HOLE XB=19.00,20.00,55.59,55.81,3.80,5.80 / Open Door

&OBST XB=15.80,16.00,45.20,52.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=15.80,18.40,52.20,52.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=18.20,18.40,50.40,52.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=18.40,21.60,50.40,50.60,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=21.60,21.80,50.40,52.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=21.60,24.80,52.20,52.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=16.00,24.80,47.00,47.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=20.00,20.20,47.20,50.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=13.00,15.80,47.80,48.00,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&HOLE XB=13.00,14.00,47.79,48.01,3.80,5.80 / Open Door

&OBST XB=10.20,13.00,47.80,48.00,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=10.20,10.40,45.20,47.80,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=12.80,13.00,45.20,47.80,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=10.40,12.80,45.40,45.60,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=0.20,24.80,45.20,59.80,3.60,3.80, SURF_ID='Mezzanine Floor'/ Mezzanine Floor

&OBST XB=0.20,24.80,45.20,59.80,6.40,6.60, SURF_ID='Mezzanine Ceiling'/ Mezzanine Ceiling

&OBST XB=0.00,25.00,45.00,60.00,7.40,7.60, SURF_ID='Second Floor'/ Second Floor

&SPEC ID='WATER VAPOR'/

&PART ID='water drops', SPEC_ID='WATER VAPOR', AGE=4.00, DIAMETER=300,
COLOR='BLUE' /

&PROP ID='ModelG', QUANTITY='SPRINKLER LINK TEMPERATURE', RTI=120.,
C_FACTOR=0.7, ACTIVATION_TEMPERATURE=74., OFFSET=0.10, PART_ID='water drops',
```

```
FLOW_RATE=380, PARTICLE_VELOCITY=10., SPRAY_ANGLE=30.,80. / Reliable Model G,
K=5.6, RTI > 80

/ &DEVC ID='SPR_A', XYZ=1.60,55.40,6.20, PROP_ID='ModelG' /
/ &DEVC ID='SPR_B', XYZ=5.40,55.40,6.20, PROP_ID='ModelG' /
/ &DEVC ID='SPR_C', XYZ=5.40,52.20,6.20, PROP_ID='ModelG' /
/ &DEVC ID='SPR_D', XYZ=1.60,52.20,6.20, PROP_ID='ModelG' /

&PROP ID='Cleary Photoelectric P1', QUANTITY='CHAMBER OBSCURATION', ALPHA_E=1.8,
BETA_E=-1.0, ALPHA_C=1.0, BETA_C=-0.8/
&DEVC ID='Cleary', PROP_ID='Cleary Photoelectric P1', XYZ=12.00,49.00,6.20, LATCH=.FALSE./

&SLCF QUANTITY='TEMPERATURE', PBX= 3.50 /
&SLCF QUANTITY='TEMPERATURE', PBX=12.50 /
&SLCF QUANTITY='TEMPERATURE', PBX=21.50 /
&SLCF QUANTITY='TEMPERATURE', PBY=49.00 /
&SLCF QUANTITY='TEMPERATURE', PBY=53.80 /
&SLCF QUANTITY='TEMPERATURE', PBZ= 5.62 /

&SLCF QUANTITY='VISIBILITY', PBX= 3.50 /
&SLCF QUANTITY='VISIBILITY', PBX=12.50 /
&SLCF QUANTITY='VISIBILITY', PBX=21.50 /
&SLCF QUANTITY='VISIBILITY', PBY=49.00 /
&SLCF QUANTITY='VISIBILITY', PBY=53.80 /
&SLCF QUANTITY='VISIBILITY', PBZ= 5.62 /

&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBX= 3.50 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBX=12.50 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBX=21.50 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBY=49.00 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBY=53.80 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ= 5.62 /

&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX= 3.50 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=12.50 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=21.50 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=49.00 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=53.80 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ= 5.62 /

&TAIL /
```

This Page Intentionally Blank

Appendix K

FDS Input File; Mezzanine Workstation Fire – Mechanical Smoke Control System

Mezzanine Fire OWOSDETACTSMOKEA.fds - Run Limiting to 694kW Smoke Control

```
&HEAD CHID='MEZZANINE FIRE OWOSDETACTSMOKEA'/
&TIME T_END=300.00/
&DUMP RENDER_FILE='MEZZANINE_FIRE_OWOSDETACTSMOKEA.GE1'/
&DUMP MASS_FILE=.TRUE.
&DUMP DT_DEVC

&MESH IJK=100,60,12, XB=0.00,25.00,45.00,60.00,3.60,6.60 / Mesh for Mezzanine

&REAC FUEL                    = 'Workstation'
        FYI                   = 'SFPE Handbook 3rd Edition Tables C.3 and 3-4.14'
        FYI                   = 'NIST The Effect of Oxygen Concentration on CO and Smoke
Produced by Flames Table 1'
        FYI                   = 'Defining primitive species assumed to be ABS plastic'
        FYI                   = 'Soot and CO yields are calculated in proportion to
combustible workstation components'
    FORMULA               = 'C15H17N'
        SOOT_YIELD            = 0.0369
        CO_YIELD              = 0.0220
        HEAT_OF_COMBUSTION    = 25436. /

&MATL ID='EXT WALL',
    SPECIFIC_HEAT=0.70,
    CONDUCTIVITY=0.038,
    DENSITY=24.00  / Glass Wool; SFPE Handbook 4th Edition Table B.7

&MATL ID='INT WALL',
    SPECIFIC_HEAT=0.84,
    CONDUCTIVITY=0.48,
    DENSITY=1440.00  / Plaster, Gypsum; SFPE Handbook 4th Edition Table B.7

&MATL ID='CONCRETE',
    SPECIFIC_HEAT=0.88,
    CONDUCTIVITY=1.37,
    DENSITY=2300.00  / SFPE Handbook 4th Edition Table B.7

&MISC VISIBILITY_FACTOR=3.00/

&SPEC ID='SOOT', MASS_EXTINCTION_COEFFICIENT=8.7000000E003/
```

```
&SURF ID='BURNER', HRRPUA=694, TAU_Q=-170, COLOR='RED' /

&OBST XB=3.00,4.00,53.30,54.30,3.80,4.60, SURF_IDS='BURNER','INERT','INERT'/ Fire

&SURF ID='Exterior Wall', MATL_ID='EXT WALL', THICKNESS=0.20, COLOR='INVISIBLE' /

&SURF ID='Second Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE'  /

&SURF ID='Mezzanine Floor', MATL_ID='CONCRETE', THICKNESS=0.20, COLOR='INVISIBLE'  /

&SURF ID='Mezzanine Ceiling', MATL_ID='INT WALL', THICKNESS=0.20, COLOR='INVISIBLE'  /

&SURF ID='Interior Wall', MATL_ID='INT WALL', THICKNESS=0.20, COLOR='PINK'  /

/ &SURF ID='MEZZSUPPLYA', VOLUME_FLUX=-0.1192, COLOR='GREEN' /
/ &VENT XB=2.00,2.50,48.50,49.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=2.50,3.00,51.50,52.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=2.00,2.50,54.50,55.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=2.00,2.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=8.00,8.50,48.50,49.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=8.00,8.50,51.50,52.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=8.00,8.50,54.50,55.00,6.40,6.40, SURF_ID='MEZZSUPPLYA' /
/ &VENT XB=8.00,8.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYA' /

/ &SURF ID='MEZZSUPPLYB', VOLUME_FLUX=-0.0908, COLOR='GREEN' /
/ &VENT XB=13.00,13.50,51.50,52.00,6.40,6.40, SURF_ID='MEZZSUPPLYB' /
/ &VENT XB=14.50,15.00,54.50,55.00,6.40,6.40, SURF_ID='MEZZSUPPLYB' /
/ &VENT XB=16.00,16.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYB' /

/ &SURF ID='MEZZSUPPLYC', VOLUME_FLUX=-0.0578, COLOR='GREEN' /
/ &VENT XB=14.00,14.50,47.00,47.50,6.40,6.40, SURF_ID='MEZZSUPPLYC' /
/ &VENT XB=16.50,17.00,50.00,50.50,6.40,6.40, SURF_ID='MEZZSUPPLYC' /
/ &VENT XB=23.00,23.50,50.00,50.50,6.40,6.40, SURF_ID='MEZZSUPPLYC' /

/ &SURF ID='MEZZSUPPLYD', VOLUME_FLUX=-0.1239, COLOR='GREEN' /
/ &VENT XB=22.00,22.50,54.00,54.50,6.40,6.40, SURF_ID='MEZZSUPPLYD' /

/ &SURF ID='MEZZSUPPLYE', VOLUME_FLUX=-0.1522, COLOR='GREEN' /
/ &VENT XB=22.00,22.50,58.00,58.50,6.40,6.40, SURF_ID='MEZZSUPPLYE' /

/ &SURF ID='MEZZEXHAUSTA', VOLUME_FLUX=0.4248, COLOR='BLUE' /
/ &VENT XB=12.00,12.50,53.00,53.50,6.40,6.40, SURF_ID='MEZZEXHAUSTA' /
/ &VENT XB=12.00,12.50,54.50,55.00,6.40,6.40, SURF_ID='MEZZEXHAUSTA' /
```

```
/ &VENT XB=12.00,12.50,57.50,58.00,6.40,6.40, SURF_ID='MEZZEXHAUSTA' /

/ &SURF ID='MEZZEXHAUSTB', VOLUME_FLUX=0.0708, COLOR='BLUE' /
/ &VENT XB=18.50,19.00,48.00,48.50,6.40,6.40, SURF_ID='MEZZEXHAUSTB' /
/ &VENT XB=20.50,21.00,48.00,48.50,6.40,6.40, SURF_ID='MEZZEXHAUSTB' /

/ &SURF ID='MEZZEXHAUSTC', VOLUME_FLUX=0.0472, COLOR='BLUE' /
/ &VENT XB=20.50,21.00,45.50,46.00,6.40,6.40, SURF_ID='MEZZEXHAUSTC' /

/ &SURF ID='MEZZEXHAUSTD', VOLUME_FLUX=0.2843, COLOR='BLUE' /
/ &VENT XB=17.50,18.00,55.00,55.50,6.40,6.40, SURF_ID='MEZZEXHAUSTD' /

/ &SURF ID='MEZZEXHAUSTE', VOLUME_FLUX=0.1652, COLOR='BLUE' /
/ &VENT XB=19.70,20.20,56.00,56.50,6.40,6.40, SURF_ID='MEZZEXHAUSTE' /

&SURF ID='EF01', VOLUME_FLUX=2.00, COLOR='BLUE' /
&VENT XB=4.00,5.00,53.00,54.00,6.40,6.40, SURF_ID='EF01' /

&SURF ID='EF02', VOLUME_FLUX=2.00, COLOR='BLUE' /
&VENT XB=4.00,5.00,48.00,49.00,6.40,6.40, SURF_ID='EF02' /

&SURF ID='EF03', VOLUME_FLUX=2.00, COLOR='BLUE' /
&VENT XB=13.00,14.00,54.00,55.00,6.40,6.40, SURF_ID='EF03' /

&SURF ID='EF04', VOLUME_FLUX=2.00, COLOR='BLUE' /
&VENT XB=13.00,14.00,49.00,50.00,6.40,6.40, SURF_ID='EF04' /

&OBST XB=0.00,25.00,45.00,45.20,3.60,7.40, SURF_ID='Interior Wall'/ South Wall

&OBST XB=24.80,25.00,45.20,59.80,3.60,7.40, SURF_ID='Interior Wall'/ East Wall

&HOLE XB=24.79,25.01,53.00,54.00,5.50,6.20 /

&OBST XB=0.00,25.00,59.80,60.00,3.60,7.60, SURF_ID='Exterior Wall'/ North Wall

&OBST XB=0.00,0.20,45.20,59.80,3.60,7.60, SURF_ID='Exterior Wall'/ Exterior Wall

&OBST XB=0.20,4.20,56.20,56.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=5.20,11.00,56.20,56.40,3.80,5.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=12.00,14.80,56.20,56.40,3.80,5.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=14.80,18.80,56.20,56.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall
```

```
&HOLE XB=17.80,18.80,56.19,56.41,3.80,5.80 / Open Door

&OBST XB=4.00,4.20,56.40,59.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&HOLE XB=3.99,4.21,56.40,57.40,3.80,5.80 / Open Door

&OBST XB=8.20,8.40,56.40,59.80,3.80,5.00, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=14.80,15.00,56.40,59.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=18.80,19.00,55.60,59.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=19.00,24.80,55.60,55.80,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&HOLE XB=19.00,20.00,55.59,55.81,3.80,5.80 / Open Door

&OBST XB=15.80,16.00,45.20,52.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=15.80,18.40,52.20,52.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=18.20,18.40,50.40,52.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=18.40,21.60,50.40,50.60,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=21.60,21.80,50.40,52.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=21.60,24.80,52.20,52.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=16.00,24.80,47.00,47.20,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=20.00,20.20,47.20,50.40,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=13.00,15.80,47.80,48.00,3.80,6.40, SURF_ID='Interior Wall'/ Interior Wall

&HOLE XB=13.00,14.00,47.79,48.01,3.80,5.80 / Open Door

&OBST XB=10.20,13.00,47.80,48.00,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=10.20,10.40,45.20,47.80,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=12.80,13.00,45.20,47.80,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall

&OBST XB=10.40,12.80,45.40,45.60,3.80,7.40, SURF_ID='Interior Wall'/ Interior Wall
```

```
&OBST XB=0.20,24.80,45.20,59.80,3.60,3.80, SURF_ID='Mezzanine Floor'/ Mezzanine Floor

&OBST XB=0.20,24.80,45.20,59.80,6.40,6.60, SURF_ID='Mezzanine Ceiling'/ Mezzanine Ceiling

&OBST XB=0.00,25.00,45.00,60.00,7.40,7.60, SURF_ID='Second Floor'/ Second Floor

&SPEC ID='WATER VAPOR'/

&PART ID='water drops', SPEC_ID='WATER VAPOR', AGE=4.00, DIAMETER=300,
COLOR='BLUE' /

&PROP ID='ModelG', QUANTITY='SPRINKLER LINK TEMPERATURE', RTI=120.,
C_FACTOR=0.7, ACTIVATION_TEMPERATURE=74., OFFSET=0.10, PART_ID='water drops',
FLOW_RATE=380, PARTICLE_VELOCITY=10., SPRAY_ANGLE=30.,80. / Reliable Model G,
K=5.6, RTI > 80

/ &DEVC ID='SPR_A', XYZ=1.60,55.40,6.20, PROP_ID='ModelG' /
/ &DEVC ID='SPR_B', XYZ=5.40,55.40,6.20, PROP_ID='ModelG' /
/ &DEVC ID='SPR_C', XYZ=5.40,52.20,6.20, PROP_ID='ModelG' /
/ &DEVC ID='SPR_D', XYZ=1.60,52.20,6.20, PROP_ID='ModelG' /

&PROP ID='Cleary Photoelectric P1', QUANTITY='CHAMBER OBSCURATION', ALPHA_E=1.8,
BETA_E=-1.0, ALPHA_C=1.0, BETA_C=-0.8/
&DEVC ID='Cleary', PROP_ID='Cleary Photoelectric P1', XYZ=12.00,49.00,6.20, LATCH=.FALSE./

&SLCF QUANTITY='TEMPERATURE', PBX= 3.50 /
&SLCF QUANTITY='TEMPERATURE', PBX=12.50 /
&SLCF QUANTITY='TEMPERATURE', PBX=21.50 /
&SLCF QUANTITY='TEMPERATURE', PBY=49.00 /
&SLCF QUANTITY='TEMPERATURE', PBY=53.80 /
&SLCF QUANTITY='TEMPERATURE', PBZ= 5.62 /

&SLCF QUANTITY='VISIBILITY', PBX= 3.50 /
&SLCF QUANTITY='VISIBILITY', PBX=12.50 /
&SLCF QUANTITY='VISIBILITY', PBX=21.50 /
&SLCF QUANTITY='VISIBILITY', PBY=49.00 /
&SLCF QUANTITY='VISIBILITY', PBY=53.80 /
&SLCF QUANTITY='VISIBILITY', PBZ= 5.62 /

&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBX= 3.50 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBX=12.50 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBX=21.50 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBY=49.00 /
```

```
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBY=53.80 /
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ= 5.62 /

&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX= 3.50 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=12.50 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBX=21.50 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=49.00 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBY=53.80 /
&SLCF QUANTITY='DENSITY', SPEC_ID='SOOT', PBZ= 5.62 /

&TAIL /
```